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Development of a Knowledge-Based Energy Damage Model to Assess Occupational Health and Safety (OHS) Construction Risks in Malaysia

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Abstract

Malaysia's construction industry has been long described as a dangerous industry, indicated by its poor health and safety performance. One of the Malaysian government's initiatives to address OHS in construction is through the widespread adoption of Industrialised Building Systems (IBS). An IBS approach is believed to affect the significance of a particular safety risk because it changes the nature of the construction process. This study proposes to examine the extent of IBS impact upon OHS in contrast with traditional construction in Malaysia, by developing a knowledge-based energy damage model that assesses the OHS risks of different construction approaches. The proposed model will provide best-practice reasoning support for designers in construction.

Introduction

The construction industry is renowned as a high-risk industry which involves complex, time consuming design and construction processes characterized by unforeseen circumstances. As a result, the construction industry has been plagued with accidents for a long time (Ren, 1994). 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 safety and health (OSH) management an important element in the construction industry.

In Malaysia, safety performance in the construction industry has lagged behind most other industries as evidenced by its disproportionally high rate of accidents and this is proven by annual report produced by the Social Security Organization (SOCSO). 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 (2000), the case 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 latest statistics in 2009 indicate that among the 4108 accidents reported in the Malaysian construction industry, 116 cases resulted in a fatality while 977 in permanent disabilities (SOCSO, 2009). This high accident and fatality rate has caused concern among the industry players and government.

It is proposed that one of the ways to improve safety and health in the construction industry is through the implementation of off-site production (OSP), commonly termed "Industrialised Building Systems (IBS)" in Malaysia (CIDB, 2004). The implementation of IBS changes the nature of activities, which are different from traditional processes. In IBS, the process is industrialised by which components of a building are conceived, planned, fabricated, transported to and then erected on site (Junid, 1986). Even though there are several studies indicating IBS can significantly reduce OHS risks in traditional construction (McKay, 2010 and Gangolelles et al., 2010), the extent of IBS impact upon safety and health in construction is still unclear as there is no current system to assess OHS risk in the construction process.

In order to address this, a study at RMIT University seeks to apply 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) 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" (Cooke et al, 2008). This paper presents the development of a model which 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 the construction of their designs. In addition to the existing model, an "energy damage model" (Viner, 1991) will be used as an underpinning framework for developing the model. The development of this model contributes by suggesting 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.

This paper serves to outline the development of a knowledge-based energy damage model to assess OHS risk in construction processes at the design stage. Initially the paper will provide an overview of the Malaysian construction industry and its OHS record, followed by its government's desire to improve OHS performance through IBS. The paper provides some further OHS risk background before discussing the concept of the model.

Overview of Malaysia Construction Industry

The construction industry in Malaysia is generally divided into two sectors, namely general construction and civil engineering construction. In 2009 during the slowing global economy, the construction sector was the only sector that plotted a positive growth during every quarter of that year in Malaysia. The Construction Sector registered a strong growth of 5.8% in 2009, and subsequently 8.7% for the first quarter of 2010 as against the overall GDP growth of 10.1% during the first quarter of this year (Mansor, 2010).

Prosperity and high economic growth in Malaysia have both created a high demand for construction activities. As a consequence, a large number of foreign workers have been attracted into the country to take up employment on site as unskilled labour doing manual jobs (Hamid *et. al*, 2008). According to the Construction Industry Development Board (CIDB) of Malaysia, 69% (552,000) out of a total of 800,000 registered workers (as at June 2007) are foreign workers (CIDB, 2007a). Regardless of the over dependence on foreign labour, the industry is still saddled with serious problems such as low quality, low productivity, poor image, economic volatility, bureaucratic delays, lack of ethics, shortage of skilled manpower and lack of data and information (CIDB, 2004). Moreover, the OHS performance of Malaysian construction industry is poor as evidenced by its high accident and injury rates.

Additionally, the huge demand for construction projects, especially building construction has fostered interest in Industrialised Building Systems (IBS), which could save on labour, cost and construction time, and confer quality and durability (Ismail, 2001 and Hamid *et al.*, 2008). The implementation of IBS is also seen as one of the initiatives to improve the industry's OHS performance (CIDB, 2004).

The importance of IBS implementation is highlighted in the *Construction Industry Master Plan* (CIMP 2006-2015), under the *Strategic Thrust 5* (CIDB, 2007b), as shown in Figure 1. The Government of Malaysia has emphasized the full utilization of IBS for government projects by the inclusion of not less than a 70% IBS component (CIDB, 2003). Further to this, the IBS Roadmap 2011-2015 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.

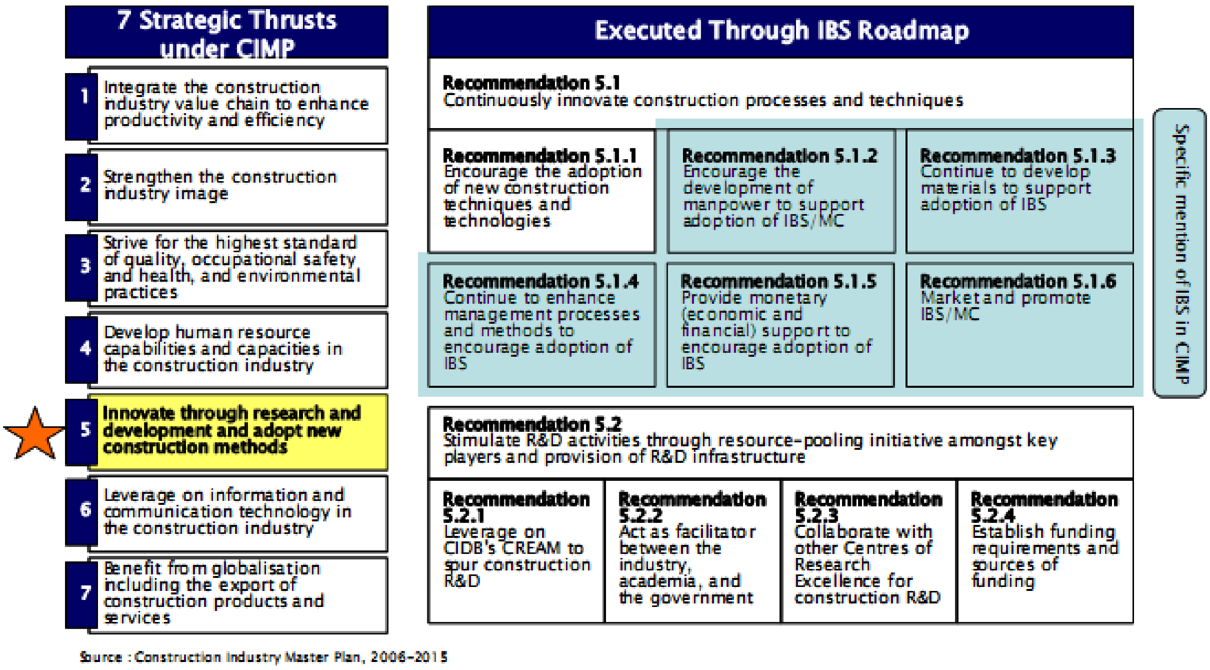

Figure 1: IBS Thrust in the CIMP 2006-2015

The context of Industrialised Building Systems (IBS) and health and safety

The Master Plan for Occupational Safety and Health in the Construction Industry 2005-2010 recommends that to improve the performance of OHS, implementation of mechanization and new methods for construction that will optimise labour utilization in the industry are needed (CIDB, 2004). It is proposed that by using an IBS approach, the hazards inherent in traditional construction activities change when the process is moved offsite, and in some cases the hazards on site are completely removed, or are easier to reduce and control in a factory.

Some researchers suggest that IBS is safer than the traditional process in a way that the work location can be shifted to a lower hazard environment (Toole and Gambatese, 2008) and from the field to the factory which allows better control of the hazards (Gibb, 1999; Toole and Gambatese, 2008). This is supported by McKay

(2010) who studied the OHS risks associated with offsite and found that offsite can significantly reduce OHS risk in traditional construction in the UK. However, that study did not present a mechanism by which a particular design could be assessed and compared to an alternative. He only suggested the ways to mitigate the residual OHS risk, but overall he did not precisely address how the risks in both offsite and traditional can be treated effectively. Therefore, there is a gap in the research to effectively address the designers' role in making decisions in their designs and further understand the level of OHS risk their designs pose.

Gibb (1999) proposes that developing a project-wide strategy at an early stage would be essential and consideration of off-site fabrication should be done from an overall project perspective rather than on an element by element basis. This strategy is essential in achieving health and safety benefits from IBS where the project could organise the whole project to minimise risk and maximise efficiency (McKay, 2010).

The Concept of Designing for Construction Safety

The potential benefits of IBS can be better understood if viewed as a 'design change' from traditional construction products and processes. "Designing for construction safety" is a perspective that has been gaining attention among researchers for the past decade to reduce and eventually eliminate construction accidents. IBS as an alternative approach offers potential to realise significant safty gains through product and process design. Cooke (1997) and Gambatese, et al. (2008) suggest that the poor safety performance of construction can be improved through preventing accidents and reducing uncertainty before it happens. In addition, Szymberski (1997) postulated that by incorporating safety earlier in the project schedule, greater influence could be exerted (Figure 2). It can be seen that by including construction site safety as a consideration (along with production, quality, project scope, etc) early in the project's life cycle, one has a greater ability to positively influence construction site safety. The evidence of the effectiveness of this strategy is confirmed by several authors such as Jeffrey and Douglas (1994); Furst (2010); Gibb et al. (2004) and Behm (2006).

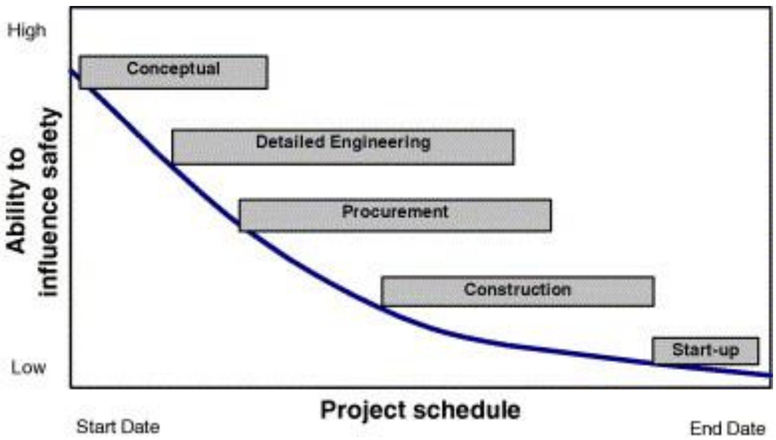

Figure 2: Time/safety influence curve (Szymberski, 1997)

Despite the awareness among designers of this concept, Toole and Gambatese (2008) argue that there is still a lack of technical principles to help designers better perform Construction Hazard Prevention through Design (CHPtD) and that there is a need to facilitate the development of additional CHPtD tools. According to Gangolelles *et al.*

(2010), most publications on this subject only offer solutions that can be directly implemented and checklists for the subsequent monitoring of the design. For example, the Health and Safety Executive (HSE) has documented and illustrated how designers could significantly improve construction safety and reduce costs or programme time using several case studies (HSE, 2003). Similar documents have been published by the Guide to Best Practice for Safety Consrtuction: Design Stage (2009) for the Australian context. Other examples include Gambatese and Heinze (1999) who accumulated design suggestions for improving construction worker safety while in the design phase.

Other tools developed by researchers to help the design decision process include "Design for Construction Safety Toolbox", a computer design tool which is built upon 400 design practices that could be used by designers to minimize or eliminate hazards in their design (Gambatese et. al, 1997); and Construction Hazard Assessment Implication Review (CHAIR), a safety in design tool in Australia developed by WorkCover, a body responsible for regulating OHS in the State of New South Wales (NSW), in 2001. CHAIR was developed to identify risk in a design of the whole project life cycle including construction, operation and maintenance, where the stakeholders are required to review the design in a prescribed manner and ensure that their OHS issues are considered in the design phase of the project (WorkCover, 2001).

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, 2007a). However, it is doubtful that Malaysian construction designers adequately understand how to identify, assess and control OHS risks in their designs.

Designing the construction process for OHS performance can play a role in evaluating the effectiveness of IBS construction over traditional approach. 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. In addition, by considering safety during the design process, hazards can be eliminated or reduced during construction, thus improving the safety performance (Behm, 2005). In this "Designing for Construction Safety" concept, the designers assess the risk of their designs created for construction, and consequently attempt to eliminate or reduce these risks within their designs.

OHS Risk Management

Inherent within the Designing for Safety Concept is the analysis of safety risk. Safety risk analysis is a foundation upon which safety management is built and risk assessment becomes a critical task which forms a part of safety management systems (Fung *et al.* (2010); Langford et al. (2000); Low and Sua (2000); Cheng *et al.* (2004); and Jung *et al.* (2008). According to Gangolelles *et al.* (2010), authors like Carter and Smith (2004), Cheung *et al.* (2004a), Cheung *et al.* (2004b), Imriyas (2009) and Seo and Choi (2008) had addressed the methods of how health and safety aspects can be integrated during the design and preparation phase, however, subjective judgements often influence the accuracy of their methods.

When the risks assessed are regarded as high, they should ideally be controlled by implementing measures to reduce the risk associated with a hazard in the order portrayed by the hierarchy of controls. The hierarchy of controls is based on the principle that control measures that target hazards at source and act on the work environment are more effective than controls that aim to change the behaviour of exposed workers (Matthews, 1993). Therefore, designing-out OHS risks is a better approach than controlling the risks using measures that are dependant on administrative controls and PPE. This is supported by Manuele (1997) and Andres (2002) who specify design as the primary method to reduce risk.

Gangolelles et al (2010) established an assessment tool providing the basis and criteria to quantitatively measure safety performance of construction projects by mitigating construction risks during the design stage. The limitations of the study are that it uses a simple quantitative methodology where there is no thorough scoring system for evaluating significance rating of the risks; and the risk exposure rating was only based on the information contained in construction documents. The outcome is doubtful due to the methodology used, as the health and safety risk indicators are based on the product, not the process. The tool would be more worthwhile if the methodology is robust and the risks indicators are built upon the construction process.

ToolSHED (Cooke *et al*., 2008) was developed to help construction designers integrate the management of occupational health and safety risk into the design process in Australia. 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". However, the example presented is only on the design-related risks of falls from heights for the maintenance of roof plant, which is post-construction. Therefore, there is a gap in the research to expand the tool into the other construction processes and phases.

Addressing the issue of safety and health in IBS construction is vital because it will affect Malaysia's construction industry as a whole. However, it is believed that there is a lack of designated IBS risk assessment methodologies addressing occupational safety and health. Even though there is one recent study which quantitatively addresses safety and health assessments, it is only based on the present safety performance of IBS construction and does not seek to design the IBS process for OHS performance (Ahmad, 2010). Therefore, it would be ideal to apply the concept of ToolSHED into the construction process and include other areas of OHS risk. The outcome would be a model that presents construction process knowledge delineated by argument trees showing the inference procedure.

Argumentation theory

ToolSHED uses "argumentation theory" to represent the modelled design OHS knowledge to support human decision making in a complex situation. The use of argument trees to model expert reasoning in solving problems in such situations represents the "open textured" concepts which are suitable for the vagueness characteristics of real world problems. Open texture concept has been adopted by many countries in their OHS legislation, in which they have reformed the legislation from detailed and prescriptive requirements to performance-based requirements, following the UK legislation shift in mid-1970s (Cooke, et al, 2008). These countries have addressed "general duties" for employers, employees, suppliers of plant and materials and others.

The "general duties" provisions are not absolute and often limited by words such as "so far as is practicable" or "reasonably practicable". For instance in Malaysia, Section 20 of Act 514 Occupational Safety and Health Act 1994, Part V General Duties of Designers, Manufacturers and Suppliers requires that:

(1) It shall be the duty of a person who designs, manufactures, imports or supplies any plant for use at work -

> *(a)* to ensure, so far as is practicable, that the plant is so designed and constructed as to be safe and without risks to health when properly used;
>
> *(b)* to carry out or arrange for the carrying out of such testing and examination as may be necessary for the performance of the duty imposed on him by paragraph (*a*); and
>
> *(c)* to take such steps as are necessary to secure that there will be available in connection with the use of the plant at work adequate information about the use for which it is designed and has been tested, and about any condition necessary to ensure that, when put to that use, it will be safe and without risks to health.

Open texture is useful for representing expert reasoning in deciding how to comply with performance-based OHS requirements due to the large number of inter-related and heterogeneous factors that revolve around the requirements. In executing their duties, duty holders would surely need to balance OHS risk against cost and technical possibility, and the phrase "how safe is safe enough" would be their dilemma in making decisions (Cooke et al., 2008). Therefore, Cooke et al. (2008) suggest the use of "argument trees" for modelling expert reasoning as better suited to solving problems in such situations.

Argument trees

Argument trees can represent the reasoning process, enacting on presenting or defending, in seeking a rational or reasonable standpoint or decision. Using argument trees as an approach to represent the knowledge of design OHS is useful because design OHS is subjective and interconnected to other issues that require concurrent considerations.

The idea of representing knowledge from argumentation was initiated by Toulmin (1958; as cited in Cooke et al., 2008), however, he loosely specifies how arguments relate to other arguments and provides no guidance as to how to evaluate the best argument (Yearwood and Stranieri, 2006). Therefore, Yearwood and Stranieri (2006) use "argument trees" graphically to clarify the hierarchical ordering of factors pertinent in decision making processes.

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).

Knowledge-based energy damage model to assess OHS risks designed

In developing a model that represents the reasoning for decisions around the construction processes, the same method of modelling as the expert reasoning system in ToolSHED, in the form of a series “argument trees”, will be used. However, the argument trees developed in this study will be underpinned by a knowledge-based energy damage model in construction processes to assess OHS risks in the design.

The energy damage model, created by Viner (1991), 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. This is underpinned by, “when an unwanted and harmful energy source is transferred unexpectedly (in type, time, speed or force) or to an unwilling or unwitting person, the problem may arises even though the energy itself is not dangerous”. Identifying such damaging energies enables a designer to provide technological control of elimination or reduction.

Figure 3 depicts the Energy Damage Model which is adapted from Viner’s original model. In order to cause damage, energy has to penetrate the barrier and transfer to the recipient. The extent of damage depends on the amount of energy that exceeds the energy threshold of the recipient. The types of damaging energies (hazards) include gravitational; noise and vibration; chemical; electrical; mechanical; thermal; pressure; radiation; microbiological; biomechanical; and psychosocial (Safetyline Institute, 2005). As the high amount of damaging energies to penetrate the shield could determine the level of injury to the recipient, reducing the amount of these energies will become increasingly important.

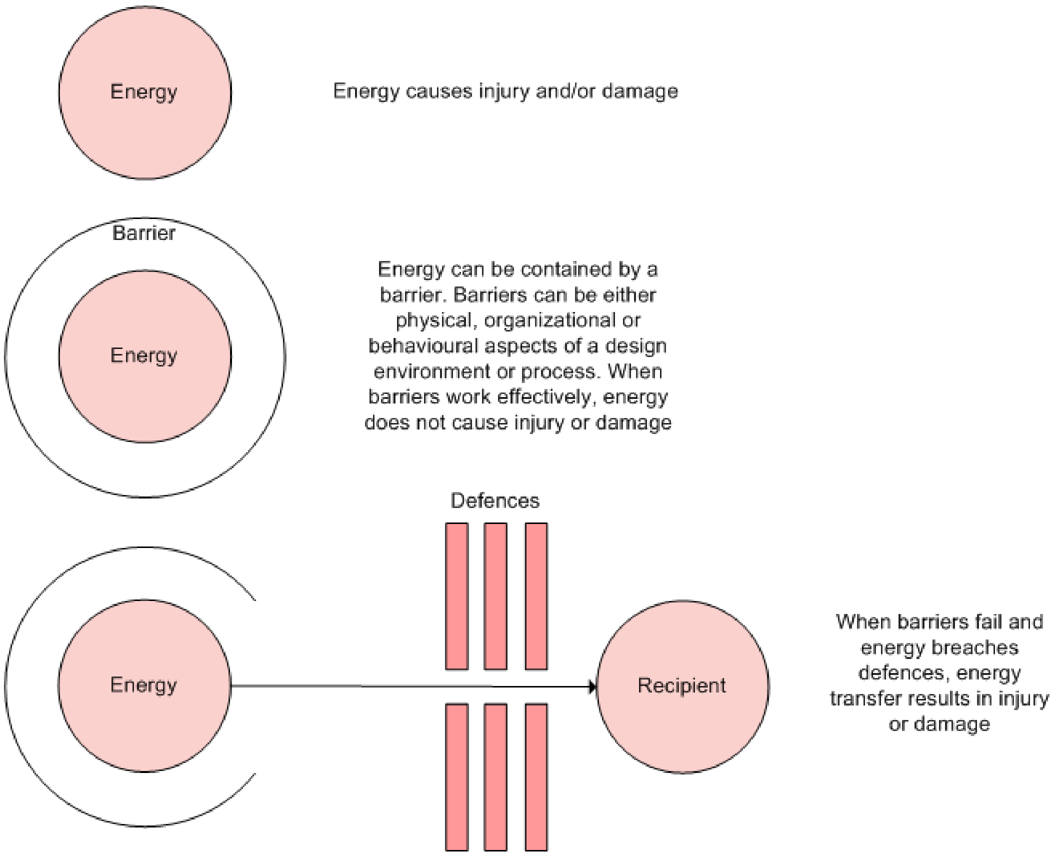

Figure 3: Energy Damage Model (Source: Guide to Best Practice for Safer Construction (2009); Adapted from Viner (1998))

The development process

Integrating the damage energy model with argument trees provides a powerful tool for assessing construction process risk. The development process of the model is depicted in Figure 4. It consists of two stages initiated with knowledge acquisition, followed by knowledge processing.

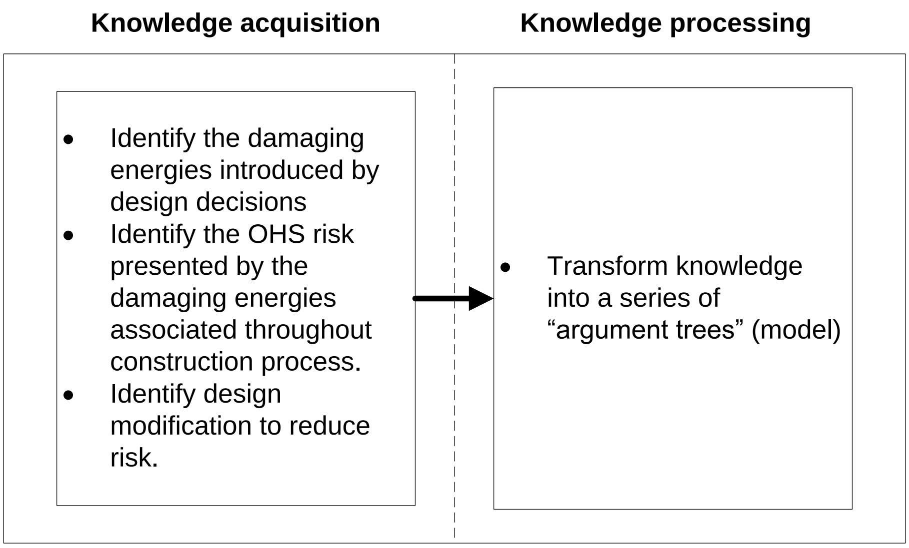

Figure 4: Model development process

Knowledge acquisition involves collecting the data that will underpin the model. To assess the construction OHS risks within a design, knowledge energy transfers (hazards) associated with the construction processes are needed. Further the identification of barriers to prevent such energies from injury or damage together in energy transfers can then be 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 trees.

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 final risk rating is calculated using the common “risk management” function of 1) likelihood that an injury or illness will occur; 2) the severity of the consequence of that injury or illness should it occur; and 3) frequency with which a person is exposed to the hazard. The magnitude of the likelihood, consequence and frequency are determined by expert panels from the relevant factors, inferred from a series of child nodes.

Figure 5 is an example of a design OHS argument tree for the likelihood of risk for concrete panels. 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. It can be seen that the tree has linguistic values with corresponding numerical values in the child nodes inferring values of parent nodes. This inference procedure, denoted by A, B, C, and D, continues until ultimately inferred at the root node, the final risk rating. The risk rating at the root node indicates either “extreme”, “high”, “medium” or “low”. It is measured by calculating the likelihood, consequence and exposure which are contingent upon 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.

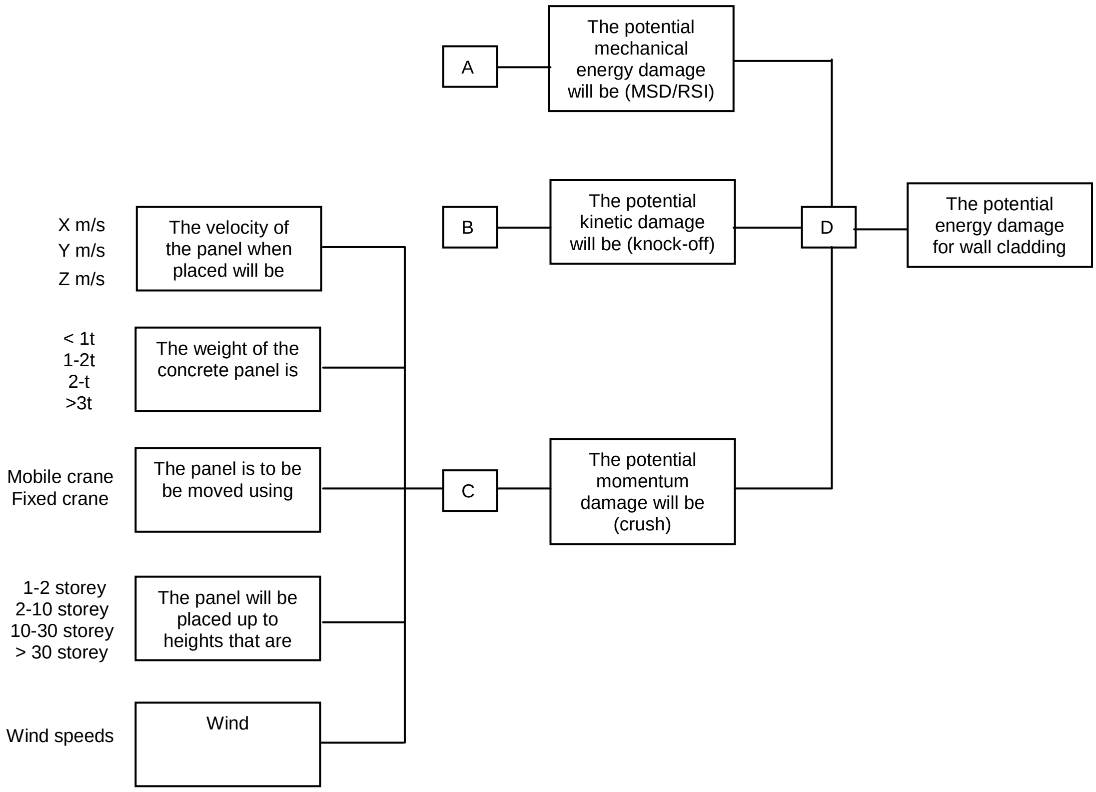

Figure 5: Example of argument tree showing the inference procedure

Scope and limitation

The scope of the project currently underway is focused on occupational health and safety risks (OHS) of IBS and traditional projects for residential building construction. The reason for focusing on residential projects is to discount the possible variation due to irregular structural layout plan if other types of projects such as hostels, universities and schools are considered. Moreover, residential projects have typical structural layout plans and are repetitive, even though minimal or variation might occur. This makes direct comparison between building systems more representative and unbiased (M.R. Abdul Kadir *et al.,* 2006).

This project will only cover the major hazards (damaging energies) involved in building construction using both IBS and traditional approaches which represent the hazards in building construction as a whole. The determination of the major hazards will be justified from the data analysis of safety performance of building construction in Malaysia. The case study will be undertaken for three construction projects that represent both IBS and traditional approaches and cover the structure and envelope of the building.

Conclusion

This paper presents the development of a knowledge-based energy damage model to assess OHS risks designed in construction processes. The model used a combination of the "argumentation theory" and "energy damage model", building on a risk assessment tool named ToolSHED. The outcome of this study will be a model for best practice reasoning used by designers or decision makers when examining the OHS risks posed by their designs. This requires integrating construction process knowledge into design to eliminate or reduce hazards during construction in both IBS and traditional approaches. 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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