8D BIM MODELLING TOOL FOR ACCIDENT PREVENTION THROUGH DESIGN

Imriyas Kamardeen[1]

Faculty of Built Environment, University of New South Wales, NSW 2052, Australia.

The construction industry's incident rate for workplace injuries has consistently remained at about double that of all other industries. There has long been compelling evidence that many safety risks are created in the early design stage of projects. Hence, it can be argued that one of the most effective means of dealing with a hazard is to eliminate it at source, that is, Prevention through Design (PtD). But until now the tools for effectively managing the links between design and safety on site have not been available. Building information modelling (BIM) is an emerging paradigm in the design and engineering field. BIM has been utilized quite extensively to simulate and optimize designs in view of feasibility studies and stakeholder concerns, value analysis, constructability analysis, sustainability analysis, site operational efficiency and site layout, and facilities management. These studies have confirmed that the utilization of BIM enhanced the optimization of the design to yield the best outcome at the design stage. Nonetheless, the potential of BIM for PtD is yet to be explored. This paper discusses the conceptual model of an 8D modelling tool for PtD.

Keywords: occupational health and safety, building information model.

INTRODUCTION

The construction industry's safety record has always been poor. It remains one of the most dangerous industries for operatives. The Australian construction industry employs approximately 5% of the Australian workforce but accounted for 9% of the workers' compensation claims (Dingsdag, Biggs and Sheahan, 2006). The construction industry has incidence rates substantially above the national rate of 14 per 1000 employees, ranging between 22 and 28, which is nearly double the national rate (ASCC, 2009). Furthermore, the construction industry recorded the highest number of fatalities; 50 fatalities per year, making a rate of 8 fatalities per 100 000 employees. This is more than triple the national average rate, which is equivalent to an incidence rate of 2.5 fatalities per 100 000 employees (ASCC, 2009). There is compelling evidence to suggest the decisions made by designers at the design stage of a facility can have significant implications on the safety of workers on site. Gibb, Haslam, Hide and Gyi (2004) conducted a detailed review of 100 construction accidents in the UK and reported that in 47 percent of cases, a design change would have at least reduced the risk of injury. Behm (2006) analysed 450 reports of construction workers' deaths and disabling injuries in the US and reported that in one-third of the cases, the risk that contributed to the incident could have been eliminated if design-for-safety measures have been implemented. In Australia, Creaser (2008) confirmed that 37% of workplace fatalities in construction had design related issues

[1] imriyas@unsw.edu.au

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involved, and design issues appeared to contribute to at least 30% of injuries. Hence, it can be argued that one of the most effective means of dealing with hazards is to eliminate them at the source, that is, Prevention through Design (PtD).

The "safe design" concept relies on designers to conduct a thorough risk assessment of each design component of the facility they design. This requires integrating construction process knowledge into the design. Cooke, Lingard and Blismas (2008) and Zarges and Giles (2008) argued that it is doubtful that construction designers are equipped to do this because occupational health and safety has not been well integrated into design curricula in tertiary institutions. Zou, Wilson and Adam (2009) confirmed this through a recent survey in Australia revealing that a majority of designers have no knowledge about the assessment of safety risk at design, and thus are not equipped to perform such tasks.

There are a number of design aids available to designers. The Construction Industry Institute (CII) of US developed over 400 design suggestions that could be used by designers. These design practices are incorporated into a computer design toolbox that can be purchased from CII. The Health and Safety Executive in the UK developed several documents that aid designers in designing for safety, which are available from their website. Safety professional in Australia developed a tool called Construction Hazard Assessment Implication Review (CHAIR), which aims at identifying risks in a design as soon as possible (Mroszczyk, 2008). The Australian Safety and Compensation Council (ASCC) published Guidance on the Principles of Safe Design for Work, and launched an educational package Safe Design for Engineering Students (ASCC, 2006 a and b). The package was designed to enable educators to incorporate examples of safe design, and the implications of not considering them. Cooke *et al.* (2008) developed a web-based knowledge-based system called ToolSHeD to help designers to assess the level of inherent risks in their design choices. The system prompts designers to enter information about relevant design features, and the data entered are then used to infer a risk rating, based upon a reasoning model. A risk report is generated as a system output, which advises the designer as to the level of risk and an explanation of the design factors contributing to this inferred level of risk. Hinze and Marini (2008) developed a similar system with an extended scope and data content. The system provides designers with direct access to hundreds of design for construction worker safety suggestions. However, the weakness of these design aids is that there is no direct active link between the risk knowledge held by the aids and the CAD model being developed by the designer. This makes it harder to analyse different design options, choose the best one, and make design changes effectively. Toole and Gambatese (2008) stressed that increased spatial investigations and considerations of designs can improve construction hazards prevention through design along a trajectory.

BIM is an emerging paradigm in the design and engineering fields that enables the creation of digital 3D models of buildings with embedded information about a project from design through to construction and into operation. It integrates information from disparate disciplines, combining these with a spatial 3D CAD platform to generate a digital representation of the physical and functional characteristics of a building design. It is more than just a 3D virtual model, but rather a repository of intelligent building objects with attributes and relationships, making it an effective vehicle for automated design decision-making. BIM has been utilized extensively to simulate performance and optimize designs in view of feasibility studies and stakeholder concerns, value analysis, constructability analysis, sustainability analysis, site layout for operational efficiency and facilities management (Whyte, 2002; Augebroe and Hensen, 2004; Onuma and Davis, 2006; Bendixen and Koch, 2007; Hartmann, Gao and Fischer, 2007; Azhar, Brown and Farooqui, 2008). All these studies confirm that the utilization of BIM technology can enhance the quality and efficiency of the various analyses and, as a result, the optimization of the design to yield the best outcome at the design stage of a project. Nonetheless, the potential of BIM for PtD is yet to be explored. Hence, the aim of this project is to research the possibility of a (3D+Safety) model analysis approach that enables designers to understand the safety consequences of their design decisions by automatically detecting and flagging safety risks as design progresses. This paper discusses the conceptual model of the proposed system. Firstly a literature review on PtD and BIM is provided followed by the conceptual model of the proposed system. Then a conclusion is drawn.

ACCIDENT PREVENTION THROUGH DESIGN (PTD)

The role of designer has traditionally been to design a facility such that it conforms to the accepted local building codes. The safety of construction workers is left up to the contractor. However, research shows that designers can have a strong influence on construction safety. The ability to influence construction safety versus time is depicted in Figure 1. As the curve shows, the ability to influence safety diminishes as the schedule moves from concept toward start-up. The ideal time to influence construction safety is during the inception, concept design and detailed design phases. In these phases, designers can influence construction safety by making better choices in the design stage of a project. This would result in fewer site decisions that have to be made by contractors. Hence, the notion of prevention through design (also known as safe design or designing for safety) transpires from this principle. By definition, prevention through design is a methodology applied to the various phases of the design process for identifying and mitigating risks and hazards that will be encountered by construction workers during the construction of the facility on site. This involves systematically identifying hazards and risks and introducing mitigating design solutions that will meet the design requirements as well as create a safe work environment for the workers. It also encompasses communicating to the contractor the remaining hazards and risks that could not be eliminated during design so that the contractor may plan for appropriate engineering controls to reduce their impacts (Furst, 2009).

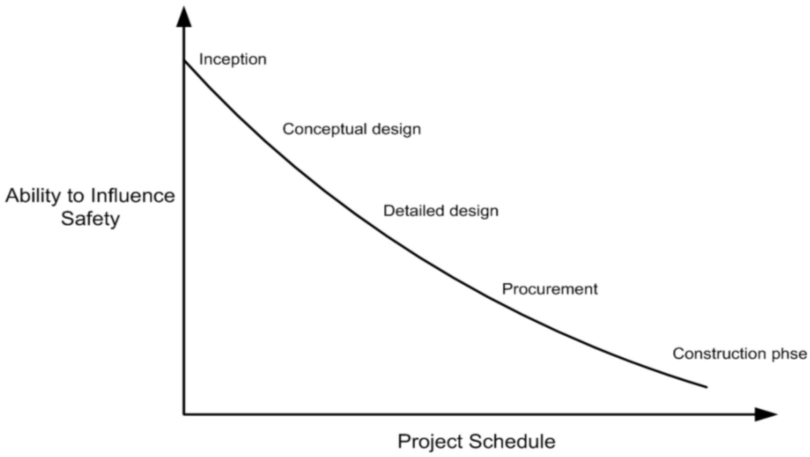

Figure 1: Project Schedule Vs Safety Influence Curve (Furst 2009 and Mroszczyk, 2008)

The key feature of PtD process is the input of site safety knowledge into design decisions. The type of knowledge that is critical to a successful PtD implementation in design organizations include.

- Construction methods of design elements and the risks faced by workers on site in the process of building the elements.
- Safe design suggestions for making design changes or incorporating safety devices in the design.
- On-site safety measures to eliminate or reduce the risks for hazards that could not be eliminated at the design stage.

BUILDING INFORMATION MODELLING

CAD systems have been used in the AEC industry for decades for designing facilities. These systems use geometric elements such as dots, lines and polygons to draw different elements and aspects of a facility and produced designs with no intelligence. This caused a major obstacle for: (1) design optimization, (2) integrated assessment and decision making, and (3) information exchange between different stakeholders such as architects, engineers, contractors and facility manager. The paradigm of building information modelling (BIM) was introduced to alleviate these bottlenecks. BIM enables the creation of virtual reality (3D) models of buildings with coordinated and reliable information about a project from design through construction and into operation. It integrates information from disparate disciplines, software and format, and combining these with a spatial 3D CAD platform and generates a digital representation of the physical and functional characteristics of a facility. It is not just a 3D virtual model but a repository of intelligent building objects with attributes that can understand the interaction between each other, and non-geometric data about the objects and the facility for decision-makings. A basic BIM includes.

1. The physical components of a building, such as walls, doors and windows, which are described and dimensioned by the phrases and methods of building design, construction and management instead of the CAD geometric elements such as dots, lines and polygons.
2. Information of construction and maintenance activities linked to the relevant building physical component.
3. The relationships among the building components and activities.

Software applications that create BIM models are developed based on a standard/specification called Industry Foundation Classes (IFC). IFC was developed by International Alliance for Interoperability (IAI) in EXPRESS language and it has been constantly updated. IFC enables the effective representation of integrated information in BIM models such as building elements, geometric and material properties, project costs, schedules and organization. Moreover, IFC supports interoperability among AEC software applications such that end-users can effectively share model data through IFC files, irrespective of the software application they use.

nD modelling

nD model is an extension of BIM, which incorporates multi-issues of design information generated and required throughout a building project lifecycle, such as accessibility, sustainability, energy savings, costing, crime-prevention, acoustic, thermal, etc.(Fu *et al.*, 2006). nD models enable users to see and simulate the whole life of a project and thereby help reduce the uncertainties in decision-making process and to realize true what-if analysis.

BIM has evolved to have its extensions such as 4D, 5D, 6D and 7D. 4D is a planning process to link the construction activities represented in time schedules with 3D models to develop a real-time graphical simulation of construction progress against time. Adding the 4th dimension “Time” offers an opportunity to evaluate the buildability and workflow planning of a project. Project participants can effectively visualize, analyse, and communicate problems regarding sequential, spatial and temporal aspects of construction progress. As a consequence, much more robust schedules, and site layout and logistic plans can be generated to improve productivity. Integrating the 5th dimension “cost” to the BIM model generates the 5D model, which enables the instant generation of cost budgets and genetic financial representations of the model against time. This reduces the time taken for quantity take-off and estimation from weeks to minutes, improves the accuracy of estimates, minimizes the incidents for disputes from ambiguities in CAD data, and allows cost consultants to spend more time on value improvement. 6D allows extending the BIM for facilities management. The core BIM model is a rich description of the building elements and engineering services that provides an integrated description for a building. This feature together with its geometry, relationships and property capabilities underpins its use as a facilities management database (CRC, 2007). Incorporating sustainability components to the BIM model generates 7D models, which enable designers to meet carbon targets for specific elements of the project and validate the design decisions accordingly or test and compare different options (Hardin, 2009). In summary, BIM allows designers more easily predict the performance of projects before they are built, respond to design changes faster, optimize designs with analyses, simulations and visualization, and deliver higher quality construction documentations. Furthermore, it enables extended teams to extract valuable data from the model to facilitate earlier decision making and more economical project delivery and facility management. On this note, safety can be regarded as one of the dimension in nD models and BIM can be extended to support PtD.

8D MODELLING FOR PTD.

PtD leveraging on BIM consists of three tasks: (1) hazard profiling of BIM model elements, (2) providing safe design suggestions for revising high hazard profiled elements, and (3) proposing on-site risk controls for hazards that are uncontrollable through design revisions. There are two central elements for this process, including IFC specifications for BIM models and a PtD knowledgebase that houses the following three sets of knowledge.

1. Hazard profiles of individual building elements with their risk intensities for various combinations of construction methods.
2. Safe design expertise.
3. On-site risk control expertise.

A schematic concept of 8D modelling for PtD is illustrated in Figure 2. The first step in PtD using BIM is hazard profiling of BIM model elements, which is carried out by integrating the IFC file of these elements and the PtD expertise in the PtD knowledgebase. In the second stage, high hazard rated elements will be recognized and safe design suggestions will be provided for design revisions. After the design has been revised for safety, a second set of suggestions will be provided for on-site control of risk that might transpire from hazards that were uncontrollable through design revisions.

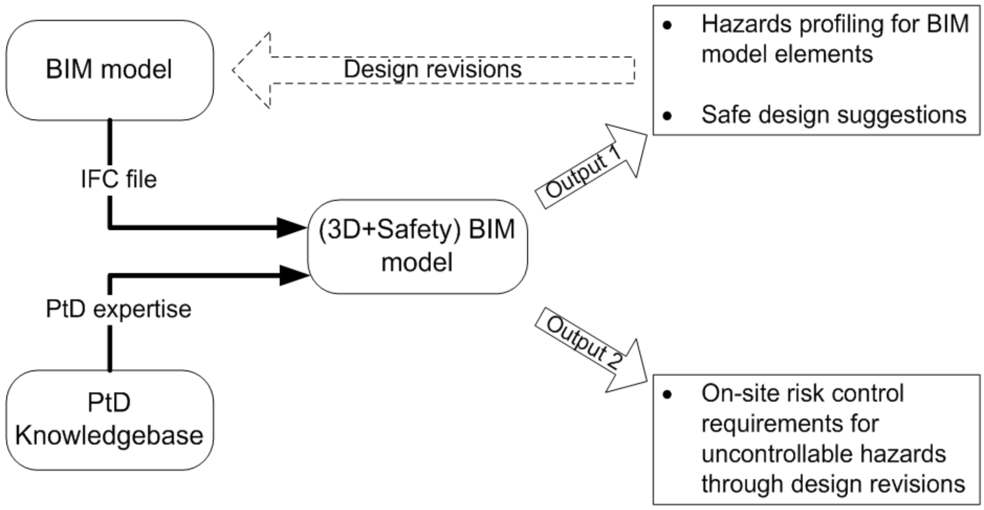

Figure 2: Framework for BIM-based PtD

SYSTEM ARCHITECTURE OF 8D MODELLING TOOL

Figure 3 illustrates the system architecture of an 8D modelling tool that translates the above conceptual framework for BIM-based PtD into a computer system. The system consists of.

1. An interface for importing IFC files of BIM models onto the PtD analysis platform.
2. A PtD knowledgebase that encompasses hazard profiles of building elements for different construction method combinations, safe design suggestions for hazardous elements and on-site hazard control suggestions for hazards that cannot be eliminated through design revisions.
3. A PtD analysis engine that automatically performs hazard audits on imported IFC files of BIM models.

When a BIM model is imported onto the PtD platform, the model information is saved in an IFC file format. The IFC file is then converted into an XML file format. Likewise, the PtD expertise in the knowledgebase is converted into an XML file of PtD knowledge. By using this method, XML extracted from IFC and XML extracted from PtD knowledgebase can be matched and hazard auditing on the building model can be performed in a neutral platform. Subsequently, the tool performs a mapping between model elements and PtD expertise and conduct a hazard audit on the model and produces three types of outputs.

1. Hazard profiles of elements with three levels of severity ratings: critical, moderate and low.
2. Design revision suggestions for elements that have been rated critical.
3. On-site hazard control suggestions for elements that have been rated moderate and for critical elements whose hazards could not be eliminated by design revisions.

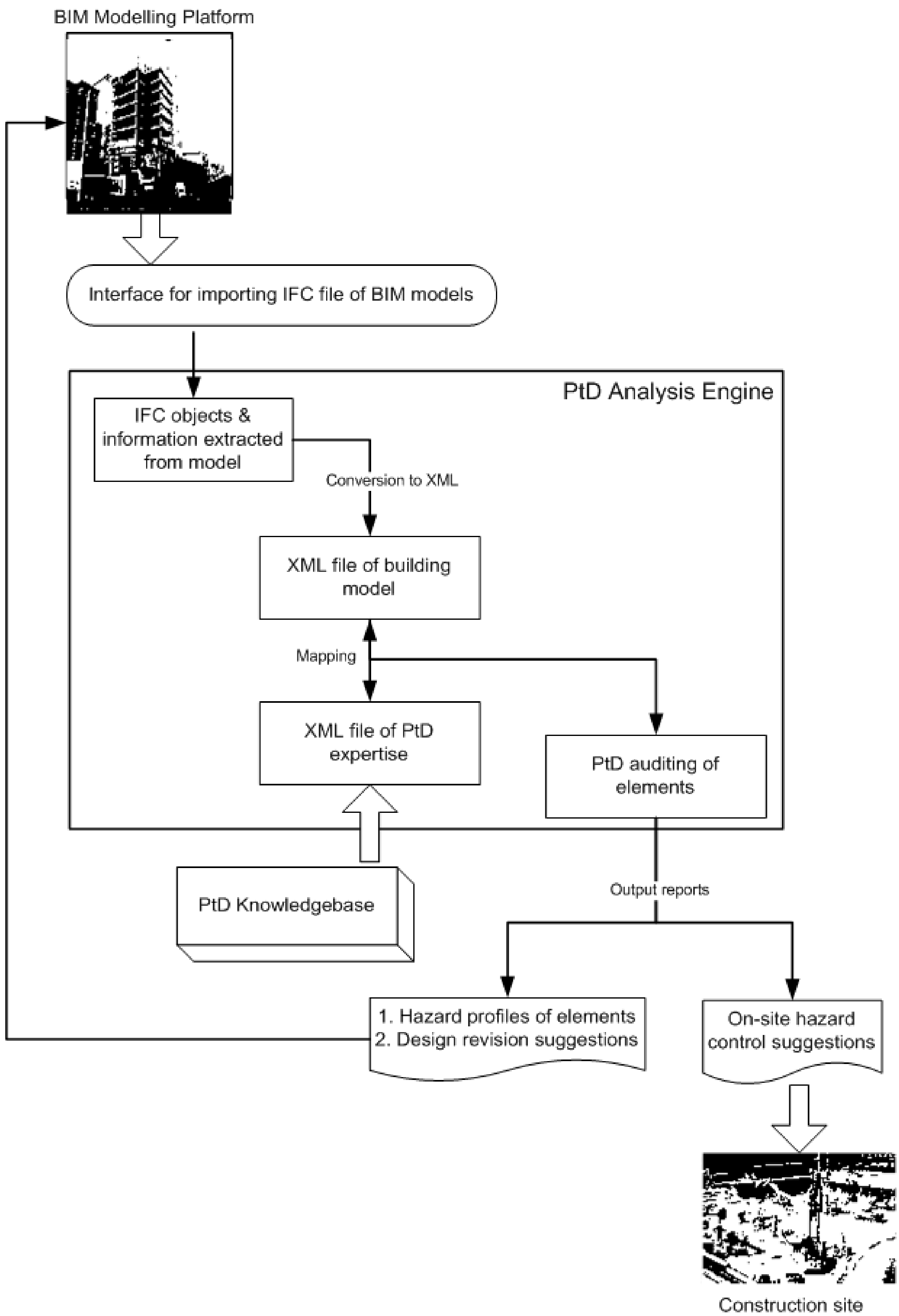

Figure 3: 8D modelling system architecture

CONCLUSION

The construction industry remains one of the most dangerous industries for employees. Accident Prevention-through-Design (PtD) is one of the most effective means of dealing with hazards. The PtD concept relies on designers to conduct a thorough risk assessment of each design component of the facility they design. Studies suggest designers are not equipped to do this due their limited knowledge about safety during construction. As a result, the successful implementation of PtD has been falling behind. The developing sophistication of building information modelling has created the opportunity for integrating multidisciplinary information in a single digital repository and thereby optimization of designs. This research aims at extending BIM for PtD to bridge the gap between design and occupational health and safety principles. To this end, the system architecture of an 8D modelling tool has been developed for BIM-based PtD. The tool would be able to perform hazard audits on BIM models and then produce hazard profiles for elements that would be rated with three levels of severity ratings; critical, moderate and low. The tool would also make suggestions for design revision for elements that have been rated critical and suggestions for on-site hazard control for elements that have been rated moderate. And, the on-site hazard control suggestions would be extended to critical elements whose hazards could not be eliminated by design revisions. The research is being continued to create a prototype of the proposed system and validate it in the industry.

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