BIM and OHS – Designer and Design Coordinator Adoption in the UK and Australia

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Abstract

Occupational Health and Safety (OHS) in the construction industry has attracted considerable interest in many countries over the years. During this period, Building Information Modelling (BIM) has emerged as an innovative evolution in a way the construction industry designs buildings. Concurrently the opportunities BIM presents have been widely touted as having the potential to significantly improve the ways in which designers engage with each other and thereby improve overall project outcomes. In the context of OHS, such collaboration has the potential to improve safe working conditions on site because designers are able to consider the implications of their designs on OHS in conference with others. A survey of UK designers shows that few use BIM on projects and can accurately define BIM. This paper reviews OHS legislation in the UK and Australia and explores the potential for BIM-enabled rule-checking systems to help identify and mitigate OHS risks.

Keywords

Collaboration, legislation, rule-checking.

INTRODUCTION

Occupational Health and Safety (OHS) in the construction industry has attracted considerable interest in many countries over the years. Although the incidence of injuries and fatalities is decreasing, the number of fatalities on construction sites remains high when compared to other industries in both the UK and Australia (SWA 2009; COSAS 2008). Reviews of construction accident data indicate that these are caused by the interaction of multiple factors (Reason 2000). One of the ways in which stakeholders have attempted to reduce accidents and fatalities is through OHS regulations. These are widely recognized as an effective method for controlling risks and reducing accident rates.

Concurrently Building Information Modelling (BIM) has emerged as an innovative evolution in the ways the construction industry designs, constructs and manages buildings (Pollock 2010). With some similarities to traditional 2D and 3D CAD technologies, BIM represents a combination of interactive policies, communicative processes and technological implementations, and provides a platform supporting project data from different disciplines in digital format (Babič *et al.*, 2010; Grilo and Jardim-Goncalves, 2010; Succar, 2009). Many industry-related and academic sources are at one in promoting the benefits of BIM. Numerous articles in the construction press

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(Hurst, 2012; Pitt, 2011; Fitzpatrick, 2012) as well as industry reports, academic journal papers and conference papers refer to the potential of these technologies to revolutionise the ways in which the construction industry conducts its business. Some of the benefits are seen to include clash detection, reducing the cost of changes, clearer scheduling and swifter fabrication of components (Nisbet and Dinesen, 2010). Not only does BIM have the potential to improve the efficiency and productivity with which buildings are designed, constructed and managed, it provides opportunities for a multitude of new applications to be developed.

However, the facilities provided by BIM are frequently flaunted as all encompassing and this raises concerns for its sensible deployment in the short term. The Gartner Hype Cycle (Fenn and Raskino, 2008) describes this as the peak of inflated expectations that is not uncommon in innovations (Figure 1). This paper investigates the contributions that BIM can make to OHS.

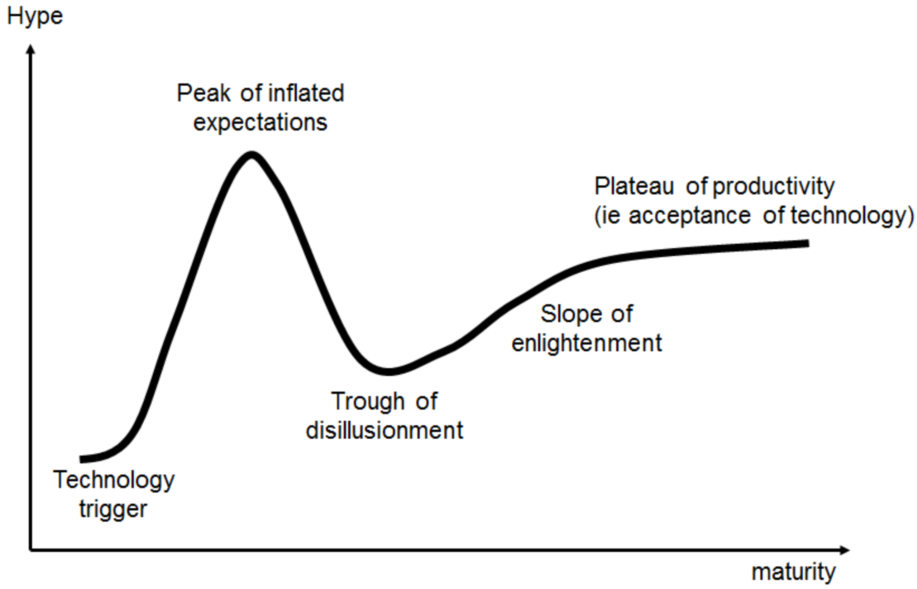

Figure 1. Gartner Hype Cycle (adapted from Fenn & Raskino 2008)

LEGISLATION TO DESIGN OUT HAZARDS DURING CONSTRUCTION

Reason (2000) argues that regulation contributes to reducing accident rates so it is pertinent to briefly contrast OHS legislation in UK and in Australia. The UK OHS regulations articulate the responsibilities for construction safety design on project members comprising architects, engineers, contractors and so on. Project managers as well as all team members have responsibilities to contribute to controlling risks and preventing hazards. However, the responsibilities of construction safety design are not evenly distributed within disciplines in many cases. In the UK the CDM regulations, based on a European Directive were introduced in 1994 and revised in 2007. In Australia the most frequent cause of fatalities on construction site include (1) chemical exposure, (2) vehicle accidents, and (3) falls at height and contact with electricity (SWA 2009; COSAS 2008). With a focus on all possible hazards, Safe Work Australia, an Australian Government statutory agency, has provided twelve codes to guide risk control. These codes of practice have been endorsed by Safe Work Australia members and can be categorized into three main topics:

Structural issues: Historical data indicates that many fatalities have been caused by falls from roofs with complex and steep geometry, as well as from scaffolding that has been unsatisfactorily erected and maintained.

Behavior issues: Including mindlessness, disobedience, poor concentration on moving vehicles and on people in the proximity of construction machinery.

Surrounding issues: Many injuries have been found to be caused by human negligence. Examples include surfaces that are either slippery or present trip hazards, disorderly traffic arrangements as well as a poor management of materials and equipment storage.

The two broad forms of legislation that cover the safety of construction stakeholders in Australia are the Occupational Health and Safety Act that covers all industries with specific clauses adapted to the safety of workers engaged within the construction industry, and the Building Code of Australia (BCA) that is within the National Construction Code (NCC) (Australian Building Codes Board 2010). This code is administered by differing State Acts of Parliament such as In NSW it is adopted under the Environment, Planning and Assessment Act. Vol.1 of the BCA deals with commercial construction by describing objectives, functions and performance requirements, whereas Vol. 2 is prescriptive and deals with residential housing and ancillary structures. These documents set out the requirements for the safe design of buildings but in contrast to the UK CDM regulations, do not address the processes by which contractors erect the said structures. Change to OHS legislation is being considered and Bluff (2003) presents a comprehensive picture of how CDM and Recent European legislation could be used to strengthen OHS legislation in Australia. This is succinctly summarised in her conclusions as follows:

> “There is a sound rationale for extending the OHS statutes and regulations to those responsible for key decisions in the design and planning phase, whether as clients or as designers. The regulatory regime proposed in this paper is designed to engage those with real control and influence in the design and planning phase in OHS risk management, with the aim of enhancing OHS for workers in the construction phase, in maintenance and repair, and in end use and occupancy. The proposals are action oriented, rather than documentation based, and address the real need to develop the knowledge, capacity and motivation of the proposed duty holders. These are areas of weakness which, with the benefit of hindsight, are clearly apparent in the European (and UK) approach to regulating OHS in construction works.” (p. 28)

The implementation of BIM is currently attracting considerable interest in Australia. Should legislation similar to the UK’s CDM regulations be implemented in Australia it is likely that BIM data will be harnessed in various ways in attempts to improve OHS. BIM should help designers to consider and evaluate multiple construction approaches and techniques and it is likely that international precedent will inform its application in Australia. However, the uptake and effective usage of BIM in Australia still has some way to go before it becomes widespread. Some of the factors inhibiting its application are described in the next section.

BIM INHIBITORS

BIM presents opportunities for construction professionals from multiple disciplines to work collaboratively when preparing their designs. These opportunities have been widely touted as having the potential to significantly improve the ways in which designers engage with each other and thereby to improve overall project outcomes (Azhar *et al.*

2008; Arayici *et al.* 2011). In the context of OHS, such collaboration has the potential to improve safe working conditions on site because designers are able to consider the implications of their designs on OHS in conference with others. However, a key enabler is collaboration and this is not dependent on BIM. Indeed, BIM could be currently viewed as an inhibitor of such interactions because so few design professionals have developed their BIM skills, abilities and working practices to the stage where they are able to focus on aspects such as OHS.

Designers and organisations need to develop and mature their BIM skills and competencies before they are able to collaborate effectively. Succar's BIM maturity matrix (2010) identifies five stages which organizations need to progress through before they are able to collaborate effectively in multi-disciplinary environments. Organisations need to develop their employees' skills and abilities, establish protocols for individual and collaborative working as well as procure and install the requisite hardware and software. This does not infer that such expertise will not eventually be developed – rather it emphasizes the current state of BIM implementation both in Australia and UK where there are currently few examples of multi-disciplinary activities.

In a recent survey Gibb found that very few designers in the UK have any meaningful experience of BIM (7 percent) and many have never even heard of it (24 percent) (Figure 2) despite 64 percent having more than 20 years' experience and 22 percent between 11 and 20 years. This survey will be covered in more detail in a paper to be submitted to the CIB World Congress in 2013.

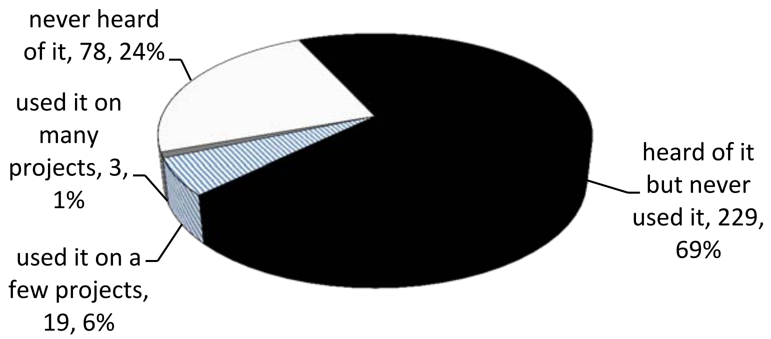

Figure 2. Survey of UK designers' experience of BIM (n=329)

When asked for definitions of BIM in their own words, only 52 (16 percent) gave a reasonably accurate definition, with 35 (11 percent) merely restating the basic words (Building Information Modelling), 110 (33 percent) not offering a definition at all and 34 (10 percent) making plainly incorrect assumptions. 32 respondents included the factor of sharing information and 57 mentioned coordination or integration of information from different project team members.

Notwithstanding the lack of designers' BIM skills and the BIM maturity of the organizations they represent, the manner in which construction projects are procured presents further barriers to effective collaboration. By implication, this brings into question the usefulness of BIM as a technology that will significantly improve OHS. Zhou, Whyte and Sacks' (2012) comprehensive review of the ways in which designers might consider / accommodate OHS is succinct and informative in this regard. They observe that

> "… the prevalence of traditional design-bid build contracting arrangements and the resulting complex hierarchy of subcontracting on any modern building create a significant organizational distance between designers in any domain and the

> relevant subcontractors who will actually perform the work. Coupled with designers' aversion to dictating means and methods due to liability concerns, there is still significant reluctance on the part of designers to take an active role in addressing construction safety. There are significant challenges in implementing these actions, even in new forms of procurement where designers and contractors do work more closely together, and concerns that changes in design are often only implemented as attempts to protect the designer from liability rather than to effect any real change in design to support safety´ (p. 104).

It is therefore clear that significant progress needs to be made before BIM can be seen as an effective OHS enabler. This is not to decry the contributions of those researching BIM. Their contributions are valuable is showcasing the various routes that may be considered. Some of these are described in the next section.

BIM-RELATED OHS APPLICATIONS

Zhou, Whyte and Sacks' (2012) note that BIM is one of several tools that can be used to assist in improving OHS. With respect to BIM, the clear message that emerges from their work is that stand-alone BIM has limited value. Simply accessing virtual spaces to identify and evaluate possible hazards presents limited benefits. The dynamic nature of construction necessitates a consideration of time. Zhou et al argue that 4D BIM is necessary to be able to evaluate hazards in a meaningful way. This extends the aforementioned list of BIM competencies required of design professionals. Zhou et al observe that the application of BIM to OHS still has a long way to go. An approach that has recently attracted attention is that of developing new software tools that can check BIM models against OHS regulations. This has the potential to improve risk assessments and hazard identification during the design process. To date few rule-checking software applications have been developed for construction safety. In addition to improving construction safety by manual checking against statutory regulations, building technologies incorporating rule-checking have the potential to minimize the accident rates in construction safety during the early design stage (Szymberski 1997).

The remainder of this paper reviews previous studies related to rule-checking systems and OHS regulations in the UK and Australia, and generalizes the requirements of rule-checking to inform the development of BIM technologies that support construction safety.

CURRENT RULE-CHECKING SYSTEMS IN OHS

Construction sites involve the frequent movement of resources from place to place. Workers, equipment, and materials may be transported from one location to another resulting in diversified and dangerous conditions. The intention of a construction safety code checking system is directed at analyzing hazards, identify hazardous locations and provide suggestions and solutions – all in virtual interactive environments. The theoretical framework of a rule-checking system comprises three main elements: (1) an interpretation of OHS regulations; (2) BIM models in specific / universal format, and (3) schedule information of workforce, equipment, material and so on (Zhang *et al.* In Press).

Checking rules that integrate OHS regulations and best practices can be applied within a building modelling tool (for example the ArchiCAD, Revit and etc.) or can be a dependent system through the use of a universal format (such as the IFC format). Moreover, such systems can provide visual suggestions and solutions along with measures of cost and schedule performance.

Additionally, rule-checking systems require facilities that generate warning as well as guidance to users about potential hazards to construction workers. A goal of rule-checking using BIM is to assist the decision-making process in the safety planning and scheduling stages. The history of determinate actions can be recorded in a database, offering empirical references or suggestions for future projects. The results will not only help safety managers identify and control risks in their safety planning and construction stages – it will provide suggestions to all stakeholders during the design phase. However, examples of existing BIM-enabled rule-checking system for construction safety appear to be limited to "working on height" or "fall hazards". Little has been accomplished to develop systems that address OHS holistically. The following sections introduce some of the rule-checking systems currently available and analyze their checking process, requirements and limitations.

System#1 – Rule-Based Safety Checking System (Zhang et al. In Press): Detections of fall hazards in this checking system are holes in slabs, unprotected edges on a floor, and openings in walls. Four steps were processed in this rule-checking system: (1) Defining a specific area that may cause a fall hazard, identifying slab, roof, and walls as the target objects from the digital model; (2) Corresponding rules are executed and visualized for supporting decision-making, showing a protection method in the detected area; (3) Detailed information of the prevention system is provided. The checking results are shown in a visualized BIM model, and (4) Additional information (such as the cost of equipment and the schedule for installation and removal) related to decision-making is also provided. In terms of the BIM file format, this checking system is only specific to Tekla software.

System#2 – Mantylinna project (Sulankivi et al. 2010): The checking process of the Mantylinna project is similar to the previous system. However, the BIM modelling process is different as the digital surface of the site was built in ArchiCAD and combined into Tekla software. The core tools supporting BIM in the construction phase are called "model organizers", "task managers", and "project visualization". This study focused on 4D fall protection planning, especially for scheduling and visualization of safety railings. Corresponding erection of precast elements and railings were created and entered into the task manager tool. This checking system incorporates a schedule of tasks and corresponding parts and suitable visualization rules for analysis. It can provide the timing of construction activities as well. In order to provide visualizations of safety protection, a component library was set up by creating custom components for the Tekla software.

System#3 – Construction Safety Checking System (Qi et al. 2011): This construction safety checking system is mainly targeted at eliminating potential fall hazards. It was developed from 30 best practices which were categorized into the following two topics: (1) precise parameters and certain materials from BIM models, such as window sills to be 42 inches (1066mm) above the floor; (2) Information not given by BIM, or only in actual existing buildings, or in the mind of inspectors, such as the consideration of anchor points. Two main components of this checking system are called "Dictionary" and "Constraint Model" and needed to be developed in this model checking system. The "Dictionary" module comprises terms, objects, properties critical for communication between the Model Checking System, BIM tools and the Constraint models. The "Constraint Model" is a set of rules in electronic format designed to provide safety suggestions. The purpose of this system is to check the BIM model in Industry Foundation Class (IFC) format. After the checking process, two types of results are shown: the identified hazards with detailed suggestions and the detection locations shown in BIM models.

Comparison of Rule-checking Systems: The classification of the rule-checking systems listed above (and summarized in Table. 1) are all specific to "fall hazards" with little consideration for overall problems related to OHS regulations. Although the aforementioned systems addressed effective ways of checking for fall hazards, the types of hazards they identified are different. In addition to integrating OHS regulations and best practices as the criteria, they provided potential to incorporate "Schedule" and "Component Library" factors into the checking system. The component of "Schedule" can be applied to suggest predictions of cost, equipment as well as the engagement and removal of workers. The "Component Library" is beneficial in defining specialized components that meet the requirements of specific or individual areas.

While only one of these checking systems adopts IFC as their BIM format, the others are specific to discrete BIM software and lack transitional interpretation tools. Using a specific BIM file format will restrict use of this BIM tool, decreasing the opportunities for further development in collaboration with other BIM tools. Furthermore, several aspects that can be improved in the rule-checking systems include: (1) providing an analysis of suggested construction solutions; (2) providing multiple solutions for checking results; (3) recording the manner in which decisions have been made in a database for future reference, and (4) analyzing BIM models against rules based on time schedules.

Table 1. Comparison of rule-checking systems

System/Project	#1 - Rule-based safety checking system	#2 - Mantylinna Buildings	#3 - Construction Safety Checking System
Approach	Rule-based	Visualization	Object-based rule
Rule sources	OHS regulations, Best practices	OHS Regulations	OHS regulations, Best practices
BIM software	Tekla	Tekla (with partly ArchiCAD)	Universal Format – IFC
Conditions	Fall hazards (Holes in Slab, roof, and walls)	Fall hazards (Railings)	Fall hazards (Windows and Roof)
Additional Extensions	Schedule	Component Library	

THE REQUIREMENTS OF BIM IN OHS DESIGN

To successfully develop rule-checking systems that exploit BIM data, project stakeholders need to transfer and integrate their compartmentalized working practices into a coherent collaborative platform through the use of BIM. BIM data can theoretically provide sufficient information to respond to enable rule-checking systems, though in practice BIM models may not provide the required information. This research, therefore, identifies the requirements of BIM models and rule-checking systems. These aspects are discussed below.

REQUIREMENTS OF BIM MODELS

Structural Design: Risks that arise from unsatisfactory designs and structures are unacceptable. Given detailed structural designs of buildings in a BIM model (such as angle of roof, layers of scaffolding etc.) hazards can be detected using rule-checking systems before the commencement of construction works.

Behavior Design: Risks resulting from human behaviors are mostly due to a lack of awareness in construction safety caused by insufficient training. Although human behavior that comprises a combination of training, thinking and decision-making is unpredictable, occupational education and training using BIM model simulations has the potential to improve workers' awareness and decision-making processes.

Surrounding Design: In addition to enhancing the awareness of personnel's "mindfulness" to OHS risks, site plan and schedule information in BIM models provide the potential to improve traffic design, as well as the arrangement of materials and equipment prior to commencing construction.

REQUIREMENTS OF RULE-CHECKING SYSTEMS

Interpretation: Since model and information exchanges are inevitable between different project stakeholders and during different project phases, several initiatives have highlighted the creation of rules and mapped various aspects of descriptive information of digital models in these rules to international building model schema. This schema has been established to support the needs of international BIM users and considers differences between information descriptions. A rule interpretation facility is required to accept mappings disparate descriptions between the concepts in real practice and the IFC schema. For example, a water closet is a well-known description in the UK and Australia while it is represented as a "sanitary flow inlet" in IFC schemas (Greenwood et al. 2010).

Independence: Current BIM tools are designed to support international building projects and their stakeholders and are not specific to individual areas or countries. In contrast, rule-checking systems are specialized for one region or country according to local regulations. For example, the regulations of England, Scotland, Wales, and North Ireland in the UK are different, as are those of Queensland, New South Wales, Southern Australia and Western Australia in Australia.

Expansion: With the gradual development of OHS regulations, both BIM technology and rule-checking software needs capacity to add and subtract the regulative modifications, and automatically adapt to the latest regulative information. Best practices for numerous safety protections need to be collected to provide multiple solutions in BIM OHS databases.

CHALLENGES FOR RULE-CHECKING SYSTEMS

In the UK risk elimination or mitigation is not solely based on applying rules as most of the legislation is of a framework nature requiring assessment, judgment and appropriate implementation. Therefore, the application of rule-checking systems may be problematic in this context. One of the leading guidance documents in the UK is the BuildingSmart Report (2011) which introduces health and safety under the context of rules and regulations alongside planning and building regulations approvals. This reflects the roots of this approach in US construction custom and practice. Therefore, in the UK, an important consideration is that, with data connected to objects, some/many designers seem to simply download ALL the OHS data, most of which covers generic issues like COSHH (Control of Substances Hazardous to Health). This does little to facilitate the careful consideration of residual hazards that would not be obvious to a competent contractor (which is the underlying philosophy of CDM) – i.e. real risk assessment may be lost in a deluge of easily downloaded 'guff' on basic, materials-based, OHS data.

Within the UK CDM context there would seem to be some opportunities to use BIM to improve OHS, in particular to develop BIM layers to cover:

- designing out hazards;
- presenting significant residual risks;
- planning out hazards (in pre-construction planning); and
- presenting significant residual risks.

CONCLUSION

This paper provides an overview of some BIM-enabled rule-checking systems that are currently available, identifying the requirements of BIM tools in OHS regulations and rule-checking systems. Not only does a rule-checking system in construction safety using BIM have potential to transfer safety knowledge in experience and regulations by developing an empirical database, it has scope for safety training for designers, and interactions among designers, engineers, contractors and other project stakeholders during the design process.

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