

2018-05-25

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### Recommended Citation

TUDublin, BIM and Coote, Ray, "Assessing the Synthesis of BIM Technology and Irish Construction Sector Health and Safety: Using 3D Immersive Environments to Improve Awareness of Risks and Hazards on Building Sites" (2018). *Capstone Reports*. 12.  
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# Assessing the Synthesis of BIM Technology and Irish Construction Sector Health and Safety: Using 3d Immersive Environments to Improve Awareness of Risks and Hazards on Building Sites

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## Abstract

Ireland is currently on an upward slope in a boom period in the construction industry and it is inevitable that workforce numbers will increase. A new approach at engaging field workers in health & safety awareness is critical to maintaining the downward trajectory in fatality and accidents, as the numbers employed in the construction industry increase.

As modelling software use in design development and delivery becomes more prevalent, it enhances the designer's ability to anticipate, spot and foresee hazards and risks in the design.

The hypothesis of this paper is that the use of Building Information Modelling (BIM) can increase the awareness of construction workers to site risks and educate them on Health and Safety (H+S). In creating an immersive 3d model experience with embedded or linked H+S regulatory information, codes of practice and general Health and Safety Authority (HSA) guidance, it is purposed that individuals can engage with a virtual environment containing simulated hazards and guidance on the control or mitigation of these hazards. This 3d environment will be referred to as the H+S BIM Module (HSBIMM) in this document.

The framework for implementation of the HSBIMM is founded upon the critical review of the standard theories and inherent assumptions contained within existing peer reviewed literature. This study is a step forward in linking BIM and Irish H+S standards. The mixed methodology used shows simplistic methods for development of a strategy for use in H+S that benefits greatly by BIM incorporation.

*Keywords* – Health and Safety, BIM, Construction

## 1 Introduction

*“...consider how health and safety information might be included in a building information model...the potential benefits in improved health and safety, by reducing accidents and deaths are so great as to be almost unquantifiable.”*

(Mordue & Finch, 2014)

### 1.1 Introduction

The Health and Safety Authority of Ireland rates the construction industry as the second most dangerous sector to work in (HSA, 2016). It is necessary to highlight the statistics relating to the number of fatalities and injuries sustained at work in this sector – see tables 1 and 2. These statistics have always been a matter of concern for the Irish Government (McDonald & Hrymak, 2002) and more recent studies note that these worries remain (Russell, Maître, & Watson, 2015). Health and Safety (H+S) initiatives from Government, and private agencies involved in this industry, are necessary to influence these statistics positively (The Health and Safety Authority, 2016; O'Reilly, Olomolaiye, Tyler, & Orr, 1994).

Table 1 – fatalities in construction 2008-2017

Number of fatalities										total
2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	
15	10	6	6	8	11	8	11	9	6	90

Table 2 – fatalities in construction 1998-2007

Number of fatalities										total
1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	
22	18	18	18	21	20	16	23	13	18	187

Initiatives such as, Safepass, the Construction Skills Certifications Scheme (CSCS), Safety Representative Facilitation Programme (SRFP), the National Irish Safety Organisation (NISO) and increased Health and Safety Authority (HSA) Inspections all combine in a positive way (Agency, 1996; HSA, 2016) and it has been argued in the past that the general decrease in fatalities is in part accredited to these initiatives (DKM, 2004).

Non-fatal injury statistics for construction sites are also a poor indictment of the sector as a safe place to work. In 2007, at the peak of the Irish construction boom, 1,558 injuries were recorded among construction workers by the HSA. For the period 2004-2008 construction injuries accounted for at least a fifth of all injuries recorded by the HSA (Russell et al., 2015). In 2015 during the economic downturn this number had decreased to 603. “Boom

and bust” economic periods can be seen to influence statistics. Ireland is currently on an upward slope in a boom period and it is inevitable that workforce numbers will increase. It can be inferred that the number of accidents and incidents will also increase. Currently there are upwards of 147,000 people employed in the construction industry in comparison to just over 100,000 in 2012. In 2007 this figure was upward of 270,000 (Central Statistics Office, 2017).

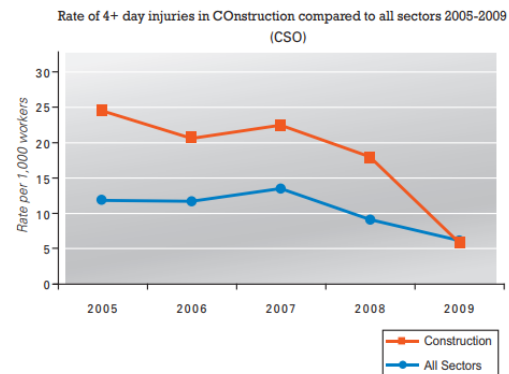


Figure 1 – Injury rate statistics

The HSA advocates the anticipation of risk. The Summary of Key Duties under the Procurement, Design and Site Management Requirements of the Safety Health and Welfare at Work (Construction) Regulations 2013 notes that designers should identify foreseeable risks (HSA, 2013). A client is obligated to employ a Project Supervisor for the Design Process (PSDP) and Project Supervisor for the Construction Stage (PSCS), two key roles in the administration of H+S (Government Publications Office, 2013).

As modelling software use in design development and delivery increases, it enhances the designer's ability to anticipate, spot and foresee hazards and risks in the design (BSi, 2017). A variety of applications can be used by designers and construction experts which enable locations to be accurately visualized, sequences and activities to be realistically demonstrated and construction programmes simulated. Use of these applications can aid in displaying and addressing H+S concerns (Azhar, 2017).

The hypothesis of this paper is that the use of Building Information Modelling (BIM) can increase the awareness of construction workers to site risks and educate them on H+S. An immersive 3d model experience with embedded and linked regulatory information, codes of practice and general HSA guidance will be created. It is purposed that individuals will engage in this virtual environment containing simulated hazards and guidance on the control or mitigation of these hazards. This 3d environment will be referred to as the H+S BIM Module (HSBIMM) in this document.

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## 1.2 Scope

The adoption of the HSBIMM into current Company H+S processes and procedures will be proposed and analysed. To complete this, a quantitative method of testing and gathering of result data from use of the HSBIMM will be undertaken. Along with this, a qualitative analysis of information retrieved by using a mix of questionnaires and semi-structured interviews with construction professionals within The Company regarding BIM and H+S will be carried out.

## 1.3 Background

The Company which will be the test-bed for this study has a family orientated philosophy regarding staff. The safety and wellbeing of everyone is paramount. The company strives to attain H+S excellence. It has attained accreditations and awards such as ISO 45001-2018 Occupational Health and Safety Management Systems certification (NSAI, 2018). The Company sends a clear signal to stakeholders that employee's health and safety is recognised as a priority within the Company.

Within the past three years BIM has become a core feature in many of the Companies departments, from business development through to contract management. The H+S department has not yet benefitted from the use of BIM and this gap will be addressed through this research. The following literature review will address the key elements of the research topic. The framework for implementation of the HSBIMM will be founded upon the critical review of the standard theories and inherent assumptions contained within the reviewed literature, and on the analysis of the literature. A further analysis of the application of Irish Construction specific agendas and initiatives will be explored.

## 1.4 Aims and Objectives

### 1.4.1 Aims and research question

The overall aim of this research is to create a platform for further educating the personnel within the Company on construction site risk, hazard identification and site awareness. The question to be answered is "Can the implementation of BIM technologies in the field of H+S help raise awareness of construction site personnel to site risk and safety rules, guidelines and regulations?"

### 1.4.2 Objectives

The objectives of this Capstone are 3-fold:

1. Analyse current Health and Safety standards, codes of practice and legislation along with safety management practice and identify the critical issues on construction sites. Map the standards to appropriate BIM activities and tools suitable to address the perceived risks and problems.

2. Develop a prototype interactive enhanced 3d Health and Safety site scenario – The HSBIMM- incorporating Irish Safety standard legislation, codes of practice, and guidance documentation dynamically linked within the model.
3. Evaluate the perceived benefits or otherwise of the HSBIMM, with emphasis on model content, knowledge gains from model interaction and potential for integration into company processes and procedures.

## 1.5 Introduction

This literature review focuses on key aspects of the subject matter to address the objectives of this capstone and its subtopics. The processes involved in construction safety management practice along with associated legislative requirements, standards and guidelines are discussed. This is followed by reviews of innovative initiatives in the field of H+S. Finally, the utilisation of BIM for risk assessment and hazard identification is reviewed.

## 1.6 Construction Safety management

BIM can only act as a bit player within a vast array of H+S legislative requirements, standards, and guidelines. A brief review of a number of these standards is covered in this section from a national and international perspective. Currently, ISO 45001 is the International standard being adopted in Ireland, only recently becoming the standard in April 2018. Up until then, OHSAS 18001:2007 had been utilized.

ISO 45001:2018, Occupational health and safety management systems - is the world's first International Standard for occupational health and safety (OH&S). It provides a framework to increase safety, reduce workplace risks and enhance health and well-being at work, enabling an organisation to proactively improve its OH&S performance (ISO, 2018).

OHSAS 18001:2007 and accompanying OHSAS 18002, note that occupational H+S is based on the following 3 criteria: Hazard identification, Risk assessment and the determination of applicable controls. In order to achieve an effective H+S system it is vital for organizations to handle these 3 criteria with greater significance (NSAI, 2007).

BS 8800 is a standard available to help organizations develop a framework for managing OH&S so employees and others, whose health and safety might be affected by the organisation's activities, are adequately protected. The standard contains guidance on: promoting an effective H+S management system, hazardous event investigation, and, risk assessment and control integration with other management systems (Mahmoudi, Ghasemi, Mohammadfam, & Soleimani, 2014).

The International Labor Office (ILO) guidelines ILO-OSH 2001 on OS&H management systems have been developed according to

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internationally agreed principles (ILO, 2001). The ILO has developed these voluntary guidelines which are tailored to address industry sectors. Article 2.3 in their guidelines reference the construction sector directly (Niu, 2010).

In the UK the Health and Safety Executive (HSE) guideline document is HS(G)65 entitled Managing for Health and Safety. Like ISO 45001, HS(G)65 can be audited for compliance and has achieved a certain level of international adoption.

In the US, the Occupational Safety and Health Administration (OSHA) is the federal government agency working to improve safety and health at work. The OSHA is directed by the US Department of Labor. Part 1926 of the OSHA regulations (Standard-29 CFR) is specific to the construction sector.

A method of rating H+S, the TR method - Introduced in Finland in 1992, uses behavior and condition based observations to calculate the likelihood of an accident occurring (Laitinen, Marjamäki, & Päiväranta, 1999). The observed safety aspects are: working habits, scaffolding and ladders, machines and equipment, protection against falling, lighting and electricity, and order and tidiness.

Recurring themes such as the “plan, do, check, act” approach, and specific focus in “designing out risk”, are relevant in each of the examples discussed above. This shows an alignment of thought regarding H+S internationally.

### 1.7 H+S innovations and Initiatives

Innovative change is driven by the speed at which technologies are deployed, and in order to stay relevant, you need to find ways to be nimble and look at technological advancement as fast as it comes (Hardin & McCool, 2015). Innovation is defined as the generation, adoption, and implementation of new ideas (J. E. Weidman, Dickerson, & Koebel, 2016). To foster a change to traditional H+S methods and practices in the construction sector, initiatives for innovation have been developed locally, internationally and on a global scale.

The UK based BIM 4 Health & Safety Working Group was established in 2015 by the HSE Construction Division. Its aim was to investigate the possibility of improving H+S outcomes using BIM, and to share information about hazards and risks. They concluded that BIM, properly applied, helps Construction Design and Management (CDM) duty holders to meet their responsibilities. (Health and Safety Executive UK, 2017).

To address the aforementioned, PAS1192.6 “Specification for collaborative sharing and use of structured hazard and risk information for Health and Safety” has been developed, and sets out to bridge the gap between traditional risk management processes and new digital processes (including BIM). The PAS explains how H+S information can

be identified, shared, and used by all members of the construction process (BSi, 2017).

The European Week for Safety and Health at Work week 2004 campaign was designed to help all stakeholders in the industry build a safer, healthier and more productive working environment (Building in Safety, 2004). Run by the European Agency for Safety and Health at Work, they initiated the Bilbao Declaration in 31 countries during that week. During the event safety awards were distributed for innovative ideas and one went to the “Silent Book”. A Swedish construction firm, NCC Group, derived this as a company initiative –simply put, it is a document that uses clear pictures to show how work can be performed safely on construction sites. Regarded as a preventive approach to work safety, The Silent Book provides information to everyone, including those that do not speak the language of the country they live in, and for anyone who may have reading difficulties (European week for safety and health at work, 2004). In a study by Clevenger, Puerto and Glick (2014) a BIM-enabled 3D visualization with the specific purpose of addressing communication of a mixed nationality workforce was developed.

In the U.S, The New York City Department of Building developed an initiative entitled Building Information Modeling Site Safety Submission Guidelines and Standards (BIM MANUAL) (NYC Building Department, 2013). The program enables the NYC safety department to virtually tour sites, see step-by-step how a building will be built, readily visualise its complexities and challenges, and run tools to check for basic code compliance prior to manual review.

The National Institute for Occupational Safety and Health (NIOSH) Prevention through Design (PtD) Initiative program focuses on preventing illness, injury, and fatality by “designing out” occupational hazards and risks (NIOSH, 2016). Research has highlighted the usefulness of this technique (Gangoellis, Casals, Forcada, Roca, & Fuertes, 2010). Technology to increase construction firm adoption of the PtD initiative is discussed in research by Weidman, Dickerson, & Koebel (2015). Hadikusumo & Rowlinson (2004) describe a “Design for safety Process Tool” which aimed to; capture tacit safety knowledge from safety engineers relating to construction safety hazards and the safety measures required; assist safety engineers to identify safety hazards in construction projects and determine the safety measures required; and train students and inexperienced safety engineers in identifying safety hazards and apply mitigating measures.

The “Design for construction safety toolbox” as proposed in research by Gambatese, Hinze, & Haas (1997) involved the team searching for, collating and developing design suggestions that would reduce or eliminate safety hazards. Tacit



knowledge from workers experiences along with implicit knowledge in existing documentation was combined in a data base that was developed into a web-based browser, so information could be sourced by construction personnel in the U.S. The principal behind this research can be seen in a similar design tool provided by the HSA – the “BeSMART.ie” risk assessment delivery tool.

### 1.8 Risk analysis, accident reports and control safety system

There is a need to ensure that all safety risks are assessed, that action is taken before commencing a project and that continual safety assessments are carried out during the project (O'Reilly et al., 1994). Where risks are traditionally annotated on drawings and added manually to a register, BIM can help capture risks, and manage them in a more convenient digital way (Cousins, 2016). Ding et al (2016) propose a framework for a construction risk management and knowledge base, where risk knowledge is stored in a “risk repository” and is retrieved and displayed by selecting the construction components in a model.

To utilise a BIM in a risk analysis capacity it is necessary to understand 3 processes.

1. hazard Identification: the process of recognizing that a hazard exists. Hazards are described as sources or situations with the potential to cause harm in terms of human injury or ill-health
2. Risk Assessment: the process of evaluating the risk arising from the hazard. Risk is described as the combination of the likelihood of a hazardous event and the severity of injury that can be caused by the event.
3. The determination of applicable control: the measure relevant to eliminate or reduce risk to an acceptable level (NSAI, 2002).

In adopting these processes, the model can be adapted and used as part of a H+S system.

In section 2.6.2 below, accident causation modeling is discussed briefly. A major part of reviewing accident data is by studying leading indicators (incident before the fact, i.e. no injury) and lagging indicators (incident after the fact involving injury). A study by Hinze, Thurman, & Wehle (2013), regarding these indicators, point towards all potential hazards foreseen and eliminated using BIM being classified as near misses, or leading indicators. This pre-emption technique may affect the way recordable safety information is treated and used in risk assessment analysis. This theory was further explored and researched in work by Shen (2017) with his development of a framework for near miss data collection and visualisation in BIM.

### 1.9 BIM –applications in H+S

Guo et al (2017) carried out research reviewing

current use of visualisation technology in conjunction with BIM. They highlighted safety training, job hazard area identification and management, worker and vehicle monitoring and environment monitoring as areas to which their study could be applied. Lai & Lin (2015) developed a conceptual framework for adopting BIM technology to aid in construction safety management. It consisted of three components: modelling and simulation, the identification of unsafe factors, and safety training. In a similar vein, technologies for identifying and communicating site hazards to the project team along with mitigation advice were proposed by Azhar & Behringer (2013) in which they propose the use of 4D simulation, 3D walkthroughs and animations produced from models to communicate site safety and site risks. Chloe & Leite (2017) propose a framework for addressing site specific temporal and spatial safety information. In their research they define temporal as who will be exposed to potential risks and when, and spatial as where the hazardous zone is. Their argument is that this information would generally be omitted from the traditional approach to safety planning. They propose the use of BIM by using 3d models with modelled work zones and integrated safety schedule and resource schedules in the creation of a 4d simulation. This 3d/4d work process expands on a study by Elbeltagi, Hegazy, & Eldosouky (2004) where-in they discuss site compounds and temporary facilities within the confines of sites with restricted space, and their potential to create hazardous situations if planned badly.

According to HSA information (The Health and Safety Authority, 2016), fatalities and injuries on construction sites generally fall under one of the following categories:

- I. Fall from height
- II. Interaction with machinery
- III. Falling objects
- IV. Engulfment / cave in
- V. Electrocution

Table 3 maps these hazards alongside Irish H+S regulations. It also aligns the hazards with BIM applications and research innovations which address the issues.

Table 3

Irish Regulation citing	Topic/critical issue	Applicable BIM Tool / Research	innovator
SI 219 of 2007 – part 4 :Work at height	Scaffold – fall from height.  Falling objects	“Integrating work sequences and temporary structures into safety planning: Automated scaffolding-related safety hazard identification and prevention in BIM”  “Automatic design and planning of scaffolding systems using BIM”  “BIM-based fall hazard identification and prevention in construction safety planning”	(Kim, Cho, & Zhang, 2016)  (Kim & Teizer, 2014)  (S. Zhang et al., 2015)
SI 291 of 2013 - Part 4: General Safety Provisions	Job site hazard identification-Interaction with machinery	“A framework for BIM based job hazard analysis”  “Integrating Safety and BIM: Automated Construction Hazard Identification and Prevention”  “Applications of BIM Technology for Onsite Safety Planning and Communication in Construction”  “A BIM-based automated site layout planning framework for congested construction sites.”	(Melzner & Bargstädt, 2015)  (S. Zhang, 2014)  (Lai & Lin, 2015)  (Kumar & Cheng, 2015)
SI 291 of 2013 – part 5: Excavations, shafts, earthworks, underground works and tunnels	Underground risk analysis – Engulfment / cave in  Tunnels	“BIM Based Risk Identification System in tunnel construction”  “Process oriented numerical simulation of mechanized tunneling using an IFC-based tunnel product model”	(L. Zhang, Wu, Ding, Skibniewski, & Lu, 2016)  (Stascheit, Koch, Hegeman, König, & Mescke, 2013)
SI 291 of 2013 – part 11: Transport, earth moving and material handling machinery	Location monitoring  RFID,GPS,GIS  Mobile cranes – interaction with machinery	“Real-time resource location data collection and visualization technology for construction safety and activity monitoring applications”  “Information technology and safety”  “Two-way integration of 3D visualization and discrete event simulation for modeling mobile crane movement under dynamically changing site layout”	(Cheng & Teizer, 2013)  (Hallowell, Hardison, & Desvignes, 2016)  (ElNimr, Fagiar, & Mohamed, 2015)
SI 291 of 2013 – part 14: Construction and site welfare facilities	Site set up and compounds	“Dynamic Layout of Construction Temporary Facilities Considering Safety”  “Mixed Reality for Mobile Construction Site”  “A BIM-based automated site layout planning framework for congested construction sites”	(Elbeltagi et al., 2004)  (Woodward et al., 2010)  (Kumar & Cheng, 2015)
SI 291 of 2013 – part 13: Roads	Infrastructure works	“Using BIM to mitigate risks associated with health and safety in the construction and maintenance of infrastructure assets”	(Ruikar, 2016)
SI 219 of 2007 – part 3: Electricity	Protection from Electrocutation	“Managing electrocution hazards in the US construction industry using VR simulation and cloud technology”	(Zhao, Thabet, McCoy, & Kleiner, 2012)

SI 291 of 2013 - Part 4: General Safety Provisions 41.		“Construction safety risk drivers: A BIM approach”	(Malekitabar, Ardeshir, Sebt, & Stouffs, 2016)
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The above table although non-exhaustive, addresses the first objective in this paper. The research literature available did not address Irish health and safety directly in relation to BIM and this study addresses the links between the two in a unique way.

### 1.10 Other influences towards safer sites

#### 1.10.1 Lean principals

Research has argued that a production system that advances towards less waste and variability on a site (i.e. A Lean system) also improves the sites safety conditions. Site safety is dependent on the type of work being carried out, the materials being used and the work flow process to complete the work (along with the design and planning processes at its foundation). Koskela (2000) notes that deficiencies in the production and work process attribute to accident rate statistics. Improvements to these processes point towards reduced accident rates. The factors that the Lean principals influence are: less material in the work area leading to orderly clean workspaces, less confusion in relation to flow of work (work methodologies), and less re-work allowing planning and preparation of activities to be carried out.

#### 1.10.2 Accident Causation models and Indicators

Although the methods of risk analysis mentioned early can contribute to risk and accident mitigation, accidents are, to some degree, chance events requiring a combination of circumstances that cannot be preempted. The accident process, human error, unsafe behavior, and, human injury mechanics, are some of the factors involved. Accident causation models attempt to understand these combinations of circumstances, factors, and processes involved in accidents. In so doing an attempt can be made to develop strategies for accident prevention. Katsakiori, Sakellaropoulos, & Manatakis (2009) researched numerous techniques in this field and advise that using a mixed method of accident causation modelling is required to give a more reliable platform for accident analysis.

#### 1.11 Literature conclusion

The intricacies and unpredictability of construction sites makes H+S management difficult to implement when compared to other industries with static working environments. All site personnel, not just the safety team, need to be properly trained in

assessing risk, planning mitigation measures, and managing their H+S concerns in an ever-changing environment.

Numerous initiatives, legislations, and studies into BIM innovations relating to H+S have been carried out and developed. The literature reviewed point toward there being a close synthesis between BIM and H+S. The conclusions extracted are:

- I. that visualization aspect of BIM enables safety and site managers to understand the evolution of the construction site and forward plan mitigating measures to risk.
- II. The visual aspect of BIM allows clearer communication of risk to all workers irrespective of native languages.
- III. Specific hazards and risks can be explored through BIM in a safe manner.



## 2 Health and Safety

### 2.1 Introduction

There is a need to ensure that all Irish health and safety legislation is fully implemented (O'Reilly et al., 1994). Under the following headings a brief description of the pertinent information relating to construction H+S is given. This information is to be accessible from the HSBIMM. The hierarchy of the importance of this information from a legal standpoint can be seen in figure 2.

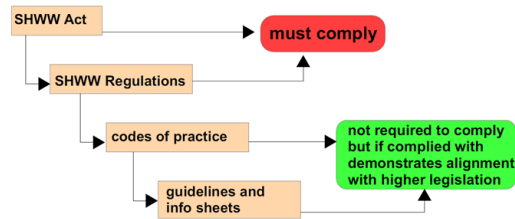


Figure 2 – H+S hierarchy of information

### 2.2 Irish H+S regulations

The two main H+S legislative documents under Irish law are Statutory Instrument no 291 of 2013, Safety, Health and Welfare at Work (construction) and Safety, Health and Welfare at Work (General Application) Regulations 2007 to 2016. It is the legal obligation of a company to comply with these regulations.

#### 2.2.1 SI no.291 of 2013 Safety, Health, and Welfare at work(construction) Regulations

The 2013 Construction Regulations came into effect on 1 August 2013. The purpose of these regulations is to prescribe the main requirements for the protection of the safety, health and welfare of persons working on construction sites. The regulations are designed to clarify and strengthen the general duties of all parties as regards securing occupational safety, health and welfare in construction (HSA, 2013).

The map in figure 5 was developed from the legislation and is integrated into the HSBIMM in an interactive format to provide a quick access point to the relevant regulations fully accessible through the 3d environment.

#### 2.2.2 Safety, Health and Welfare at Work (General Application) Regulations 2007 to 2016

These regulations replaced, simplified and updated 25 older sets of regulations and orders (including SI 299 of 2007) and apply to all places of work. The 2016 amendment specifically addresses abrasive wheel use, abrasive blasting and the use of woodworking machinery so is particularly relevant to the construction industry. A map depicting construction specific regulations can be viewed in

figure 6.

### 2.2.3 Ancillary documents- HSA Codes of Practice

There are currently 8 HSA codes of practice relating to construction companies with more than three employees:

title	year
code of practice for the chemical agents regulations	2016
code of practice for safety in roof work	2016
code of practice for rider operated lift trucks	2001
code of practice for avoiding danger from underground services	2016
code of practice for working in confined spaces	2017
code of practice for avoiding danger from overhead electricity lines	2008
code of practice for access and working scaffolds	2009
code of practice for the design and installation of anchors	2017

Figure 3 – codes of practice

A person cannot be prosecuted for not complying with a code of practice and a person with health and safety duties under Irish legislation is not obligated to use the codes to comply. That being said, a failure to follow a reasonably practicable step set out in a code is likely to result in the court finding a breach of the health and safety legislation in the case of an incident on a site. It is therefore good practice to observe all applicable codes.

### 2.2.4 HSA information sheets and other construction related published material

The HSA provide a wealth of information to the construction sector. For identifying current areas of concern, and useful measures to rectify them it delivers a valuable resource.

title	year
safe load securing on curtain sided vehicles	2017
delivering safely	2013
safe use of explosives in construction	2014
forklift safety tips	2013
chainsaw safety training advice	2015
lighten the load - manual handling	2008
pedestrian safety in the workplace	2013
reducing the manual handling of glazing units	2015
reducing the manual handling of roof panels	2013
safe load securing of round timber	2017
safe load securing of plant and machinery	2016
safe load securing of structural steel loads	2016
safe use of site dumpers on construction sites	2014
safe use of work platforms / trestles	2013
safer work stairs and steps	2017
safety and health signs	2012
manual handling risk reduction	2014
use of mobile machinery on construction sites	2008
using ladders safely	2014
preventing vehicle related slips, trips and falls	2016
wood working	2010
falls from vehicles	2010
reversing vehicles	2009
workplace transport safety management	2008
safe load securing of precast concrete loads	2016
safe load securing of site cabins and prefabricated accommodation units	2017

Figure 4 – HSA information sheets

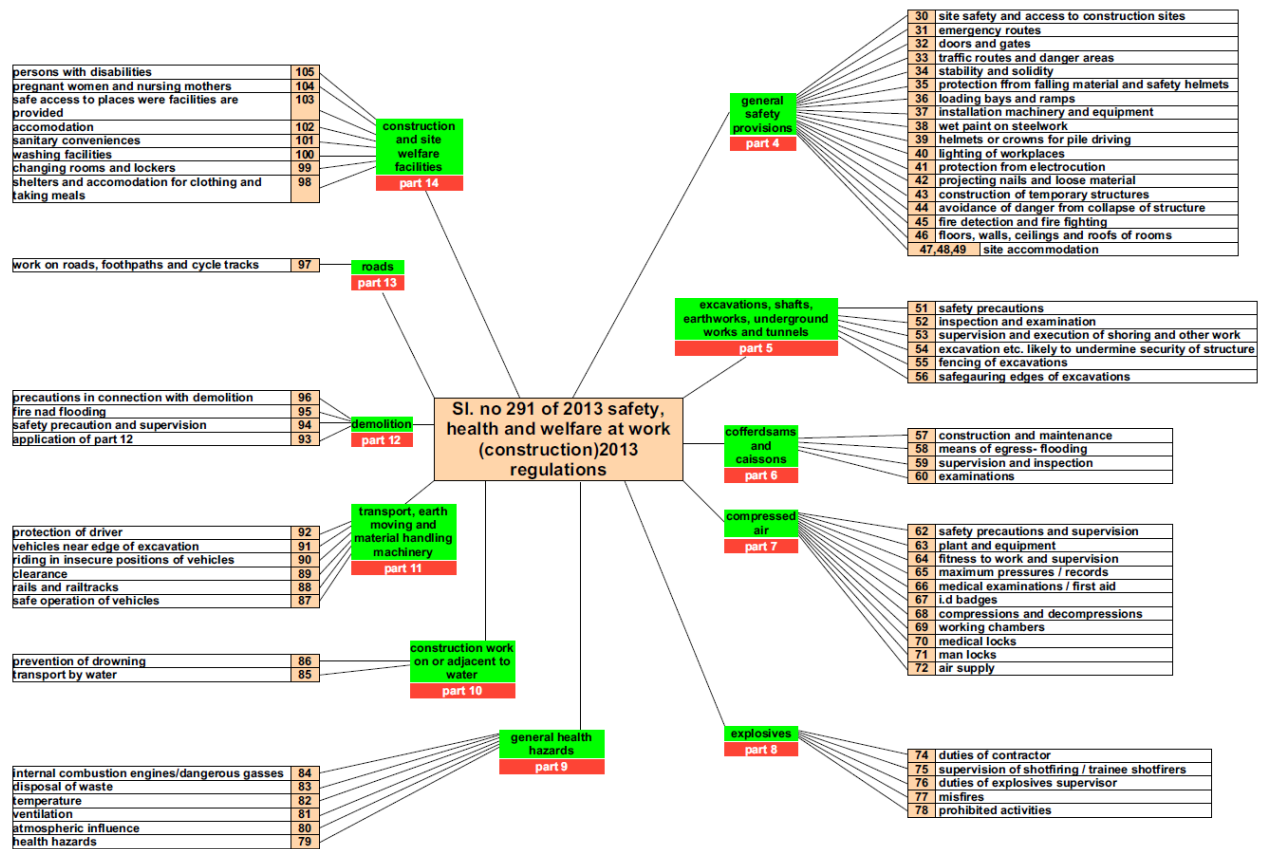


Figure 5 – SI no. 291 of 2013 map

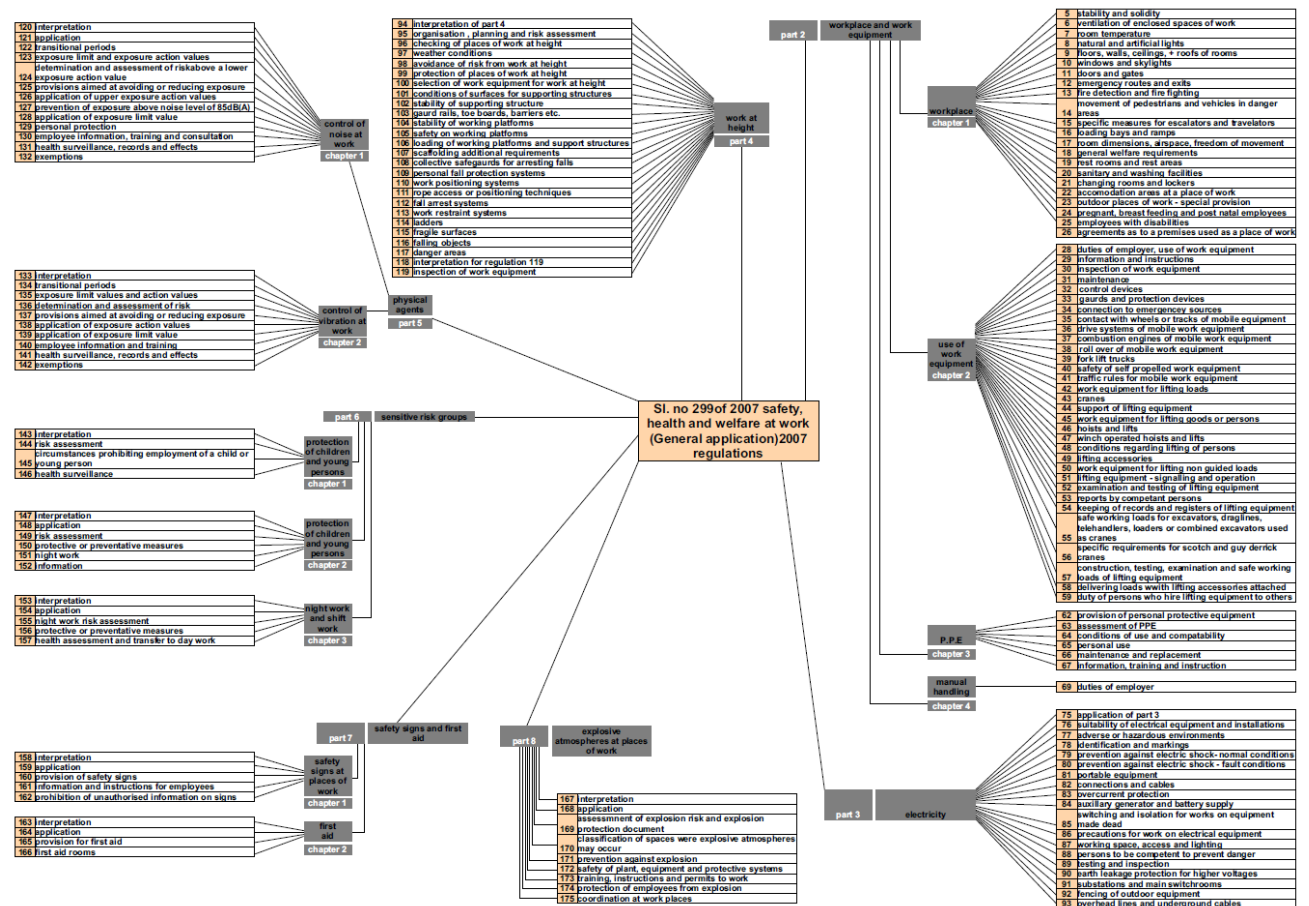


Figure 6 – S.I no 299 of 2007 map

### 2.2.5 Principles of prevention

To further explore the premise of this paper it was important to understand how risks and hazards can be treated. The Principles of Prevention apply to construction work and are broken down into 9 headings:

1	The avoidance of risks
2	The evaluation of unavoidable risks
3	The combating of risks at source.
4	The adaptation of work to the individual to alleviating monotonous work and work at a predetermined work rate.
5	The adaptation of the place of work to technical progress
6	The replacement of dangerous articles, substances, or systems of work by non-dangerous or less dangerous articles, substances, or systems of work
7	The giving of priority to collective protective measures over individual protective measures.
8	The development of an adequate prevention policy in relation to safety, health and welfare at work, the Safety and Health Plan, and/or the Safety Statement.
9	The giving of appropriate training and instruction to employees.

Figure 7 – principles of prevention

Although the implementation of the Principles of Prevention should be primarily at design stage, the 9-point guidance system can be the starting point for the preparation of the site risk assessment process. Figure 8 depicts the hierarchy associated with the persons affected by safety contraventions versus the persons with the ability to influence safety.

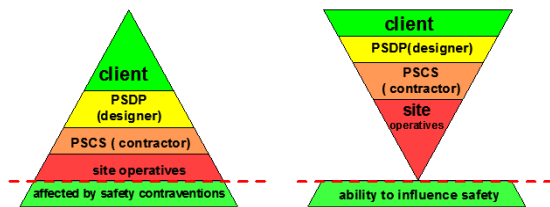


Figure 8 – Hierarchy of safety contraventions

With the utilisation of the H+S BIM tool proposed in this capstone, the author believes the ability to influence safety should be depicted as in figure 9 below, with site operatives becoming more central to the process.

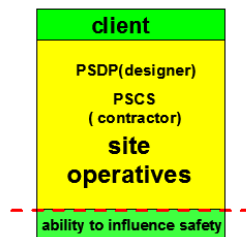


Figure 9 – hierarchy of safety contraventions modified with BIM usage

### 2.3 Training and Learning – BIM and H+S

Success in using BIM to enhance safety partly depends on the familiarity of project personnel with BIM tools and the extent to which the tools can be used to identify and eliminate safety hazards. Increasing the general knowledge of this technology will overcome drawbacks associated with perceptions that BIM can have limited benefit (Rajendran & Clarke, 2011; Alomari, Gambatese, & Anderson, 2017). Training should not only seek to foster awareness of hazard and risk but it should reinforce knowledge and skills in managing

hazardous situations effectually (McDonald & Hrymak, 2002). To this end, Company strategy should encourage the use of BIM through concentrated educational courses to meet legislative and project directed demands (A. Ganah & John, 2015).

During the pre-construction period, 3d and 4d technology can improve safety performance through visual, interactive, and cooperative behaviours, as well as facilitating risk and hazard identification and management. In a study by Guo et al (2017) they reported on improved efficiency and effectiveness of accident prevention by using these technologies. Visual and safety materials positively impact safety communications and site specific hazard awareness (Choe & Leite, 2017) and should be included in all training programmes. A study by Peterson et al (2011), involving students of Stanford University and Twente University in construction based courses, showed that problems presented in a medium such as BIM and 3d visualisation allows greater understanding of the direct consequences of project programming. In another study workers representing projects that offered high-engagement training were able to identify a larger proportion of hazards, and consequently perceived the safety risk as a critical factor (Namian, Albert, Zuluaga, & Behm, 2016).

To establish a training process for construction staff it is necessary to understand different approaches to teaching and learning. In this case study the prevalent demographic is adult staff. Consequently, an andragogical, learner focused approach to training is appropriate. This method of training gives the learner the initiative to define their own learning goals (Wilkins, 2011). Andragogy makes the following assumptions about learning:

1. Adults need to know why they need to learn something,
2. Adults need to learn experientially,
3. Adults approach learning as problem-solving, and
4. Adults learn best when the topic is of immediate value (Knowles, 1984)

### 2.4 Conclusion

The research shows a distinct relationship between positive outcomes and training methods using a BIM component. The theory behind adult learning has a direct correlation with visualisation and interactivity within a training environment. It is these factors that will be included as constituents for the training framework proposed as part of the HSBIMM. The availability and ease of access to H+S literature will allow for the integration of this data to allow the objectives of this paper to be fulfilled



One of the fundamentals of the utilised BIM software was Geometric Description Language (GDL). Creating a GDL object is based on 3 main principles: move a local coordinate system using and managing the transformation stack (move, rotate, mirror, scale), place 3D primitives or bodies (cubes, spheres, cones, cylinders) into the coordinate system (i.e. build the object with a reference point) and set the representation attributes of the used primitives (materials, shadows, transparency etc). Most objects can be modelled in GDL space following this simple logic. The availability of numerous pre-made GDL objects significantly decreased the modelling time required in the project. Although object quality was often an issue, this was resolved by importing and modifying said models in Archicad with GDL scripting. The importation and manipulation of model objects also enabled the author to integrate relevant information to the objects that would be used downstream. Objects modelled specifically within Archicad were coded and data tagged as part of the modelling process.

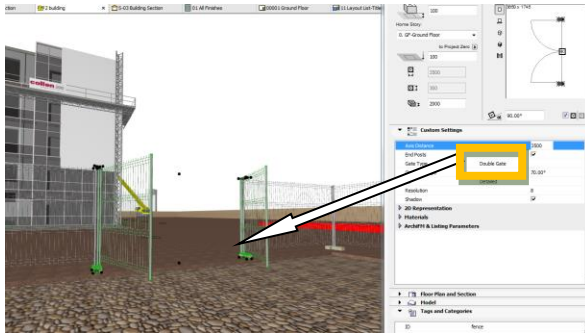


Figure 13 – example of parametric capacity of fence object (gate)

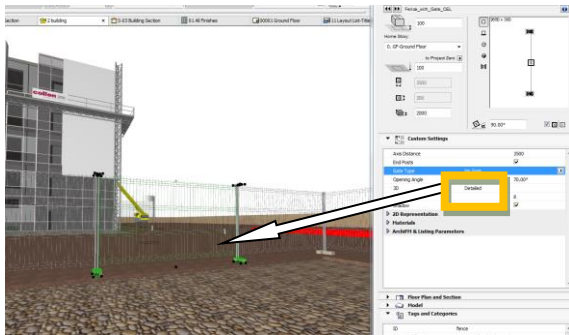


Figure 14- example of parametric capacity of fence object (fence)

The process for developing the building model was simpler when compared to GDL object modelling. In this process the software's in-built tools and parametric elements such as walls, slabs, curtain walls, and columns were used to virtually construct a building and its context (including site and surrounding environment). In conjunction with these construction elements the building model was developed using zones and stories. This would allow the objects and assets (linked to risks and hazards) to be viewed in a location-based method. A risk object could be pinpointed to a position in space relative to elevation height (story) and location in plan (zone). This was a requirement to produce an intelligent schedule of identified risks.

### 3.2.2.2 Industry Foundation Class (IFC) exchange format

The information noted in section 3.2.2.1 relates to IFC data. IFC is an open and neutral format for model sharing in the process known as openBIM. An important part of the modelling process was to create models with embedded information that could be utilised in other software. The extraction of risk related data for the creation of risk assessments formed part of the initial objectives. To do this it was necessary to utilise a PsetRisk IFC schema – see figure 15.

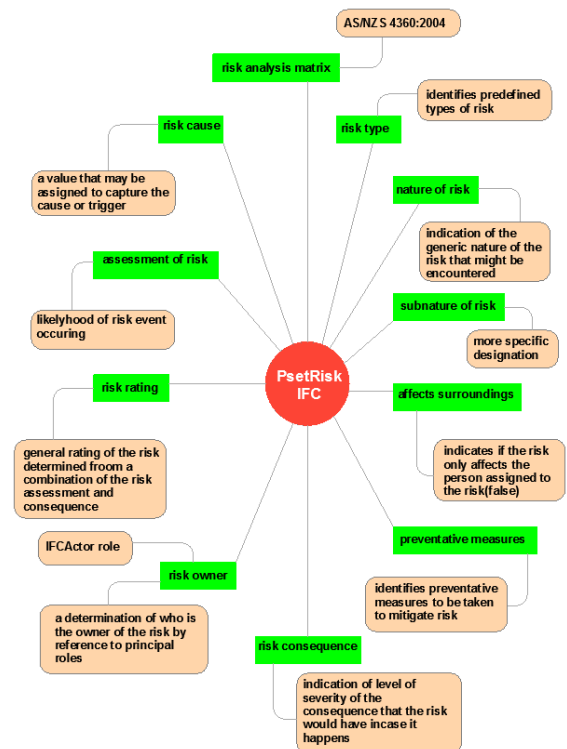


Figure 15 – IFC PsetRisk map

Objects with the PsetRisk property activated can be embedded with the data required for establishing if the object is a hazard or related to another hazard. Figures 17 show an element (edge protection handrail) with risk data attached through its IFC parameters. The schedule shown has headings aligned with the IFCPsetRisk map in figure 15.

A similarly powerful IFC property used in the risk identification mapping process was PsetSpaceCommon. This is a derivative of the zone tool within Archicad described in 3.2.2.1 above and is used to convey information relating to an objects location within a defined area. Figure 16 below shows a 360° Excavator with 2 zones adjacent to specific IFC property information.

The authoring software gives access to multiple export formats. IFC and NWC were used in this project to show differences in structure of embedded data when viewed through review software. The IFC export function was found to embed substantially more information than the software specific NWC (Navisworks) format. One problem experienced was the loss of attribute information such as surface material.

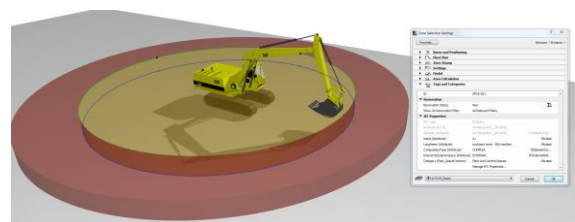


Figure 16 – PsetSpaceCommon - restricted zone



Risk Assessment for edge edges and openings	Library Object Name	Quantity	Height (Z Size)	Affects Surroundings	Assessment	Isolated Object	Preventive Measures	Root Cause	Root Consequence	Root Cause	Root Consequence	Root Cause	Root Consequence	Root Cause	Root Consequence
Concrete Wall	100	10,000	2.0	Yes	Low	Yes	None	Open edge	None	None	None	None	None	None	None
Steel Fence	20	10,000	1.0	Yes	Low	Yes	None	Open edge	None	None	None	None	None	None	None

Figure 17 – PsetRisk data output to spreadsheet

### 3.2.3 3d review software

Navisworks Manage, the chosen tool for combining all elements in this project allows users to open and combine 3D models, navigate around them in real-time and review the model using a set of tools including comments, redlining, viewpoint, and measurements. Its capability of handling and compressing large amounts of data to create a smooth interactive experience was critical to the development of the HSBIMM.

Import and export options facilitate the use of multiple file formats including but not limited to IFC, NWC, Sketchup (SKP) and 3dStudio (3ds). This follows an “OPEN BIM” methodology which supports an open workflow, allowing project members to participate in a model authoring process regardless of the software tools they use.

#### 3.2.3.1 Federating model information

Multiple models were built in authoring software applications and several file formats were resultant of this process. The amalgamation of models was a simple process and a relatively seamless one once a strict coordinate system was used.

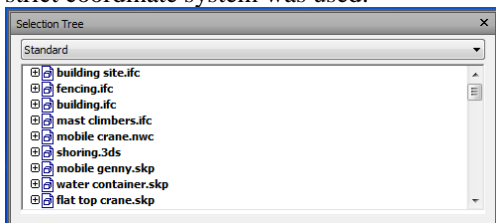


Figure 18 – models federated showing various file extensions

#### 3.2.3.2 Navisworks features

Built in features in the Navisworks toolbox such as Viewpoints, Comments, Links, Sets, Render and Review were all combined in an effort to create an interactive and realistic site environment. A series of designated views were established to allow ease of navigation within the overall site such. Such examples are views from machinery cabs, views from the bottom of deep excavations etc.

#### 3.2.3.3 Model export for use in free reader software

The main premise in developing the federated model was the ability to share a completed usable file with personnel within a company for educational use. Navisworks allowed the model to be saved in a “zipped” file structure – NWD. All models in the federated model, inclusive of all linked data could be exported in this file format. During the model development process, the author was cognisant of file size increasing and the final model was only 50mb which meant easy sharing and downloading.

The free reader software, Navisworks Freedom is readily accessible to download from the Autodesk website. Once installed, a series of minor changes to the interface of the software was carried out to optimise the user interface and display for viewing the HSBIMM. This optimisation process was prescribed in a document issued to each participant with the model file.

### 3.3 Model interaction – Case study

Participants in the HSBIMM test presented with differing levels of skill and comfort in using models. Some had adequate knowledge of BIM software and the use thereof, but others had never used a BIM tool. It was necessary to put in place a measure to allow non-technical participants to engage with the model.

#### 3.3.1 User interface

To overcome the lack of experience with BIM tools from participants it was necessary to include a documented set of instructions with the HSBIMM file. The instructions included information on easy navigation of the BIM environment using preset constrained views or Viewpoints and a brief instruction on using built in Navisworks navigation tools such as Orbit, Look around, and Walk. This allowed for an unconstrained method of viewing the model.

Tabs and menu descriptions were also included in the instructions to allow a new user of Navisworks to easily access information to make their experience easier and more enjoyable.

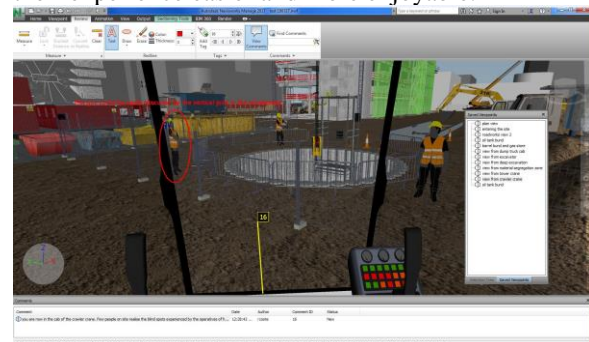


Figure 19 – HSBIMM screenshot

### 3.3.2 Information links

Care was taken when producing the model to create a realistic looking virtual space, but most importantly was the ease of access to the H+S data within the model. The Link tool within Navisworks Manage was used to create a hyperlink between model objects in the scene and the relevant. The data was saved in a cloud-based repository. A single click on the link within the scene initiated a pop-up window to appear with the data relevant to that link including text, image, video, and audio files. At this point the participant could now download the information to their own computer.

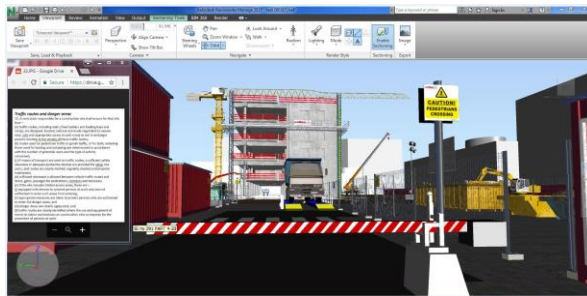


Figure 20 - HSBIMM screenshot

### 3.4 Conclusion

Export formats from authoring software platforms were unproblematic and so the modelling methods used were deemed particularly suitable for this project. Realism was achieved in the model environment using material mapping, lighting, camera views, ambient occlusions, and the software's in-built rendering engine. Using the link tool was extremely effective in providing a single click interaction between the user and the information. The ability to navigate all areas of the scene, not only preset views, created an interactive experience for participants in a "game like" scenario. In summary the developed training scenario met and exceeded the initial provisos; ease of sharing, ease of use and information extraction and realism.

## 4 Presentation of findings

### 4.1 Introduction

Prior to engaging participants in the HSBIMM study they were required to answer a questionnaire to gauge knowledge of the subject matter – BIM, Irish H+S legislation and site risk. The feedback was analysed and used in the implementation of the model development strategy. Based on the feedback an attempt was made to address concerns raised in the questionnaire with pre-programmed scenarios in the model.

### 4.2 Participants views

After participation in the trialling of the HSBIMM a response to a statement was requested. A Likert scale

was used to organise responses. As can be seen in table 4 the feedback was strongly positive with 96.5% either agreeing or strongly agreeing with the statement.

Table 4- feedback from participants answering research question

Interacting with the H+S BIM Module increased my awareness of site risks and HSA legislation and literature.					
	highly disagree	disagree	neither agree or disagree	agree	highly agree
H+S specialists	0	0	3	4	0
contract managers	0	0	0	3	1
site managers	0	0	0	0	3
M+E specialists	0	0	0	2	2
Project Managers	0	0	0	4	2
General operatives	0	0	0	0	2
percentatge	0	0	12.5	54	32.5

### 4.3 Arising themes

Feedback was also gathered with regards the participants perceived satisfaction using the HSBIMM based on data content, visual acuity of model and future use. Proposals to modify or add to the interactive environment were also gathered and collated. Safety professionals commented on the embedded legislation and noted that it was extremely important to them, but possibly too high-level for most interactors. Another recurring theme was in relation to embedding links to relevant forms and permits.

### 4.4 Gap analysis

The research highlighted the gap between Irish H+S information and links to BIM. It is the authors opinion that this study bridges that gap and opens a gateway to explore areas for further implementation of BIM and H+S integration.

### 4.5 Study constraints

The study was confined to one company. Anonymity was requisite for participants but answers to the questionnaire may still be biased. Software used was vendor specific and any limitation in the chosen software was carried through the study. Other solutions were not explored. The HSBIMM was a prototype and only partially complete for testing purposes. A completed working model will need to be further investigated. Irish H+S was the focus. International H+S information and data links to it through the HSBIMM were not explored.

Although there are numerous constraints issues raised, the research will be common to main contractors in Ireland and internationally and as such it is hypothesised that the generalised results would be common also.

### 4.6 Summary

The purpose of this chapter was to practically apply the research design and methodology to answer the overall research question and satisfy the overall aims and objectives of the study. The data collected

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through the questionnaire process required a strategy to identify the key themes. Semi structured questions formed the basis of the questionnaire. This allowed a certain level of organisation to be applied to the answers. The answers were reviewed and any concerns arising were assimilated into usable data. This data fed into the model to produce a 3d environment that addressed participants concerns.

## 5 Conclusions and recommendations

### 5.1 Introduction

This study is a step forward in linking BIM and Irish H+S standards. The mixed methodology used shows simplistic methods for development of a strategy for use in H+S that benefits greatly by BIM incorporation.

### 5.2 Review of research question

Interpretation of the feedback and results from the research allow an answer to the research question to be determined. The 96.5% positive feedback to the research question gives a clear justification in stating that indeed, the implementation of BIM technologies in H+S training can help raise awareness of construction site personnel to site risk.

#### 5.2.1 Objective 1 - conclusion

Analysis of the current available literature and company accident report documentation identified the critical H+S issues on construction sites. These issues were assessed in relation to BIM research and tools developed. Table 3 links these developed BIM tools to the main critical issues identified. Standards and legislation addressing each of the critical issues were integrated into the table thereby creating a visible correlation between the three topics of objective 1, i.e. critical H+S site issues, H+S Standards and BIM.

#### 5.2.2 Objective 2 - conclusion

The available BIM software allowed the creation of an immersive site environment that contained relevant information for H+S training. Participants in the testing process had a high degree of satisfaction with the HSBIMM and agreed to its potential for furthering their knowledge of H+S subject matter. A determination was made on the findings of the assessment of the HSBIMM that an immersive 3d environment does create a strong interactive H+S training platform for site personnel.

At a functional level an evaluation of the HSBIMM showed that a product with educational benefits has been developed with a built-in mechanism for ease of sharing. A critical evaluation of the model interaction outcomes generates a set of criteria that can be used to further its development.

#### 5.2.3 Objective 3 - conclusion

The chosen BIM tool, Archicad, proved to be

successful in producing information pertinent to risk register document creation. Through the processes described in chapter 3.3 a more automated and job specific risk register could be created by inclusion of the specifically designed and coded GDL objects. The automatic extraction of the H+S information contained within the models to a formatted risk schedule is proof of concept.

The experience of participants in the test was extremely positive with over 95% claiming to have gained some knowledge from their interaction with the model. Positivity was also highlighted in relation to participant satisfaction and enjoyment when engaging with the model. The non-challenging reaction to this new process alleviates any apprehension for integration of the training module in day to day Company processes.

Combining the information retrieved during the literature review process and the findings of the HSBIMM test proves that the use of BIM in 3d simulation at various stages of construction can provide new and innovative approaches to hazard identification and risk evaluation.

### 5.2.4 Overall conclusion

A new approach at engaging field workers in H+S awareness is critical to maintaining the downward trajectory in fatality and accidents, as the numbers employed in the construction industry increase. A reflective evaluation of this research points towards the value of BIM in this new approach. With the insightful knowledge gained through the research of this papers themes, it is envisaged that the study can lead and initiate activity in the field of H+S and BIM. It is hoped that the basis of this study and the HSBIMM created can be utilized as a tool to enact change to existing dangerous social norms on construction sites.

## 5.3 Recommendations based on findings

### 5.3.1 Introduction of HSBIMM in The Company training and induction processes - conclusion

Feedback on the HSBIMM was extremely positive. Director and Managerial level reaction to the feedback was also encouraging. The use of the Module in relation to site inductions and toolbox talks will be introduced. The process of generating a live project to include all relevant H+S library information will act as a test bed to take the HSBIMM concept to the next level of development.

### 5.3.2 BIM training in specific software for extended participation by H+S team – conclusion

Training with Navisworks Freedom, described earlier, will form part of the continual professional development in The Company. It is also envisaged

that H+S staff will be trained on Navisworks Manage which will allow them an extra level of control within the HSBIMM to streamline inductions, programme their own preset scenarios and add new links when they deem so necessary.

#### 5.4 Recommendations for further research

It is recommended that further research into the integration of BIM with existing H+S processes and procedures is undertaken in direct liaison with the HSA and Construction Industry Federation (CIF). Considering the recent publication of PAS 1192.6 the use of structured hazard and risk information for health and safety will be high on the agenda going forwards and will be highly relevant to the development of any comparative ISO standard in 2019.

##### 5.4.1 Virtual reality (VR) training

The next progressive step is to develop a VR version of the HSBIMM using BIM and game technology. The author has begun research into the utilization of BIM tools and data integrated via the Unity gaming engine. Using this method will enable production of a fully interactive, dynamic and physics orientated H+S training platform.

## 6 Glossary

3d	3 dimensional
3ds	3d Studio (software)
API	Application programming interface
BIM	Building information modelling
CFR	Code of Federal Regulations
CSCS	Construction Skills Certification Scheme
GDL	Geometric Description Language
H+S	Health and Safety
HSA	Health and Safety Authority
HSBIMM	Health and Safety Building Information Model Module
HSE	Health Service Executive
IFC	Industry Foundation Class
ILO	International Labor Office
ISO	International Organisation for Standardisation
NIOSH	National Institute of Occupational Safety and Health
NISO	National Irish Safety Organisation
NSAI	National Standards Association of Ireland
NWC	Navisworks Cache
NWD	Navisworks published file
NWF	Navisworks File format
OH&S	Occupational Health and Safety
OSHA	Occupational Safety and Health Administration (USA)
OHSAS	Occupational Health and Safety

PAS	Assessment Series
PtD	Publicly Available Specification
PSCS	Prevention through Design
	Project Supervisor for the Construction Stage
PSDP	Project supervisor for the Design process
SHWW	Safety Health and Welfare at Work
SRFP	Safety Representative Facilitation Programme

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