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Building Information Modeling for Construction Sites Safety Planning

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STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.

I further declare that I have fully acknowledged the Code of ethics and conduct of Politecnico di Milano.

SOMMARIO

Building Information Modeling per la pianificazione della sicurezza dei cantieri

La salute e la sicurezza sono un aspetto molto importante per tutte le aree del settore edile, che è considerato un settore ampiamente esposto agli infortuni sul lavoro. I più alti tassi di incidenti tra tutti i settori industriali sono registrati infatti nel settore delle costruzioni. Il verificarsi di incidenti può essere attribuito a ragioni principalmente a sottovalutazione nell'individuazione di condizioni di pericolo prima dell'esecuzione dell'attività.

Un fattore chiave nella pianificazione della sicurezza e della gestione nel settore edile è identificare adeguatamente tutti i possibili pericoli prima che siano accaduti. Uno sviluppo promettente nel settore delle costruzioni che può essere applicato per le questioni relative alla salute e alla sicurezza sul lavoro è il Building Information Modeling (BIM). Il BIM consente infatti di visualizzare le condizioni del cantiere e il riconoscimento dei pericoli, fornendo a sua volta tempo sufficiente per sviluppare piani per il riconoscimento dei pericoli ben prima delle attività di costruzione.

Esistono diversi studi che testimoniano il potenziale del BIM nella gestione della salute e della sicurezza, principalmente incentrati sulla formazione sulla sicurezza attraverso la tecnologia di visualizzazione e la conservazione delle informazioni. Inoltre ci sono studi incentrati sulla definizione dei flussi di lavoro per l'identificazione del rischio e l'integrazione delle informazioni nel BIM.

Questa tesi mira a colmare la lacuna contribuendo alla gestione della salute e sicurezza (H&S) identificando un processo per utilizzare il BIM per la gestione della salute e della sicurezza. Inizialmente, verrà presentata una panoramica della letteratura specializzata e della ricerca nel campo della gestione della salute e sicurezza delle costruzioni. Inoltre, verrà proposta una metodologia per integrare salute e sicurezza (H&S) in una piattaforma BIM, seguita da un'applicazione concreta proposta per la valutazione dell'integrazione di salute e sicurezza (H&S) nel BIM.

Parole chiave: (Building Information Modeling, health and safety, BIM, H&S, pianificazione della sicurezza, salute e sicurezza sul lavoro, realtà virtuale, revisione della costruibilità)

ABSTRACT

H&S is an essential aspect of all areas in the construction industry. It is considered to be a vastly exposed sector pertaining to occupational accidents. The highest accident rates among all industrial sectors are recorded from the construction industry. The occurrence of accidents can be attributed to reasons such as shortcomings in identifying unsafe conditions before the execution of an activity.

A key factor in planning Safety and management in construction industry is to identify any possible hazards correctly before their occurrence. A promising development in the construction industry which can be applied for relating occupational H&S issues is Building Information Modelling (BIM). BIM. BIM allows for visual access to Jobsite conditions and hazard recognition, in turn, providing sufficient time to develop plans for hazard recognition well ahead of the construction activities.

There are several studies performed to explore the potential of BIM in H&S management, mostly focused on Safety training through BIM integrated visualisation technology and studying the role of psychology in knowledge information retention and effectiveness through the use of visualisation technology. However, there are limited studies focused on defining workflows for risk identification and information integration in BIM.

This paper aims to fill the gap by contributing to the H&S (H&S) management by identifying a process to use BIM for H&S management. Initially, a prior knowledge overview of technology and research in the field of construction H&S management will be presented. Further, a methodology to integrate H&S (H&S) in a BIM platform will be proposed followed by a case study application of the proposed methodology for the assessment of the H&S (H&S) integration in BIM.

Keywords: (Building Information Modelling, Safety planning, Occupational H&S, VR, Constructability review)

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1. INTRODUCTION

In this current generation of ever-evolving technology advancement, there is a need to keep up with the pace. There is high motivation for finding ways to enhance and simplify the process of different activities. The AEC industry is one such where there are constant efforts made to improve the aspects of the activities involved in the life cycle of the projects. BIM is the current buzz, and it is not for nothing that it is the talk of the town. Its potential seems to be high. Many studies are done on its implementation to enhance and explore its potential. H&S is a critical aspect of all areas in the construction industry. It is considered to be a vastly exposed sector on occupational accidents. The highest accident rates among all industrial sectors are recorded from the construction industry. The occurrences of accidents are because of reasons such as shortcomings in identifying unsafe conditions before the execution of an activity. Integrating knowledge of construction Safety in the digital model of a building can enhance the quality and details of assessment if hazard and Safety planning in a project (Melzner, 2017). A promising development in the construction industry which can be applied for relating occupational H&S issues is Building Information Modelling (BIM). BIM can be defined as a progressed evolution of Computer-Aided Design. It is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle, defined as existing from earliest conception to demolition.

Construction Safety management can be divided into the pre-construction stage, construction stage and post-construction stage. Several studies are performed to explore the potential of BIM in H&S management, mostly focused on Safety training through BIM integrated visualisation technology and studying the role of psychology in knowledge information retention and effectiveness through the use of visualisation technology. However, there are limited studies focused on defining workflows for risk identification and information integration in BIM (Zhang, et al., 2014). Also, there is lack of study on integration between the construction process and Safety issues. Construction management is focused on productivity, and the Safety constraints within the construction process are seldom disregarded, resulting in consistently high accident statistics (Chan et al., 2016). This paper aims to fill the gap by contributing to the H&S (H&S) management by identifying a process to use BIM for H&S management during the pre-construction phase to share H&S information. The initial focus is on realising the state of the art of BIM and the technology advancement in the AEC industry.

Research objectives for this study are defined and listed below:

- Exploring the state of the art of H&S in the construction industry
- Exploring BIM implementation in managing H&S in the construction industry
- Formulate a methodology to integrate H&S in BIM in the construction industry.

The research methodology consists of three stages:

1. A literature review of the H&S in construction and the state of art of BIM for managing H&S.
2. Proposing a framework for H&S integration in BIM
3. Assessment of the proposed integration through a case study.

The thesis is structured in four chapters:

Chapter 1: This chapter introduces my study and result

Chapter 2: This chapter provides a literature review of studies/articles relevant to the objectives stated in this study.

Chapter 3: This chapter presents the process of proposing the methodology to integrate H&S (Health&Safety) in BIM

Chapter 4: This chapter presents the case study application to assess the effectiveness of the proposed methodology of integrating H&S in BIM.

Chapter 5: This is the final chapter which presents a summary of conclusions and recommendations/further steps from the research work.

2. LITERATURE REVIEW

2.1. Introduction

An important component of any research project is a literature review. A literature review helps in mapping and assessing relevant intellectual theory to develop the knowledge base. The literature review is done to underline all related knowledge that can be utilised and linked to the subject matter, to establish comprehension of the considered problem or gap. This review will deliver a background to H&S in the construction industry and then proceed to realise the state of the art of BIM implementation for addressing H&S in construction. The approach in this study concentrated on the analysis of literature in which studies were focused on identifying risks and hazards associated with the construction industry and the use of available tools and technology for enhancing H&S management. To accomplish this, search databases like Elsevier, ResearchGate and Google search engine were used and keywords like "Construction site Safety", "Construction hazard prevention through design, "Safety planning", "Occupational H&S", "VR and BIM", "Constructability reviews", etc., were used. Conference proceedings were also used. Papers were then filtered and selected based on the topic of relevance and by reading the abstract contents. Then they were categorised broadly under three Topic: Construction site Safety, VR and BIM, and Constructability review. Figure 1. shows the paper selection process for the literature review. The literature review is divided into different topics and discussed in the following sub-chapters.

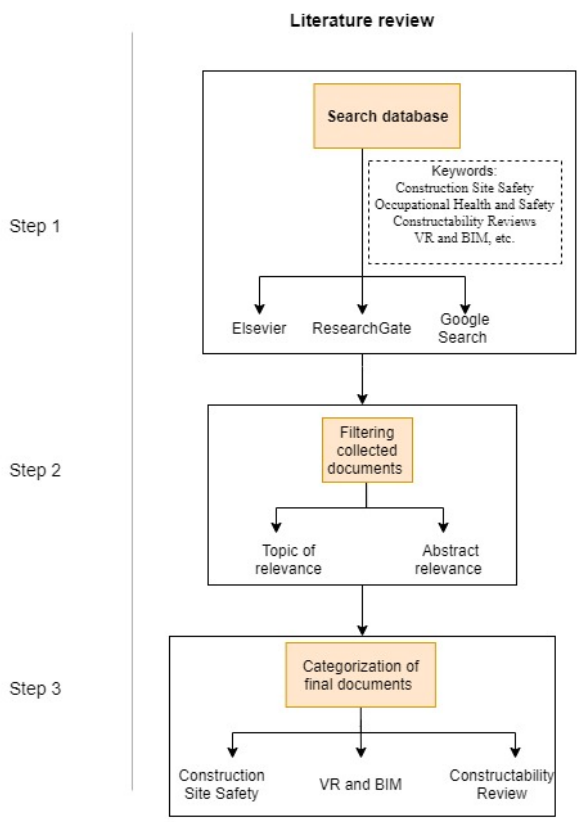

Figure 1 - Approach for the Literature review

2.2. Building Information Modelling (BIM)

BIM is the progressed evolution of Computer-Aided Design. BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle, defined as existing from earliest conception to demolition. Benefits associated with BIM use can range from its technical superiority, interoperability capabilities, early building information capture, use throughout the building lifecycle, integrated procurement, improved cost control mechanisms, reduced conflict and project team benefits (Ghaffarianhoseini et al., 2016). BIM use encompasses huge possibilities, some of which, according to Azhar are shown in Table 1.

Table 1 BIM uses (Azhar, 2011)

BIM uses	Description
Visualization	3D renderings can be easily generated in house with little additional effort
Fabrication and shop drawings	It is easy to generate shop drawings for various building systems. For example, the sheet metal ductwork shop drawings can be quickly produced once the model is complete
Code review	Fire departments and other officials may use these models for their review of building projects
Cost Estimating	BIM software has built-in cost estimating features. Material quantities are automatically extracted and updated when any changes are made in the model.
Construction sequencing	A building information model can be effectively used to coordinate material ordering, fabrication, and delivery schedules for all building components
Conflict, interference and collision detection	BIM models are created in a 3D space which allows the instant and automatically checking of interferences. For example, this process can verify that piping does not intersect with steel beams, ducts, or walls
Forensic analysis	A building information model can be easily adapted to graphically illustrate potential failures, leaks, evaluation plans, and so forth.
Facilities management	Facilities management departments can use it for renovations, space planning, and maintenance operations.

2.3. H&S in the construction industry

H&S issues generally have a substantial impact on areas of life, such as economic activity business and daily occupations. It plays a crucial role in the industry. It is of great importance because it concerns humans, the environment and economy due to its intimate connection to the welfare of humans in general. Before discussion of H&S issues, some basic terms need to be familiarised. It is is necessary for having a clear perspective on the particular nature of the sector. Some definitions relating to H&S (H&S) are described below (PAS 1192-6:2018):

Augmented Reality (AR): Augmented Reality is an interactive experience of a real-world environment where the objects that reside in the real world are enhanced by computer-generated perceptual information, sometimes across multiple sensory modalities, including visual, auditory, haptic, somatosensory and olfactory (Wikipedia).

Context information: Information or information model relating to a built asset, site and/or project indicative of the level of risk to be taken as moderate

Game Engine: A Game Engine is a software-development environment designed for perople to build video games (Wikipedia).

Harm: Injury or damage to the health of people, or damage to property or the environment

Hazard: Potential source of harm

Information: Representation of data in a format manner suitable for communication, interpretation or processing by human beings or computer applications

Level of risk: Magnitude of risk or combinations of risks, expressed in terms of the combination of consequences and their likelihood

Mitigation: informed decisions, measures and activities undertaken to remove or manage the identified, known, or perceived risks based on the general principles of prevention

Proposed mitigation: Action and changes to mitigate a risk that have been agreed and incorporated

Risk: Combination of the probability of occurrence of harm and the severity of that harm

Risk information: Information of records relating ot hazards, risks, opportunities, assessments, and mitigations

Risk likelihood: chance of something happening

Risk consequence: outcome of an event affecting objectives

Risk matrix: Tool for ranking and displaying risks by defining ranges for consequence and likelihood

Virtual Reality (VR): Virtual reality is an artificial environment which is experienced through sensory stimuli (such as sights and sounds) provided by a computer and in which one's actions partially determine what happens in the environment (Webster dictionary).

The construction industry has been recording the highest number of fatalities and accidents among all industry sectors across the globe (Chan et al., 2016). There are many causes of fatalities in construction. Out of the four categories are considered to be the leading cause, according to United states Occupational Safety and Health Administration (OSHA). The OSHA defines those four categories as Falls, Stuck-by, Caught-in/between and electrocutions. As per the statistics in the calendar year 2018, 33.5% of worker fatalities in the private industry was attributed to falls, 11.1% to struck by object, 5.5% to caught-in/between and 8.5% to electrocutions (Figure 2). This is a considerably high rate. Further, some of the most violated Safety standards identified were fall protection, scaffolding, ladders, eye and face protection (OSHA).

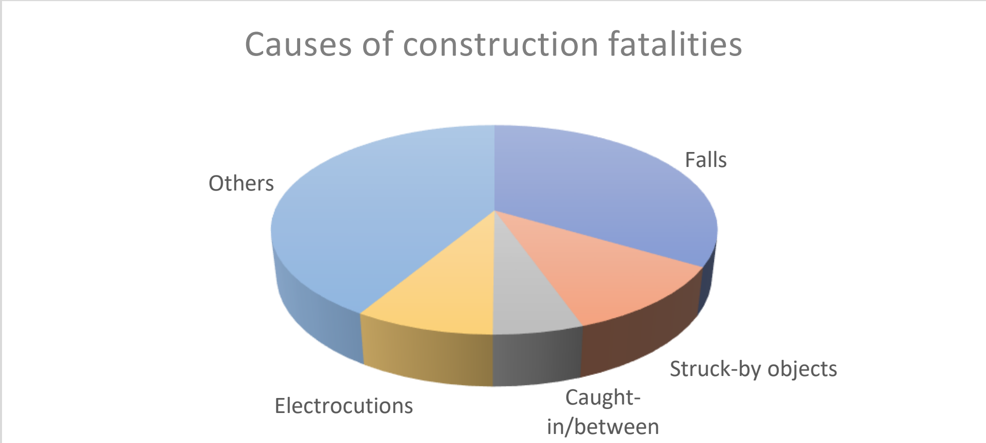

Figure 2 - Proportion of accidents attributed to Fatal Four in construction as reported by OSHA, 2018.

Findings from European statistics on Accidents at Work (ESAW) states that construction industry reports the highest accidental injuries than any other sector. The highest reported accidental injuries at work among categories of workers are skilled manual workers. "Struck by object in motion", "collision with" (Figure 3) constitutes the highest among all fatal accidents and accidents occurred at work within more than three days of absence (European Commission., 2010). The complexity of legal obligations, paperwork and lack of time and staff constituted the top three highest reasons for major difficulties in addressing H&S (European Commission., 2010)

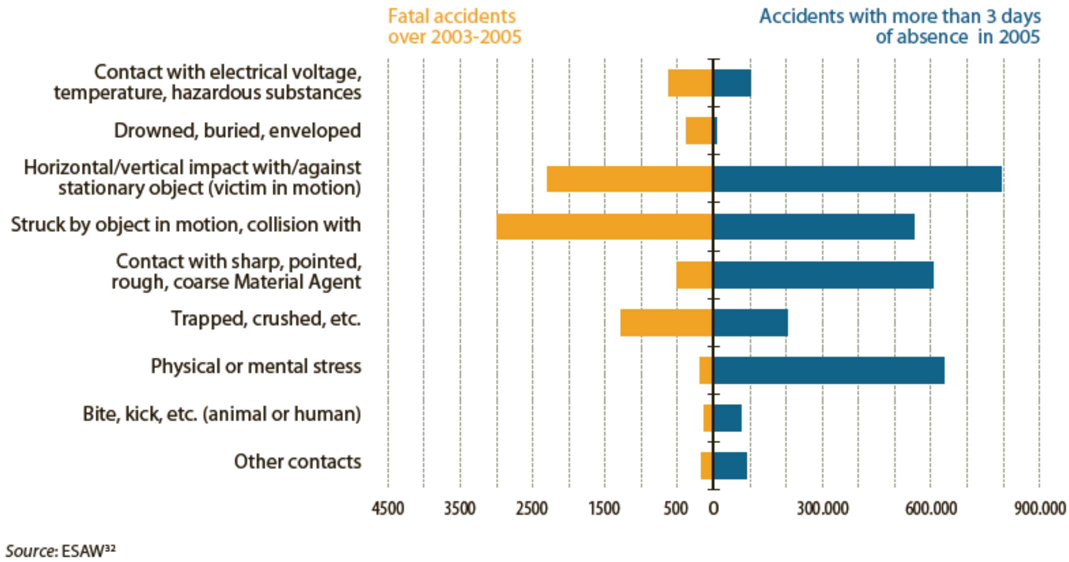

Figure 3 - Number of fatal accidents and accidents at work with more than three days of absence by type of contact-mode of injury as reported by the European Statistical Office (EUROSTAT), 2010.

2.4. State of the art: BIM-based management of H&S in the construction industry

(Chan et al., 2016) states that an essential part of the construction planning process is Safety planning. The field of Occupational H&S management is multi-dimensional and has a heterogeneous nature concerning the results of the nature of its research and development. It has links to basic science such as psychology and has strong ties to applied sciences such as engineering, management, and education. Variations in studies are being done on BIM and its use to facilitate and manage construction Safety management. Sulankivi et al., (2010) identified two main approaches for improving construction site Safety and security, stating that proper collaborative planning and sufficient awareness of working conditions and relating to potential hazards. There are many ways of managing construction Safety issues, some of which are: Education and training, Analysis and anticipation of Safety conditions, monitoring of conditions, and communication and collaboration (Sulankivi et al.,. 2010). Visualization technologies are found to be very effective in construction site Safety education and training in both formal and informal settings (Azhar 2017). Also, developing Safety planning procedures to find the planning tasks which could be supported by BIM is suggested by Sulankivi et al., (2010).

In a case study performed to model a school building using Revit, MS Project, Synchro, linking OSHA Safety guidelines to the 4D model, and making a comparison of the 4D model and a 2D drawing based on the Safety plans to identify hazards, it was found that linking Safety regulations to the BIM model can improve site Safety. It was also suggested that BIM is more realistic and accurate in identifying risks at a workplace in the planning stage and that BIM is more efficient than a 2D method in risk identification such as detecting obstruction by crane, emergency exit plan, etc. (Abed et al., 2019).

Webb and Langar (2019) in their study suggested that to foster Safety on construction projects, adequate project planning, and hazard recognition must be conducted collaboratively (among the major projects' stakeholders) and throughout the project lifecycle (from design inception to project operations). There is a need to integrate BIM-enabled visualisation in undergraduate courses because groups identified to be prone to incidents on job sites are interns and fresh construction management graduates (Webb, 2019). Also, it is of the utmost importance that the scientific community remains steadfast in rigorous and empirical research in construction Safety (Hardison and Hallowell, 2019) It is worth mentioning that BIM does not address construction Safety directly. Instead, it provides a visual and data-driven system that can be used by practitioners as a method to recognize Safety hazards during design and pre-project planning (Qi et al., 2011). Considering uniqueness and complexity of construction projects, organizational learning on OHS cannot be complete if it is based only on generic Safety guidelines and regulations. For Safety practices to be successful it is needed to for it to be based on knowledge-based reasoning (Duryan et al., 2020).

2.4.1. Use of VR and Game Engine for managing construction Safety

The current curiosities in BIM and in general new technologies are progressively bringing the applications of ICT to the field of occupational H&S management. Among the different ways in which BIM is used in the construction industry, the current field of innovation that is being tapped is VR and AR. VR use has gained the attention of the construction industry and is being used mostly for project visualization. Game engines serve as the foundation for VR. Originally Game engine is mostly video game based. The concept lies in developing environment/ scenarios of construction activity and using

VR devices to view the simulation of the environment created. One such related study was performed by Smith et al., (2014), where the validity of the process of creating a virtual environment is tested by identifying a conversion pipeline using Revit 2014 and Unity3D version 4.3.4. (Figure 3). Findings suggest that exploring interaction requirements in the final environment supporting the refinement of BIM is necessary to extend BIM utility to game engine process. The study identifies a BIM database approach (Figure 4) that exports BIM meta-data to a database and then import to Unity3D (Smith et al., 2014).

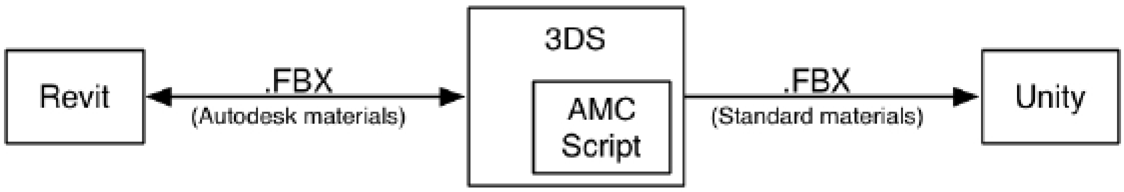

Figure 4 - Revit to Unity 3D conversion pipeline (Smith et al., 2014)

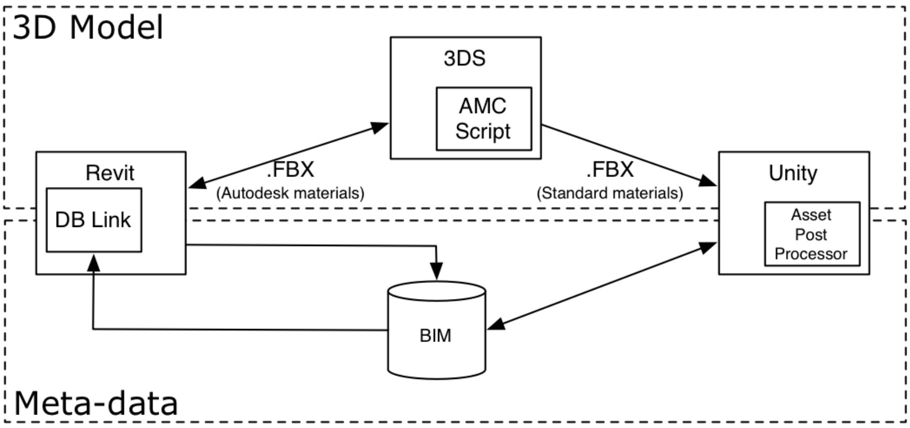

Figure 5 - Proposed Revit to unity 3D pipeline (Smith et al., 2014)

In another study by Azhar et al., (2017) case studies were performed on three different projects using Revit, Google SketchUp, Synchro, MS Project, Unity 3D, Oculus Rift VR headset, 3Ds Max Camtasia and MS movie maker, to address the fatal four Safety issues: falls, struck by objects, caught-in/between, electrocutions. It was suggested from the study that 3D/4D dynamic tools were more effective in planning Safety and management as compared to static 2D drawings and that Visualization technologies are found to be very effective in construction site Safety education and training in both formal and informal settings. An important finding suggests that non-English speaking construction workers would benefit from tenacious advancement in integrating BIM and visualisation technologies such as VR and AR, where virtual walkthroughs would help them understand better and prepare them for sequencing of tasks (Webb and Langar, 2019). Using BIM in Safety training through visualization does away with language barriers and enables better clarity for foreign workers in understanding site conditions (Azhar, 2017).

Studies are done not only on using VR but also on comparison on the effectiveness of VR in identifying risks such as a comparative study which was performed by developing two platforms using 360-degree panorama and VR to compare the efficacy and differences based on two variables: sense of presence and hazard identification index (Eiris, et al., 2020). Results on performing the simulation showed that students perceived the 360-degree panorama condition as more realistic than the VR condition, but professionals perceived no difference between them. Also, challenges were experienced in hazard identification in 360-degree panorama environment in contrast to the VR environment, which presented a less complicated version of a real Jobsite.

A methodology was proposed by Getuli et al., (2020) consisted of 5 objectives: activity workspace modelling, VR activity simulation, Data collection and analysis, workspace modification and on-site validation of the proposed workspace based on a case study. Immersive VR simulation is developed in unity and an automatic track acquisition algorithm developed in Dynamo. It was concluded from the study that advanced information technologies could be used to improve the configuration of workspaces in a construction project site plan, as well as Safety procedures defined in project's H&S plan (Getuli et al., 2020).

Challenges in the application of visualization technologies for Safety planning are additional cost, lack of proficiency in tools by S&H professionals (Azhar et al., 2017). Although much research has focused on developing BIM and AR/VR tools that can be used to improve Safety though constructability reviews, design suggestions, and the automation of Safety systems; research has yet to understand how different formats of design information stimuli (e.g. CAD, BIM, AR/VR, etc.) affect hazard recognition and performance during design (Hardison and Hallowell, 2019).

Table 2 List of software/ technologies used for performing key activities in BIM for Safety demonstration/visualization

Software	Function/purpose	Pros	Cons	Ref Author and year
Revit	BIM tool	• Multiple fall hazards identified through the 3D view • Streamlines repetitive tasks • Multiple discipline coordination • data management • variety of plugins available	• Non-availability of Safety equipment in the software library • Heavy burden on the system with regards to installation requirements	Azhar, 2017; Smith, Brewer and Maud, 2014
Google SketchUp	3d design software	• Editing and exporting 3d equipment, characters and related families. Needed on-site • Open library 3D warehouse • Ease of use	Hard to use for complex modelling	

Synchro	4D construction project management tool	• Developing 4D simulations • Complete details of the general and sub-contractors such as location and date when Safety items are to be installed or removed • 4D simulations are helpful to fully involve owners in the Safety process	
Microsoft Project (MSP)	Project management software	• Scheduling • Organizes tasks efficiently • Can integrate with other Microsoft tools	• Can be difficult for first-timers • Project progress tracking is not friendly
3ds max	Modeling, rendering and animation software	Model clean-up	It takes time to learn
3ds max	Modeling, rendering and animation software	Model clean-up	It takes time to learn
Unity3D	Game engine	• Rendering the model • Creating VR environment • Can be run on both Windows and Apple macOS based computers • Comes in free and commercial forms	• Non-availability of Safety equipment in the library • Requires a certain level of proficiency
CryENGINE		Games developed can be played on major computers and console platforms: Windows, PlayStation and Xbox	• Generally used for high-end computer games • Limited to windows
Oculus Rift (Headset)	**VR headset**	• Viewing the model in VR environment • Lightweight • Interactive and effective • Promising to assess potential danger without being put in the actual simulation	• Complaint of motion sickness by some people • Expensive

2.4.2. Constructability review and BIM

A critical issue within the timing of the project development process is the timing of the reviews. The flexibility in changing various elements in the construction phase becomes less flexible hence diminishing the ability to impact cost and delivery time. (Nikiforos et al., 2017). Because of this reason, it is of utmost importance to conduct reviews in the early design stages to maximize flexibility in plans and avoid any potential redesigns, as well as prevent additional expenses and time. Reviewing the Safety aspect of designs can be performed in BIM at an early stage before construction takes place. The increased use of BIM provides more significant opportunities to identify "foreseeable risk" much earlier, and continuously, throughout a project's lifecycle, and to communicate the risks more clearly for use by others.

In a particular study by Nikiforos Stamatiadis et al., (2017) case studies were used to determine and demonstrate the potential gains from constructability reviews, by developing a list of criteria to select the appropriate case: Project Characteristics, Reviewer, Project stage, Number of review comments, and Geographic distribution. The chosen cases were to have conducted reviews at the final joint inspection or where plans we indicated to advance near completion because projects in the early stage would not have enough detail to support the comments of the accuracy of the value of constructability review. Benefit metric at project and comment level (qualitative and quantitative) were established. Six potential explanatory variables: Error type, category type, severity type, quality level, number of comments and construction estimate, were the data sets chosen to develop the regression analysis which was performed on SPSS software. Results from the research indicated a 1.25% savings for projects reviewed. Benefits accrued could have intangible benefits such as project delay and scope changes.

Boton (2018), with an objective to provide professionals with a co-located and synchronous space for collaboration where VR can be an efficient support to constructability analysis, performed a collaborative persona-based cased study by proposing a framework consisting of 4 steps: setting up the VR environment, creating 4D simulation, preparation and transfer of the model to support VR-based collaborative 4D simulation in construction. Three metamodels also proposed: VR equipment metal model, Constructability factors metamodel, and metamodel of interactions in VR Environments. Game engines which can be used were suggested: quest 3D, Blender, CryEngine, Torque 3D, Unreal, Unity. Collaborative personas were proposed: the doer, the done for and the done with, which provides elements to understand the simulation team's needs. The project considered was related to the construction of an office building in Canada. The study demonstrated the possibility to propose and use a neutral, comprehensive framework (Figure 6). A significant contribution of the study was defining the passage of 4D Navisworks simulation to an immersive VR environment. The study was, however limited to the 4D interaction and result sharing of the simulation, the export and management of spatial-temporal conflicts.

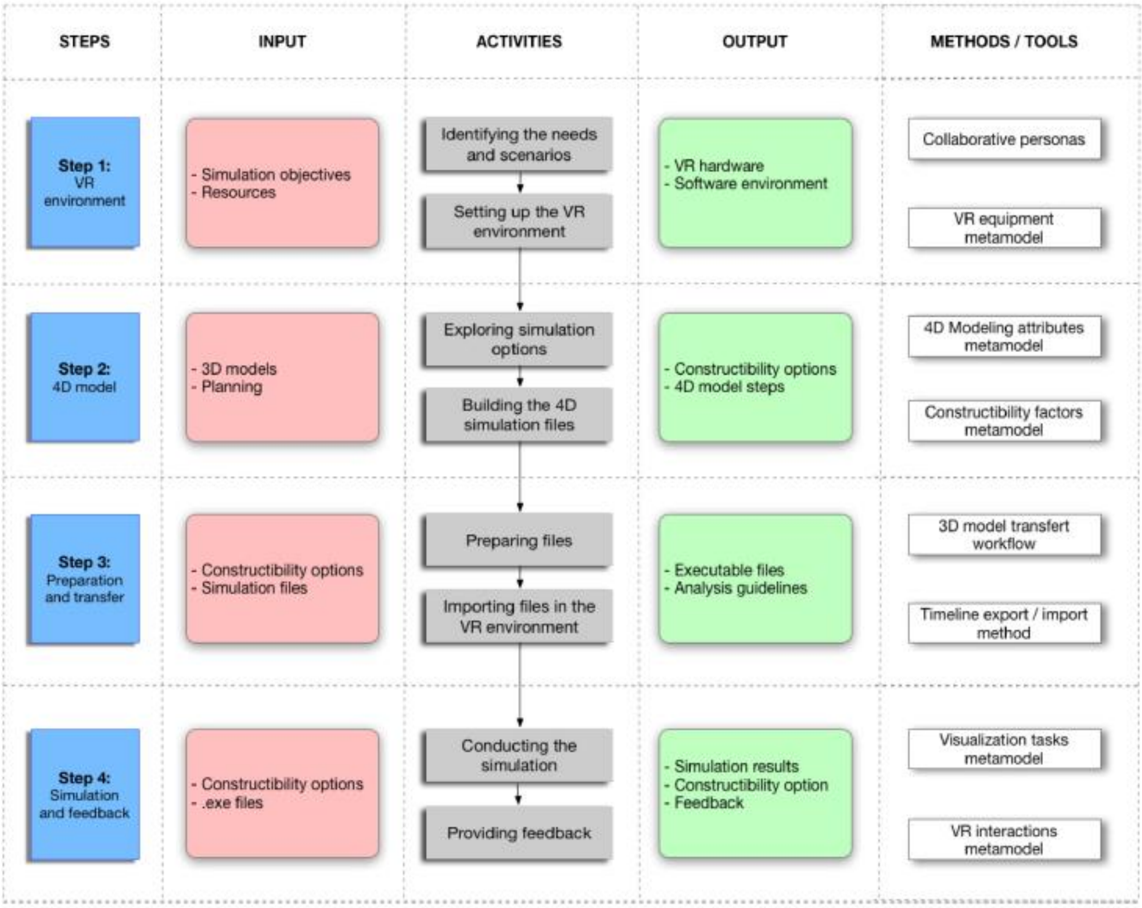

Figure 6 - Proposed framework for immersive VR-based collaborative BIM 4D simulation (Bolton, 2018)

A study with a purpose to identify trends that enable or hinder different user behaviours in the context of design and constructability review was performed by Alsafouri and Ayer (2019) to understand the effect of different mobile computing technologies by making a comparison between presenting the same technical AR environment of a hypothetical office space giving the participants the freedom to choose the AR device and a previous similar study where the participants were not given a choice for selecting the AR device. Eight devices in total, were tested. Seven codes of behaviour: describe, explain, evaluate, predict, formulate an alternative, negotiate and decide (DEEPAND) were identified and analyzed as either a time or event-based dataset. Findings indicated that users of a particular device type may be able to engage in a specific behaviour even if the choice to select a preferred device is not given. The novelty of this work was to demonstrate the context in which devices are applied impacts how they are used. This study may contribute to strategic decision making on whether to use certain device types to elicit specific behaviors.

In a significant work by Cortés-Péreza, et al., (2020), a methodology for integrating H&S risk management into the design phase of buildings was developed. Risk identification criteria as 32 parameters were identified from the National Institute of Occupational H&S (INSST). These parameters were associated with each constructive element of the model so that each specific risk generated by the execution of the element can be activated. A risk parameter (NRi) was created in each BIM object of the model with value 1 to 32, and it is the product of probability(Pi) and severity of the risk (Gi). Color codes based on the value of risk level parameter (NR) was proposed which makes it possible for the Health and Saefty Coordinator (H&SCD) to determine the severity a probability of a risk when a filter is applied to a construction element. Risk generated by the execution of risk parameters were assigned to each constructive element by activating them for the facade wall of the building. Findings from the proposed methodology suggest that this methodology allows the requirements established by the Spanish H&S regulations to be fulfilled at the level of development of mandatory documents such as risk traceability and preventive measures, decreasing the number of occupational accidents also, that the final risk level after the application of measures can be determined.

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3. FRAMEWORK FOR INTEGRATING H&S IN BIM

3.1. Introduction

This chapter presents the process of proposing a framework to integrate risks associated with the H&S in construction into a BIM platform. To develop the framework, an existing well-structured reference to serve as a guide was considered essential, and hence the BSI PAS (Publicly Available Specifications) 1192-6:2018: Specification for collaborative sharing and use of structured H&S information using BIM was used, which was comprehensively analysed. This guide acts as the prime source of reference to establish the basis to develop the framework for integrating H&S in BIM.

There are many ways in which Risk information can be represented in BIM such as documenting risk as being associated to product entity, documenting risk by associating it to a location, use of Gantt chart with a risk associated to a specific entity, and use of risk symbol annotations for emergency planning (PAS 1192-6:2018). For this study, it was decided to document risk information as information associated with a product entity. BIM can be applied using different modelling, management and planning software (Cortés-Pérez et al., 2020). The framework proposed utilized three software applications: (1) Autodesk Revit 2020; (2) Dynamo 2.1, a built-in visual scripting environment; and (3) Microsoft (MS) Excel.
The steps involved in proposing the framework are listed below:

1. Identification of H&S risk
2. Identifying and creating risk parameter
3. Project browser organization
4. Risk assessment matrix
5. Color filters for visualising risk level

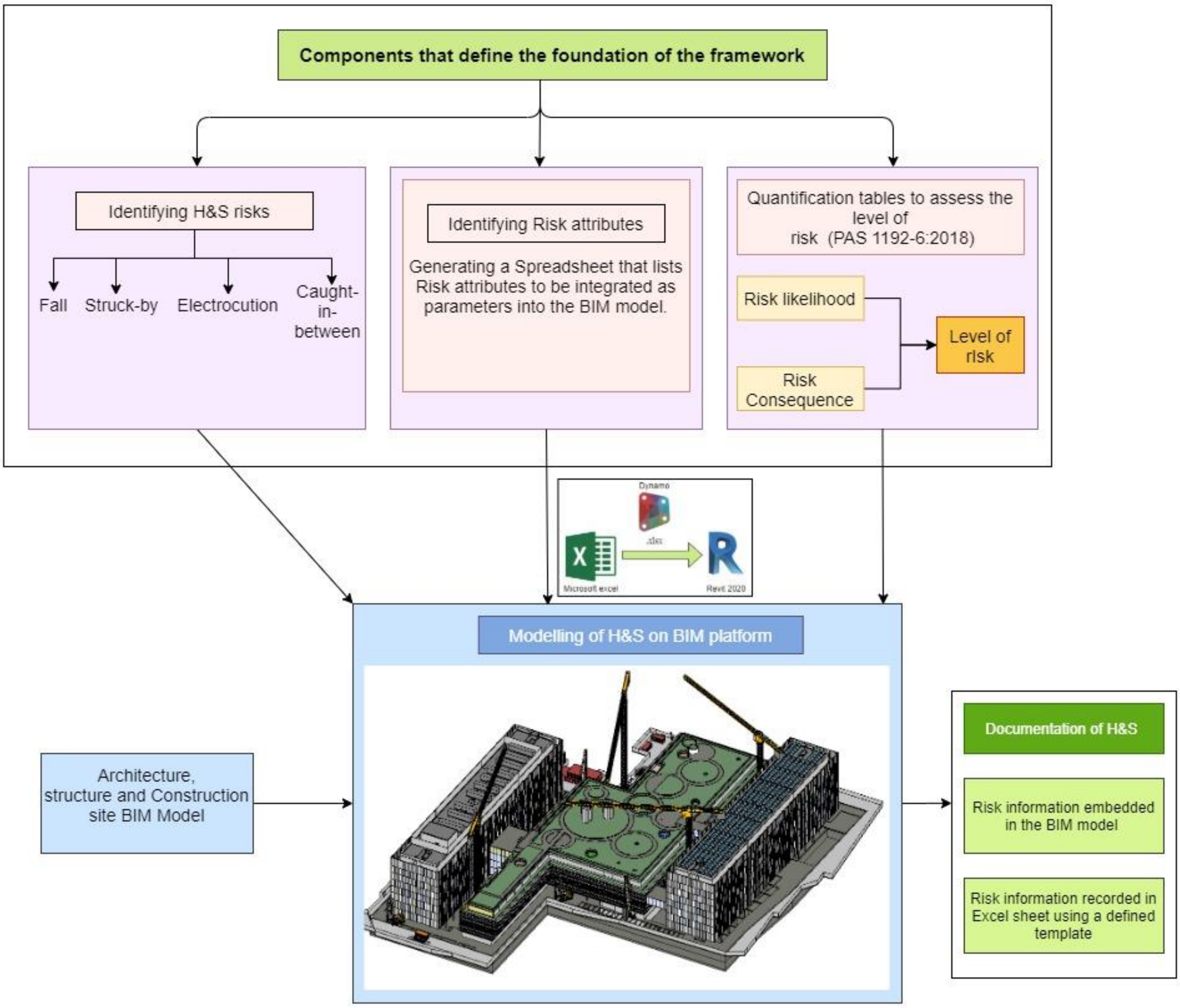


Figure 7 - Proposed Framework for integrating H&S in BIM

3.2. Identification of H&S risks

There are varieties of factors leading to fatalities in construction. An essential component in the framework development was to identify significant causes of construction fatalities. In this study, the Occupational Safety and Health Administration (OSHA) focus four is considered. The OSHA categorizes the top four causes of construction fatalities as the Fatal four: Falls, Struck-by, Caught-in/between and Electrocution. Below are these hazards as defined by OSHA:

- A Fall hazard is anything at your worksite that could cause you to lose your balance or lose bodily support and result in a fall.
- Struck is defined as injuries produced by forcible contact or impact between the injured person and an object or piece of equipment

- Caught-in-or between hazards are defined as injuries resulting from a person being squeezed, caught, crushed, pinched, or compressed between two or more objects or between parts of an object.
- An electrical hazard can be defined as a serious workplace hazard that exposes workers to burns, electrocution, shock, arc flash/arc blast, fire and explosions.

Different risks fall under each hazard category. The PAS 1192-6:2018 consist of a list of risks associated with fatalities in construction. A list of risks identified and categorized is generated based on the PAS 1192-6:2018, OSHA Focus Four, and Safety data sourcing table (Pham et al., 2020). Table 1 represents the risk categories

Table 3 H&S Risks (adopted from PAS 1192-6:2018, OSHA Focus Four and Pham et al., 2020)

Safety Category	Risk Description/Hazard scenarios	Associated Elements/Components/Area
Fall	Fall from open edge Fall from floor opening Fall from scaffold Fall from ladder Fall through fragile material Slip or trip on the same level	Floor Scaffold Ladder Roof Fall protection
Struck by	Struck by falling object Struck-by flying object Struck-by swinging object Struck by machinery or part Struck by moving vehicle Struck-by rolling object	Crane Swing radius of crane Trucks Excavator Piling machine
Electrocutions	Contact with power lines Path to Ground missing or Discontinuous Equipment not used in proper manner described Improper use of extension and flexible cord	Electric outlets Extension and application cords Plugs Overhead power lines
Caught-in or-between	Crushed by excavation Confinement Unintended collapse Cave-ins (trenching) Pulled into or caught in machinery and equipment	Excavation area Machinery Site equipment

3.3. Identifying and creating risk parameter

There are many characteristics which are essential to be defined to add context to a risk. These characteristics will give meaning to the risk, representing all necessary information to be known about the risk. Hence, it was considered essential to identify the attributes of risks so that context information can be added to the risk. In this step of the methodology, risk attributes and the type of information suitable to describe the attributes of the risks are identified. A table consisting of the typical contents of attributes of the risk information was created and adopted from PAS 1192-6:2018 (Table 4). Further, an empty template (Table 5) was created to be used for recording all information about the risk.

Sections of Table 4 are explained below:

- **Content or risk attribute**: Every risk consists of different attributes which are necessary for the risk to be understood in detail and which are essential for managing the risk. Such attributes are risk name, risk description, risk likelihood, etc.
- **Risk information sharing**: This section suggests whether the information regarding the risk attributes are necessary to be shared or not. Some information of risk attributes are mandatory and need to be addressed, hence cannot be skipped. Other information are recommended, meaning they are not a mandate but are advisable to be addressed. However, some risk information may or may not be addressed.
- **Type of data**: Data types that are well suited and describes the risk attributes are varied. Some attributes are suited to be described in the text, while information about certain attribute would be better suited through links. Other attributes like Date raised is better suited to be described using a date. Some attribute information are suited to be represented through a file reference or link.

Table 4 Attributes for Risk Information, suggestion and data type of risk

Content or risk attribute	Risk Information Sharing	Type of data
Risk Name	mandatory	Text
Risk Category	mandatory	Text
Risk Description	mandatory	Text
Associated product	mandatory	Text or link
Associated Activity	mandatory	Text or link
Associated Location	mandatory	Text or link
Risk Assessment Methodology	recommended	Text
Agreed mitigation	mandatory	Text
Risk Likelihood	recommended	Text
Risk Consequence	recommended	Text

Level of Risk	mandatory	Text
Proposed Mitigation	optional	Text
Date Raised	optional	Date
Date Updated	optional	Date
Date Review	optional	Date
Owner Discipline	mandatory	Text
Risk Documentation	optional	File reference or URL

Table 5 Template created to record risk information

Name	Option	Type	Risk associated Element
Risk Name	Mandatory	Text	
Risk Category	Mandatory	Text	
Risk Description	Mandatory	Text	
Associated product	Mandatory	Text	
Associated Activity	Mandatory	Text	
Associated Location	Mandatory	Text	
Risk Assessment methodology	Recommended	Text	
Agreed mitigation	Mandatory	Text	
Risk Likelihood	Mandatory	Text	
Risk Consequence	Mandatory	Text	
Level of Risk	Mandatory	Text	
Proposed mitigation	optional	Text	
Date Raised	optional	Text	
Date Updated	optional	Text	
Date Review	Mandatory	Text	
Owner discipline	Mandatory	Text	
Risk Documentation	optional	Text	

The type of information entered for risk attributes (Table 4) are explained below:

Risk Name: Short unique name of the content or risk entry, for each risk associated element unique to the project or library were entered for risk name

Risk Category: The classification that the risk falls under. E.g.: Safety issue, Health issue, etc were entered for risk category.

Risk Description: Information regarding description of the context or hazard were be entered for the risk description. However, associated location, product and process of risk should be omitted for this attribute.

Associated product: Associated product could be a product, material, type, component, system or facility associated to the risk. The information maybe a name, category, description or spec/bill or entity reference. For this study, the associated product considered were floors, Crane, Piling machine, Excavator and dumper truck.

Associated activity: Associated activity maybe an activity, process, task, job type, package or project associated to the risk. The information maybe a name, category description or plan/Gantt or entry reference.

Associate location: Associated location maybe the location, space, level, region, zone, or site associated to the risk. Information maybe a name, category, description or drawing or entity reference.

Agreed mitigation: Information regarding decisions made on measures to take to resolve a risk after proper consultation/meeting were entered for agreed mitigation. The agreed mitigation considered for this study on the risks were considered by referring to

Risk likelihood: The likelihood of the risk after realising the agreed mitigation were entered in this field. The risk likelihood was rated from the proposed Risk likelihood table (Figure 14) which was adapted from PAS 1192-6:2018.

Risk consequence: The grade of consequence of the risk after realising the agreed mitigation will be entered in this field. The risk consequence was rated from the proposed Risk consequence table (Figure 14) which was adapted from PAS 1192-6:2018.

Level of risk: The grade of the risk after realising the agreed risk mitigation strategy were entered under level of risk. The level of risk was rated from the proposed risk assessment matrix table (Figure 15) which was adapted from PAS 1192-6:2018. The matrix consist of five levels ranging from very low to very high.

Date raised: The date when the entry was first logged will be entered for this attribute date raised.

Date updated: The date when the entry was last updated will be entered for this attribute

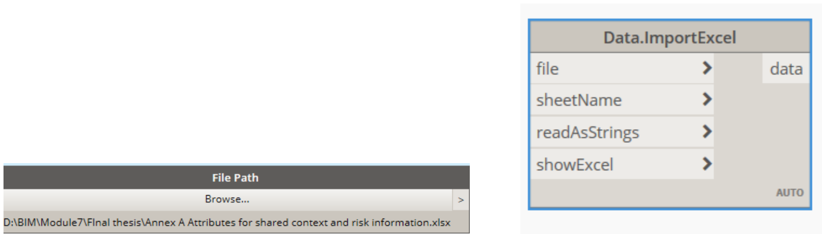
Date review: The date when the entry was last reviewed or due will be entered for this attribute

Owner discipline: Name of relevant sub-discipline or sub-contractor or trade will be entered for this attribute.

The process of integrating the risk information in the BIM platform requires risk attributes to be generated in the BIM platform Revit 2020 as shared parameters. The process of creating parameters manually is typically time consuming and hence, to automate this process, a Dynamo script was generated (Figure 11). The generated shared parameters are shown in Figure 12. Dynamo is a built-in visual scripting environment and allows actions to be programmed by accessing the Application programming interface on Revit. Dynamo serves as a medium to automatically generate Safety parameters in Revit by importing the risk attributes. The workflow defined for the Excel to Revit import via Dynamo can be seen in Figure 8. Table 5 was used as the database for this process. Description of the functions of the Dynamo nodes used to create the script :

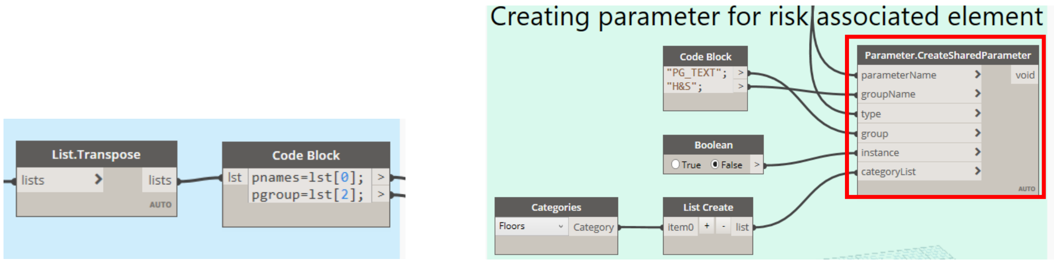
- The “File Path” node (Figure 9(a))was used to locate the database (Table 5).
- “Data.ImportExcel” node (Figure 9(b)) was used to import data from the database. This node required the excel file and the sheet name and generated the list of items of the excel sheet.
- Data from the imported sheet are only listed and not organized. The “List Transpose” node (Figure 10 (a))was then used to generate the list of items according to the way they are organized in the excel sheet.
- To create the parameter and the parameter type “Code Block” (Figure 10(a)) was used to extract only the first and the second column from the linked database. The first column listed the risk attributes and the third column the type of parameter of each attribute.
- The node “Parameter.CreateSharedParameter” (Figure 10(b)) was the output node. This node required the inputs: parameter name, group name, type, group, and the lists of categories of elements that were required for the parameters creation. With these inputs, on running the dynamo script, the parameters were generated and embedded in the selected elements.

Figure 8 - Creating parameters in Revit from Excel via Dynamo workflow



(a) **(b)**

Figure 9 - (a) node to locate database (b) node to import data from excel sheet



(a) **(b)**

Figure 10 - (a) nodes to organize data from excel and select desired items (b) output node that generates shared parameters in Revit

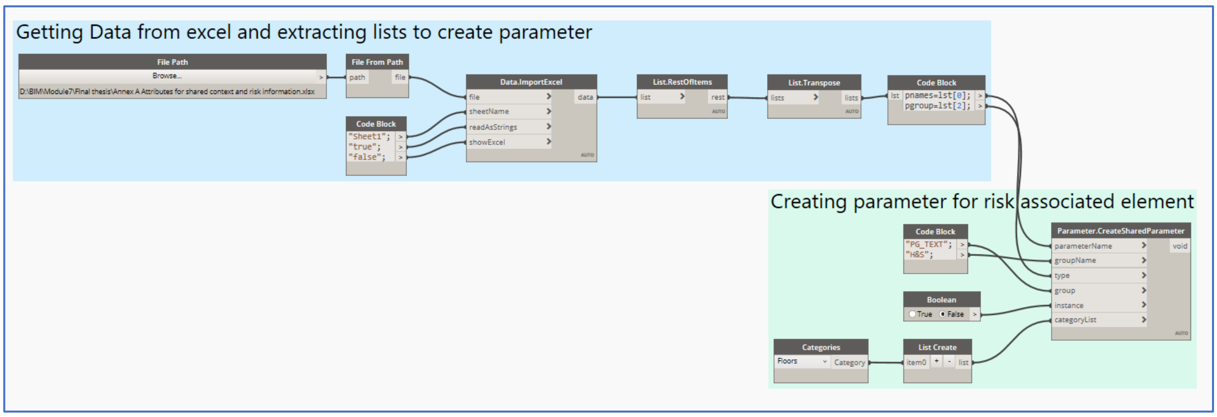
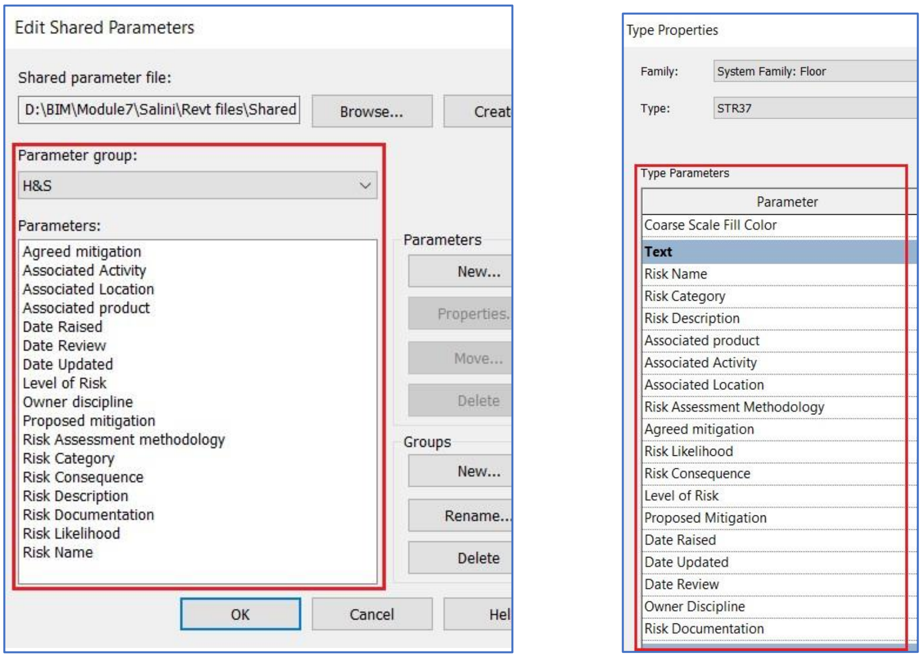


Figure 11 - Dynamo script to create H&S risk parameters in Revit

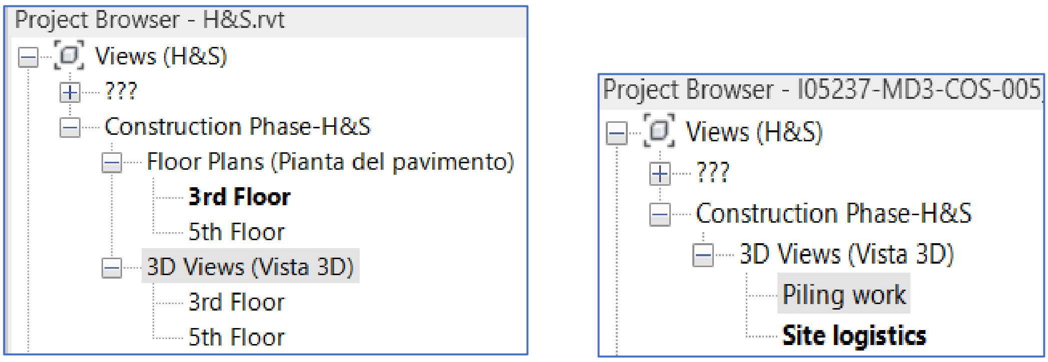


(a) **(b)**

Figure 12 - (a) Shared risk parameter created under the name H&S (b) Risk Parameters embedded in the risk associated element: Floor

3.4. Project browser organization

BIM's are generally organized by discipline: Structure, architecture, Construction site, etc. Construction phases are excavation, structural framings, masonry work, finishes, etc. A specific H&S view was proposed with a sub-discipline to introduce and manage H&S information in the model. Pre-construction phase was considered, and activities of this phase were identified. The sub-discipline represents the pre-construction phase, and activities were organized under the sub-discipline (Figure 13)



(a) **(b)**

Figure 13 - Phase organization in Revit for: (a) Structure model (b) Construction site model

3.5. Risk assessment matrix

H&S information can be integrated into BIM based on risks. Different risk assessment methodologies have been developed at an international level that guarantees systematic analysis (Cortés-Pérez et al., 2020). There are qualitative and quantitative ways of rating risks. Qualitative scales are considered to be more easily reviewed and less ambiguous in exchanges than quantitative scales. (PAS 1192-6:2018). For this study, the risk rating is considered to be done on a qualitative scale adapted from the PAS 1192-6:2018 (Figure 14 &15). This method is based on a five-term scale, where risks are rated on a level from very low to very high. There are three separate tables defined for Risk likelihood, consequence, and level of risk. Appropriate levels for the risk consequence and likelihood will be selected with reference to Figure 14. After the selection, the level of risk are worked out from the risk assessment matrix, as shown in Figure 15. Finally, for visual representation of risk, color filters are adopted and created corresponding to the risk assessment matrix. The color filters can be assigned to every element where risks are associated and linked to the “level of risk” parameter. The output of this step will be a BIM model where elements associated with risks will display different colors with respect to the level of risks.

Scale	Likelihood
Very High	Very probable or repeated
High	Probable or frequent
Moderate	Possible
Low	Unlikely or remote
Very Low	Remote

Scale	Consequence
Very High	Catastrophic
High	Severe
Moderate	Serious
Low	Marginal
Very Low	Minor

Scale	Level of Risk
Very High	Exceptional, including the highest possible
High	Above moderate
Moderate	Typical or normal
Low	Below moderate
Very Low	Well below moderate including the lowest possible

Figure 14 - Table defined for Risk likelihood, Consequence and Level of risk adopted from PAS 1192-6:2018

Likelihood						
Very High	*Moderate*	*Moderate*	*High*	*Very High*	*Very High*	
High	*Moderate*	*Moderate*	*Moderate*	*High*	*Very High*	
Moderate	*Low*	*Moderate*	*Moderate*	*Moderate*	*High*	
Low	*Very Low*	*Low*	*Moderate*	*Moderate*	*Moderate*	
Very Low	*Very Low*	*Very Low*	*Low*	*Moderate*	*Moderate*	
	Very Low	Low	Moderate	High	Very High	Consequence

Figure 15 - Risk assessment matrix to assess the Level of risk, adopted from PAS 1192-6:2018

3.6. Color filters for visualising risk level

For risk visualisation, color filters were created for different risk levels from the Visibility and Graphics dialog. In this process, element category floors, which was associated with risks were selected, followed by selecting the "Level of Risk" parameter, assigning a certain color to a particular value of the parameter and applying the rule "All rules must be true". Thus, depending on the value of the "Level of risk" in each element, color filters were applied, and there was a change in element colors (Figure 16 &17).

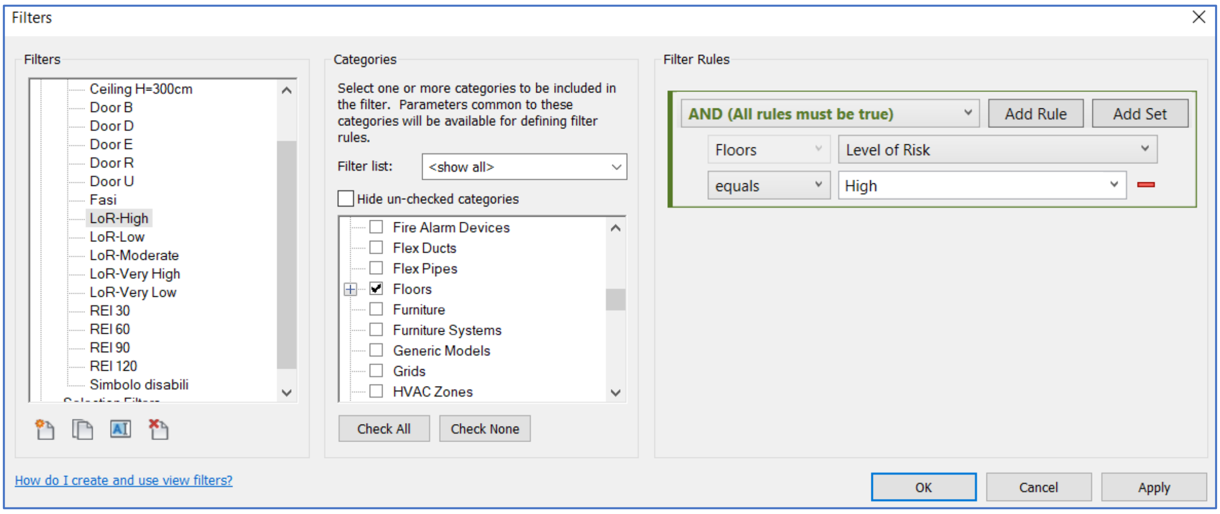


Figure 16 - Creating Color filter with rules for the five Risk levels

Model Categories | Annotation Categories | Analytical Model Categories | Imported Categories | Filters

Name	Visibility	Projection/Surface			Cut		Halftone
		Lines	Patterns	Transparen...	Lines	Patterns	
LoR-Very High	☑						☐
LoR-High	☑						☐
LoR-Moderate	☑						☐
LoR-Low	☑						☐
LoR-Very Low	☑						☐

Figure 17 - View filters created for the five Risk levels

4. CASES STUDY- ASSESSMENT OF THE H&S INTEGRATION IN BIM WITHIN CONSTRUCTION INDUSTRY.

4.1. Case scenario

The case study was tested on a BIM model of an important Italian Hospital, which was provided by WeBuild (formerly known as Salini Impregilo). The BIM model is a ten floors building developed in Autodesk Revit. It is a complete model with:

- Site reference Model (AutoCAD drawing)
- Surroundings Model
- Structural Model
- Architectural model
- Construction Site Model
- Temporary Works
- Façade Model
- Excavation by phases
  (without mechanical, electrical, and plumbing (MEP))

The models were the Structural and Construction Site Model. Risk documentation method selected for this study was representing risk information by associating information on a product entity. Model elements which are potentially associated with risks were selected: slabs from the structural model, and the site equipment: Crane, Piling machine, Excavator and Dumper. For the case study, two risk categories under OSHA, i.e., Falls and Struck-by were selected, two risks were selected from the fall category and three from the struck-by category. Table 6 shows the risk category risk type and elements associated that were chosen for the case study. The purpose of this case study is to assess the integration of H&S in BIM by adopting the proposed framework for integrating H&S in BIM the previous chapter.

Table 6 Risk category and associated elements selected for the case study

Safety Category	Risk Description/Hazard scenarios	Associated Elements/Components
Fall	Fall from open edge	Floor
	Fall from floor opening	Floor
Struck by	Struck by falling object	Tower Crane
	Struck by machinery or part	Crawler crane with grab Excavator Pile boring equipment

Struck by moving vehicle	Truck

4.2. Automated generation of H&S parameters in BIM

This step describes the process of linking H&S parameters to BIM. After the identification of risk parameters, the next step was to create those parameters in Revit. The risk parameters generated were those listed in the Excel sheet (Table 5). The workflow defined in Figure 8 was used for this step. To automate this process, the Dynamo script was used (Figure 11). The script served as a medium to import the risk attributes and automatically generate Safety parameters as a "text type" parameter in Revit and was assigned to all the elements identified for representing risks. Figure 18 and 19 illustrates an example of the safety parameters generated and assigned to a tower crane and a floor.

4.3. Risk visualization

The final step was a visualisation of risks in the BIM model. Pre-construction phase was considered for this case study. A specific H&S View was created with a sub-discipline to introduce and manage H&S information in the model. To represent the risk phase wise, a "Construction Phase-H&S" parameter was created under which phase-wise 3D views and floor plans were created. For the Structural model, the third and fifth floor construction phase was considered, and for the construction site model, phases considered were piling work and site logistics. A project navigator was configured by using a filter based on H&S parameter to enable an organized visualisation of the construction phase. Risk levels of the elements were identified by first assigning individual values to the risk likelihood and risk consequence from Figure 14, and the level of risk was identified form the risk assessment matrix (Figure 15) by comparing the value of risk likelihood and risk consequence.

Color filters were generated, and the purpose of applying color filters was to enhance the ability of risk visualisation. Filters were created for the structural model only and not for the construction site model. For the Construction site model, to display the risk information, the site equipment needs to be selected to see the list of details in the equipment properties. For the structural model, risk information are embedded in the elements and also color filters are applied. Example of a color filter applied in the third floor in the structural BIM model is shown in Figure 20, floors representing high and moderate risk levels. The computation of the value of risk likelihood and consequence was assigned as a hypothetical example. Other information relating to all the risks attributes: Associated Activity, Associated Location and Agreed Mitigation were assigned based on the commonly associated actions performed for the particular kind of risk. The template generated in Figure 5 was used as a database to document all risk related information of the different risk associated elements. The data were recorded together in a sheet (Figure 21), element-wise and also separate sheets were created to record the same information for each element. (Annex 2-7).

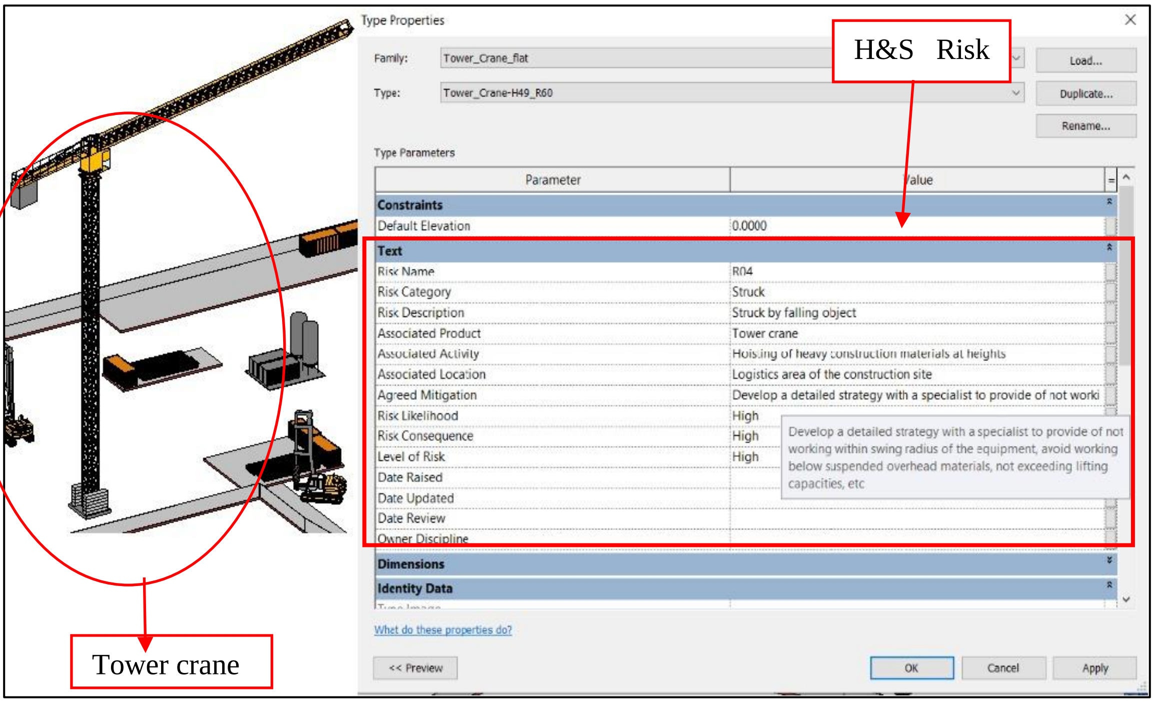


Figure 18 - H&S risk information of Struck by risk integrated in the tower crane properties

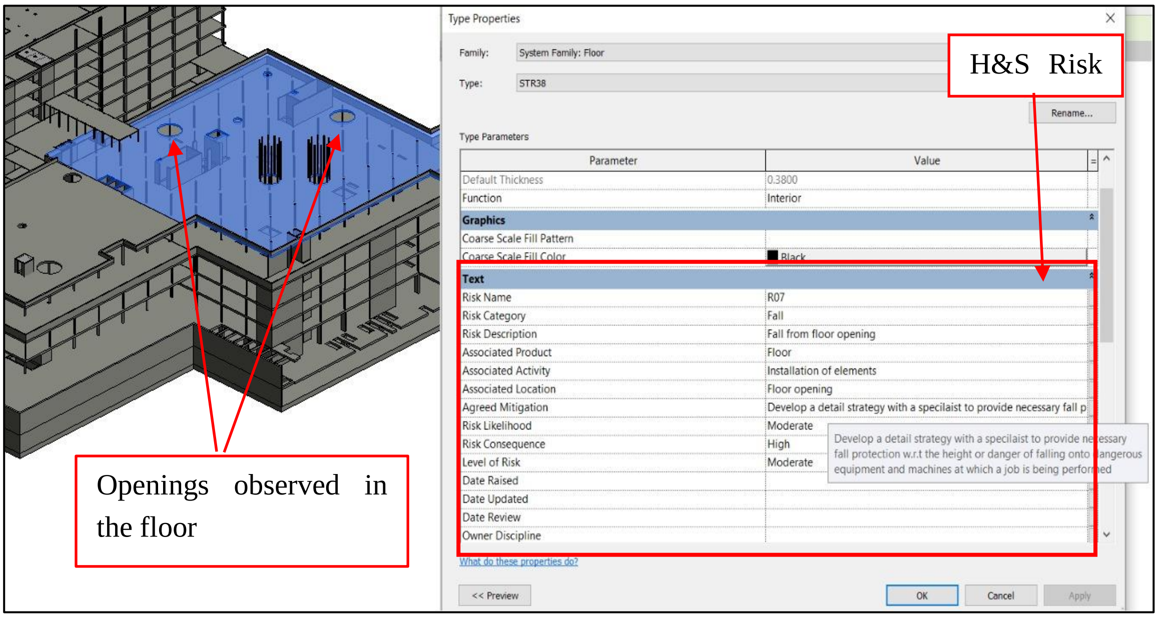


Figure 19 - H&S risk information of a "Fall through opening" risk integrated in the floor properties

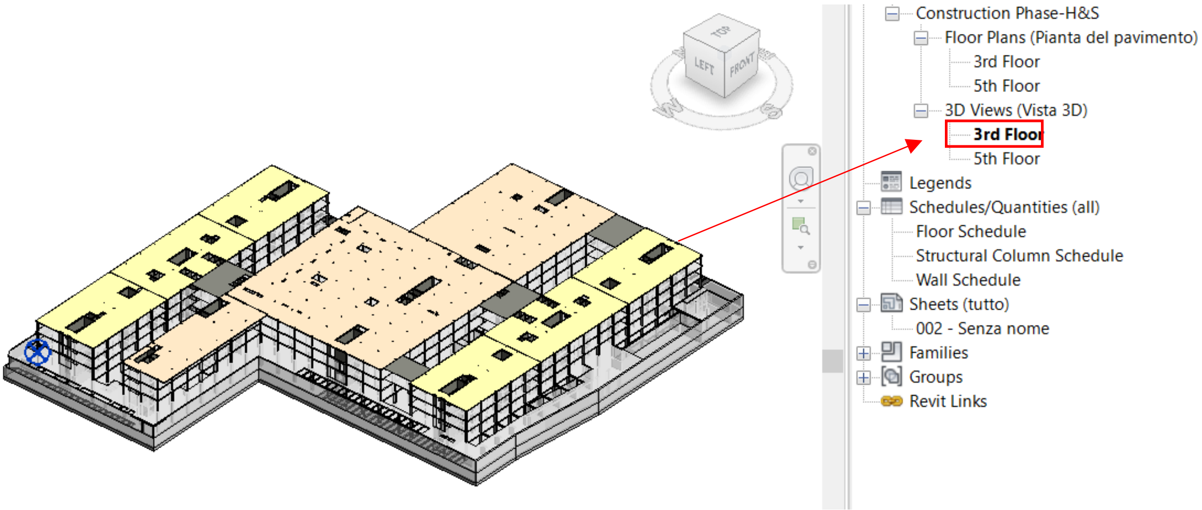


Figure 20 - Risk filter applied on the third floor of the building.

Name	Option	Type	Crane with cable grab	Excavator	PilingMachine	Crane	Dumper	Slab	Slab2
Risk Name	Mandatory	Text	R01	R02	R03	R04	R05	R06	R07
Risk Category	Mandatory	Text	Struck	Struck	Struck	Struck	Struck	Fall	Fall
Risk Description	Mandatory	Text	Struck by Machinery or part	Struck by Machinery or part	Struck by Machinery or part	Struck by falling object	Struck by moving vehicle	Fall from open edge	Fall from floor opening
Associated product	Mandatory	Text	Crawler crane with grab	Excavator	Pile boring equipment	Tower Crane	Truck	Slab	Slab
Associated Activity	Mandatory	Text	Lifting items or materials in the construction site	Digging, removing materials on site	Drilling a hole into the soil	Hoisting of heavy construction materials at heights	Carrying materials in construction sites	Installation of window panels	Installation of elements
Associated Location	Mandatory	Text	Area of clearing/lifting items in the construction site	Logistics area of the construction site	Foundation area in construction site	Logistics area of the construction site	Logistics area of the construction site	Edges of the slab	Floor opening
Agreed mitigation	Mandatory	Text	Provide and maintain a system of work for the operation, Ensure the use of PPE for the workers, well trained operators, etc.	Develop a detailed strategy with a specialist to provide and maintain a system of work for the operation, ensure the use of PPE for the workers, well trained operators, etc.,	Develop a detailed strategy with a specialist to provide and maintain a system of work for the operation, ensure the use of PPE for the workers, well trained operators, etc.,	Develop a detailed strategy with a specialist to provide of not working within swing radius of the equipment, avoid working below suspended overhead materials, not exceeding lifting capacities, etc	Develop a detailed strategy with a specialist to provide and maintain a system of work for the operation, ensure the use of PPE for the workers, well trained operators, etc.,	Develop a detail strategy with a specilaist to provide necessary fall protection w.r.t the height or danger of falling onto dangerous equipment and machines at which a job is being performed	Develop a detail strategy with a specilaist to provide necessary fall protection w.r.t the height or danger of falling onto dangerous equipment and machines at which a job is being performed, Cover and secure floor openings and label floor opening covers.
Risk Likelihood	Mandatory	Text	Qualitative scale, Table 2, PAS_1192-6:2018	Qualitative scale, Table 2, PAS_1192-6:2018	Qualitative scale Table 2, PAS_1192-6:2018	Qualitative scale, Table 2, PAS_1192-6:2018	Qualitative scale, Table 2, PAS_1192-6:2018	Qualitative scale, Table 2, PAS_1192-6:2018	Qualitative scale, Table 2, PAS_1192-6:2018
Risk Consequence	Mandatory	Text	Qualitative scale Table 2, PAS_1192-6:2018	Qualitative scale Table 2, PAS_1192-6:2018	Qualitative scale Table 2, PAS_1192-6:2018	Qualitative scale Table 2, PAS_1192-6:2018	Qualitative scale Table 2, PAS_1192-6:2018	Qualitative scale Table 2, PAS_1192-6:2018	Qualitative scale Table 2, PAS_1192-6:2018
Level of Risk	Mandatory	Text	Assessed from the risk assesment matrix, Table 3, PAS 1192-6:2018	Assessed from the risk assesment matrix, Table 3, PAS 1192-6:2018	Assessed from the risk assesment matrix, Table 3, PAS 1192-6:2018	Assessed from the risk assesment matrix, Table 3, PAS 1192-6:2018	Assessed from the risk assesment matrix, Table 3, PAS 1192-6:2018	Assessed from the risk assesment matrix, Table 3, PAS 1192-6:2018	Assessed from the risk assesment matrix, Table 3, PAS 1192-6:2018
Date Raised	optional	Text	Date entry first logged	Date entry first logged	Date entry first logged	Date entry first logged	Date entry first logged	Date entry first logged	Date entry first logged
Date Updated	optional	Text	Date entry last updated	Date entry last updated	Date entry last updated	Date entry last updated	Date entry last updated	Date entry last updated	Date entry last updated
Date Review	optional	Text	Date entry last reviewed or due	Date entry last reviewed or due	Date entry last reviewed or due	Date entry last reviewed or due	Date entry last reviewed or due	Date entry last reviewed or due	Date entry last reviewed or due
Owner Discipline	Mandatory	Text	Name of relevant sub-discipline or sub-contractor or trade	Name of relevant sub-discipline or sub-contractor or trade	Name of relevant sub-discipline or sub-contractor or trade	Name of relevant sub-discipline or sub-contractor or trade	Name of relevant sub-discipline or sub-contractor or trade	Name of relevant sub-discipline or sub-contractor or trade	Name of relevant sub-discipline or sub-contractor or trade

Figure 21 - Database recording risk information of all risk associated elements

5. CONCLUSIONS

The adoption of BIM in construction has been increasing, and its versatility is believed to be readily extendable to other aspects of construction such as construction Safety management. H&S is a vital aspect to all areas in the construction industry and is considered to be a vastly exposed sector pertaining to occupational accidents. Majority of fatalities in the construction sector can be attributed to the Fatal Four defined by Occupational Safety and Health Administration (OSHA) as Falls, Stuck-by, Caught-in/between and electrocutions. Analysis of Safety conditions is one way of managing construction Safety issues. Technologies such as VR and Game Engine, although still very new to the construction field, enhance BIM functionality by producing simulations which don’t require presence at the actual Jobsite and hence provide a safe environment to dissipate Safety-related information seamlessly to potentially risk associated people and people managing H&S. Despite the advantage of visualisation technologies for Safety planning the challenges posed in their application are an additional cost, lack of proficiency in tools by professionals, etc. Tools used for Safety management such as Revit, Synchro, Unity3D, etc. are identified in this study from the literature.

It is identified that conducting early-stage reviews is important to maximize flexibility plans and avoid any potential redesigns, as well as avoid additional expenses and time. Use of BIM provides the advantage of identifying “foreseeable risks” much earlier in a project and contributes to communicating risks clearly. Benefits of performing constructability reviews before construction could have intangible benefits such as project delays and scope changes. A methodology to integrate H&S in BIM was proposed in this study and applied on a case study to validate the proposed methodology. Commonly occurring risks are identified and listed then set as parameters in the BIM platform with the help of a Dynamo script to automate the process of parameter creation. Activities in the pre-construction phases were considered to represent different risks types associated to a particular phase, and color filters were applied to the BIM model elements where risks were associated to enhance the risk identification concerning the level of risk. Risk assessment was used to identify the level of risk. Finally, a database recording all attributes of risk information was generated.

The works carried out in this study can be perceived as an addition to the body of knowledge concerning H&S risks occurring in the construction industry. The proposed methodology possesses the benefit that different researchers suggested would be achieved with the application of BIM in H&S. For example, it can prove to be beneficial in information sharing during the pre-construction phase in the design process where there is a need for communicating and understanding the potential Safety issues that encompass a project among different technicians and also during constructability review meetings. Not only can it be beneficial in representing risks and risk information, but it can also be helpful to understand necessary steps required to prioritize the type of risks that needs to be addressed.

This study is limited to static risk representation. Also, the value of risk likelihood and consequence was assigned as a hypothetical example. There are many ways of assessing and managing risks which can be performed by referring ISO 31010:2019 and ISO 31000:2018. Data entry for risk attributes were manual.

The present study is limited to generating risk parameters in elements. It would be an advancement in risk representation to develop a complete catalogue of BIM objects which should be parametrised according to regulations that regulate them. These objects can be used to indicate risks in a specific location or area. Improvements of this study may be made by performing dynamic risk representation by using tools such as SynchroPro and Navisworks to represent risks phase-wise of the entire project and use VR and Game Engine to enhance information delivery, risk identification and visualisation. Automated rule-based checking and resolution of risks according to standards can be an anticipated area of development. Additionally, automated extraction of risk information from the BIM platform to MS Excel can be an area for development. Development could also be done for generating standard risk information documentation for sharing of risk information by adopting standardised format such as COBie.

6. REFERENCES

Journals

Azhar, S. (2017) 'Role of Visualization Technologies in Safety Planning and Management at Construction Jobsites', in Procedia Engineering. Elsevier Ltd, pp. 215–226. doi: 10.1016/j.proeng.2017.01.329.

Alsafouri, S. and Ayer, S. K. (2019). 'Leveraging mobile AR devices for enabling specific human behaviors in design and constructability review', Advances in Civil Engineering, 2019. doi: 10.1155/2019/3951986.

Abed, H. R., Hatem., W. A., Jasim, N.A. (2019) 'Possibility of Bim Technology in Site Safety Analysis at Iraqi Construction Industry', International Journal of Civil Engineering and Technology (IJCIET), 10(06), pp. 399–410. Available at: http://www.iaeme.com/ijciet/issues.asp?JType=IJCIET&VType=10&IType=06http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=10&IType=06http://www.iaeme.com/IJCIET/index.asp400.

Bille, R. et al., (2014) 'Extending building information models into game engines', in ACM International Conference Proceeding Series. Association for Computing Machinery. doi: 10.1145/2677758.2677764.

Boton, C. (2018) 'Supporting constructability analysis meetings with Immersive VR-based collaborative BIM 4D simulation', Automation in Construction, 96, pp. 1–15. doi: 10.1016/j.autcon.2018.08.020.

Chan, I.Y.S., Leung, H.Y., Fung, I.W.H., Leung, M. (2016) 'How can BIM support Construction Safety Management? Development of SIM'. doi: 10.1051/00018.

Cortés-Pérez, J. P., Cortés-Pérez, A. and Prieto-Muriel, P. (2020) 'BIM-integrated management of occupational hazards in building construction and maintenance', Automation in Construction, 113. doi: 10.1016/j.autcon.2020.103115.

Duryan, M. *et al.*,. Meri, Smyth, H., Roberts, A., Rowlinson, S., and Sherratt, F. (2020) 'Knowledge transfer for occupational H&S: Cultivating H&S learning culture in construction firms', Accident Analysis and Prevention, 139. doi: 10.1016/j.aap.2020.105496.

Eiris, R., Gheisari, M. and Esmaeili, B. (2020) 'Desktop-based Safety training using 360-degree panorama and static VR techniques: A comparative experimental study', Automation in Construction, 109. doi: 10.1016/j.autcon.2019.102969.

Ghaffarianhoseini, A., Tookey, J., Naismith, N., Azhar, S., Efimova, O., Raahemifar, K. (2017) 'Building Information Modelling (BIM) uptake: Clear benefits, understanding its implementation, risks and challenges', Renewable and Sustainable Energy Reviews, pp. 1046–1053. doi: 10.1016/j.rser.2016.11.083.

Getuli, V. *et al.*,. (2020) 'BIM-based immersive VR for construction workspace planning: A Safety-oriented approach', Automation in Construction, 114. doi: 10.1016/j.autcon.2020.103160.

Hardison, D. and Hallowell, M. (2019) 'Construction hazard prevention through design: Review of perspectives, evidence, and future objective research agenda', Safety Science. Elsevier B.V., pp. 517–526. doi: 10.1016/j.ssci.2019.08.001.

Melzner, D. (2017). 'Acquisition and processing of input data for an object - oriented Safety risk simulation in building construction'. Proceedings of the 2017 Winter Simulation Conference, pp. 2425-2435. doi: 978-1-5386-3428-8/17/$31.00.

Pham, K. T. Vu, D. N., Hong, P.L. H., and Park, C. (2020) '4D-BIM-based workspace planning for temporary Safety facilities in construction SMES', International Journal of Environmental Research and Public Health, 17(10), pp. 1–22. doi: 10.3390/ijerph17103403.

Stamatiadis, N., Sturgill, R. and Amiridis, K. (2017) 'Benefits from Constructability Reviews', in Transportation Research Procedia. Elsevier B.V., pp. 2889–2897. doi: 10.1016/j.trpro.2017.05.275.

Shi, Y. et al., (2019) 'Impact assessment of reinforced learning methods on construction workers' fall risk behavior using VR', Automation in Construction, 104, pp. 197–214. doi: 10.1016/j.autcon.2019.04.015.

Zhang L., Wu X., Skibniewski M.J., Zhong J., Lu Y., (2014) 'Bayesian-network-based Safety risk analysis in construction projects'. Reliability Engineering & System Safety. 131 29–39, doi. 10.1016/j.ress.2014.06.006.

3D Repo, 'Making Construction Safer' (no date).

Conference proceedings

Azhar, S., Behringer, A., Khalfan, M., Sattineni, A., & Maqsood, T. (2012) 'BIM for Facilitating Construction Safety Planning and Management at Jobsite', Proceeding of the CIB W099 International Conference on "Modelling and Building H&S", pp. 82–92. Available at: https://www.irbnet.de/daten/iconda/CIB_DC25800.pdf.

European Commission. (2010) H&S at work in Europe (1999-2007): a statistical portrait. Publications Office of the European Union.

Third European Survey of Enterprises on New and Emerging Risks (ESENER 3) (no date).

Webb, T. (2019). 'Utilizing BIM as a Tool for Managing Construction Site Safety: A Review of Literature'. Available at: http://www.ascpro.ascweb.org.

Sulankivi, K., Kähkönen, K., Mäkelä, T., and Kiviniemi, M. (2010). '4D-BIM for Construction Safety Planning'. Available at: http://www.vtt.fi/sites/bimSafety/.

Sulankivi, K. (2014). 'BIM promoting construction site Safety: Industry examples'. Available at: http://www.cibworld.nl/site/innovation/detail/2.html.

Dissertations

Mohammed, A. R. (2014) 'H&S Management on Construction Sites', (February), pp. 1–140. Available at: http://i-rep.emu.edu.tr:8080/xmlui/handle/11129/1511%0Ahttp://i-rep.emu.edu.tr:8080/xmlui/bitstream/handle/11129/1511/MohammedRaad.pdf?sequence=1.

Petrus, M. and Van Rijn, A. (2017) 'A BIM-based tool to support time risk management in construction projects'. Master of Science, Tecnico Lisboa.

Zekri, M.K.S. (2013) ‘Construction Safety and Health performance in Dubai’. Master thesis, Heriot Watt University.

Standards

British Standards Institution. (2018). ‘BSI 1192-6:2018 Specification for collaborative sharing and use of structured H&S information using BIM’, pp. 1–66.

Websites

‘Augmented_reality @ en.wikipedia.org’ (no date). Available at: https://en.wikipedia.org/wiki/Augmented_reality.

‘Game_engine @ en.wikipedia.org’ (no date). Available at: https://en.wikipedia.org/wiki/Game_engine.

how-to-prevent-oshas-fatal-four-hazards-on-construction-sites Available at: https://www.grainger.com/know-how/industry/commercial/kh-how-to-prevent-oshas-fatal-four-hazards-on-construction-sites.

OSHA (2011) ‘Construction Focus Four : Struck-By Hazards’, 1(April), p. 65.OSHA (2011) ‘Construction Focus Four : Caught - In or - Between Hazards’, (April). Available at: https://www.osha.gov/dte/outreach/construction/focus_four/caught/caught_iorb_ig.pdf.

OSHA (2011) ‘Construction Focus Four: Electrocution Hazards’, OSHA Training Institute, (April), p. 83. Available at: https://www.osha.gov/dte/outreach/construction/focus_four/electrocution/electr_ig.pdf.

OSHA Training Institute (2011) ‘Construction Focus Four: Fall Hazards’, Occupational Safety and Health Administration (OSHA), 1(September). Available at: https://www.osha.gov/dte/outreach/construction/focus_four/falls/falls_ig.pdf.

OSHA (2011) ‘Construction Focus Four: Electrocution Hazards’, OSHA Training Institute, (April), p. 83. Available at: https://www.osha.gov/dte/outreach/construction/focus_four/electrocution/electr_ig.pdf.

United states Department of Labor. Top four construction hazards [Online]. Available at: https://www.osha.gov/Publications/3216-6N-06-english-06-27-2007.html

United states Department of Labor. Commonly used statistics. Available at: https://www.osha.gov/data/commonstats

LIST OF ACRONYMS AND ABBREVIATIONS

AR	Augmented Reality
BIM	Building Information Modelling
BSI	British Standards Institution
EU	European Union
ESENER	European Survey of Enterprises on New and Emerging Risks
ESAW	European Statistics on Accidents at Work
H&S	Health and Safety
H&SCD	Health and Safety Coordinator
ICT	Information Communications Technology
INSST	National Institute of Occupational Health and Safety
OSHA	Occupational Health and Safety Administration
OHS	Occupational Health and Safety
PAS	Publicly Available Standards
VR	Virtual Reality

APPENDICES

APPENDIX 1: DATABASE OF RISK INFORMATION RECORDING ALL THE DATA FOR RISK ASSOCIATED ELMENTS

Name	Option	Type	Crane with cable grab	Excavator	PilingMachine	Crane	Dumper	Slab	Slab2
Risk Name	Mandatory	Text	R01	R02	R03	R04	R05	R06	R07
Risk Category	Mandatory	Text	Struck	Struck	Struck	Struck	Struck	Fall	Fall
Risk Description	Mandatory	Text	Struck by Machinery or part	Struck by Machinery or part	Struck by Machinery or part	Struck by falling object	Struck by moving vehicle	Fall from open edge	Fall from floor opening
Associated product	Mandatory	Text	Crawler crane with grab	Excavator	Pile boring equipment	Tower Crane	Truck	Slab	Slab
Associated Activity	Mandatory	Text	Lifting items or materials in the construction site	Digging, removing materials on site	Drilling a hole into the soil	Hoisting of heavy construction materials at heights	Carrying materials in construction sites	Installation of window panels	Installation of elements
Associated Location	Mandatory	Text	Area of clearing/lifting items in the construction site	Logistics area of the construction site	Foundation area in construction site	Logistics area of the construction site	Logistics area of the construction site	Edges of the slab	Floor opening
Agreed mitigation	Mandatory	Text	Provide and maintain a system of work for the operation, Ensure the use of PPE for the workers, well trained operators, etc.	Develop a detailed strategy with a specialist to provide and maintain a system of work for the operation, ensure the use of PPE for the workers, well trained operators, etc.,	Develop a detailed strategy with a specialist to provide and maintain a system of work for the operation, ensure the use of PPE for the workers, well trained operators, etc.,	Develop a detailed strategy with a specialist to provide of not working within swing radius of the equipment, avoid working below suspended overhead materials, not exceeding lifting capacities, etc	Develop a detailed strategy with a specialist to provide and maintain a system of work for the operation, ensure the use of PPE for the workers, well trained operators, etc.,	Develop a detail strategy with a specilaist to provide necessary fall protection w.r.t the height or danger of falling onto dangerous equipment and machines at which a job is being performed	Develop a detail strategy with a specilaist to provide necessary fall protection w.r.t the height or danger of falling onto dangerous equipment and machines at which a job is being performed, Cover and secure floor openings and label floor opening covers.
Risk Likelihood	Mandatory	Text	Qualitative scale, Table 2, PAS_1192-6:2018	Qualitative scale, Table 2, PAS_1192-6:2018	Qualitative scale Table 2, PAS_1192-6:2018	Qualitative scale, Table 2, PAS_1192-6:2018	Qualitative scale, Table 2, PAS_1192-6:2018	Qualitative scale, Table 2, PAS_1192-6:2018	Qualitative scale, Table 2, PAS_1192-6:2018
Risk Consequence	Mandatory	Text	Qualitative scale Table 2, PAS_1192-6:2018	Qualitative scale Table 2, PAS_1192-6:2018	Qualitative scale Table 2, PAS_1192-6:2018	Qualitative scale Table 2, PAS_1192-6:2018	Qualitative scale Table 2, PAS_1192-6:2018	Qualitative scale Table 2, PAS_1192-6:2018	Qualitative scale Table 2, PAS_1192-6:2018
Level of Risk	Mandatory	Text	Assessed from the risk assesment matrix, Table 3, PAS 1192-6:2018	Assessed from the risk assesment matrix, Table 3, PAS 1192-6:2018	Assessed from the risk assesment matrix, Table 3, PAS 1192-6:2018	Assessed from the risk assesment matrix, Table 3, PAS 1192-6:2018	Assessed from the risk assesment matrix, Table 3, PAS 1192-6:2018	Assessed from the risk assesment matrix, Table 3, PAS 1192-6:2018	Assessed from the risk assesment matrix, Table 3, PAS 1192-6:2018
Date Raised	optional	Text	Date entry first logged	Date entry first logged	Date entry first logged	Date entry first logged	Date entry first logged	Date entry first logged	Date entry first logged
Date Updated	optional	Text	Date entry last updated	Date entry last updated	Date entry last updated	Date entry last updated	Date entry last updated	Date entry last updated	Date entry last updated
Date Review	optional	Text	Date entry last reviewed or due	Date entry last reviewed or due	Date entry last reviewed or due	Date entry last reviewed or due	Date entry last reviewed or due	Date entry last reviewed or due	Date entry last reviewed or due
Owner Discipline	Mandatory	Text	Name of relevant sub-discipline or sub-contractor or trade	Name of relevant sub-discipline or sub-contractor or trade	Name of relevant sub-discipline or sub-contractor or trade	Name of relevant sub-discipline or sub-contractor or trade	Name of relevant sub-discipline or sub-contractor or trade	Name of relevant sub-discipline or sub-contractor or trade	Name of relevant sub-discipline or sub-contractor or trade

APPENDIX 2: EXCAVATOR ASSOCIATED RISK INFORMATION

Name	Option	Type	Excavator
Risk Name	Mandatory	Text	R02
Risk Category	Mandatory	Text	Struck
Risk Description	Mandatory	Text	Struck by Machinery or part
Associated product	Mandatory	Text	Excavator
Associated Activity	Mandatory	Text	Digging, removing materials on site
Associated Location	Mandatory	Text	Logistics area of the construction site
Agreed mitigation	Mandatory	Text	Develop a detailed strategy with a specialist to provide and maintain a system of work for the operation, ensure the use of PPE for the workers, well trained operators, etc.,
Risk Likelihood	Mandatory	Text	Qualitative scale, Table 2, PAS_1192-6:2018
Risk Consequence	Mandatory	Text	Qualitative scale Table 2, PAS_1192-6:2018
Level of Risk	Mandatory	Text	Assessed from the risk assessment matrix, Table 3, PAS 1192-6:2018
Date Raised	optional	Text	Date entry first logged
Date Updated	optional	Text	Date entry last updated
Date Review	optional	Text	Date entry last reviewed or due
Owner Discipline	Mandatory	Text	Name of relevant sub-discipline or sub-contractor or trade

APPENDIX 3: PILING MACHINE ASSOCIATED RISK INFORMATION

Name	Option	Type	Piling Machine
Risk Name	Mandatory	Text	R03
Risk Category	Mandatory	Text	Struck
Risk Description	Mandatory	Text	Struck by Machinery or part
Associated product	Mandatory	Text	Pile boring equipment
Associated Activity	Mandatory	Text	Drilling a hole into the soil
Associated Location	Mandatory	Text	Foundation area in construction site
Agreed mitigation	Mandatory	Text	Develop a detailed strategy with a specialist to provide and maintain a system of work for the operation, ensure the use of PPE for the workers, well trained operators, etc.,
Risk Likelihood	Mandatory	Text	Qualitative scale Table 2, PAS_1192-6:2018
Risk Consequence	Mandatory	Text	Qualitative scale Table 2, PAS_1192-6:2018
Level of Risk	Mandatory	Text	Assessed from the risk assessment matrix, Table 3, PAS 1192-6:2018
Date Raised	optional	Text	Date entry first logged
Date Updated	optional	Text	Date entry last updated
Date Review	optional	Text	Date entry last reviewed or due
Owner Discipline	Mandatory	Text	Name of relevant sub-discipline or sub-contractor or trade

APPENDIX 4: TOWER CRANE ASSOCIATED RISK INFORMATION

Name	Option	Type	Crane
Risk Name	Mandatory	Text	R04
Risk Category	Mandatory	Text	Struck
Risk Description	Mandatory	Text	Struck by falling object
Associated product	Mandatory	Text	Tower Crane
Associated Activity	Mandatory	Text	Hoisting of heavy construction materials at heights
Associated Location	Mandatory	Text	Logistics area of the construction site
Agreed mitigation	Mandatory	Text	Develop a detailed strategy with a specialist to provide of not working within swing radius of the equipment, avoid working below suspended overhead materials, not exceeding lifting capacities, etc
Risk Likelihood	Mandatory	Text	Qualitative scale, Table 2, PAS_1192-6:2018
Risk Consequence	Mandatory	Text	Qualitative scale Table 2, PAS_1192-6:2018
Level of Risk	Mandatory	Text	Assessed from the risk assessment matrix, Table 3, PAS 1192-6:2018
Date Raised	optional	Text	Date entry first logged
Date Updated	optional	Text	Date entry last updated
Date Review	optional	Text	Date entry last reviewed or due
Owner Discipline	Mandatory	Text	Name of relevant sub-discipline or sub-contractor or trade

APPENDIX 5: DUMPER ASSOCIATED RISK INFORMATION

Name	Option	Type	Dumper
Risk Name	Mandatory	Text	R05
Risk Category	Mandatory	Text	Struck
Risk Description	Mandatory	Text	Struck by moving vehicle
Associated product	Mandatory	Text	Truck
Associated Activity	Mandatory	Text	Carrying materials in construction sites
Associated Location	Mandatory	Text	Logistics area of the construction site
Agreed mitigation	Mandatory	Text	Develop a detailed strategy with a specialist to provide and maintain a system of work for the operation, ensure the use of PPE for the workers, well trained operators, etc.,
Risk Likelihood	Mandatory	Text	Qualitative scale, Table 2, PAS_1192-6:2018
Risk Consequence	Mandatory	Text	Qualitative scale Table 2, PAS_1192-6:2018
Level of Risk	Mandatory	Text	Assessed from the risk assessment matrix, Table 3, PAS 1192-6:2018
Date Raised	optional	Text	Date entry first logged
Date Updated	optional	Text	Date entry last updated
Date Review	optional	Text	Date entry last reviewed or due
Owner Discipline	Mandatory	Text	Name of relevant sub-discipline or sub-contractor or trade

APPENDIX 6: "FALL FROM OPEN EDGE" RISK INFORMATION OF A SLAB

Name	Option	Type	Slab
Risk Name	Mandatory	Text	R06
Risk Category	Mandatory	Text	Fall
Risk Description	Mandatory	Text	Fall from open edge
Associated product	Mandatory	Text	Slab
Associated Activity	Mandatory	Text	Installation of window panels
Associated Location	Mandatory	Text	Edges of the slab
Agreed mitigation	Mandatory	Text	Develop a detail strategy with a specialist to provide necessary fall protection w.r.t the height or danger of falling onto dangerous equipment and machines at which a job is being performed
Risk Likelihood	Mandatory	Text	Qualitative scale, Table 2, PAS_1192-6:2018
Risk Consequence	Mandatory	Text	Qualitative scale Table 2, PAS_1192-6:2018
Level of Risk	Mandatory	Text	Assessed from the risk assessment matrix, Table 3, PAS 1192-6:2018
Date Raised	optional	Text	Date entry first logged
Date Updated	optional	Text	Date entry last updated
Date Review	optional	Text	Date entry last reviewed or due
Owner Discipline	Mandatory	Text	Name of relevant sub-discipline or sub-contractor or trade

APPENDIX 7: "FALL FROM FLOOR OPENING" RISK INFORMATION OF A SLAB

Name	Option	Type	Slab2
Risk Name	Mandatory	Text	R07
Risk Category	Mandatory	Text	Fall
Risk Description	Mandatory	Text	Fall from floor opening
Associated product	Mandatory	Text	Slab
Associated Activity	Mandatory	Text	Installation of elements
Associated Location	Mandatory	Text	Floor opening
Agreed mitigation	Mandatory	Text	Develop a detail strategy with a specialist to provide necessary fall protection w.r.t the height or danger of falling onto dangerous equipment and machines at which a job is being performed
Risk Likelihood	Mandatory	Text	Qualitative scale, Table 2, PAS_1192-6:2018
Risk Consequence	Mandatory	Text	Qualitative scale Table 2, PAS_1192-6:2018
Level of Risk	Mandatory	Text	Assessed from the risk assessment matrix, Table 3, PAS 1192-6:2018
Date Raised	optional	Text	Date entry first logged
Date Updated	optional	Text	Date entry last updated
Date Review	optional	Text	Date entry last reviewed or due
Owner Discipline	Mandatory	Text	Name of relevant sub-discipline or sub-contractor or trade