

**BIM-based Accident Investigation: Central Repository
and Visualization for Accident / Incident Data**

BY

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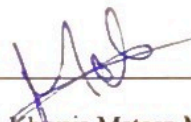
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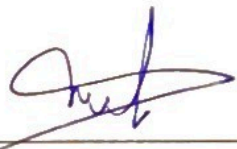
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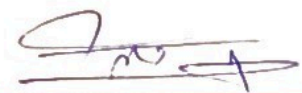
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LIST OF ABBREVIATIONS

AECM - Architectural Engineering and Construction Management

BIM - Building Information Modeling

OSHA - Occupational Health and Safety

HSE - Health and Safety Executive

ILO - International Labour Organization

NIOSH - National Institute of Occupational Safety and Health

GOSI - General Organization for Social Insurance

KM - Knowledge Management

LFI - Learning From Incidents

KSM - Knowledge Sharing Management

DFSP - Design-for-Safety-Process

OHSMS - Occupational Health and Safety Management System

PMIS - Project Management Information System

API - Application Programming Interface

CA/IKDMS – Construction Accident/Incident Knowledge Database Management System

CL - Cognitive Load

ABSTRACT

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Despite notable safety advancements over the past three decades, the construction sector's accident and sickness rates remain quintuple the global industry average due to its inherent size, complexity, and dynamic nature. Construction-related incidents, including accidents and near-misses, present opportunities for learning and future prevention. In the Middle East, particularly Saudi Arabia, construction projects are at an unprecedented peak. According to data from Saudi Arabia's General Organization for Social Insurance (GOSI) during the third quarter of 2018, 47% of all occupational injuries reported in the kingdom were related to construction. The increase in projects suggests a potential rise in injury rates. Effective incident learning (LFI) processes, which analyze and share incident data to prevent recurrences, are currently underutilized. Integrating knowledge management (KM) systems and Building Information Modeling (BIM) can improve safety practices by systematically categorizing and sharing incident data, thereby enhancing learning from past incidents.

This research aimed to identify critical barriers and the reasons behind the inability to learn from past incidents in construction by empirically evaluating the perceptions of construction professionals in the Kingdom of Saudi Arabia (KSA) and to enhance knowledge management of construction incident data by identifying challenges in the sector and designing a BIM-based

system to efficiently handle construction incident data. Firstly, barriers to LFI were identified by literature and construction experts and a questionnaire survey was conducted with the health and safety professionals in multiple construction organizations. The primary factors that contribute to learning problems are ‘poor quality of actions’, ‘lack of commitment by management’, ‘limited dissemination of findings’, ‘lack of understanding of how and what to report’, and ‘limited quality of reports’. Participants identified that the intervening phase (performing recommended actions) in the LFI model was the most significant phase in terms of possible loss of learning in construction organizations. Then, as mentioned how improved knowledge management techniques are essential to enhance the learning process, the study identified and addressed KM issues in construction through literature and expert input, leading to the development of a BIM-based Construction Accident/Incident Knowledge and Data Management System (BIM-CA/IKDMS). The system included a central repository for all incidents, including details, reconstructed incident films from the published reports, and visual proof. The system was assessed by specialists in construction health and safety and an experiment with construction engineering management students. The results showed that problems like disintegrated systems, lack of a database, non-standard file formats, paper-based information exchange, restricted information sharing, and limited accessibility could be rectified. However, paper-based comprehension was found to be the most cognitively demanding and time-consuming as compared to visual-based comprehension of incidents. Experts suggested further enhancements by including data analytics for yearly incident numbers and searching incidents by training type to identify safety training needed to prevent mishaps in the future.

المخلص

الاسم الكامل: وليد امتياز عثمان

عنوان الأطروحة: التحقيق في الحوادث المعتمد على BIM مستودع مركزي وتصور لبيانات الحوادث / الحوادث

التخصص الرئيسي: هندسة وإدارة الإنشاءات

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على الرغم من التقدم الملحوظ في السلامة على مدار العقود الثلاثة الماضية، تظل معدلات الحوادث والأمراض في قطاع البناء خمسة أضعاف المعدل الصناعي العالمي بسبب حجمه وتعقيده وطبيعته الديناميكية. تُعد الحوادث المرتبطة بالبناء، بما في ذلك الحوادث والاقتراب من الحوادث، فرصًا للتعليم والوقاية المستقبلية. في الشرق الأوسط، وخاصة المملكة العربية السعودية، تصل مشاريع البناء إلى ذروتها غير المسبوقة. وفقًا لبيانات من المؤسسة العامة للتأمينات الاجتماعية في السعودية (GOSI) خلال الربع الثالث من عام 2018، كانت 47٪ من جميع الإصابات المهنية المبلغ عنها في المملكة تتعلق بالبناء. تشير الزيادة في المشاريع إلى احتمال ارتفاع معدلات الإصابات. تُعد عمليات التعلم الفعال من الحوادث (LFI)، التي تحلل وتشارك بيانات الحوادث لمنع تكرارها، غير مستغلة بشكل كافٍ حاليًا. يمكن أن يؤدي دمج أنظمة إدارة المعرفة (KM) ونمذجة معلومات البناء (BIM) إلى تحسين ممارسات السلامة من خلال تصنيف ومشاركة بيانات الحوادث بشكل منهجي، مما يعزز التعلم من الحوادث السابقة. هدفت هذه الدراسة إلى تحديد العوائق الحرجة والأسباب الكامنة وراء عدم القدرة على التعلم من الحوادث السابقة في البناء من خلال تقييم تصورات المهنيين في قطاع البناء في المملكة العربية السعودية (KSA) وتعزيز إدارة المعرفة لبيانات حوادث البناء من خلال تحديد التحديات في القطاع وتصميم نظام يعتمد على نمذجة معلومات البناء (BIM) للتعامل بكفاءة مع بيانات حوادث البناء. أولاً، تم تحديد العوائق أمام التعلم من الحوادث (LFI) من خلال الأدبيات وخبراء البناء وتم إجراء استبيان مع محترفي الصحة والسلامة في العديد من منظمات البناء. العوامل الأساسية

التي تساهم في مشكلات التعلم هي 'رداءة جودة الإجراءات'، 'عدم التزام الإدارة'، 'الانتشار المحدود للنتائج'، 'عدم فهم كيفية وماذا يبلغ عنه'، و'جودة التقارير المحدودة'. حدد المشاركون أن المرحلة المتدخلة (تنفيذ الإجراءات الموصى بها) في نموذج التعلم من الحوادث (LFI) كانت المرحلة الأكثر أهمية من حيث فقدان التعلم المحتمل في منظمات البناء. بعد ذلك، كما ذكر أن تقنيات إدارة المعرفة المحسنة ضرورية لتعزيز عملية التعلم، حددت الدراسة وتناولت قضايا إدارة المعرفة في البناء من خلال الأدبيات ومدخلات الخبراء، مما أدى إلى تطوير نظام إدارة المعرفة والبيانات لحوادث البناء (BIM-CA/IKDMS) القائم على نمذجة معلومات البناء. تضمن النظام مستودعًا مركزيًا لجميع الحوادث، بما في ذلك التفاصيل، وأفلام الحوادث المعاد بناؤها من التقارير المنشورة، والدليل البصري. تم تقييم النظام من قبل متخصصين في صحة وسلامة البناء وتجربة مع طلاب إدارة الهندسة الإنشائية. أظهرت النتائج أن المشاكل مثل الأنظمة غير المتكاملة، وعدم وجود قاعدة بيانات، وصيغ الملفات غير القياسية، وتبادل المعلومات الورقية، والمشاركة المحدودة للمعلومات، وإمكانية الوصول المحدودة يمكن تصحيحها. ومع ذلك، وجد أن الفهم الورقي كان الأكثر تطلبًا إدراكياً والأكثر استهلاكًا للوقت مقارنة بالفهم المعتمد على الوسائل البصرية للحوادث. اقترح الخبراء تحسينات إضافية تتضمن تحليلات البيانات لأعداد الحوادث السنوية والبحث في الحوادث حسب نوع التدريب لتحديد التدريب على السلامة اللازم لمنع الحوادث في المستقبل.

CHAPTER 1

INTRODUCTION

Despite advances in safety performance over the last 30 years, the construction sector continues to have a five-fold higher accident and sickness rate than the industry average. Accidents are unintended events, that result in unexpected injuries, illnesses, and fatalities, whereas an incident is defined as any unforeseen event, ranging from a near-miss to a serious health and safety breach, that causes property damage but does not endanger anyone (OSHA, 2023). The risks involved in such accidents in the construction industry are far higher amongst all industry sectors worldwide, because construction is a vast, dynamic, and complex industry that employs millions of people throughout the world (Rostami et al., 2015).

As per Health and Safety Executive (HSE) UK statistics, construction has 1.62 fatalities per 100,000 workers, four times the industry average, 2.5 times higher than manufacturing, and 0.85 times higher than the transportation and storage industry (HSM, 2022). Whereas this number accounts for 9.4 fatalities per 100,000 workers in the United States. 21 percent of all US worker fatalities are related to construction (Jonny Finity, 2023). According to the International Labour Organization's (ILO) website, 160 people are injured at work every 15 seconds (ILO, 2014). This means that more than 38,000 individuals are involved in an accident every hour around the world, and about 6.5 million people are involved in an accident every week, which is more than Denmark's population (Drupsteen-Sint, 2014). In 2020, the highest occurrence of non-fatal accidents in the EU accounted for the construction industry (Eurostat Statistics, 2022). In terms of fatalities, Health and Safety Executive (HSE) revealed that falls from height accounted for 51% of the fatalities in the construction sector in Great Britain, making it the highest contributor in fatalities statistics, whereas, trapped-by accidents

accounted for 14%, struck-by accidents with 19%, and electrocution constitutes 6% of the total fatalities (HSE, 2020). The statistics of National Institute for Occupational Safety and Health (NIOSH) highlight that more than one-third (36.4%) of all fatalities in the construction sector in the USA are caused by falls, which are the primary cause of work-related deaths. The proportion of fatalities from struck-by and electrocutions turned out to be 15.4% and 7.2% respectively, while caught-in/between incidents remained to be about 5.4% (NIOSH, 2019).

Construction projects in middle eastern countries are at an all-time high as the region works to improve its infrastructure. Umar et al., (2019) presented the Health and Safety statistics of well-renowned Gulf countries. Ten credible construction firms revealed that more than 3500 workers were medically treated because of work-related injuries. According to data from Saudi Arabia's General Organization for Social Insurance (GOSI) during the third quarter of 2018, 47% of all occupational injuries reported in the kingdom were related to construction. (GOSI, 2018). According to numerous researchers, Kuwait's construction sector is the most hazardous of the industries, accounting for 48% of work-related deaths (Al-Kandary & Al-Waheeb, 2015). The fatalities of construction workers while building the stadiums for the 2022 FIFA World Cup sparked media attention and international organizations (Umar et al., 2019). The construction of these football stadiums in Qatar resulted in 1200 mortalities from 2010 to 2017.

Despite significant efforts by government, industry, and academics to improve construction project safety performance, construction employees' occupational incident rates remain high (Dodshon & Hassall, 2017; Sandberg & Albrechtsen, 2018). Construction site mishaps, such as accidents and near-misses, present opportunity to learn from them, improve favorable results, and lessen the likelihood that undesired occurrences will happen again (Q. Zhang et al., 2023). The frequency of similar incidents in the construction industry may signal that learning from incidents (LFI) is not a good practice in the industry (Gibb et al., 2014; Hoła & Szóstak, 2015; Kari & Niemel, 2015).

Recent studies have shown how companies might "fail" to learn despite efforts to collect data on previous minor failures and their causes to understand how to prevent more major occurrences (Maslen & Hayes, 2016). Industries as diverse as oil and gas extraction, nuclear power generation, and air traffic control have all embraced the concept of learning from modest mistakes with enthusiasm, which has resulted in the growth of database systems for logging and categorizing event reports (Maslen & Hayes, 2016). It is also believed that incident reporting and organizational learning research might benefit from adopting 'knowledge,' specifically 'collective knowledge,' as a reference point (Maslen & Hayes, 2016).

Knowledge has a crucial role in terms of people making decisions involved in complex projects, which means monumental outcomes can be controlled based on the knowledge that individuals possess. According to Ho et al., (2013), knowledge management (KM) is a set of processes that govern the generation, storage, reuse, evaluation, and application of experience-based knowledge in a specific situation or problem-solving context. Based on the significance of knowledge management, several firms now view incident databases as a crucial learning tool or even as a library of experience (Maslen & Hayes, 2016). The best strategy to prevent accidents is to maintain track of previously occurring reasons for incidents and work to address these so that they never occur again (Rashid, 2021).

Construction companies must implement effective KM procedures since their distinctive and dynamic projects frequently result in lost information owing to unrecorded ideas (Woo et al., 2004). Construction companies frequently gather safety knowledge from a variety of internal and external sources, but their inadequate knowledge storage and transfer methods prevent their workers from acquiring the essential information they need to address pressing safety-related issues (Hallowell, 2012). It was discovered through exploratory case studies in the construction sector that the primary medium for information interchange between project stakeholders is paper, which is both sluggish and inefficient in retrieval, and there are no

effective links between departmental systems for electronic information access (Vidogah et al., 2004).

1.1. Significance of Health and Safety

Occupational Safety and Health is a multidisciplinary notion that focuses on promoting the safety, health, and welfare of those who work or are employed. Additionally, it goes further to safeguard everyone affected by the work environment, including co-workers, family members, employers, clients, suppliers, surrounding neighbourhoods, and other members of the public (Ferris and Buckley, 2006). It is critical to underline that both the employee and the employer are equal participants in the effort to maintain a high standard of workplace health and safety (E.E. & Osiamoje, 2015). Hence, it is crucial to understand why it is critical to uphold a high level of health and safety. Occupational health and safety encompass the worker's mental, emotional, and physical well-being in connection to the performance of his job and, as a result, is a crucial area of study that has a beneficial influence on the accomplishment of organizational objectives (Amponsah-Tawiah & Mensah, 2016). An employee should not be burdened with the onerous obligation of continuously being concerned about the possibility of injury or death on the job. Such a thought process has enormous implications for the productivity of the employee (E.E. & Osiamoje, 2015). The companies themselves also suffer losses in terms of litigation costs, fines levied against them, compensatory damages, lost production, and diminished goodwill from staff and other stakeholders. Scientific investigations have indicated that the costs of occupational accidents far outnumber the costs of security measures to ensure OHS (Yilmaz & Yildiz, 2021).

1.2. Health and Safety in Construction

Construction is a vast, dynamic, and complex industry that employs millions of people throughout the world (Rostami et al., 2015). The construction sector has long been held responsible for the high incidence of fatalities and accidents, despite its benefits to economic development. As a result, it is now considered to have one of the excessive rates of accidents, permanent and non-permanent disabilities, and even fatalities (Hosseinian & Torghabeh, 2012). According to the statistics of EuroStat published back in 2015, fifth of the total workplace accidents occurred in the construction industry. Construction accidents cause project delays, increase costs, and tarnish builders' reputations and dependability (Wang et al., 2006). Workers should be able to rely on a safe working environment that consistently reduces the risk of injury. This is the cornerstone for keeping a healthy labour force. The failure to provide health and safety in the construction industry is mostly because costs for health and safety, are exempted during design and tendering processes, and are viewed as unnecessary expenses during the building phase and are therefore avoided (Yilmaz & Yildiz, 2021).

Based on the significance of health and safety in the construction sector, and some alarming statistics globally, it goes without saying that safety management requires the same level of careful project planning and control as other parts of project management. To do so, a successful safety and health management system needs to be implemented in construction organizations. The system not only enhances working conditions for employees but also benefits the bottom line through greater productivity, a decrease in accidents and illnesses, high staff morale, lower staff turnover, and a favorable reputation with customers. According to (Shariff, 2011) competent safety and health management system constitutes :

- 1. Policy Development:** Protection of safety and health for workers, adherence to appropriate Occupational Safety and Health national laws, and continuous improvement in the performance of the OSH management system.

2. **Responsibility / Accountability:** Assigning various occupational safety and health responsibilities to designated individuals, ensuring that the specified individuals possess the necessary skills, making sure the necessary safety and health training is received, and record-keeping of inspections, accidents, and ill health.
3. **Planning and Implementation:** implementing national legislation, international standards, and collective bargaining agreements, data analysis for accidents, sickness, and inspection of present hazards and risks.
4. **Evaluation:** Monitoring safety performance regularly, safety performances, and fine-tuning to enhance safety performance.

To build a culture that values health and safety, everyone in the organization must understand the organization's health and safety standards, as well as their responsibility in achieving and sustaining those standards (Hughes and Ferrett, 2009). Standards should clearly define the measures that people must do to enhance health and safety. Good health and safety standards will result in fewer lost production, accidents and compensation claims, and cheaper insurance costs (Hughes and Ferrett, 2009).

Numerous health and safety issues arise due to inadequate communication. There are more parties involved than only the workers and management. It results from ambiguity or even unintentional message distortion (Hughes and Ferrett, 2009). Worker health and safety (H&S) is a crucial project management objective in the construction industry (Oswald et al., 2019). A high level of collaboration between project teams is necessary for construction projects to be successful (Wu et al., 2017), and efficient safety communication is crucial to the performance of safety measures (Jin et al., 2015).

Employees' awareness and understanding of the unique dangers and risks associated with their occupations and working environment will be developed through the provision of information and training (Hughes and Ferrett, 2009). The Management of Health and Safety at Work Rules

and other regulations make it mandatory for employers to offer health and safety training, which is a crucial element of workplace safety culture (Hughes and Ferrett, 2009). Many people in the construction sector agree, and studies has shown that comprehensive worker safety and health training is one method to minimize the number of construction accidents (Goldenhar et al., 2001).

In the construction sector, identifying safety risks typically relies on professional estimations to establish the potential components. Professionals detect safety concerns by drawing on their prior experience, which is an important source of domain knowledge (Goldenhar et al., 2001). Accident reports are used in the construction sector to document the origins, effects, and overall course of incidents. Numerous accident reports combine to form a useful knowledge base. Finding common construction safety risk variables through analysis of accident description reports contributes to the domain knowledge used to direct future safety management (Goldenhar et al., 2001).

1.3. KM in the Construction Industry and Health and Safety

Knowledge has a crucial role in terms of people making decisions involved in complex projects, which means monumental outcomes can be controlled based on the knowledge that individuals possess. According to Ho et al., (2013), knowledge management (KM) is a set of processes that govern the generation, storage, reuse, evaluation, and application of experience-based knowledge in a specific situation or problem-solving context.

The disproportionate number of illnesses and injuries has been largely attributed to the complex, dynamic, and transient character of building projects. To cope with these complications, it is essential for a construction firm to recognize, capture, store, and share safety knowledge effectively (Hallowell, 2012). Construction companies frequently gather safety knowledge from a variety of internal and external sources, but their inadequate

knowledge storage and transfer methods prevent their workers from acquiring the essential information they need to address pressing safety-related issues (Hallowell, 2012).

Building information modeling has been already facilitating the process of knowledge management in the construction industry. Ho et al., (2013) developed a BIM-based Knowledge Sharing Management (BIMKSM) system capable of combining all construction information into a single source by incorporating outside elements, such as problem and solution descriptions, comments, and ideas. Another quite similar Construction BIM-based Knowledge Management (CBIMKM) system was proposed by Lin, (2014), which utilizes both explicit and tacit knowledge of field engineers which can be shared and reused using knowledge map built on 3D platform.

The BIM application, which has emerged as a promising visualization technology, through its ability to supply a rich plethora of digital construction data, has paved the road for safety performance (S. Zhang et al., 2013). Dadashi & Behrouz, (2022) proposed a BIM-based safety management framework by integrating the safety leading indicators database and BIM and implemented it in a case study. The most serious consequence of poor safety planning and execution is worker fatality. When on-the-job injuries occur, significant time and financial resources are lost. Zhang et al., (2013) integrated BIM and safety into a rule-based checking system for safety planning and simulation. Additionally, BIM has developed into a platform for collecting safety data with DFSP (Design-for-Safety-Process) application (Hadikusumo & Rowlinson, 2016).

It is also believed that incident reporting and organizational learning research might benefit from adopting 'knowledge,' specifically 'collective knowledge,' as a reference point (Maslen & Hayes, 2016). Different kinds of incident data, including incident reports, investigation results, and remedial measures performed, can be stored in knowledge management (KM) systems (Wiig, 1997). Organizations may quickly access historical data to examine trends and patterns

in incidents by centralizing this information. A systematic framework for managing incident data, using knowledge management systems, would make it simpler to categorize accidents based on variables such as severity, location, and underlying causes (Alavi & Leidner, 2001). Such a KM-based system would also encourage the exchange of best practices and lessons gained from previous occurrences among different departments and teams within a company (Davenport & Prusak, 2000). This shared culture encourages ongoing development and allows staff to make educated decisions to avoid future occurrences.

BIM enhances knowledge management by providing a digital representation of the physical and functional properties of buildings and infrastructure. BIM improves KM and incident learning by consolidating several data sources such as design papers, construction plans, and facility management information. Integrating incident data into BIM models gives a full view of the built environment and aids in studying how design and construction elements relate to events (Succar, 2009).

Past accidents can greatly contribute to the recognition of potential hazards (Tran et al., 2021). Nevertheless, this reporting data as well as its investigation is dependent on a paper-based approach, without any visual insight. The implementation of visualization technologies is already in practice for forensic investigation of crime scenes and accidents to depict the overall case in courtrooms (Ma et al., 2010). BIM has been recognized as a cornerstone by the construction industry for design, communication, and project visualization purposes during the project's lifespan (Azhar, 2011).

To summarize, integrating BIM with Knowledge Management enhances methodologies by offering a centralized, easily accessible platform for real-time data sharing and collaboration, thereby improving the accuracy and efficiency of information management (Liu et al., 2012). BIM's visualization features allow for better documentation and retrieval of incident-related knowledge, encouraging a more proactive approach to safety and risk management (Succar et

al., 2013). This collaboration promotes continual learning and aids decision-making processes (Gu & London, 2010). Effective knowledge management methods promote learning from previous incidents by systematically gathering, preserving, and communicating useful information, fostering continuous development and preventing recurrences (Argote & Miron-Spektor, 2011; Nonaka, 1994). These strategies help to build an organizational memory that promotes informed decision-making and adaptive learning (Davenport & Prusak, 2000).

The overall relationship between LFI, KM and BIM is shown in the figure below.

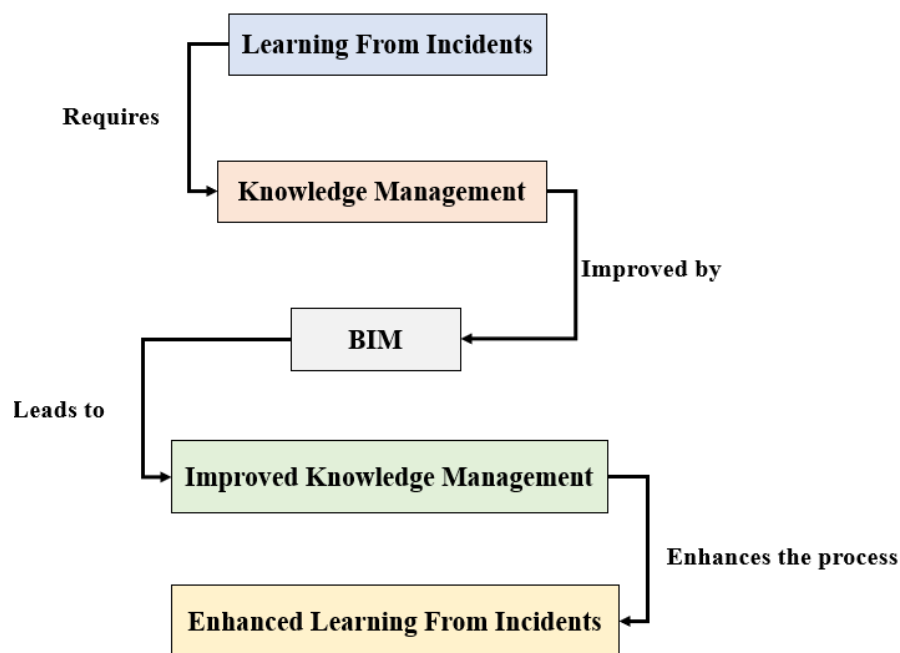


Figure 1: Integration of BIM and KM to enhance learning from incidents

1.4. Problem Statement

Construction site mishaps, such as accidents and near-misses, present an opportunity to learn from them, improve favorable results, and lessen the likelihood that undesired occurrences will happen again (Q. Zhang et al., 2023). The prevalence of such incidents in the construction sector might indicate that learning from incidents, or LFI, is not a recommended approach there (Gibb et al., 2014; Hoła & Szóstak, 2015; Kari & Niemel, 2015). Learning from incidents (LFI) is a process that seeks, analyzes, and disseminates the severity and causes of occurrences to

prevent such events from occurring again (Chan et al., 2023). It is highlighted by Chan et al., (2023) that understanding the interconnections between various aspects of LFI is crucial for the development of a more effective safety management strategy. Construction companies frequently gather safety knowledge from a variety of internal and external sources, but their inadequate knowledge storage and transfer methods prevent their workers from acquiring the essential information they need to address pressing safety-related issues (Hallowell, 2012). It was discovered through exploratory case studies in the construction sector that the primary medium for information interchange between project stakeholders is paper, which is both sluggish and inefficient in retrieval, and there are no effective links between departmental systems for electronic information access (Vidogah et al., 2004). When learning from incidents as an outsider, there isn't anything substantial to convey other than the knowledge of how it happened and how it may have been avoided (Pasman, 2009). Recent studies have shown how companies might "fail" to learn despite efforts to collect data on previous minor failures and their causes to understand how to prevent more major occurrences (Maslen & Hayes, 2016). Although there is a plethora of information on the topics of KM for construction and health and safety separately, there has been little research on the function of knowledge acquisition, storage, and transfer in construction safety management. The integration between accident data and BIM is something unaddressed (Kim et al., 2015). There is a lack of employing the visualization aspect of BIM on accident investigation data to recreate construction accident scenarios to the extent that the generated phasing animations could be utilized for safety training, identification of root causes, safety communication, and prevention of similar events in the future.

BIM in conjunction with knowledge management, is essential to learning from incidents as it makes it easier to gather, arrange, share, and analyze incident data and best practices. By using an integrated strategy, firms may reduce risks, increase safety, and boost productivity by

applying the knowledge gained from previous accidents. BIM technology to create central repository for Accident/Incident investigation data would neutralize the knowledge management issues to improve the acquiring information, and investigation processes which eventually would have an impact on effective learning as stated. Moreover, the visualization aspect of the system will also be explored from the cognitive load perspective to provide awareness to the workers regarding the safety procedures needed to implement at the site. It would also allow the safety officers to conduct training sessions via accident simulations rather than exposing the workers to the site itself, providing zero-risk environments. The proposed approach would also allow the safety managers to identify the root cause behind such events, modify or amend any causal changes in the database, and prevent the occurrence of similar events.

1.5. Research Objectives

There is a need to improve key elements of health and management systems in the construction industry due to the disproportionately high number of fatalities. Safety communication is one of the crucial components of managing health and safety. Current methods to disseminate information amongst the project teams are still utilizing ad-hoc approaches, consuming more storage spaces, and implementing filing systems making information accessibility a challenge for the concerned entities. Similarly, companies use a convoluted writing style, organizational structure, tiny text, and few pictures for safety training, leaving workers frequently bored, unmotivated, and bewildered, which eventually translates to ignorant behaviour of the workers (Xie et al., 2006). As discussed, compiling accident reports plays a vital role to take remedial measures to prevent similar events in the future. Conventional structuring of data is labour intensive, time-consuming, and non-parametric (change of information in one place does not reflect in other places). It is important to realize that getting to the bottom of an accident at a construction site would prevent similar mishaps in the future. As the accidents occurring at the

site are something that usually isn't monitored in real-time, it is essential to backtrack the incident to determine the root cause of such incidents, as well as spread awareness amongst the laborers for future projects. Although there is a plethora of information on the topics of KM for construction and health and safety separately, there has been little research on the function of knowledge acquisition, storage, and transfer in construction safety management. Furthermore, existing research emphasizes the significance of LFI on construction safety performance but falls short of highlighting the factors that are barriers to learning from the past incidents (Drupsteen, Groeneweg, et al., 2013; Drupsteen & Hasle, 2014; Littlejohn et al., 2017). The following are the primary research goals for this research:

1. To identify and analyze barriers that hinder the process of learning from past incidents in the construction industry (Saudi construction industry).
2. To develop a BIM-based construction accident/incident knowledge database management system.
3. To validate the feasibility of the proposed system for knowledge management of construction accidents/incidents data.
4. To assess the potential of the proposed system for learning from past incidents based on cognitive load measurements.

1.6. Research Significance

The developed system will ensure collaboration among the stakeholders and will also enable them to record, review, and simulate the accident/incident investigation data. BIM-based database tools would immensely enhance communication efficiency, be easy to operate, and disseminate accident information to other project teams. Moreover, the visualization aspect of the system will provide awareness to the workers regarding the safety procedures needed to be implemented at the site. It would also allow the safety officers to conduct training sessions via accident simulations rather than exposing the workers to the site itself, providing zero risk

environments. The proposed approach would also allow the safety managers to identify the root cause behind such events, modify or amend any causal changes in the database, and prevent the occurrence of similar events. Moreover, by deploying the developed system it would be relatively easy to retrieve the information at any given time rather than consuming storage space.

1.7. Limitations

The limitations of this research study are as follows:

- The developed BIM based accident/incident database management system is only applicable on building construction projects. The tool has been developed on Autodesk Revit as a proof of concept only.
- This study's findings are confined to accidents that occur within the confines of the building and do not include accidents that occur outside on the surrounding site or grounds. As a result, it may not capture the complete range of incidents that might occur in outdoor situations or during activities undertaken outside of building structures.

CHAPTER 2

LITERATURE REVIEW

This chapter initially discusses occupational health and safety in general, and then focuses on the most prevalent accidents in the construction business. Following that, this chapter discusses the importance, benefits, and ways to enhance health and safety management systems, followed by a brief discussion about accident investigation and their importance in preventing recurring accidents. Then, a broad definition of learning from incidents (LFI) is presented. Previous research on learning from incidents (LFI), its relevance, and how diverse sectors such as process, oil and gas, and chemical have identified several important hurdles to learning from previous incidents have been elaborated. Furthermore, an introduction to knowledge management is presented and it is discussed in detail to show its importance in the construction sector in terms of learning from the previous lapses, particularly in construction health and safety. This chapter also discusses the function of BIM in the construction sector and research on BIM for knowledge management and its significance in the construction industry. This section also includes a basic introduction to cognitive load and discusses how visualization approaches enhance data cognition. It accomplishes this by showcasing many studies in which visualization methods have been utilized to examine building safety surroundings using BIM, as well as employing different animation software to replicate past incidents in the mining and aviation sectors.

2.1. Construction Health and Safety

Workplace health and safety relates to the identification and prevention of risks that could result in accidents, injuries, mental and physical illness, and fatalities from work-related

activities. Organizations operate under extremely stressful circumstances to satisfy client demands in a global, competitive and rapidly expanding commercial environment. The primary resource involved in the construction site is manpower. Without construction experts being aware of the safety-related difficulties, construction projects can never fulfill their goals (Akmal Shamsuddin et al., 2015), which would eventually cause delays, extra work, and of course loss of manpower. The lack of systematic and thorough measures to oversee health and safety on construction sites, such as safety planning, workplace analysis, hazard prevention, and safety health training, would not eradicate occupational hazards. According to the International Labour Organization (ILO), 2.3 million people die each year as a result of workplace accidents or illnesses, which equates to more than 6,000 deaths every day. (Yilmaz & Yildiz, 2021).

2.2. Accidents in the Construction Industry

Construction site accidents are the result of mishaps by either the workers or the construction companies (Wahab, 2017). Accidents in the construction industry also affect projects' costs and timelines. This would also result in non-competitive tenders for the involved companies, dissatisfaction among stakeholders, financial losses for the companies due to property damage, and the removal of costs, compensation, and penalties from authorities (Hamid et al., 2014). This exhibits that construction-related accidents are crucial events that need to be analyzed to identify their root causes (Betsis et al., 2019).

According to OSHA the Fatal Four accidents on construction sites that specifically stick out are namely; Falls, Electrocution, Caught-in, and Struck-by (Albert et al., 2020).

2.2.1. Falls

Falls are by far the most common type of accident, and as a result, fractures are the most common type of injury (Betsis et al., 2019). This often happens because of workers falling

from scaffolding, ladders, roofs, etc. The severity of the injury depends upon the height from which the worker fell. Additionally, OSHA emphasizes fall protection setup when performing construction activities over lethal equipment and machinery, regardless of the fall distance.

2.2.2. Electrocution

There are times that often construction works takes place near power lines and sources, which makes equipment and machinery vulnerable as there are slight chances that they mistakenly make contact with power lines. Electric shocks, electrical burns, and arc blasts are all common in electrical accidents, and the majority of these cause significant tissue damage (Lee & Dougherty, 2003).

2.2.3. Caught in-between

Caught in-between accidents can occur in different scenarios such as cave-ins, body parts caught in unguarded machinery, working around heavy equipment, standing within a swing radius of rotating equipment, hands or body near moving parts, and loading and stacking materials (Occupational Safety and Health Administration (OSHA), 2008). To avoid such circumstances, one should be properly trained to handle such machinery and equipment.

2.2.4. Struck-By

Forceful contact or impact between the injured person and an object or piece of machinery results in struck-by injuries (OSHA, 2011). Struck-by accidents are classified as follows:

- **Struck-by flying object:** Grinding materials, Oil particles due to high air pressure.
- **Struck by falling objects:** Exposure to falling objects while working below elevated surfaces, moving materials overhead, and suspended loads.
- **Struck-by swinging object:** Working under a lifted loaded, uneven lifting of loads causes slipping.

- **Struck-by rolling object:** Heavy equipment, moving materials, working near vehicle traffic without any fences.

2.3. Health and Safety Management Systems

Occupational Health and Safety Management Systems (OHSMSs) are effective, methodical tools that assist managers in addressing workplace health and safety issues and enable firms to manage occupational risks (Granerud & Rocha, 2011). According to recent studies, OHSMSs are essential for addressing Occupational Health and Safety (OHS) issues, enhancing worker safety, lowering workplace risks, and establishing better, safer working conditions (Podgórski, 2015). ISO 45001:2018 specifies the requirements for an occupational health and safety (OH&S) management system and provides recommendations for its implementation in order to make it possible for businesses to offer secure, healthy working environments by guarding against occupational diseases and accidents and actively enhancing their OH&S performance. The key benefit of this standard is that it is simple to incorporate into management system criteria like quality, environment, and social responsibility (Darabont et al., 2018).

2.3.1. ISO 45001 Health and Safety Management System Framework

ISO 45001-based health and safety management system is based upon the following key aspects:

2.3.1.1. Context of the organization

The organization must address the challenges outlined in the standard, including understanding the organization and its context, as well as addressing the needs and objectives of workers and other interested parties (ISO 45001 Guide, 2018). The ISO 45001 standard urges enterprises to examine both internal and external context concerns, such as cultural, social, political, and legal factors, as well as the introduction of new rivals, vendors, partners, and service providers. The foundation for the OH&S management system's breadth should be a thorough grasp of the

organizational context and the expectations of workers and other interested parties (ISO 45001 Guide, 2018).

2.3.1.2. Leadership

Although it is acknowledged that overall responsibility for the OH&S (Occupational Health and Safety) management system rests with 'Top Management,' people must consider both their own health and the health and safety of others (ISO 45001 Guide, 2018). A clear line of communication, consultation, and worker participation, along with adequate time and resource allocation, are essential for an OH&S system to succeed. The company's senior management needs to promote the idea that everyone, from executives to employees, plays a part in the OHS management system and that every member's effort should complement one another. Management should conduct a personalized training course for each management level and worker, involving the OHS Committee, worker OHS representatives, and internal/external preventative and protective services (ISO 45001 Guide, 2018).

2.3.1.3. Planning

The company must identify and manage the risks and opportunities associated with operating its OH&S management system within the planning frameworks specified by the ISO 45001 standard. The organization must implement a procedure for proactive hazard identification and risk assessment. The company must be sure that it is complying with the most recent applicable legal and regulatory standards during the risk assessment process (ISO 45001 Guide, 2018). Furthermore, to accomplish these goals, the organization must create OH&S objectives and a plan.

2.3.1.4. Support

The Organization shall identify and implement appropriate steps to provide the resources, competencies, knowledge, information, and communication obligatory for the proper functioning of the OH&S management system by the requirements of the Standard (Guide,

2018). Resources include things like people, the environment, infrastructure, technology, and money. Competence for each role is determined by considering: qualifications, training, education, and experience needed by employees, restrictions and preventative measures put in place (legal and other requirements), and obligations and duties connected with the jobs (ISO 45001 Guide, 2018). Additionally, the company must identify the necessary documented information and put appropriate controls in place for it.

2.3.1.5. Operation

The Standard lays out precise guidelines for the following areas: operational planning and control, change management, outsourcing, contractor selection, and emergency readiness and response. In addition to the requirements in the Standard, other tools that could be employed during this phase such as training to ensure employees are competent and to update their knowledge as part of managing change, internal audits concentrated on whether preventive laws and equipment manufacturer's instructions are being followed, and OHS checklists and questionnaires for vendors and contractors (ISO 45001 Guide, 2018).

2.3.1.6. Performance evaluation

The company must develop, implement, and maintain a procedure for monitoring, measurement, and evaluation to comply with the standard. The assessment of conformity with all legal and other standards that the organization abides by is the most important part of this procedure. (ISO 45001 Guide, 2018). The monitoring, measurement, and evaluation method must address OHS domain complaints, accidents, illnesses, and injuries at work, and the status of found weaknesses in requirements compliance. Planning, establishing, implementing, and maintaining an internal audit program to give data on the OH&S management system's compliance with the business's standard requirements is another prerequisite for the organization. The primary directive of the Standard for top management is to periodically

assess the organization's OHS management system to guarantee its sufficiency and effectiveness (ISO 45001 Guide, 2018).

2.3.1.7. Improvement

Based on the evaluation discussed in the preceding section, the organization is required to create, execute, and maintain a process for managing incidents/accident investigations and nonconformity, as well as taking the necessary remedial steps (ISO 45001 Guide, 2018). Depending on the structure, operations, and risk of the organization, the system may employ a variety of strategies for capturing improvement possibilities which include: ways to report, including incident reporting, the timescale of reporting, documentation procedure for near-miss report cards, accident reports, defect reports, or reports to top leadership, participation of workers in investigations, and workers' competence and training.

Although the OHSMS is widely used, its usefulness is not universally agreed upon (Y. M. Goh & Chua, 2013). According to Fernández-Muñiz et al., (2009) the performance of a corporation as a whole benefits from OHSMS. On contrary, Robson et al., (2007) revealed that there is a good chance that OHSMS failure rates will be at least as high as the failure rate of quality management systems i.e., between 67% and 93%. Quinlan and Mayhew (2000) voiced concerns regarding the OHSMS's usefulness in light of the changing work environment. According to Robson et al., (2007), an OHSMS will only be successful if informal factors like trust and commitment support the formal system.

2.4. Accident Investigation

Accidents on construction sites are unprecedented events that include the movement of people, objects, or materials that could cause harm to people and properties. The general cause of such events is dangerous behavior and hazardous working circumstances (Akmal Shamsuddin et al., 2015). When compared to other industrial sectors worldwide, the construction industry has the

largest frequency of work accidents (Fang & Wu, 2013), accounting for five deaths each working day (S. Zhang et al., 2013). Identifying the characteristics of accidents could immensely contribute to preventing injuries and fatalities at construction sites. Scrutinizing an incident such as a fatality, injury, illness, or near-miss provides an opportunity for workers and employers to identify and analyze any deficiencies in their health and safety practices, and eventually formulate and take the appropriate corrective actions to avoid such instances. According to OSHA, (2015), there are four vital steps to carry out an investigation.

2.4.1. Preserve / Document the scene

Preserve the Scene: Use cones, tape, or guards to set the scene aside so that important evidence doesn't get taken or changed.

Document the Scene: Keep a record of the incident details, including the investigation start date and investigators. Note down the credentials of the injured worker, his name, description of injury, and the date and location of the incident. The scene can also be captured on camera, photographed, or sketched by investigators.

2.4.2. Collect information

Relating incident information is collected through interviews, document reviews, and other means. Other useful sources can also be utilized such as:

- Equipment manuals
- Industry guidance documents
- Company procedures and documents
- Maintenance plans, logs, and records
- Records of training

- Audit and follow-up reports
- Enforcement guidelines and documentation
- Previous corrective action suggestions

2.4.3. Determine root causes

The need for determining the root causes cannot be emphasized enough for an incident investigation to be successful. Fault and blame culture are one of the major reasons for an ineffective investigation. This requires constant “digging”, usually entailed by repeatedly asking “Why”.

2.4.4. Implement corrective actions

The root causes identified in the previous step must be addressed with the implementation of corrective actions. The conclusions and how they are presented will influence opinions and subsequent corrective measures. Ineffective corrective measures have little chance of enhancing safety protocols or averting further incidents.

2.5. Learning From Incidents (LFI)

2.5.1. Background

Numerous incidents have happened as a result of organizations' failure to take prior mistakes into account. This suggests that there is room for improvement in how firms assess incidents, devise solutions to address vulnerabilities identified, and prevent recurrence (Drupsteen, Groeneweg, et al., 2013). Therefore, learning from incidents refers to a process that starts with acquiring information and ends with evaluating the actions performed in light of the results of these lessons (Drupsteen-Sint, 2014). The process of learning from incidents is classified into five stages: acquiring information, investigating and analyzing incidents, preparing interventions, intervening, and evaluating (Drupsteen, Groeneweg, et al., 2013). Each stage

results in an output that contributes as a significant input into the next stage of the learning process. When the outcomes are poor or non-existent, the next stage is predicted to be less effective causing a loss of learning potential (Drupsteen, Groeneweg, et al., 2013).

The stage of incident reporting aims to identify valuable lessons learned from a specific situation. It involves reporting incidents, explaining them, and promoting organizational learning. Incident investigation involves fact-finding and analysis, with iterations needed to validate ideas (Smith et al., 2015). Understanding the origins of incidents, their causes, and potential solutions is crucial for learning from incidents, providing unbiased insights into root causes (Parker et al., 2018 , Burggraaf & Groeneweg, 2016). Planning interventions involves three steps: developing suggestions, establishing urgency, and creating an action plan. Prioritizing effective solutions and identifying recommendations requiring priority are key aspects (Weber, 2006). Action plans should be detailed, measurable, realistic, and relevant, with a specific intervention start date.(Parker et al., 2018). It's crucial to document at least 20 incidents per real accident to promote learning and identify lessons for subsequent investigation and analysis (Littlejohn et al., 2017 , Smith et al., 2015). The action plan's implementation phase involves distributing and locating resources, informing accountable individuals, and ensuring effective communication. Practical and meticulous development of the action plan significantly influences its effectiveness (Drupsteen-Sint, 2014). The final phase of the learning process assesses the execution process, effectiveness, and learning process itself, enhancing the organization's capacity for learning and potentially leading to enhancements (Parker et al., 2018).

2.5.2. Recent studies

Organizational learning is crucial for the construction sector to keep and improve its safety performance (Albert P.C. Chan et al., 2023). According to Carroll & Fahlbruch, (2011) and Drupsteen & Hasle, (2014), more effective organizational learning from events reduces the

likelihood of incident incidence and severity occurrences. By strengthening the organizational learning system, the chance of undesirable events may be decreased (Albert P.C. Chan et al., 2023). Despite widespread acceptance of the importance of organizational learning and knowledge management, some claim that existing organizational approaches neglect the difficulties and complexities associated with the process of knowledge generation and learning (Styhre, 2006). An organization with an increased capacity to learn from errors will encounter fewer occurrences than one with limited learning capability. (Cooke & Rohleder, 2006). There have been some studies regarding the LFI in different sectors. Littlejohn et al., (2017) developed the Learning from Incident Questionnaire (LFIQ), a tool that assesses the effectiveness of LFI procedures and practices in an organization and performed pilot research with 781 participants from two international energy companies to validate the LFIQ instrument. In another study, Drupsteen, Groeneweg, et al., (2013) developed a five-phase model for organizations to analyze LFI steps and identify bottlenecks, utilizing this model in a survey to examine learning from incidents procedures in three Dutch organizations. The findings of the study indicated that learning potential is not being fully utilized, particularly during the evaluation stage. In another study Drupsteen & Guldenmund, (2014) examined the literature on incident learning and compared it to Argyris's (1997) organizational learning theory. It emphasizes three gaps: inadequate research on follow-up stages after incident investigation, further research needed on the factors that influence learning achievement, and very little empirical study on learning from incidents. By recognizing the factors that affect the learning processes, learning can be made more effective and successful. To organize these conditions as a beginning point, Drupsteen, Bos, et al., (2013) employed a framework of the learning process. Four initial conditions were extracted from the literature, renamed, and added to five categories: people, communications, information quality, organizational aspects, and formal conditions or resources, based on four case studies. To pinpoint the factors and circumstances underpinning the learning challenges Drupsteen & Hasle, (2014) conducted a study. The

results, derived from seven focus group interviews conducted within industrial and construction organizations, identify five categories of factors that contribute to ineffective learning: time constraints, fear of negative outcomes, mental models or beliefs, a lack of knowledge and competence on the part of the participants, and a lack of urgency. Drupsteen & Wybo (2015) provided a set of metrics that organizations can use to predict whether they will learn from mishaps and other unpleasant events. The indicators include attitudes toward information sharing, learning process performance, systems facilitating information sharing, management commitment, openness, communication, and knowledge transfer. There are various barriers to overcome between 'reporting' and 'evaluating the effect of actions'. Furthermore, companies incorrectly assume that by officially structuring each phase, they remove the obstacles. For this purpose, Drupsteen et al., (2012) undertook a survey of several hundred safety specialists in the Netherlands and workers at a tank storage company to discover the hindrances within their firms and describe whether or not each phase was officially arranged and how it worked in practice. The survey results highlighted that the learning potential from accidents is lowered because many of the steps in the learning from events process are not completed in most companies, in particular, translating findings into recommendations and assessing their impact. To provide further insight into the most likely source of lost learning potential as shown in the aforementioned study, Parker et al., (2018) claimed that the possible explanation for this lack of advancement is a potential divergence between "those who investigate" and "those who implement". Learning from prior experiences is hampered by a number of issues, including human factors, technical challenges with information storage and retrieval, limitations with knowledge management, and policy and decision-making. Pasman, (2009) focused on the definition of these barriers, offered concrete instances, and explained the reasons why information gained from prior incidents is lost, ignored, or simply not employed. The study concluded that by neglecting to uncover the

underlying elements in accidents, evaluate latent conditions, and assess the influence on safety barriers, a large quantity of information is squandered.

Construction site safety accidents are difficult to eliminate (Peciłło, 2016). Previous incident cases should be purposefully acquired and used for extracting experience to prevent bad effects and maximize good results of safety events (D. Zhang et al., 2012). LFI has a direct impact on reactive measures of safety performance, such as the incidence of accidents, near misses, and improving construction safety performance (Q. Zhang et al., 2023).

2.6. Knowledge Management (KM)

2.6.1. Background

Knowledge has a crucial role in terms of people making decisions involved in complex projects, which means monumental outcomes can be controlled based on the knowledge that individuals possess. According to Ho et al., (2013), knowledge management (KM) is a set of processes that govern the generation, storage, reuse, evaluation, and application of experience-based knowledge in a specific situation or problem-solving context. The significance of knowledge management in modern disciplines stems from its significant impact on enhancing the value of organizations and institutions and the economy in general, as it increases these bodies' competitive advantage and contributes to decision-making that is balanced with the least number of mistakes. Knowledge management also creates an environment that fosters creativity and innovation through knowledge sharing and networking with experienced individuals (Subramaniam et al., 2011). Knowledge management is motivated by the desire to exchange and transfer information, yet the process encounters various challenges. It's possible that not everyone engaged has the knowledge, only some of them. Pasman, (2009) highlighted a zinc refinery plant explosion in France, where the lowest-level employees had said that the sounds and vibrations of the column were frightful and could result in explosions a few days

before the accident because they were unaware of other instances or the information exchange in Paris. Their message was either not heard at the top or it may have been disregarded.

2.6.2. KM in Construction Health and Safety

The complex, dynamic, and temporary nature of building projects has been partially blamed for this disproportionate injury and illness rate. To cope with these complications, a construction firm needs to recognize, capture, store, and share safety knowledge effectively (Hallowell, 2012). KM is not a recent term for construction firms, it has been adopted from its existence. Yet, organizations must regularly assess the performance of their KM-enabling capabilities (Okere, 2017).

To analyze the knowledge management strategies being implemented in the construction sector, Hallowell, (2012) performed 11 case studies of general contractors. It was observed that the construction firms frequently gather safety knowledge from a variety of internal and external sources, but their inadequate knowledge storage and transfer methods prevent their workers from acquiring the essential information they need to address pressing safety-related issues, while the capacity of high-performing organizations to manage tacit safety knowledge through formal procedures, such as data-entry systems that capture responses to safety concerns from experienced workers and safety mentoring, was found to be a critical distinction.

To identify where failures in learning from incidents are occurring, Stemn et al., (2018) used bowtie analysis to organize the literature on failing to learn from accidents so that scholars and practitioners are aware of the top priority areas. It was indicated that lessons must be transmitted more widely and stored in a fashion that is not dependent on humans, and the workforce must be able to retrieve and use stored lessons efficiently when needed. Maslen & Hayes, (2016) analysed incident-reporting systems used for the synchronization and mediation of knowledge within and between professional groups and organizations. The study stressed

that using Hecker's idea of collective knowledge, which considers information as shared, complementary, or incorporated inside artifacts such as incident databases, allows for the creation of successful knowledge management systems targeted at averting unplanned incidents. This emphasizes the fundamental link between learning from incidents and implementing knowledge management solutions.

2.7. BIM for Health and Safety

BIM is a sophisticated, 3D model-based technique for developing and managing construction project information throughout the project's lifetime (Santhiya et al., 2020). It is a parameterized model, which means that if you change one parameter of one component, all the relevant parameters are automatically changed. In contrast to traditional CAD software, BIM software offers Application Programming Interfaces (API) for designing and modifying programs to the required needs (Eadie et al., 2013).

The advent of BIM as a promising visualization tool, with the ability to give a full variety of digital construction data, has improved safety performance. (S. Zhang et al., 2013). Dadashi & Behrouz, (2022) proposed a BIM-based safety management framework by integrating the safety leading indicators database and BIM and implemented it in a case study. A heat map was used to display the effects of the safety-leading indicators daily. The most serious consequence of poor safety planning and execution is worker fatality. When on-the-job injuries occur, significant time and financial resources are lost. S. Zhang et al., (2013) integrated BIM and safety into a rule-based checking system for safety planning and simulation. The automatic safety-rule model checker has shown significant practical utility in building modeling and task planning for fall protection. As a coordination-based and centralized virtual model, BIM promotes open communication to assess the level of actual collaboration between the architect and the client during the building design process. This helps to ensure the project's success (Goh et al., 2014). Ganah & John, (2015) researched the use of BIM to improve worker training

was investigated. Their study looked at how effective this technology was at increasing workers' and project stakeholders' understanding of safety challenges during construction. Additionally, BIM has developed into a platform for collecting safety data with (DFSP) Design-for-Safety-Process application (Hadikusumo & Rowlinson, 2016).

2.7.1. BIM for Knowledge Management

The building project's transient character might make it challenging to communicate, share, and reuse knowledge (H. Wang & Meng, 2018). BIM had been already facilitating the process of knowledge management in construction industry. Ho et al., (2013) developed a BIM-based Knowledge Sharing Management (BIMKSM) system that brings together all construction information into one place by including external elements like problem descriptions, solutions, comments, and ideas. The system was implemented in a case study in Taiwan, and the findings demonstrated that engineers obtained a better knowledge of previously recorded information and experience from everyone involved in various projects with constructability issues based on its visual capabilities addressing such problems. Another quite similar Construction BIM-based Knowledge Management (CBIMKM) system was proposed by Lin, (2014), which utilizes both explicit and tacit knowledge of field engineers which can be shared and reused using knowledge map built on 3D platform. It was evident that the proposed system is effectual for knowledge management by utilizing BIM and web technology during the construction phase. For the purpose of decision making in building maintenance Almarshad & Motawa, (2012) proposed a Knowledge Management of Building Maintenance (KMoBM) system capable of retrieving pertinent operation cases as well as its associated damage building elements using BIM. Based on the case studies and interviews it was concluded that the proposed system may help in establishing the history of maintenance issues with a facility and offering thorough insight to enhance the decision-making process. To explore the potential enhancement of knowledge management using BIM, Wang & Meng, (2018) conducted a

research study in UK construction organizations based on a quantitative questionnaire survey on improvement of proactive KM, lifecycle KM, and KM processes. The identified KM improvements included collaboration, database for retrieving data and knowledge, and visualization for improving knowledge representation and communication.

2.8. Cognitive Load (CL)

Human cognitive-behavioral studies explore how the connection of the mind, brain, and body by measuring cognitive activities such as CL, situational awareness, perceptual processing, and information processing (Curtin & Ayaz, 2017). Although there are several definitions of CL, Brünken et al., (2003) believe that it is the mental effort one does when processing information. Human working memory can only handle an average of seven unconnected objects at once, according to Doswell & Skinner's (2014) CL theory, and thus, cognitive overload often happens when human working memory is pushed to absorb higher quantities of information more quickly. As a result, the volume of information that must be managed can have a big impact on task performance. From a cognitive standpoint, information-intensive procedures are involved in every significant task in the AEC sector (Doswell & Skinner, 2014). According to Kalyuga (2008) dynamic interactive animations can support cognitive processes that are critical for learning while also assisting in lowering the needless burden brought on by poorly designed instructions or difficult activities. Furthermore, a number of research have examined the broad connection between cognitive problems and performance. In particular, it was discovered by Lindblom & Thorvald, (2014) and Paas et al., (2004) that performance problems might arise from both an excessive amount of CL (overload) and insufficient CL (underload). Cognitive underload, for instance, might happen when a user depends so much on a system to complete activities that they become disinterested in them, which increases the likelihood of task-related mistakes. On the other hand, systems can produce volumes of data that are larger than the capacity of the human mind to handle. These realizations prompted Mendel & Pak,

(2009) to contend that lowering CL during information-intensive activities might improve user performance.

The concept of cognitive load has substantial significance to our methodology, which involves developing an accident/incident knowledge database system and reconstructing the sequence of events derived from accident/incident reports to discover the underlying causes of accidents in the construction sector. During the analysis process, people may get cognitively overloaded with information retrieval, integration, and problem-solving duties. This might make it more difficult for them to pinpoint the root reasons for the incident (F. P. Paas et al., 2016). Furthermore, cognitive load affects people's ability to process safety-critical information and make wise judgments in fast-paced, high-risk work conditions, which has an impact on health and safety in the construction industry. Therefore, assessing cognitive load is critical for verifying the notion that the developed system may greatly lower the cognitive load of comprehending the incident.

2.9. Visualization for Health and Safety

Chiu & Russell, (2011) discovered that visualizing construction data improves data cognition. Although visualization in the construction industry is primarily used to enhance communication in architectural design, its advantages can be realized at any stage of a project's lifecycle (Bouchlaghem et al., 2005). The high incidence of accidents and fatalities in the construction sector paves the way for carrying out more effective and efficient safety management practices. A compelling method for enhancing safety management in the industry is through safety training (Sawacha et al., 1999), which would allow the workers to acquire mandatory safety knowledge in a relatively shorter period in a zero-risk environment. Construction operations and the surroundings can be graphically illustrated in 3D using visualization technology, which offers a visual approach to safety instruction (Guo et al., 2017). Conventional safety training is teacher-student based, which is incapable of assessing both

trainer and trainee performance during and after training sessions. Teizer et al., (2013) presented a novel strategy by integrating three-dimensional data visualization and real-time location tracking technologies into current iron workers' education and safety training. The proposed framework would detect and visualize unsafe practices in a training environment. Wang et al., (2012) developed a Virtual Reality (VR) model for modular construction, capable of assessing the idle and cycle time to improve productivity for residential floor panel framing activities. This tool can be used to plan and create module systems in manufacturing lines to improve worker safety and productivity. Pedro et al., (2020) proposed a scenario-based evaluation framework for visualization-enhanced safety education, to address the constraints of the current construction safety education assessment methods. The system was implemented with students majoring in construction management, and learner assessment is carried out using visualization-enhanced: safety theory questions, site inspection scenarios, and job safety analysis review. The findings revealed that the suggested method has a great deal of potential as a cutting-edge assessment tool for safety education by bridging the disconnect between teaching and actual workplace circumstances. According to the educators, one of the main advantages of this tool is its capacity to accommodate a variety of assessment tasks providing the opportunity for the students to showcase their safety skills. Azhar, (2017) drew attention to construction site safety planning by presenting three case studies, where a comparative analysis between 2D static drawings and 3D/4D dynamic tools was done. The results highlighted those visualization technologies (3D/4D) were more effective in communicating and implementing the site safety plans, as they accurately reflect the conditions found on a job site. A proof of concept with regards to firefighting situational awareness was presented by Chen et al., (2021) to train the on-field individuals by integrating AR/VR technologies with BIM. The proposed system would allow firefighters to make more informed decisions in haphazard scenarios. Shen et al., (2015) developed a system for near-miss data collection and location-based visualization,

where they collected the near-miss data within BIM and highlighted the location of the near-miss events in the 3D model.

2.10. Knowledge Management and Visualization for Accident Investigation

To prevent construction accidents in the future, it is essential to comprehend necessary information from past incidents, which includes informing stakeholders about various safety elements and values related to the time, location, causes, and severity of accidents. This has encouraged researchers to develop a database of accident cases to facilitate the effective use of safety determinants and values found via the analysis of accident reports. Like, Kim et al., (2018) proposed a framework for collecting accident data that could generate automated queries based on tasks and site conditions. The developed system allows the users to choose the most appropriate plans among those that were generated by automatically identifying temporary structure-related hazards. Similarly, Zhang et al., (2016) created a database containing 249 incidents to help with risk management for the metro project, capable of identifying trends in the previous incidents and forecasting the prevention of future accidents. Another way to utilize previous hazard and accident information, Goh & Chua, (2010) developed a CBR (Case-based reasoning) model, to improve the effectiveness and sufficiency of the current hazard-identification methods. Kim et al., (2015) proposed an information retrieval system established from past accidents, that can automatically look for and present similar accidents. BIM objects are extracted by the retrieval system, which then integrates them with a project management information system to create a query set (PMIS). As a result, query generation can be drastically decreased by end users (managers and workers). Another problem is where numerous concurrent activities may overlap in terms of space and time, making them more susceptible to repetitive accidents and spatial-temporal exposure. Tran et al., (2021) developed an approach HITSEA a cutting-edge method for hazard detection using spatial-temporal exposure analysis, and incorporated accident case scenario analysis into 4D BIM.

Based on the past accident data provided by OSHA, the current project activities are analyzed in the 4D environment to make sure that there isn't any spatial conflict between the activities, if so then the hazard is identified and added to the hazard database.

2.11. Conclusion

Construction site mishaps, such as accidents and near-misses, present an opportunity to learn from them, improve favorable results, and lessen the likelihood that undesired occurrences will happen again (Q. Zhang et al., 2023). Despite significant efforts by government, industry, and academics to enhance safety performance in construction projects, the occupational incident rates among construction employees continue to remain elevated (Dodshon & Hassall, 2017; Sandberg & Albrechtsen, 2018). The frequency of similar incidents in the construction industry may signal that LFI is not a good practice in the industry (Gibb et al., 2014; Hoła & Szóstak, 2015; Kari & Niemel, 2015). Existing research emphasizes the significance of LFI on construction safety performance but falls short of highlighting the factors that are barriers to learning from past incidents (Drupsteen, Groeneweg, et al., 2013; Drupsteen & Hasle, 2014; Littlejohn et al., 2017).

Knowledge has a crucial role in terms of people making decisions involved in complex projects, which means monumental outcomes can be controlled based on the knowledge that individuals possess. It was observed that the construction firms frequently gather safety knowledge from a variety of internal and external sources, but their inadequate knowledge storage and transfer methods prevent their workers from acquiring the essential information they need to address pressing safety-related issues (Hallowell, 2012). One of the main differences between high-performing and low-performing firms is their ability to manage tacit safety knowledge through formal procedures, such data-entry systems that record experienced workers' reactions to safety concerns and safety mentoring (Hallowell, 2012).

Building information modelling had been already facilitating the process of knowledge management in construction industry. Ho et al., (2013) developed a BIM-based Knowledge Sharing Management (BIMKSM) system capable of combining all construction information into a single source by incorporating outside elements, such as problem and solution descriptions, comments, and ideas. Another quite similar Construction BIM-based Knowledge Management (CBIMKM) system was proposed by Lin, (2014), which utilizes both explicit and tacit knowledge of field engineers which can be shared and reused using knowledge map built on a 3D platform. BIM in conjunction with knowledge management, is essential to learning from incidents as it makes it easier to gather, arrange, share, and analyze incident data and best practices. The advent of Building Information Modeling (BIM) as a promising visualization tool, with the ability to give a full variety of digital construction data, has permitted improvements in safety performance. (S. Zhang et al., 2013). Dadashi & Behrouz, (2022) proposed a BIM-based safety management framework by integrating the safety leading indicators database and BIM and implemented it in a case study. The most serious consequence of poor safety planning and execution is worker fatality. When on-the-job injuries occur, significant time and financial resources are lost. S. Zhang et al., (2013) integrated BIM and safety into a rule-based checking system for safety planning and simulation. Additionally, BIM has developed into a platform for collecting safety data with DFSP (Design-for-Safety-Process) application (Hadikusumo & Rowlinson, 2016).

Moreover, visualization tools have been acquired for accident / incident reconstruction in different industries e.g. Aviation. Whenever a plane crashes, all the evidence is retrieved from the black box to find the root cause of the air crash incident. D'Anniballe et al., (2020) established a full-scale 3D representation of a real aircraft crash scene created using augmented reality technology, including details about the location of the wreckage and the surrounding area for air accident investigation and training purposes. Such accident recreation would

highlight the chain of events that caused the incident to happen and also would allow the aircraft crew to get acquired with appropriate safety knowledge in such unprecedented scenarios. Visualization technologies can be pioneers for accident prevention in different industries as well. Bogacki, (2005) recreated the accidents that occurred in coal mines using computer vision technology. The screenplay was based on the investigation data (witnesses' statements) carried out at the mine, spreading awareness among the workers to follow necessary safety rules.

None of these studies attempted to link / integrate construction model visual parameters to a centralized database that contained accident-related data for a specific location on the model to which they were connected. It could have been used to understand each component's and the project's overall impact by visualizing the accident components of a project in a realistic virtual environment. The aim of this study is to exploit BIM technology to create central repository for Accident/Incident investigation data to neutralize the knowledge management issues to improve the acquiring information, and investigation processes which eventually would have an impact on effective learning as stated. Moreover, the utility of the proposed system will also be explored from the cognitive load perspective to determine how the proposed BIM based tool may be useful for H&S training and communication.

CHAPTER 3

RESEARCH METHODOLOGY

This chapter explains the proposed methodology to fulfill the relevant objectives defined in Chapter 1. Data collection, research methods, and case study validation have been described explicitly for each of the objectives. Furthermore, the research methods employed to achieve the proposed objectives for this study are shown in the table below (**Table 1**). In this chapter, a thorough explanation will be provided for each objective and the methodology implemented to accomplish these objectives.

Table 1: Research methods

Research Objectives	Research Methods	Analysis Techniques	Development Techniques
1. To identify and analyze barriers that hinder the process of learning from past incidents in the construction industry (Saudi construction industry).	1. Literature Review 2. Expert Interviews 3. Pilot Study 4. Questionnaire Survey	1. Cronbach's Alpha 2. Mean score ranking 3. Agreement analysis	1. Pilot Study 2. Questionnaire Design
2. To develop a BIM based construction accident / incident knowledge database management system	1. Literature Review 2. Case Studies	Content Analysis	1. Autodesk Revit 2. Microsoft Access 3. Revit APIs 4. Standard incident report template
3. To validate the feasibility of the proposed system for knowledge management of construction accidents/incidents data	1. Case Studies 2. Semi-Structured Interview 3. Questionnaire Survey	RII based ranking	Questionnaire Design
4. To develop a framework that outlines the process of creating character animations based on construction accident/incident reports	1. Literature Review 2. Case Studies	Content Analysis	Framework development
5. To assess the potential of the proposed system for learning from past incidents based on cognitive load measurements	1. Experimental Study 2. NASA-TLX questionnaire	Mean score ranking	Questionnaire Design

The research framework for the proposed objectives is shown below in **Figure 2**.

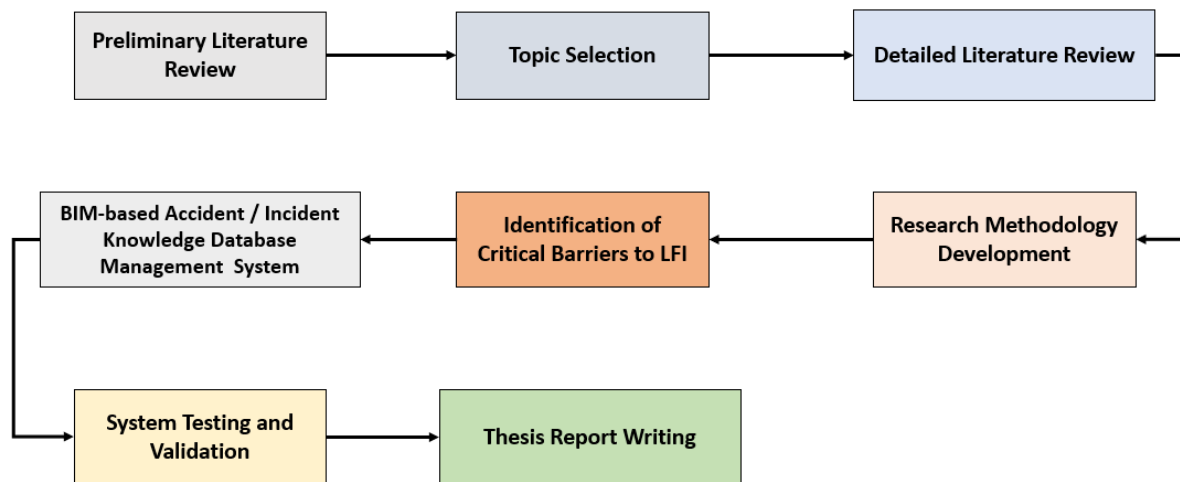


Figure 2: Research framework

3.1. Barriers to LFI in Saudi Construction Industry

Objective 1: To identify and analyze barriers that hinder the process of learning from past incidents in the construction industry (Saudi construction industry).

3.1.1. Identification of barriers to LFI

There have been several studies that have directly or indirectly indicated multiple barriers to learning from past incidents and how it is essential to avoid recurring mishaps in the future. In terms of direct barriers, under-reporting, poor quality reports, limited sharing of information, lack of evaluation of recommended actions, and others were highlighted by Drupsteen et al., (2012), Drupsteen, Bos, et al., (2013), Drupsteen & Hasle, (2014), Littlejohn et al., (2017), Parker et al., (2018) as barriers to learning from the past events. Whereas, indirect barriers such as capturing tacit knowledge, lack of transformational leadership, and disparity among recommendations and actions were alluded by Dechy et al., (2015), Drupsteen et al., (2012), and Parker et al., (2018). As discussed previously there hasn't been any comprehensive study that specifically highlights these barriers in the field of construction. Therefore, analysis of literary works was conducted utilizing a thorough assessment of academic articles available on

Google Scholar. After the selection of a suitable database for accessing relevant articles, numerous research articles related to health and safety were read to recognize keywords such as “organizational learning”, “learning from incidents”, “effective learning”, “incident reporting” “barriers”, “factors”, “hindrances, and “enhance learning” to aid in shortlisting of articles to identify the critical barriers to LFI. Around 8 relevant articles were shortlisted highlighting critical barriers to LFI in the fields of chemical, oil and gas, and process industries. After a thorough review of these relevant studies, 21 potential barriers were identified in this study as shown in **Table 2**. The barriers were categorized into five LFI process phases (acquiring information, investigation and analysis, Planning interventions, intervening, and evaluation) described by Parker et al., (2018). The elements obtained can be construed as barriers to LFI, which have been reported in the extant literature. It is recommended to consider the factors that are well-known and frequently discussed in the previous literature, making it easier for the respondents to answer (Rowlinson, 1988). For instance, the literature frequently acknowledges under-reporting, lack of communication, and a lack of visual learning as major obstacles to learning from experiences.

Table 2: Barriers to LFI from literature

LFI processes	Barriers	References
Acquiring Information	Limited quality of initial reports	Drupsteen-Sint, (2014) , Drupsteen et al., (2013)
	Under-reporting	Smith et al., (2015) , Drupsteen-Sint, (2014)
	Complex reporting systems	Smith et al., (2015)
	Lack of understanding of how and what to report	Drupsteen-Sint, (2014) , Smith et al., (2015)
Investigation and Analysis	Limited dissemination of findings	Drupsteen et al., (2013) , Littlejohn et al., (2019)
	Lengthy investigation reports	Smith et al., (2015)
	Non-identification of systematic causes	Drupsteen-Sint, (2014)
	Selection of incidents to investigate	Drupsteen-Sint, (2014) , Smith et al., (2015)
	Difficulty identifying broader lessons	Smith et al., (2015)
Planning Intervention	Lack of visual insights	Parker et al., (2018) , Drupsteen et al., (2012)
	Lack of contextualizing	Smith et al., (2015)
	Difficulty in translating findings into recommendations	Drupsteen et al., (2012)
	Too many and vague recommendations	Smith et al., (2015)
	Poor quality of actions	Smith et al., (2015)
Intervening	Resistance to change	Dechy et al., (2015) , Smith et al., (2015)
	Disparity of actions and recommendations	Drupsteen et al., (2012)
	Inadequate monitoring	Dechy et al., (2015)
	Corporate amnesia	Smith et al., (2015)
	Inadequate resources	Dechy et al., (2015)
Evaluating	Lack of system evaluation	Dechy et al., (2015) , Smith et al., (2015)
	Lack of structural feedback on follow-up reports	Drupsteen et al., (2013)

3.1.2. Pilot Study

A quantitative questionnaire based on the refined variables from the literature was created to rank the important issues preventing construction organizations from learning from previous

accidents. A three-step method was used to evaluate the suitability and rationale of the questionnaire before it was distributed to the respondents. First, six senior experts with several years of experience in the local construction sector having relevant experience in health and safety were interviewed. They were asked to evaluate if the questionnaire addressed all potential barriers, taking into account the failure to learn from previous construction mishaps, and whether any elements could be added to or deleted from the survey. **Table 3** shows the profile of the experts.

Table 3: Profile of interviewees

Profiles	Category	Frequency
Organization	Contractor	2
	Consultant	4
Years of Experience	5-10 years	2
	11-15 years	1
	15 & above years	3
Job Role	Health and Safety Supervisor	2
	HSE Engineer	1
	Health and Safety Manager	3

In their response, 26 further factors influencing the process of learning were added resulting in a total 47 potential barriers as shown in **Table 4**. These extra barriers were explored and underlined in some detail by the experts, either in person or by written comments. These included lack of training and competence in root cause analysis, employees' commitment, policy implementation, self-complacency, resource constraints, and many similar direct and indirect barriers as from the literature but from a different standpoint. Many of these barriers

were later on analyzed and shortlisted for the final list of the factors causing hindrances to the process of learning in an organization based on the repetition, similar meaning, and irrelevancy to the topic of the study.

Table 4: Barriers to LFI based on literature and interviews

LFI processes	Barriers	References
Acquiring Information	Limited quality of initial reports	Drupsteen-Sint, (2014) , Drupsteen, Bos, et al., (2013)
	Under-reporting	Smith et al., (2015) , Drupsteen-Sint, (2014)
	Complex reporting systems	Smith et al., (2015)
	Lack of understanding of how and what to report	Drupsteen-Sint, (2014) , Smith et al., (2015)
	Risk Perception	Expert Interview
	Lack of awareness and training	Expert Interview
	Lack of organizational communication policy	Expert Interview
	Lack of awareness and training	Expert Interview
Investigation and Analysis	Limited dissemination of findings	Drupsteen, Bos, et al., (2013) , Littlejohn et al., (2019)
	Lengthy investigation reports	Smith et al., (2015)
	Non-identification of systematic causes	Drupsteen-Sint, (2014)
	Selection of incidents to investigate	Drupsteen-Sint, (2014) , Smith et al., (2015)
	Difficulty identifying broader lessons	Smith et al., (2015)
	Lack of training / competence of investigation team	Expert Interview
	Fear of legal actions against an organization	Expert Interview
	Blame and shame culture	Expert Interview
	Authenticity of witness statements	Expert Interview
	Lack of sufficient evidence including photos	Expert Interview
	Disturbance of evidence and witness by organization key personnel	Expert Interview
	Lack of visual insights	Parker et al., (2018) , Drupsteen et al., (2012)
	Lack of contextualizing	Smith et al., (2015)
	Difficulty in translating findings into recommendations	Drupsteen et al., (2012)

LFI processes	Barriers	References
Planning Intervention	• Too many and vague recommendations	Smith et al., (2015)
	• Poor quality of actions	Smith et al., (2015)
	• Lack of training and competence in root cause analysis	Expert Interview
	• Failure to prioritize key actions	Expert Interview
	• Stretched Resources	Expert Interview
	• Intention of the organization	Expert Interview
	• Employees commitment	Expert Interview
	• Policy implementation	Expert Interview
	• Execution as utmost goal	Expert Interview
Intervening	• Resistance to change	Dechy et al., (2015) , Smith et al., (2015)
	• Disparity of actions and recommendations	Drupsteen et al., (2012)
	• Inadequate monitoring	Dechy et al., (2015)
	• Corporate amnesia	Smith et al., (2015)
	• Inadequate resources	Dechy et al., (2015)
	• Lack of management commitment to communicating and implementing actions	Expert Interview
	• Lack of internal responsibility system	Expert Interview
	• Self-complacency of employees	Expert Interview
	• Intention of the organization for implementing HSE management system	Expert Interview
	• Commitment of the top management	Expert Interview
	• Communication among the organization	Expert Interview
Evaluating	• Lack of system evaluation	Dechy et al., (2015) , Smith et al., (2015)
	• Lack of structural feedback on follow-up reports	Drupsteen, Bos, et al., (2013)
	• Key personnel not engaged in implementation and evaluation	Expert Interview
	• Budget, cost and time constraints	Expert Interview
	• Ineffective approaches	Expert Interview

Second, experts were asked to rate the importance of the 21 LFI obstacles obtained from the extant literature on a five-point scale (1 = not critical, 2 = less critical, 3 = neutral, 4 = critical,

and 5 = very critical). Afterward, the mean scores for their responses were calculated, and factors having a mean score of less than 2.50 as in Wuni et al., (2022) were eliminated from the questionnaire considering such factors to be of low significance for LFI. Similarly, numerous factors were merged based on their similar description e.g., factors like “Stretched resources” and “Budget, cost and time constraints” are merged with “Inadequate resources” to form a single factor, or simply discarded due to the repetition, or too many vague or irrelevant barriers which has no greater influence on the learning process. Based on these aforementioned approaches the total of 47 barriers were reduced to a total of 22 barriers as shown in **Table 5**, and were used in the finalized questionnaire.

Table 5: Finalized list of barriers to LFI

LFI processes	Code	Barriers	References
Acquiring Information	BAI01	Limited quality of initial reports	Drupsteen-Sint, (2014) , Drupsteen, Bos, et al., (2013)
	BAI02	Under-reporting	Smith et al., (2015) , Drupsteen-Sint, (2014)
	BAI03	Complex reporting systems	Smith et al., (2015)
	BAI04	Lack of understanding of how and what to report	Drupsteen-Sint, (2014) , Smith et al., (2015)
Investigation and Analysis	BIA01	Limited dissemination of findings	Drupsteen et al., (2013) , Littlejohn et al., (2019)
	BIA02	Lengthy investigation reports	Smith et al., (2015)
	BIA03	Non-identification of systematic causes	Drupsteen-Sint, (2014)
	BIA04	Selection of incidents to investigate	Drupsteen-Sint, (2014) , Smith et al., (2015)
	BIA05	Difficulty identifying broader lessons	Smith et al., (2015)
	BIA06	Lack of training / competence of investigation team	Expert Interview
Planning Intervention	BPI01	Lack of visual insights	Parker et al., (2018) , Drupsteen et al., (2012)
	BPI02	Lack of contextualizing	Smith et al., (2015)
	BPI03	Difficulty in translating findings into recommendations	Drupsteen et al., (2012)
	BPI04	Poor quality of actions	Smith et al., (2015)
	BPI05	Failure to prioritize key actions	Expert Interview
Intervening	BI01	Disparity of actions and recommendations	Drupsteen et al., (2012)
	BI02	Inadequate monitoring	Dechy et al., (2015)
	BI03	Inadequate resources	Dechy et al., (2015)
	BI04	Lack of commitment by management	Expert Interview
	BI05	Employees' casual / laid back behavior	Expert Interview
Evaluating	BE01	Lack of system evaluation	Dechy et al., (2015) , Smith et al., (2015)
	BE02	Lack of structural feedback on follow-up reports	Drupsteen, Bos, et al., (2013)

3.1.3. Data Collection

After finalizing the list of barriers to LFI in the construction industry, a questionnaire was developed to conduct an industry-wide survey. The questionnaire consisted of four sections.

The first section was a brief introduction to the topic of the research along with its significance

in the construction industry. Section two collected the background information of the respondents (email, company type, company size, designation, and work experience in the respective industry). The third section of the questionnaire briefly describes each of the phases of the learning process to enlighten the respondents about the concept of LFI. The final section of the questionnaire consisted of the final list of barriers within their respective phases and for each barrier the respondent was asked to rate the importance of it on a five-point Likert scale (1 = not critical, 2 = less critical, 3 = neutral, 4 = critical, and 5 = very critical) (Chan et al., 2018). The questionnaire was created on Google Forms and was distributed to numerous professionals via google forms link. These professionals were also requested to distribute and share this link within their organization and among other health and safety professionals in their social network. The questionnaire is shown in **Appendix A** in detail.

All professionals in the field who had knowledge of and experience with health and safety in the construction sector made up the population for the survey. The sample in this study was a non-probability sample since there was no sampling frame. When respondents are chosen for the research based on their willingness to participate rather than being chosen at random from the overall population, the nonprobability sampling strategy can be utilized to generate a representative sample (Wilkins, 2011). In order to get a reliable total sample size for this study, the snowball sampling technique was employed. The snowball method, which allows for the gathering and sharing of data and responders through referral or social networks, was also employed in earlier barrier studies in construction management (Mao et al., 2015; X. Zhang et al., 2011). The participants in the study were health and safety experts working in the construction sector in Saudi Arabia. They were first found through personal connections inside the contractor, client, and consultant organizations. These experts were then requested to recommend other health and safety experts employed by Saudi Arabia's construction industry. Currently, the Kingdom of Saudi Arabia (KSA) is involved in hosting many breakthrough

construction megaprojects that have sparked substantial interest from prominent international contractors and design consultants. Among these famous projects are those managed by well-known companies such as Bechtel, AECOM, ARUP, PARSONS, Mcdermott, and others. These projects not only highlight Saudi Arabia's ambitious development objectives but also work as a catalyst for recruiting top-tier construction engineering consultants and contractors from the worldwide market. This method was used to administer 120 survey questionnaires to contractors, consultants, and developer companies to get their responses. The final results showed a 62.5% response rate from 75 sets of valid questionnaire responses. Despite the small sample size, statistical analyses could still be carried out because, according to the generally accepted practice, the central limit theorem holds valid with a sample size of 30 or more (Ott and Longnecker., 2010, Hwang et al., 2015, Chan et al., 2018).

The respondents consisted of 30 health and safety managers, 21 health and safety supervisors, 17 safety engineers, 2 safety officers, 2 safety inspectors, 1 project manager, 1 health and safety consultant, and 1 Health safety security environment administrator (HSSE AD), among which 42, and 33 were from contractor and consultant organizations, respectively as evident in **Table 6**.

Table 6: Profile of respondents

Characteristics	Frequency	Percent	Years of Experience									
			Construction Industry					Health and Safety				
			1-5	6-10	11-15	16-20	>20	1-5	6-10	11-15	16-20	>20
Professions												
Health and safety Manager	30	39.62	1	8	7	5	9	1	6	8	5	10
Health and safety Supervisor	21	24.53	8	8	3	2	0	8	4	7	2	0
Health and safety engineer	17	22.64	6	6	4	0	1	5	7	3	0	2
Safety inspector	2	3.77	1	1	0	0	0	2	0	0	0	0
Safety Officer	2	3.77	1	1	0	0	0	0	2	0	0	0
Project manager	1	1.89	0	1	0	0	0	0	1	0	0	0
Health and safety consultant	1	1.89	0	1	0	0	0	0	1	0	0	0
HSSE AD	1	1.89	0	0	0	0	1	0	0	0	0	1
Total	75	100.00	17	26	14	7	11	16	21	18	7	13
% by year	-	-	22.64	33.96	18.87	9.43	15.09	20.75	28.30	24.53	9.43	16.98
Companies												
Contractor	42	56	6	16	8	4	8	5	11	13	4	9
Consultant	33	44	11	10	6	3	3	11	10	5	3	4
Total	75	100	17	26	14	7	11	16	21	18	7	13
% by year	-	-	22.64	33.96	18.87	9.43	15.09	20.75	28.30	24.53	9.43	16.98

3.1.4. Data Analysis Techniques

3.1.4.1. Cronbach's alpha technique

Cronbach's alpha is a statistical metric used to assess the average correlation or internal consistency among factors within a survey questionnaire, to evaluate its validity. Ranging from 0 to 1, Cronbach's alpha coefficient (α) provides insights into the reliability of components retrieved from multipoint scales or questionnaires (Santos, 1999). Higher α values indicate more reliability in the measuring scale utilized. The computed α value for the 22 LFI barriers was 0.961 using the SPSS 22 statistical program, suggesting that the barriers are internally consistent. Consequently, the collected sample can be treated as a cohesive unit, making it ideal for further ranking analysis (Mao et al., 2015).

3.1.4.2. Mean score ranking technique

In this study, the relative ranking of the 22 LFI obstacles in descending order of criticality, as assessed by the respondents, was determined using the mean score (MS) ranking technique as done in similar factor-based studies as in Chan et al., (2018), and Darko et al., (2017). In cases where multiple barriers exhibited identical mean scores, prioritization was determined based on the barrier with the lowest standard deviation (SD) (Mao et al., 2015). Subsequently, the critical barriers within the 22 LFI hindrances were then determined using normalized mean score (Xu et al., 2010, Zhao et al., 2015). Barriers with normalized values greater than 0.50 are indicated as important barriers impeding learning from previous accidents in the construction sector. The normalization equation used for this purpose is shown in Eq 1 (Srivastav.A.K, 2024). After the mean score ranking of the individual factors, the mean scores of five phases were calculated to determine the most influential phase on the learning aspect.

$$x' = \frac{x - x_{min}}{x_{max} - x_{min}} \quad \text{Eq (1)}$$

Where x' denotes normalized value, x is the original value which is to be normalized, x_{min} is the minimum value of all the means, and x_{max} is the maximum value of all the mean values. The ranking of the barriers have been discussed in more detail in Chapter 4.

3.1.4.3. Agreement analysis technique

Kendall's coefficient of concordance, commonly known as Kendall's W, is a nonparametric statistical test used to determine the degree of concordance between sets of ranks (Salkind, 2012). In this study, Kendall's W was used to determine if different respondents from a certain group demonstrated unanimity about the ranking of the barriers. The Kendall's W test's null hypothesis is that "there is no agreement between the rankings provided by the respondents." Kendall's W has a value between 0 and 1, with a value of 0 denoting "no agreement" and a value of 1 denoting "complete agreement." If the significance level of Kendall's W test is found

to be low (≤ 0.001), the rejection of the null hypothesis suggests that there exists a certain degree of consensus among the respondents (Salkind, 2012). Given that the respondents were from diverse companies (contractors and consultants), it was crucial to perform analysis in addition to Kendall's W test to determine whether there were any significant differences between respondents from various companies. To do this, an analysis of variance (ANOVA) test was run to see if there were any statistically significant variations in the mean scores from the two respondent groups according to the type of company.

3.2. BIM-based accident/incident KDMS for construction

Objective 2: To develop a BIM-based construction accident/incident knowledge database management system

3.2.1. KM for enhancing LFI

Knowledge management (KM) refers to methods and techniques for efficiently capturing, organizing, and sharing knowledge within organizations to improve performance and stimulate innovation (Wiig, 1997). In terms of learning from incidents, KM is critical in supporting the proper recording and management of accidents or occurrences in a structured database. Organizations may utilize knowledge management strategies to create centralized repositories where incident data, such as descriptions, underlying causes, and remedial actions, are consistently documented and easily available (Alavi & Leidner, 2001). However, the efficiency of KM in incident learning may be further increased by the utilization of BIM. Organizations may better assess the effects of events on the built environment and gain a more thorough understanding of the contextual elements leading to incidents by integrating incident data into BIM-based systems. Furthermore, BIM makes it easier to visualize and simulate possible outcomes, allowing stakeholders to evaluate how design choices may affect risk and safety (Succar, 2009). Therefore, a BIM-based accident and incident database provides considerable

benefits in terms of improving knowledge management procedures, allowing organizations to identify and rectify safety concerns before they occur again.

3.2.2. Identification of KM issues in the construction industry

Firstly, challenges in KM for the construction sector were short-listed after a thorough review of existing literature. As mentioned, before very limited research has been conducted regarding the knowledge management domain, especially in the field of construction health and safety. For this process, Google Scholar was chosen as the primary source of research articles. The keywords used to search relevant articles were “knowledge”, “knowledge management”, “effective knowledge management”, “barriers”, “critical factors”, “implicit knowledge”, “explicit knowledge”, “BIM for knowledge management”, and “KM for Health and Safety”. By utilizing these search keywords around 9 relevant publications related to KM in the construction industry were shortlisted. Additionally, as previously discussed and emphasized in earlier academic studies, there is an intrinsic relationship between KM and LFI, highlighting how the adoption of strong KM practices can significantly increase the effectiveness of the LFI process. As a result, papers focusing on Learning from Incidents (LFI) were also included in this process. Moreover, it has been highlighted by previous research that enhanced KM techniques enabled by BIM technology might benefit the LFI process. Therefore, the objective is to assess how creating and deploying a cutting-edge BIM-based knowledge management system might not only remove barriers to effective KM but also deal with issues that are preventing LFI initiatives from moving forward. After reviewing the LFI and KM papers, 16 barriers were obtained. After that, content analysis was done to assess the problems with overlapping concerns. In addition, the list of problems was presented to six construction health and safety specialists to get their opinions on these knowledge management difficulties and were asked to evaluate if the following list contained all potential issues in construction incidents knowledge management, and whether any elements could be added to or deleted from

the list. The profile of the experts is shown in **Table 7**. As a result, barriers with various names but similar meanings were either combined or removed. It resulted in the identification of 13 significant knowledge management as well as learning from incidents (LFI) issues as shown in **Table 8**. It can be noticed that issues from 8-13 are similar to those occurring in the LFI process.

Table 7: Profile of experts

Profiles	Category	Frequency
Organization	Contractor	2
	Consultant	4
Years of Experience	5-10 years	2
	11-15 years	1
	15 & above years	3
Job Role	Health and Safety Supervisor	2
	HSE Engineer	1
	Health and Safety Manager	3

Table 8: Barriers to KM issues in construction health and safety

Challenges	References
1. Inadequate resource that serves as a "one stop shop" for accessing pertinent data, lessons learned, and best practices	Okere, (2017) , Ayatollahi & Zeraatkar, (2020)
2. Disintegrated system, thereby increasing work repetition.	Okere, (2017)
3. Inaccessibility of information anytime and anywhere	Okere, (2017)
4. No communication tool to share tacit knowledge	Ayatollahi & Zeraatkar, (2020)
5. Non-standardization of file directories, file plans, and document templates	Okere, (2017)
6. Paper-based exchange of information (slow and inefficient)	Vidogah et al., (2004)
7. Non-existence of efficient interfaces between departmental systems to access information electronically	Vidogah et al., (2004)
8. Limited quality of initial reports	Drupsteen-Sint, (2014) , Drupsteen, Bos, et al., (2013), Okere, (2017)
9. Complex reporting systems	Smith et al., (2015)
10. Limited dissemination of findings	Drupsteen, Bos, et al., (2013) , Littlejohn et al., (2019)
11. Non-identification of systemic causes	Drupsteen-Sint, (2014)
12. Lack of contextualizing	Smith et al., (2015)
13. Lack of visual insights	Parker et al., (2018) , Drupsteen et al., (2012)

3.2.3. Prototype Development

A template was developed for recording accident and incident data on construction projects.

For this purpose, existing templates by HSE and OSHA were reviewed along with other

standard templates and finally, a template existing with OSHA for accident/incident investigation was adopted for this research. The purpose of using a standard template was to ensure the systematic development of a BIM-integrated database containing extensive data about incidents and accidents. This approach aimed to establish uniformity and consistency in the processes of data collection, storage, and retrieval. This would enable the establishment of a centralized repository that would efficiently capture all pertinent facts about safety-related incidents that occur within the construction context. To develop a BIM-based incident knowledge database management system, Autodesk Revit BIM platform is utilized along with its Application Programming Interface (API) to integrate the incident database created in Microsoft Access.

The integration of Revit and MS Access was chosen for a variety of reasons, each originating from the unique benefits provided by both systems. Revit is the industry's leading BIM technology, widely known and used for its strong capabilities in architectural design, modeling, and collaboration in the construction sector. In contrast, MS Access provides a user-friendly interface for database building and manipulation, including easy tools for data entry, querying, and editing. By combining these platforms, the aim is to leverage Revit's extensive features as well as MS Access' accessibility and usability. One important aspect of Revit is its ability to communicate with external databases using Application Programming Interfaces (APIs). This feature allows for smooth communication between Revit models and external databases, such as the one created in Microsoft Access. As a result, relevant data from incidents recorded in the BIM environment may be automatically connected to the associated database entries, ensuring real-time information synchronization between the two platforms. Furthermore, this interface gives users the freedom to access the database from outside of the Revit program as needed, which makes it easier for stakeholders who might not have direct access to the BIM model to retrieve and analyze data. Moreover, this conjunction improves the process of

exporting and sharing data, resulting in a simplified workflow for information transmission. This seamless interchange of information improves collaboration and transparency, encouraging informed decision-making and proactive risk management techniques throughout the building project lifecycle.

The primary goal of developing this system is to facilitate construction personnel's interaction with project models within a BIM environment, allowing them to visualize accidents and incidents documented in the developed database. This database acts as a repository for previous safety-related incidents, providing several advantages in terms of information retrieval, access, learning, cognition, communication, and lesson sharing.

Firstly, the database makes information retrieval easier by offering a consolidated platform for storing all past accident and event reports. Construction professionals may immediately obtain important data from previous occurrences, including complete investigation reports, without having to trawl through several sources or documents. Secondly, the system improves access by allowing construction people to interact with project models directly within the BIM environment. This seamless connection allows users to see the spatial context of accidents and events, which improves their knowledge of the circumstances surrounding each one. Furthermore, it improves learning and cognition by including visual representations of previous incidents in the project model. By viewing accidents and occurrences in form of 3D character animations, construction workers may better understand the sequence of events and contributing variables, allowing for deeper learning and recall of safety lessons. It also increases communication and dissemination of lessons learned allowing construction professionals to collaborate and discuss previous incidents within BIM environment. Through interactive visualization and access to investigation, team members may effectively share insights and methods for avoiding similar situations in the future.

Then accident/incident knowledge database management system supports the option for input from the user to the incident database and is capable of distinct outputs: **1)** filtered data requested by the user based on accident type, date, department, and name; **2)** 2D and 3D accident location visualization within project BIM model; **3)** visualize the recreated simulation based on the incident report and **4)** exporting/printing the incident report. By employing tailored programming code for the visualization and management of accident data, seamless communication between the user interface and database can be facilitated. The system required the development of a plug-in to integrate the project's 3D model with MS Access database. This plug-in was developed and customized using python programming language. The plug-in constitutes of the following functions: **1)** Create an incident report, **2)** view and edit the data for each one that already exists, **3)** view the accident report's spatial location, **4)** filter accidents using different criteria, **5)** print the incident report, **6)** show/hide incident points in 3D model, **7)** track monitoring and control status, and **8)** review and write lessons learned. There are categories as per OSHA requirements utilized for data entry including the following: date, time, accident ID number, project name, company name, witnesses, the crew involved, etc. The user can create an accident report by accessing the MS Access database through BIM platform, assign a severity level (type of incident), and access details of the previously reported accident, and accident data. Another, and arguably the preferred option, is for users to locate a specific location within a BIM and begin the information-input process using location-based information from each accident. This would establish a linkage between the database and the existing model. To transform gathered data into information that safety managers can use, filtering collected incident data is a crucial step. The developed database interface enables the user to filter accident data by accident identification, severity level, date, name of the employee, and additional measurable parameters specific to the project. Multiple project stakeholders can use this data filtering to isolate high-severity accident reports for immediate mitigation or to compile only accidents linked to a specific root cause. By using a filter, based on the incident

number, users can also just search for a specifically reported accident. The process map for the BIM-based accident incident knowledge database management is illustrated in **Figure 3**.

In the initial stage of the process map, known as the Data Input phase, users will initiate the incident reporting process by inputting various data points (such as name, date, incident type, incident description, department, job role, equipment details, as well as supplementary materials like photos, drawings, and videos) into the designated MS Access database. This systematic data input ensures that all pertinent information related to the incident is comprehensively captured within the database, facilitating seamless tracking and effortless retrieval of data as needed.

In the second phase, users can generate a new incident directly within the project model, specifying its precise location. This generated point will then be associated with its respective incident report, which has been previously archived within the database. A comprehensive delineation of this process is provided in the subsequent section of this chapter. Similarly, users can employ the functionalities within the BIM platform to conduct targeted searches for specific incidents based on a variety of criteria, including name, department, incident type, and Revit ID. A detailed elucidation of the sequential steps involved in this process will be expounded upon in the ensuing section. The database plugin interface is shown in **Fig. 4**. Similarly, incident location points within the project model are shown in both 2D and 3D views in **Fig. 5** and **Fig. 6** respectively.

The next phase within this map entails the output phase, providing users with the capability to access specific records within the database. Users can visualize the incident's location, as created in the prior phase, in both 2D and 3D formats within the Revit platform. Furthermore, users have the option to print specific incident reports for documentation purposes. Additionally, the FBX file for the project's 3D model can be exported, serving as input for further utilization within 3D animation software.

During the final phase, the FBX file representing the project model is imported to the 3D animation software to establish the 3D environment. Subsequently, characters, settings, equipment, and various scenarios are animated to portray a storyboard narrative detailing the sequence of events leading to the occurrence of the incident, as outlined in the incident report. The resulting 3D animation video is then imported into the database and linked to its respective incident report. Users can conveniently access and view the video directly from the database by accessing the corresponding incident record.

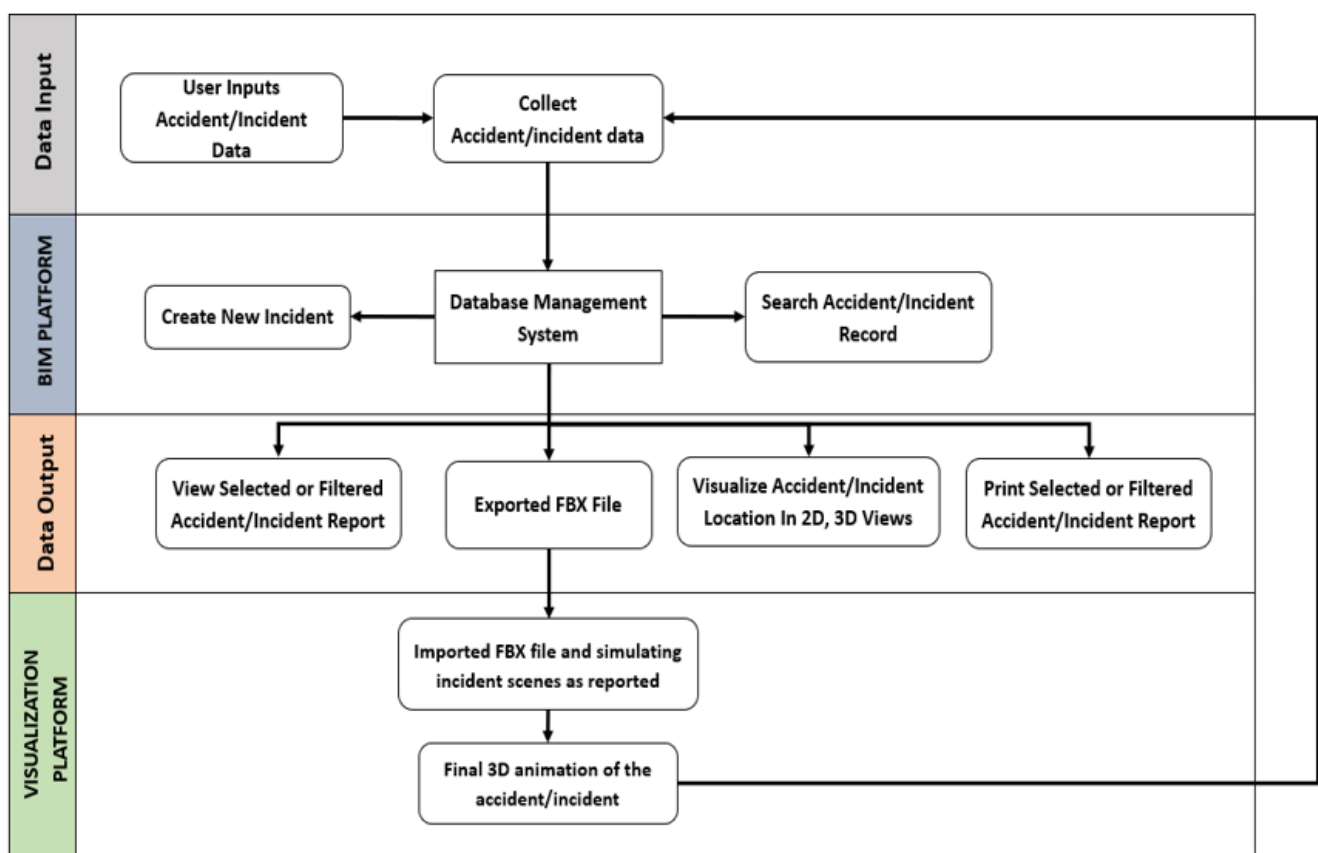


Figure 3: BIM-based accident/incident KDMS process map

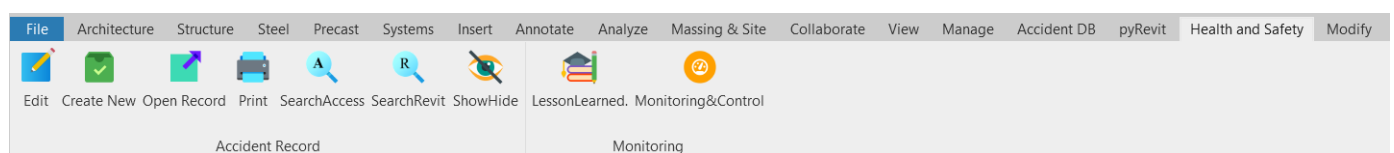


Figure 4: Incidents database plugin

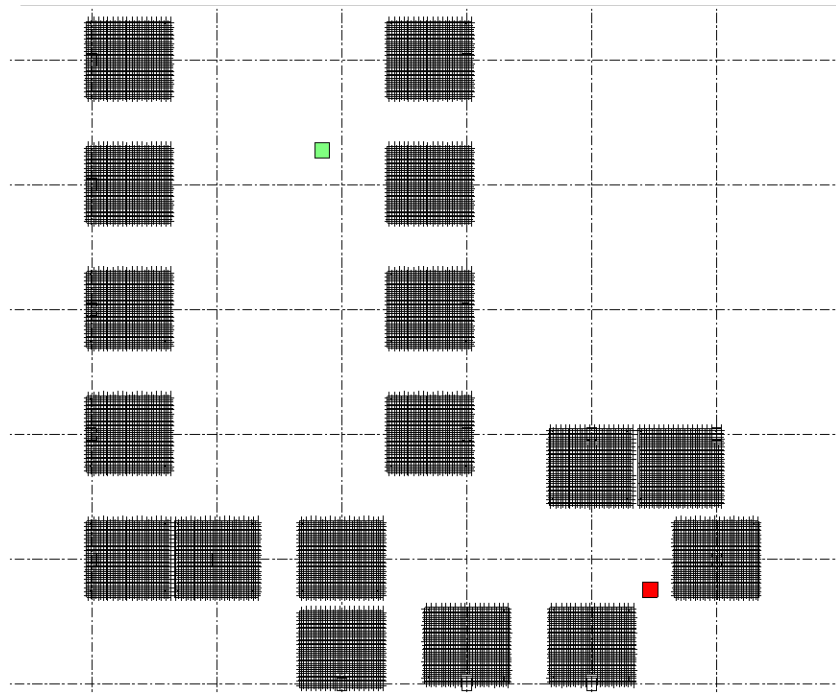


Figure 5: Incident locations visualization in 2D

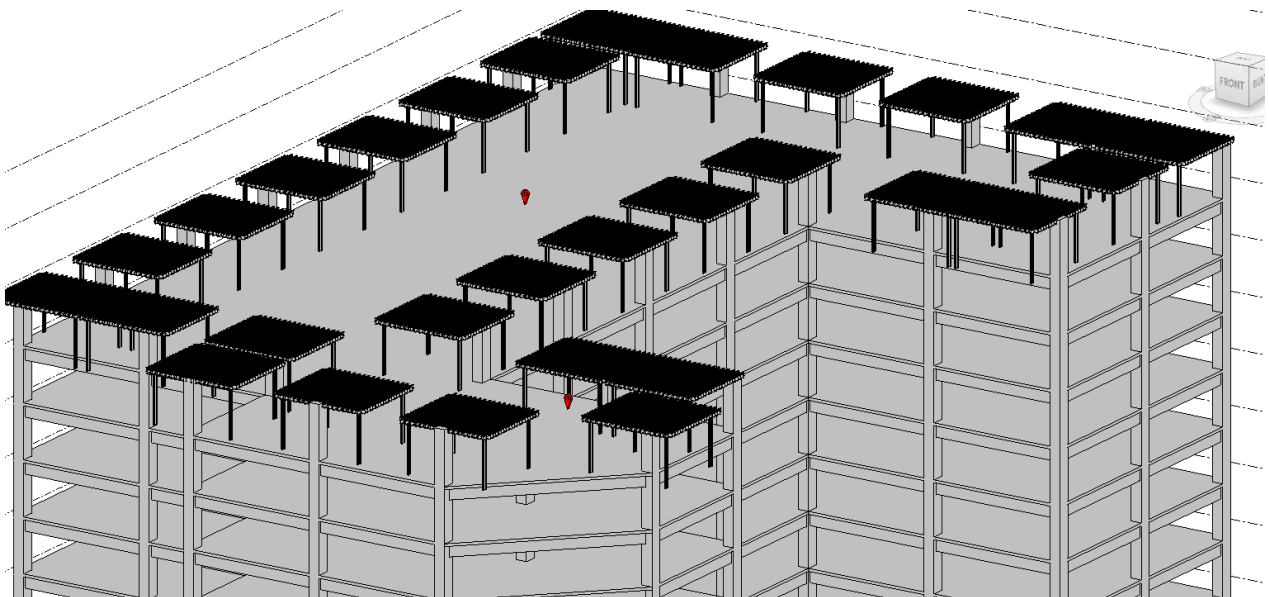


Figure 6: Incident locations visualization in 3D

3.2.4. Prototype Modules

This section contains an in-depth study of each function provided by the database management system plugin. This provides detailed instructions for creating new incidents, retrieving and modifying existing records, and doing searches inside the database and the project model.

Additionally, instructions for exporting incident reports are provided, ensuring a complete understanding of the database's features and possibilities.

3.2.4.1. Create New

The “Create New” pushbutton in the panel will pop up a small window where it asks the user to select the type of incident from the drop-down list, along with its coordinates in the 2D view on the current view or floor plan as shown in **Fig. 8**. The type of incidents are color-coded accordingly i.e., Red: Death, Green: Near Miss, Dr. Visit: Yellow, First Aid: Blue, and Lost Time: Orange. After selecting the incident type and entering the XY coordinates, the Revit element ID of this particular created point will be assigned and will be copied by the user as shown in **Fig. 9**. When the user clicks the “Okay” button, a new incident record form will be opened directly in the MS Access database as evident in **Fig. 10**. The user will paste the copied Revit ID in the Revit ID field along with other essential details of the entire incident as shown in **Fig. 11**. After filling out the necessary data in the form the user will save the record, and hence a new incident has been created in the database as well as in the Revit model.

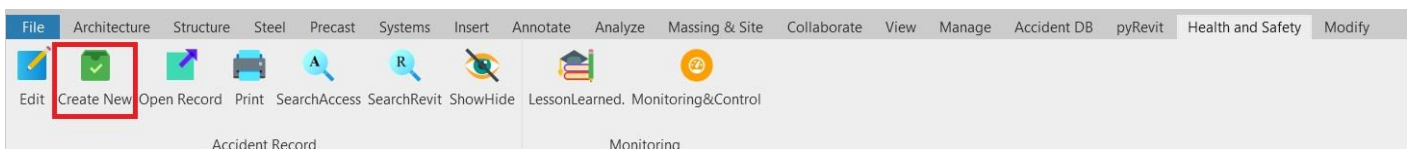


Figure 7: Create new button in health and safety ribbon

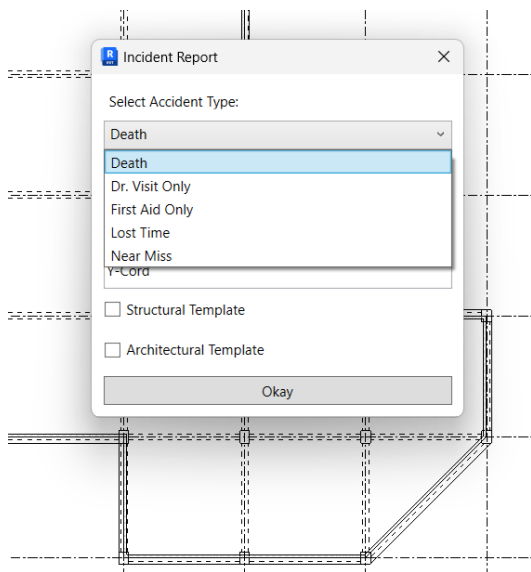


Figure 9: Incident type selection window

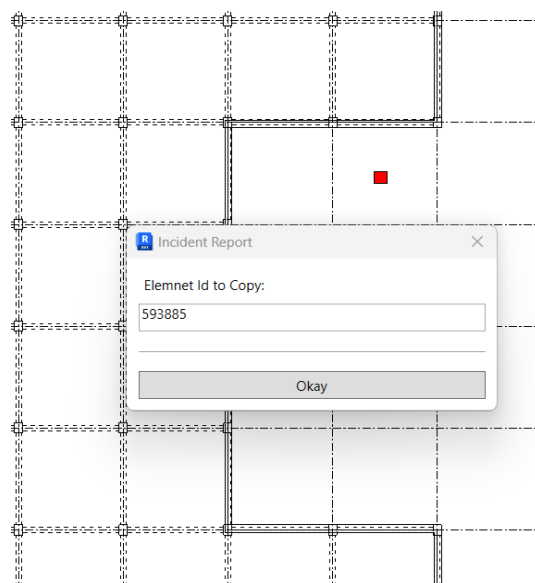


Figure 9: Revit ID

IncidentForm

Incident Report

Initials

Accident ID (New) Employee Name Age Department Date of Incident Sex: ☐ Male ☐ Female	This is a report of a: ☐ Death ☐ Lost Time ☐ Dr Visit Only ☐ First Aid Only ☐ Near Miss	This report is made by: ☐ Employee ☐ Supervisor ☐ Team Other Revit ID 0
---	--	---

Nature of Injury

Job title at time of incident

Nature of Injury: (most serious one)

☐ Abrasion, scrapes	☐ Amputation	☐ Broken bone	☐ Bruise	☐ Burn (heat)	☐ Burn (chemical)
☐ Concussion (to the head)	☐ Crushing Injury	☐ Cut, laceration, puncture	☐ Hernia		
☐ Sprain, strain	☐ Illness	☐ Damage to a body system	Other		

This employee works:

☐ Regular full time	☐ Regular part time
☐ Seasonal	☐ Temporary

Months with this employer

Months doing this job

New
Save
Print

Record: 1 of 5
Unfiltered
Search

Figure 10: New incident form

Figure 11: Entering Revit ID to map the incident point

3.2.4.2. Open Record

To open a specific incident record, firstly the user will click on the created incident point in the 2D view (**Fig. 12**), then from the Health and Safety tab “Open Record” pushbutton shall be pressed (**Fig. 13**) and the incident report of the selected incident point will be opened in MS Access and user can view the details of the incident as shown in **Fig. 14, 15, and 16**.

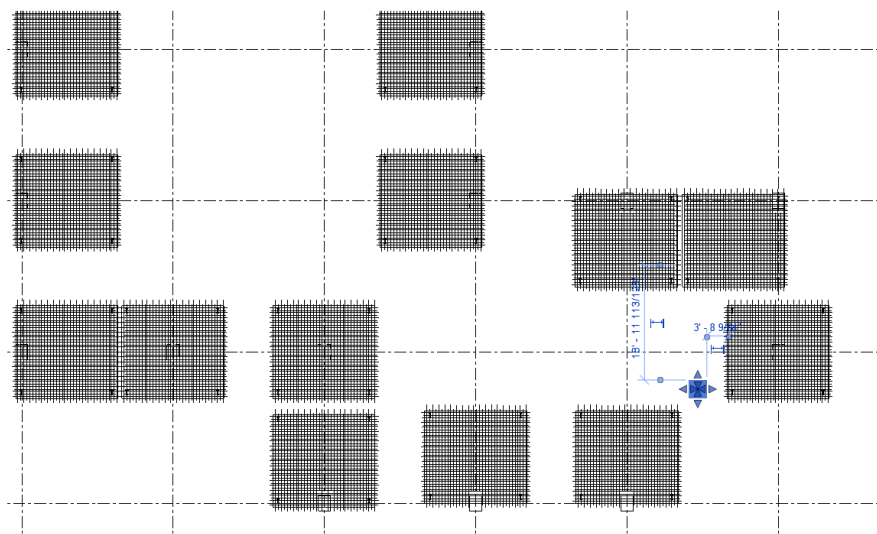


Figure 12: Selecting incident point to open the record



Figure 13: Open record button in health and safety ribbon

Incident Report

Initials

Accident ID: [] This is a report of a: ☒ Death ☐ Lost Time ☐ Dr Visit Only ☐ First Aid Only ☐ Near Miss This report is made by: ☐ Employee ☐ Supervisor ☒ Team Other: [] Sex: ☒ Male ☐ Female Revit ID: 593490

Nature of Injury

Job title at time of incident: []

Nature of Injury: (most serious one)

☐ Abrasion, scrapes ☐ Amputation ☒ Broken bone ☐ Bruise ☐ Burn (heat) ☐ Burn (chemical) ☐ Concussion (to the head) ☐ Crushing Injury ☐ Cut, laceration, puncture ☐ Hemria ☐ Sprain, strain ☐ Illness ☐ Damage to a body system Other: []

This employee works:

☒ Regular full time ☐ Regular part time ☐ Seasonal ☐ Temporary Months with this employer: [] Months doing this job: []

Record: 1 of 1 Filtered Search

Figure 15: Incident record of the selected incident point

Incident Report

Incident Description

Exact location of the incident: 3 THIRTY THREE DOWNTOWN" at 333 Fern Street, West Palm Beach, FL, 33401

Exact time: 7:00 am

What part of employee's workday?

☐ Entering or leaving work ☒ Doing normal work activities ☐ During meal period ☐ During break ☐ Working overtime Other: []

Name of witnesses: []

What personal protective equipment was being used? Miller Falcon MP20G-27/20FT cable lifeline

Describe, step by step the events that led up to the injury: On the day of the incident, the table-setting crews arrived at the site around 6:30 a.m. They held a planning meeting for about half an hour, and

Attachments

Written witness statements: [] Video: [] Photographs: [] Maps / Drawings: []

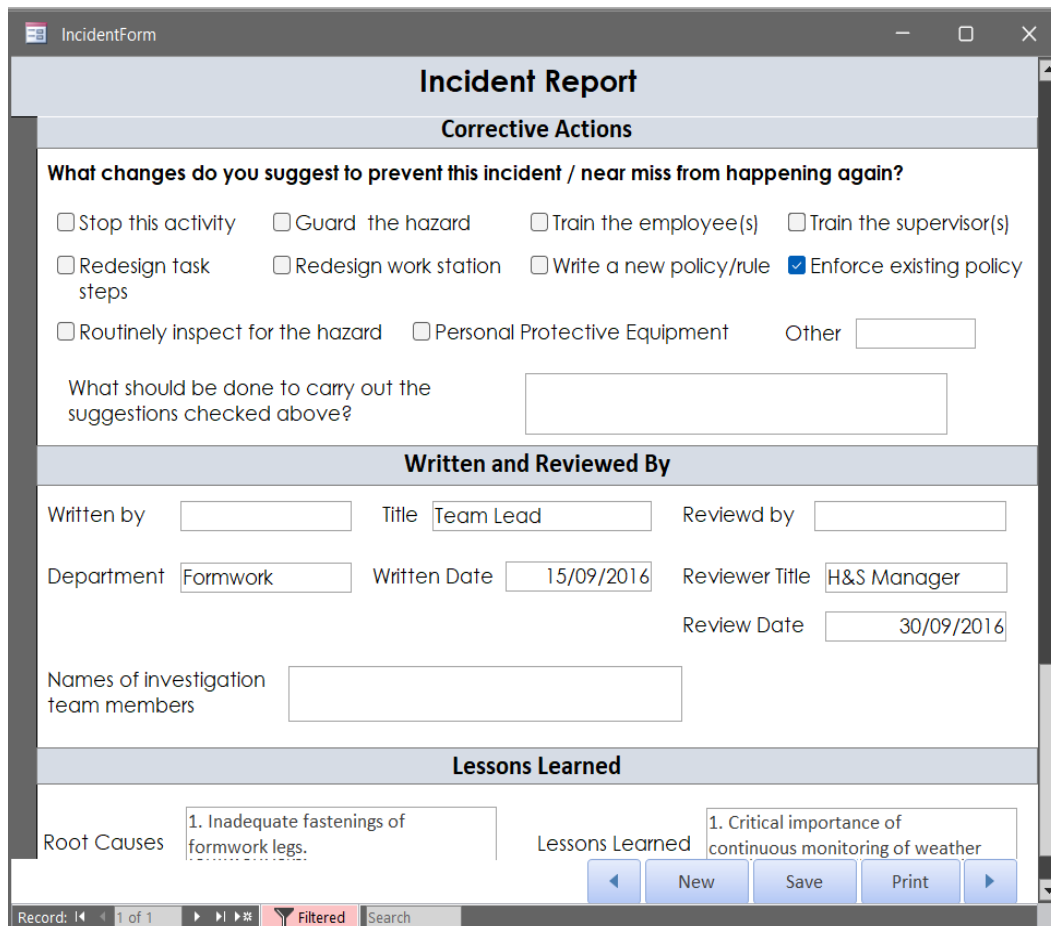
Incident Causes

Unsafe Workplace Conditions (Check all that apply)

☐ Inadequate guard ☐ Unguarded hazard ☐ Safety device is defective

Record: 1 of 1 Filtered Search

Figure 15: Incident record of the selected incident point



Incident Report

Corrective Actions

What changes do you suggest to prevent this incident / near miss from happening again?

☐ Stop this activity
 ☐ Guard the hazard
 ☐ Train the employee(s)
 ☐ Train the supervisor(s)

☐ Redesign task
 ☐ Redesign work station
 ☐ Write a new policy/rule
☒ Enforce existing policy steps

☐ Routinely inspect for the hazard
☐ Personal Protective Equipment
 Other

What should be done to carry out the suggestions checked above?

Written and Reviewed By

Written by
 Title
 Reviewed by

Department
 Written Date
 Reviewer Title

Review Date

Names of investigation team members

Lessons Learned

Root Causes
 Lessons Learned

Record: 1 of 1 Filtered Search

Figure 16: Incident record of the selected incident point

3.2.4.3. Edit

To edit any incident record, the “Edit” pushbutton shall be used to open a list of records in the database where the user can query/search for any incident based on name, date, type of incident, department, etc (**Fig. 17**). The user can either simply click on the edit button on the bottom left or double click the record in incidents record list (**Fig. 18**) and the incident form of that record would be opened and can be edited accordingly as shown in **Fig. 19**.

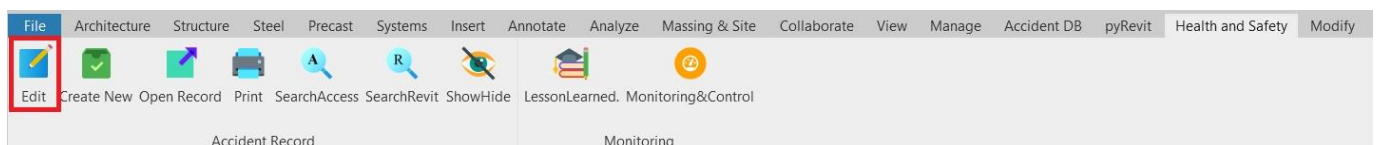


Figure 17: Edit pushbutton in the health and safety ribbon

Accident ID	Revit ID	Employee Name	Department	Date of Incident
1	593490	Worker1	Formwork	01/09/2016
2	593552	Worker2	Formwork	01/09/2016
*(New)	0			

Figure 18: Incident records list for editing

Incident Report

Initials

Accident ID: 1
 Employee Name: Worker1
 Age:
 Department: Formwork
 Date of Incident: 01/09/2016
 Sex: ☒ Male ☐ Female
 This is a report of a: ☒ Death ☐ Lost Time ☐ Dr Visit Only ☐ First Aid Only ☐ Near Miss
 This report is made by: ☐ Employee ☐ Supervisor ☒ Team Other
 Revit ID: 593490

Nature of Injury

Job title at time of incident:
 Nature of Injury: (most serious one)
☐ Abrasion, scrapes ☐ Amputation ☒ Broken bone ☐ Bruise ☐ Burn (heat) ☐ Burn (chemical)
☐ Concussion (to the head) ☐ Crushing Injury ☐ Cut, laceration, puncture ☐ Hernia
☐ Sprain, strain ☐ Illness ☐ Damage to a body system Other
 This employee works:
☒ Regular full time ☐ Regular part time ☐ Seasonal ☐ Temporary
 Months with this employer: 0
 Months doing this job: 0
 Buttons: New, Save, Print

Figure 19: Incident record to be edited

3.2.4.4. Print

To print out the incident record, simply “Print” pushbutton shall be pressed to open a list of records in the database, and based on the query by the user any specific incident can be printed by either clicking the print button below on the bottom left of the incidents records list (**Fig. 21**) or by opening the incident form and clicking on the print option on bottom right of the form, and user can print preview the report as well before printing it out **Fig. 22**.

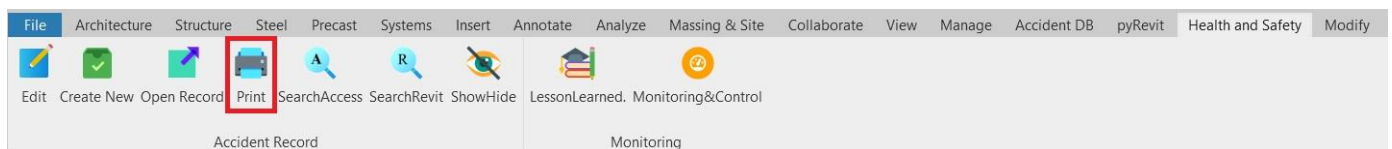


Figure 20: Print pushbutton in health and safety ribbon

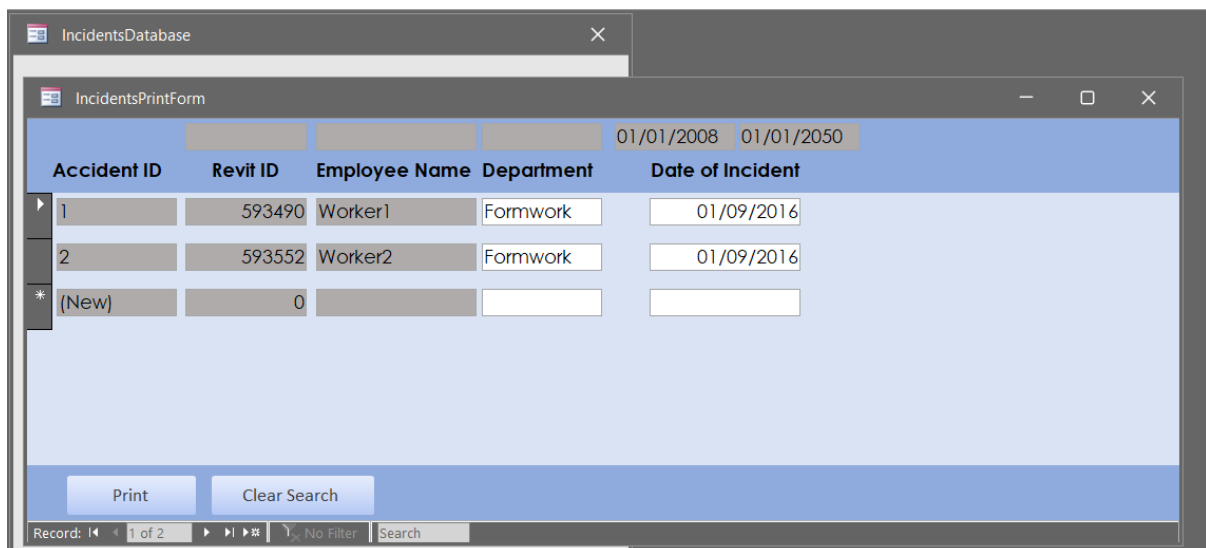


Figure 21: Incidents record list for printing

Incident Report

Initials

Accident ID: This is a report of a ☒ Death ☐ Last Time ☐ Supervisor ☐ Team ☐ Other

Employee Name: Age: Date of Incident: Sex: ☒ Male ☐ Female

Nature of Injury

Job title at time of incident:

Nature of Injury: (most serious one)

☐ Abrasion, scrape ☐ Amputation ☒ Broken bone ☐ Bruis ☐ Burn (heat) ☐ Burn (chemical)

☐ Concussion (to the head) ☐ Crushing injury ☐ Cut, laceration, punctur ☐ Hernia

☐ Sprain, strain ☐ Illness ☐ Damage to a body system ☐ Other

This employee works:

☒ Regular full time ☐ Regular part time ☐ Seasonal ☐ Temporary

Months with this employer: Months doing this job:

Incident Description

Exact location of the incident: Exact time:

What part of employee's workday

☐ Entering or leaving work ☒ During normal work activities ☐ During meal period ☐ During break ☐ Working overtime ☐ Other

Name of witnesses:

What personal protective equipment was being:

Describe, step by step the events that led up to the injury:

On the day of the incident, the table-setting crew arrived at the site:

Attachments

Written witness statements: ☐ Video ☐ Photographs ☐ Maps / ☐

Unsafe Workplace Conditions (Check all that apply)

☐ Inadequate guard ☐ Unguarded hazard ☐ Safety device is defective

☒ Tool or equipment defective ☐ Workstation layout is hazardous ☐ Unsafe lighting

☐ Unsafe ventilation ☐ Lack of needed personal protective equipment ☐ Unsafe clothing

☐ No training or insufficient training ☒ Lack of appropriate equipment / tools ☐ Other

Unsafe acts by people (Check all that apply)

☐ Operating without permission ☐ Operating at unsafe speed ☐ Unsafe lifting

☐ Servicing equipment that has power to it ☐ Making a safety device inoperative ☐ Using defective equipment

☒ Using equipment in an unapproved way ☐ Taking an unsafe position or posture ☐ Distraction, teasing, horseplay

☐ Failure to wear personal protective equipment ☒ Failure to use the available equipment / tools ☐ Other

Why did unsafe conditions exist? Why did unsafe acts occur?

Were the unsafe acts or conditions reported prior to the event? ☐ Yes ☒ No

Have there have been incidents or near misses prior to this one? ☐ Yes ☒ No

Is there a reward that may have encouraged the unsafe conditions? ☐ Yes ☒ No

Corrective Actions

What changes do you suggest to prevent this incident / near miss from happening again?

☐ Stop this activity ☐ Guard the hazard ☐ Train the employees ☐ Train the supervisor(s)

☐ Redesign task ☐ Redesign work station ☐ Write a new policy/rule ☒ Enforce existing policy steps

☐ Routinely inspect for the hazard ☐ Personal Protective Equipment ☐ Other

What should be done to carry out the suggestions checked above?

Written and Reviewed By

Written by: Title: Reviewed by:

Department: Written Date: Reviewer Title:

Review Date:

Names of investigation team:

Lessons Learned

Figure 22: Print preview of the incident report

3.2.4.5. Search Access and Search Revit

To search for any record in the database, the “Search Access” pushbutton in Health and Safety ribbon will be pressed which would open the list of records as shown in **Fig. 24**, where the user can search any record based on the fields in the search form. Once the record has been found in the database, if the user desires to search the location point of this incident in the 3D model, the first step is to copy the Revit ID from the record in the database (**Fig. 25**), secondly, user will select the “Search Revit” pushbutton in Revit (**Fig. 26**) to open a pop-up window as shown in **Fig. 27**, where the Revit ID copied from the database would be pasted, so that the incident point would be highlighted by a squarish area around the point of the location as shown in **Fig. 27**.



Figure 23: Search access pushbutton

IncidentsDatabase

IncidentsSearchForm

01/01/2008 01/01/2050

Accident ID	Revit ID	Employee Name	Department	Date of Incident	Death	Lost Time	Dr Visit Only	First Aid Only	Near Miss
1	593490	Worker1	Formwork	01/09/2016	☒	☐	☐	☐	☐
2	593552	Worker2	Formwork	01/09/2016	☐	☐	☐	☐	☒
3	593623	worker3	Finishing	02/09/2018	☐	☐	☐	☒	☐
4	593705	worker	Excavation	05/05/2020	☐	☒	☐	☐	☐
5	593885	worker5	Site works	08/12/2021	☐	☐	☐	☒	☐
(New)	0				☐	☐	☐	☐	☐

Open Clear Search

Record: 1 of 5 No Filter Search

Figure 24: Incident records list for searching

IncidentsDatabase

IncidentsSearchForm

worker1 01/01/2008 01/01/2050

Accident ID	Revit ID	Employee Name	Department	Date of Incident	Death	Lost Time	Dr Visit Only	First Aid Only	Near Miss
1	593490	Worker1	Formwork	01/09/2016	☒	☐	☐	☐	☐
(New)	0				☐	☐	☐	☐	☐

Open Clear Search

Record: 1 of 1 No Filter Search

Figure 25: Searched record

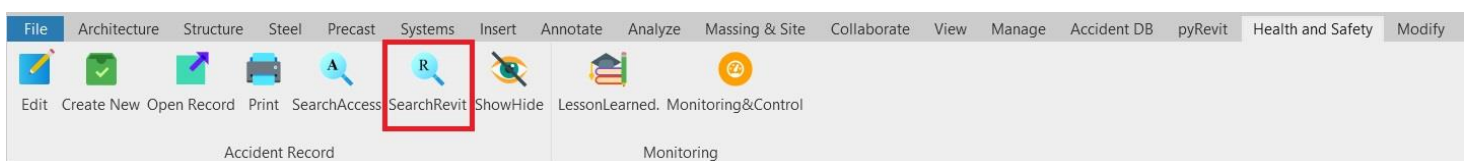


Figure 26 : Search Revit pushbutton in health and safety ribbon

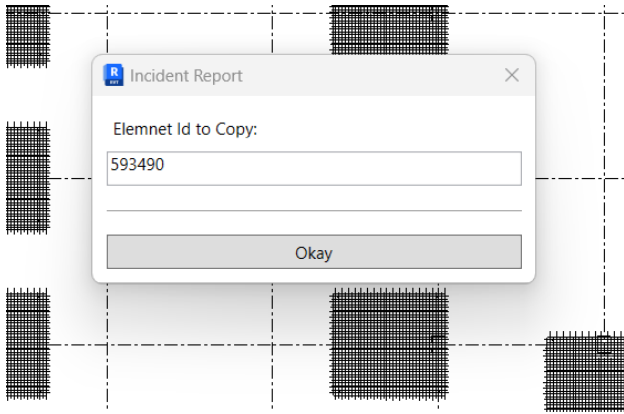


Figure 28: Revit ID copied from the database

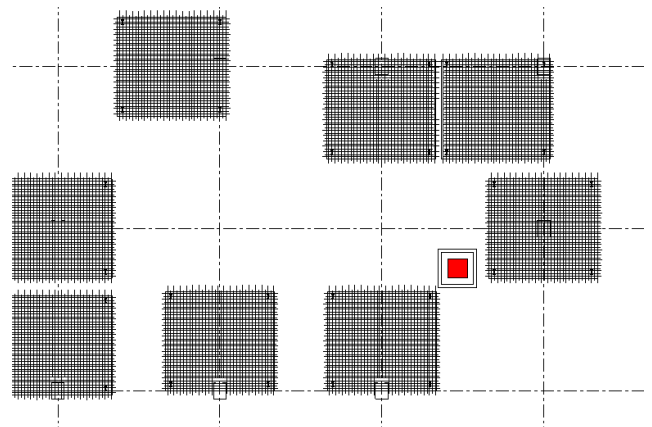


Figure 27: Incident point highlighted in Revit

3.2.4.6. Monitoring and Control

To monitor and control the highlighted incidents, the “Monitoring and Control” pushbutton will be selected to view the list of incidents along with multiple fields where the senior personnel can assign responsibility to a particular individual, view the status of completion, and can also brief the planned actions to mitigate the incident from reoccurrence **Fig 30**.



Figure 29: Monitoring and control pushbutton in health and safety ribbon

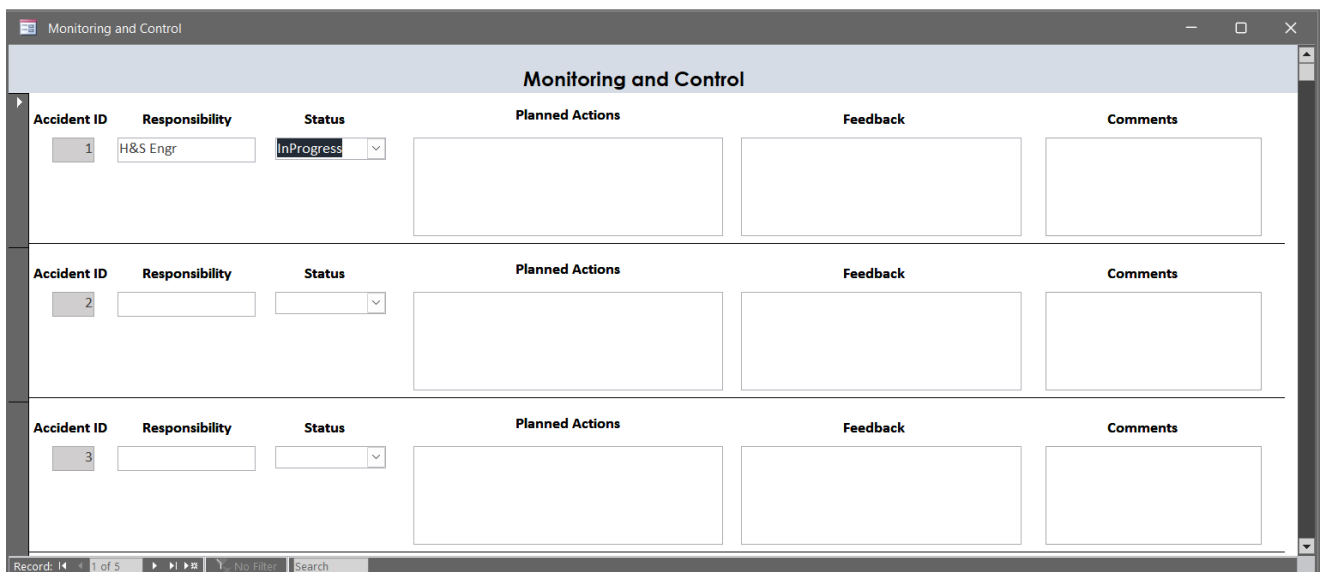


Figure 30: Monitoring and control interface

3.2.4.7. Lessons Learned

To view the root causes and lessons learned for each incident “Lessons Learned” pushbutton is selected to open the lessons learned form in the MS Access database. The list of incidents will be displayed along with their corresponding root causes and lessons learned highlighted from the report (**Fig. 32**). Also, there is an “Overall lessons learned” field for the manager to summarize all the key lessons learned from all the incidents throughout the entire project which can be disseminated within the organization.

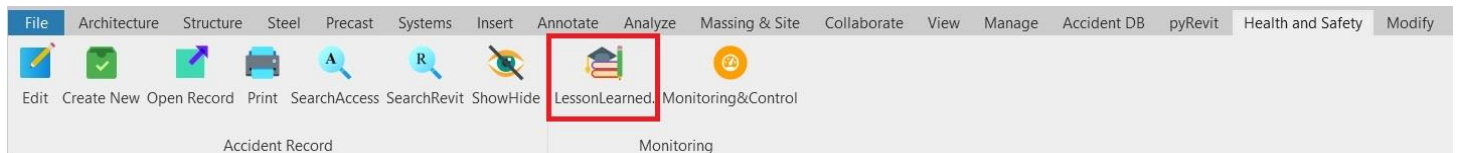


Figure 31: Lessons learned pushbutton in health and safety ribbon

A screenshot of the 'Lessons Learned' form interface. The form has a title bar 'Lessons Learned' and a table with four columns: 'Accident ID', 'Root Causes', 'Lessons Learned', and 'Comments'. The first row contains data for Accident ID 1, listing root causes like 'Inadequate fastenings of formwork legs' and lessons learned like 'Critical importance of continuous monitoring of weather conditions'. The second row is empty. Below the table is a section titled 'Overall Lessons Learned' with a large text area for input. At the bottom, there is a status bar showing 'Record: 1 of 5' and a search field.

Figure 32: Lessons learned interface

Objective 3: To validate the feasibility of the proposed system for knowledge management of construction accidents/incidents data.

In this stage, the developed prototype was assessed to determine how well it met the goals for which it was created and to find to what extent is the system capable of mitigating the identified barriers to effective accident/incident knowledge management barriers. Though objective measures (quantitative or observable criteria based on facts, or data) have been used in a few studies to evaluate such newly designed systems (Li et al., 2017), subjective measurements (qualitative or assessments based on opinions, perceptions and experiences) have also been used effectively (Shen et al., 2015).

3.3.1. Questionnaire Survey

A questionnaire was developed to assess the efficacy, need, usability, benefits, and implementation of the produced system. The questionnaire consisted of three sections. The first section was a brief introduction to the topic of the research along with its significance in the construction industry. Section two collected the background information of the respondents (email, company type, company size, designation, and work experience in the respective industry). The final section of the questionnaire consisted of the final list of barriers to effective accident/incident knowledge management. A 5-point Likert scale was used to gauge the respondents' opinions, with 1 denoting "strongly disagree" and 5 denoting "strongly agree." All safety experts received a comprehensive list of problematic issues (13) in knowledge management (mentioned in **Section 3.2.2**) of construction occurrences to assess the system's advantages. This exercise was carried out to have a better understanding of how the built system is resolving the problems found throughout the knowledge management of construction accidents/incidents.

10 health and safety specialists with in-depth expertise of the topic were carefully chosen for the review panel of experts. Despite the sample size being small, it included each major category of stakeholder involved in construction health and safety (Ali et al., 2020, Shen et al., 2015). The profile of these experts are shown in **Table 9**. The experts were evaluated individually in one-on-one meetings. Each participant was given a research backdrop, a BIM platform, and an explanation and demonstration of the tool. Instructions, presentations, and animations of all the tool's features were included in the demonstration. The key justification for choosing a more subjective method for evaluating BIM-CA/IKDMS was the necessity to comprehend the viewpoints and views of experts in the field to have a comprehensive understanding.

Table 9: Profile of interviewees

Profiles	Category	Frequency
Organization	Contractor	5
	Consultant	5
Years of Experience	5-10 years	5
	11-15 years	3
	15 & above years	2
Job Role	Health and Safety Supervisor	3
	HSE Group Leader	2
	HSE Specialist	1
	Health and Safety Manager	2
	HSE Engineer	2

Another factor was that most safety experts with ten years or more of experience lacked appropriate knowledge of BIM technology. Thus, a background presentation on BIM was provided to them before the created system's operation was explained. Afterwards, their responses were recorded. After the demonstration, semi-structured interviews were conducted and a questionnaire was completed. The questionnaire is shown in **Appendix B**.

The relative important index (RII) approach was also used to rank the created system's 'problems resolution capabilities'. The equation to calculate the RII is given in Eq.

$$RII = \frac{\sum W}{A \times N} \quad (0 \leq RII \leq 1)$$

After the collection of accident data and visualizing its location within the BIM project, the next step is to simulate the scene and event of the accident based on the evidence collected. It was found that obtaining actual accident/incident reports would be difficult given the sensitive nature of the subject for any organization. As a result, publicly accessible data was used to gather the case studies for this research. For this purpose, three published incident reports were selected as case studies, one from OSHA's construction incidents investigation reports database (OSHA), and other two from Government of Alberta's worksite fatality investigation reports (Alberta OHS), Canada, to recreate the chain of events based on tabular description in the selected documents. Since we intended to exploit the visualization capabilities of BIM and other accessible technologies, character animations were generated for the selected case studies.

Character animation is a widely used technique in animation, gaming, cinema, and education to successfully portray tales and emotions by giving computer figures movement and expression to mimic human behaviors and movements (Molly Howe, 2022). There are several animation platforms in the animation industry, each with its own set of features designed to meet the demands of different users. Some of the renowned animation platforms include

Autodesk Mays, 3ds Max, Cienma 4D, Adobe Animate and Blender. The animation software utilized for these case studies was Blender. Blender is a strong and adaptable open-source 3D animation software with a plethora of capabilities such as: 3D Modelling, sculpting, rigging and animation, physics simulation, rendering, texturing and materials, compositing, video editing, and motion tracking (Zou et al., 2023). It features a robust import/export tool that supports GLB, FBX, STL, and other formats, making it an ideal platform for character animation integration with BIM projects (Zou et al., 2023). These characteristics make this software a strong and versatile option for 3D artists, animators, and developers working on a range of projects, from animations and visual effects to architectural visualization. With the aid of the visualization tool, one can create photorealistic representations of buildings, virtual occupants, and the surrounding landscape.

The developed project BIM model is exported as an FBX or OBJ file from Autodesk Revit and then imported to Blender software. Based on the descriptive data from the reports, the above mentioned features were utilized by recreating the chain of events that led to each accident and using virtual locations and characters to dynamically and illustratively portray the scenario. This would allow safety managers to evaluate and analyze the circumstances surrounding each event, resulting in a greater knowledge of the contributing elements and underlying causes. Furthermore, the output video animation from the software will be uploaded to the incident record within the database. The framework to recreate the accident/incident scene is shown in **Figure 33**.

3.3.2. Framework for creating character animations from incident reports

Collecting relevant input data is crucial for developing animations that portray a full incident scenario. This critical data includes all of the components needed to correctly recreate the sequence of events. First and foremost, witness testimonies provide firsthand descriptions of the occurrence, providing insightful viewpoints on the conditions and acts preceding it. Site

photos also function as visual documentation by encapsulating important elements from the accident scene and placing the events in perspective. For the animation recreation to be accurate, accident investigation data is essential. This includes relevant parameters such the date, time, people's employment duties, equipment involved, safety gear used, and site environment features.

The next step of the framework is to generate incident animation based on the input data obtained in the previous phase. Firstly, a Revit Model is created, precisely including the real details of the event scene. This process assures the integrity and precision of the virtual world in which the animation will be displayed. Then a storyboard is created to illustrate the sequence of events pre- and post-incident, outlining the actions, activities, and site scenarios that took place. The storyboard serves as a visual guide for the animation, marking key points and contextualizing the occurrence within its larger context. Finally, incident attributes are determined, which include events that occurred both before and after the incident, the spatial location and extent of the incident site, ideal view angles, and camera placements for best animation depiction. In addition, all applicable regulations and procedures that may have been broken are considered, ensuring that the animation appropriately portrays the regulatory context in which the incident took place. All of the incident's properties are rigorously designed, rigged, and animated inside the selected animation platform.

Following the recreation of incident animation, a critical validation process takes place to confirm the realism and correctness of the represented scenario. During this step, witnesses and other critical people who were there at the time of the incident are asked to compare the animation to their memories of the real event. This validation procedure is crucial in determining the animation's authenticity since it provides for direct feedback from persons who witnessed the occurrence firsthand. If inconsistencies or flaws are discovered between the animation and the actual occurrence, further input data may be requested to improve the

relevance and accuracy of the video animation. This iterative process to validation guarantees that the animation accurately depicts the occurrence, harmonizing with the collective memories and experiences of individuals directly engaged. By including comments from witnesses and important staff, the validation process improves the credibility and dependability of the video animation as a depiction of the real occurrence that occurred.

Once, the incident animation is validated and proven to appropriately portray the context of the real incident, then it can be integrated with its corresponding record in the database. This integration procedure involves linking the completed animation with the extensive incident record kept in the database. This would allow the users to easily access and retrieve incident-related visual and contextual information. This integration improves the database's usability and usefulness as a complete repository of incident-related information, allowing for more efficient analysis, comprehension, and communication of incidents. The framework to recreate the accident/incident scene is shown in **Figure 33**.

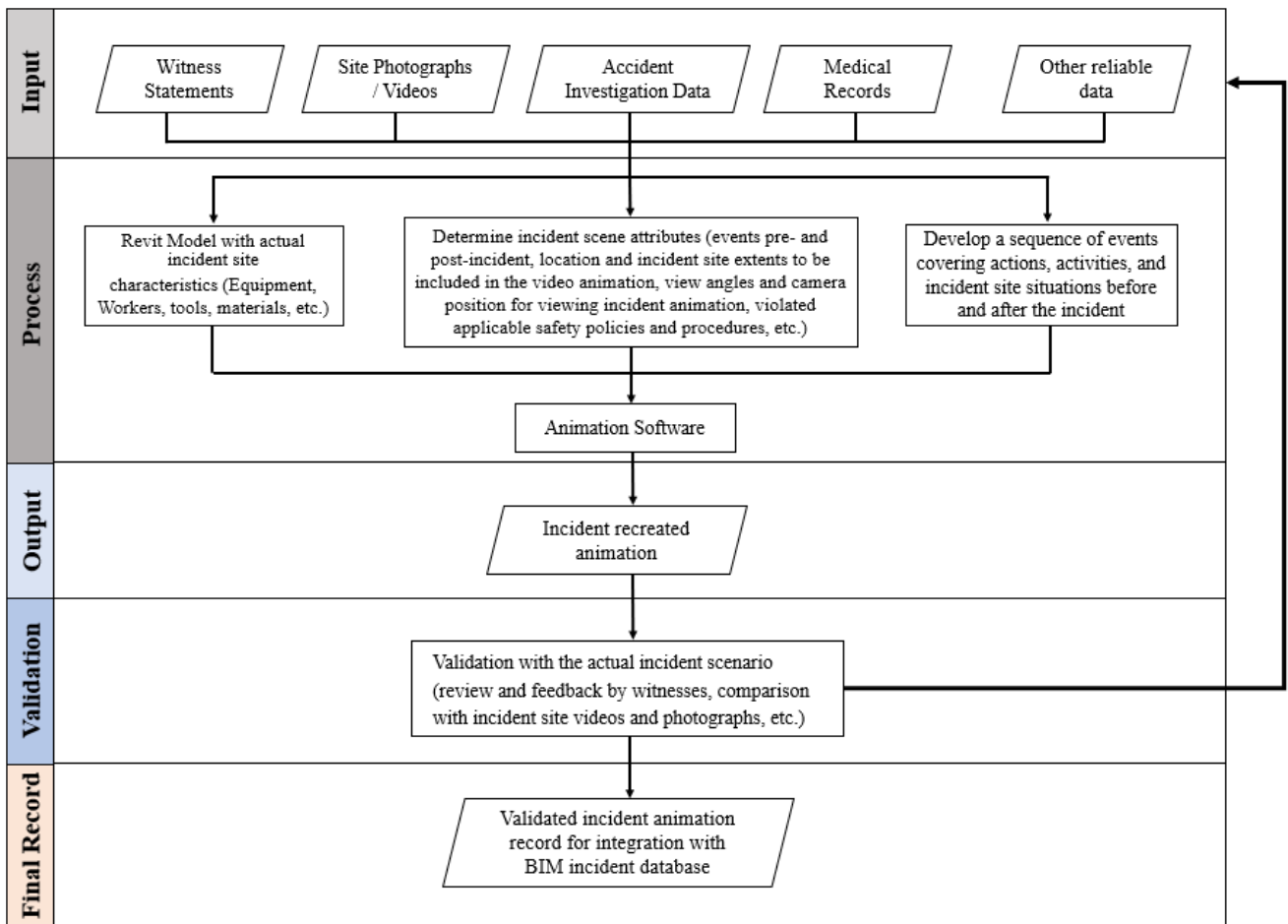


Figure 33: Process map of incident recreation

3.4. Assessment of learning potential using cognitive load measurement

Objective 4: To assess the potential of the proposed system for learning from past incidents based on cognitive load measurements.

Measuring cognitive load is one of the most significant components of evaluating the effectiveness of a system to improve learning, problem-solving, and decision-making. The hypothesis given in this study emphasizes the need to decrease cognitive load to promote a better comprehension of earlier accidents/incidents, encouraging efficient transmission of lessons learned throughout the organization. According to cognitive psychology research, cognitive load has a significant impact on people's capacity to absorb and comprehend information (Sweller, 1994). The cognitive load hypothesis suggests that learning and problem-

solving abilities may be compromised when cognitive resources are overworked due to unnecessary processing demands (Sweller, 2010). Therefore, assessing cognitive load is critical for verifying the notion that the developed system may greatly lower the cognitive load of comprehending the incident.

3.4.1. Paper-based VS Visual-based experiment

To meet the research goal of this study, we randomly assigned individuals to one of two incident assessment groups: one reading the descriptive chain of events mentioned in the selected reports used for case studies, and another visualizing the sequence of events in the animations created from those same reports. This experiment was conducted to measure and differentiate the cognitive load of the participants performing the aforementioned tasks. For the experiment, a sample of 12 Masters students from the King Fahad University of Petroleum and Minerals' Department of Architectural Engineering and Construction Management (AECM) were chosen. All of the participants were familiar with construction health and safety because they had previously completed numerous construction management and had some professional experience in this sector. They were randomly divided into two groups, each of which would observe the incident using different methods as discussed and develop their understanding of the entire incident (i.e., paper-based, visual animations). Prior to the experimental sessions, we gave each participant explicit instructions about how to conduct the experiment by using well-organized materials by first introducing the research topic and its purpose that this experiment aims to assess the difference between the cognitive load that a person feels while understanding the incident reports in two distinct formats: paper-based reports and character animation videos. The confidentiality of the participants' information and responses was ensured. Both of the groups were asked to note their start and finish times on the questionnaire to track how long they spent comprehending the incident. For the paper-based group, hard copies of the incident reports and questionnaires were provided, they were instructed to thoroughly read the reports

to ensure they don't miss any important details, and were told to answer the questions based on their understanding. For the animation group, questionnaires were distributed along with the access of the animation videos portraying the incidents reports, they were encouraged to watch the videos thoroughly to understand the chain of events leading to the incident and were asked to answer the questions based on their interpretation of these video animations.

3.4.2. NASA TLX questionnaire

To measure cognitive load, we employed the NASA-TLX approach , which has been frequently used in the past (Hou & Wang, 2013). The NASA Task Load Index (NASA-TLX) is a globally acknowledged and frequently employed instrument that evaluates the subjective workload that individuals encounter while doing diverse tasks or activities. It offers a multifaceted evaluation of workload by taking into account six factors: mental, physical, and temporal demands, performance, effort and level of frustration (Hart, 2006). NASA-TLX is a user-friendly, cost-effective, dependable, and responsive to minor workload changes (Dadi et al., 2014, et al., 2016). It offers insightful information about people's subjective experiences, illuminating variables that impact how much work people perceive to be done and providing guidance for the development of interventions or systems meant to maximize output while lowering stress. Out of the six dimensions, physical demand, which is the amount of physical activity necessary during a task, was deemed unimportant to our research and was therefore left out of the NASA-TLX version that was employed. The, participants in each experiment were assessed on a scale from 1=Low to 5=High based on mental demand, performance, temporal demand, effort, and frustration level as shown in **Table 10**. While for task performance assessment, we employed objective measures, considering both the actual time participants took to complete their assigned incident tasks and the accuracy with which they comprehended and summarized the chain of events in alignment with the reported or displayed information. Both of the groups were provided with incident related materials as mentioned above and were asked these two

questions: “In your words, please explain how the incident occurred”, this was to gain the insights of the participant’s level of understanding of the whole incident. Second question posed to them was: “Based on your knowledge of the incident, in your opinion, what can be done to avoid similar incidents in the future?”, it was supposed to shed light on their understanding of the sequence of events and their ability to identify probable contributing elements or fundamental causes of the incident. Understanding the events leading up to the incident allows participants to better grasp the context and conditions around it, which is critical for proposing effective preventive actions. Second, by analyzing how participants perceive the sequence of events, researchers can acquire useful insights on their cognitive processes and thought patterns. This understanding can assist in identifying any misunderstandings, gaps in information, or biases that may impact participants' perceptions and recommendations for preventative actions.

The responses to the questions were evaluated based on their correctness and relevance to the incident reports or exhibited information. Participants' replies were graded using a 10-point scoring system. Each answer was carefully reviewed to ensure that it was consistent with the factual information and contextual subtleties contained in the incident reports. Scores were assigned based on the correctness, clarity, and depth of participants' answers, with higher scores indicating a more thorough comprehension of the occurrences and their implications for future safety measures. The questionnaire is shown in **Appendix C**.

Table 10: The five NASA-TLX questions used for measuring cognitive load

Dimension	Question
Mental Demand	How mentally demanding was the task?
Temporal Demand	How temporally demanding was the task?
Performance	How successful were you in accomplishing what you were asked to do?
Effort	How hard did you have to work to achieve your level of performance?
Frustration	How insecure, discouraged, irritated, or stressed were you during the task?

CHAPTER 4

RESULTS AND DISCUSSION

This chapter consists of the results of the methodologies described in the previous section for each of the objectives.

4.1. Barriers to LFI in Saudi Construction Industry

Objective 1: To identify and analyze barriers that hinder the process of learning from past incidents in the construction industry (Saudi construction industry).

4.1.1. Questionnaire survey results

An overview of the ranking analysis findings about the barriers to LFI is shown in **Table 11**. The criticality of the barriers' mean ratings ranges from 3.19 to 3.95. According to **Table 11**, 14 of the 22 barriers have normalized values larger than 0.50 and are consequently categorized as critical barriers (Albert Ping Chuen Chan et al., 2018). "Poor quality of actions", which belongs to the "Planning intervention" phase, came in first with the highest mean score, showing that the biggest obstacle to learning from prior accidents is a lack of planning for systematic remedial actions. This finding is consistent with the findings of numerous earlier research conducted in the context of incident learning in other industries (Drupsteen-Sint, 2014; Drupsteen & Hasle, 2014). The respondents identified "lack of commitment by management" as the second most critical issue, followed by "limited dissemination of findings" in third place. The fourth barrier indicated was a "lack of understanding of how and what to report", with "limited quality of reports" as the fifth most important barrier. The Kendall's W value of 0.057 and significance level < 0.001 for ranking the 22 barriers indicates that, there is a significant degree of agreement among all the respondents on the ranking of these obstacles to LFI in the

construction sector. According to the ANOVA results, 20 barriers had significance values larger than 0.05, as shown in **Table 11**. This suggests that there were no statistically significant differences in the importance of these barriers as seen by contractors, and consultants.

Table 11: Ranking of barriers to LFI in the Saudi construction industry

Code	All Respondents				Contractor			Consultant			ANOVA
	Mean	SD	Rank	Normalization	Mean	SD	Rank	Mean	SD	Rank	
BPI04	3.95	1.022	1	1.00	3.63	1.135	3	4.37	0.684	1	0.016
BI04	3.88	1.138	2	0.91	3.79	1.318	1	4.00	0.882	7	0.558
BIA01	3.79	1.081	3	0.79	3.54	1.285	6	4.11	0.658	2	0.090
BAI04	3.79	1.264	4	0.79	3.54	1.414	7	4.11	0.994	3	0.149
BAI01	3.74	1.026	5	0.72	3.67	1.09	2	3.84	0.958	13	0.584
BAI02	3.74	1.197	6	0.72	3.46	1.285	10	4.11	0.994	4	0.078
BIA06	3.72	1.120	7	0.70	3.58	1.283	4	3.89	0.875	9	0.371
BI02	3.70	1.124	8	0.67	3.54	1.103	5	3.89	1.15	11	0.312
BIA03	3.70	1.225	9	0.67	3.38	1.313	13	4.11	0.994	5	0.051
BPI02	3.67	1.040	10	0.63	3.42	1.06	12	3.89	0.937	10	0.221
BPI05	3.67	1.393	11	0.63	3.33	1.579	14	4.11	0.994	6	0.070
BI03	3.63	1.291	12	0.58	3.46	1.25	9	3.84	1.344	14	0.339
BI05	3.60	1.218	13	0.54	3.50	1.285	8	3.74	1.147	17	0.533
BE02	3.58	1.258	14	0.51	3.29	1.301	17	3.95	1.129	8	0.090
BIA05	3.56	1.119	15	0.49	3.46	1.285	11	3.68	0.885	18	0.518
BPI03	3.53	1.008	16	0.45	3.29	1.042	16	3.84	0.898	12	0.075
BI01	3.49	1.121	17	0.39	3.25	1.113	18	3.79	1.084	15	0.118
BE01	3.42	1.314	18	0.30	3.21	1.318	19	3.68	1.293	19	0.243
BPI01	3.37	1.070	19	0.24	3.08	1.1	22	3.74	0.933	16	0.045
BIA02	3.30	1.013	20	0.14	3.29	0.955	15	3.32	1.108	21	0.939
BIA04	3.28	1.120	21	0.12	3.17	1.09	20	3.42	1.17	20	0.466
BAI03	3.19	1.006	22	0.00	3.13	1.035	21	3.26	0.991	22	0.660

The overall mean score ranking of LFI phases is shown in **Table 12**. It is evident that the difference of the mean score of each phase is a minor one, however among these, “Intervening” has the highest mean score indicating that performing actions according to the action plan is one of the influential phases where potential learning from past incidents is affected. The second is the “Planning interventions” phase which suggests that developing corrective actions based on the findings from the investigation plays a crucial role in gaining knowledge from

previous incidents. This is followed by the third phase in terms of ranking “Acquiring information” which depicts that obtaining initial raw information regarding incidents is a challenging phase, and as it is the first step in the learning process, which means it is one of the significant phases of the learning process as further analysis and decision are done based on the quality of this phase.

Table 12: Mean score ranking for LFI phases

Phase	Code	Barrier	Barrier Mean	Phase Mean
Intervening	BI01	Disparity of actions and recommendations	3.49	3.66
	BI02	Inadequate monitoring	3.7	
	BI03	Inadequate resources	3.63	
	BI04	Lack of commitment by management	3.88	
	BI05	Employee's casual / laid back behaviour	3.6	
Planning intervention	BPI01	Lack of Visual Insights	3.37	3.64
	BPI02	Lack of contextualizing	3.67	
	BPI03	Difficulty in translating findings into recommendations	3.53	
	BPI04	Poor quality of actions	3.95	
	BPI05	Failure to prioritize key actions	3.67	
Acquiring Information	BAI01	Limited quality of reports	3.74	3.62
	BAI02	Under-reporting	3.74	
	BAI03	Complex reporting systems	3.19	
	BAI04	Lack of understanding of how and what to report	3.79	
Investigation and Analysis	BIA01	Limited dissemination of findings	3.79	3.56
	BIA02	Lengthy investigation reports	3.3	
	BIA03	Non-identification of systematic causes	3.7	
	BIA04	Selection of incidents to investigate	3.28	
	BIA05	Difficulty identifying broader lessons learned	3.56	
	BIA06	Lack of training / competence of investigation team	3.72	
Evaluation	BE01	Lack of system evaluation	3.42	3.5
	BE02	Lack of structural feedback on follow up reports	3.58	

4.1.2. Discussion

Our goal was to increase the depth of knowledge on incident learning in the construction sector by conducting a thorough analysis of the literature on the subject and its related barriers. This

initiative aims to illuminate potential rationales for inadequate learning approaches and identify areas within incident learning that deserve additional examination.

One of the major obstacles to learning from earlier incidents, according to the majority of responders, is low quality planning, which includes minimal employee involvement for developing recommendations and more emphasis on quick solutions and technical activities. This barrier was significant in a study by Drupsteen & Hasle, (2014) based on seven focus group interviews conducted in industrial and construction companies, out of which five of them indicated poor planning of actions needed to address the root causes as a hindrance in the process of learning. So, inadequate planning can impede learning, increase safety concerns, and result in ineffective corrective measures in the construction business. Putting careful planning and practical action at the top of the list is essential for promoting ongoing progress.

For a learning environment to be effective, leadership is essential. Leaders should promote the open reporting of incidents, serve as inquiry advocates, spark change in reaction to knowledge gained, and persuade people to draw on their own experience and use it in their day-to-day work. According to the stats it is highlighted that lack of commitment by top management was another critical factor in the learning process. The expert interviewees explicitly mentioned that the priority of the management is to deliver the project timely by compromising communication and implementation of the health and safety management system.

The sharing of incident information is regarded as a flaw in the learning process (Lundberg et al., 2009). The lessons should be widely disseminated and documented so that the entire workforce may access them and use them as needed. Another factor underlined by the responders that is an obstacle to learning from past incidents, is the limited dissemination of findings obtained during the investigation phase. The foundation of many organizations' initiatives to aid employees in learning from incidents is the sharing of the findings from incident investigations (Lundberg et al., 2009; Phimister et al., 2003). Workers usually

overestimate their capacity to control accident risks, therefore sharing accident data among coworkers can help minimize the frequency of incidents.

It is important to report an incident before it may be investigated. Therefore, the risk perception of the individuals of how and what to report while reporting an incident is critical in acquiring information phase. Lack of awareness about what is essential to report could lead to misunderstandings over whether incidents are reportable (Smith et al., 2015). According to the interview, lack of training and awareness of relevant reportable events was one of the key factors why organizations fail to learn from the past.

The quality of the reports is critical since they serve as the basis for learning (Drupsteen, Bos, et al., 2013). Some reports are ineffective in finding safety improvements. The information gathered may be incomplete (facts lacking, confusing sequence of events, inadequate explanation of the event's context). Since a person reporting an incident will inevitably include some subjective details about the incident, the data may also be biased because the reporter may try to persuade the reader to view the incident in a way that favors him or his colleagues (Dechy et al., 2015). It is evident from the **Table 11** that many of the safety professionals think that the contents of the reports are inadequate to determine relevance and to choose further actions (e.g authenticity of witness statements, lack of photo evidence etc).

Systems for reporting incidents voluntarily frequently experience chronic underreporting or under-logging, where incidents are merely never recorded. This implies that chances to learn are lost. It may result in erroneous faith in the security of one's system (Dechy et al., 2015). The most common reasons for under-reporting includes, blame culture, image problems, or an extra workload (Drupsteen & Hasle, 2014). Numerous responses acknowledged the fact that under-reporting culture is due to employees' fear of job security, or negative performance assessment. Rather, the culture of the organization should be to provide incentives for those reporting the insights of any incident in order to prevent such events in the future.

The results of this study also identified other critical barriers to learn from the incidents; lack of training of investigation team, Inadequate monitoring, non-identification of root causes, lack of contextualizing, failure to prioritize key actions, inadequate resources, employees' laid-back behavior, and no structural feedback on follow-up reports.

The overall phase analysis results (**Table 12**) reveal that the phase of “Intervening” (conveying the action plan and allocating resources to carry it out), is the most critical phase in terms of loss of learning potential from previous incidents. It is argued by Lukic, (2012), the dissemination of incident information does not necessarily result in a change in risky behavior or procedures. Therefore, by addressing when to do, what resources to assign, and who to conduct activities, the lessons gained should be transformed into actions that are successfully implemented (Drupsteen & Hasle, 2014).

With the second highest mean score “Planning intervention” phase (establishing the priority and urgency of activities, developing recommendations, and developing an action plan) is the other influential phase in terms of hindrance to LFI. This is validated by Drupsteen, Groeneweg, et al., (2013), that planning phase turned to be a bottleneck to LFI in process industry, and as a result, many organizations seldom employ incident analysis information to enhance their processes. Lack of an overall picture of the reasons to address, a lack of time, a weak feeling of urgency, and a lack of ownership are the factors that prevent effective action planning (Drupsteen & Hasle, 2014).

The third most recognized phase by the respondents was “Acquiring information” (reporting and registration of incidents) that proved to be an obstacle to LFI. The performance of this phase must be top notch because it forms the basic foundation of the entire learning process and will be used as the basis for subsequent inquiry and analysis. Therefore, both the quantity and caliber of reported incidents are crucial since they serve as the basis for learning. Organizations may learn more about how to improve safety by examining incident reports

(Cooke & Rohleder, 2006). A no-blame culture must exist in order for reporting to be possible, and some sort of reporting structure is necessary (Armitage et al., 2007; Matters, 2004; Thornton et al., 2004).

The survey analysis highlighted "Investigation and analysis" (fact finding, and incident analysis) as the fourth most important phase influencing the LFI. Understanding how incidents are caused, including their underlying reasons, is necessary for the process of learning from incidents and for alternatives to stop future recurrence (van Vuuren, 1998). Accident investigation and determining the core cause of a catastrophe are critical (CCPS, 1989). Sanne, (2012) emphasized that the investigative team's perspective affects the examination and analysis of occurrences. The sharing of incident investigation results is at the heart of many firms' initiatives to assist employees to learn from incidents (Lundberg et al., 2009; Phimister et al., 2003).

Lastly, the "Evaluation" phase was determined by the respondents as another obscure to LFI. Both levels are included in the evaluation stage; that is, whether or not activities are undertaken should be assessed, as well as whether or not those actions were successful (Drupsteen, Groeneweg, et al., 2013). Many supervisors are not used to receiving evaluations based on criteria other than formal requirement fulfillment. The transition to assessing the effectiveness of the system as a whole necessitates the development of a mature culture and a set of pertinent performance indicators (Drupsteen et al., 2012). According to Parker et al., (2018), the weakest part of the LFI process is still evaluating the results of remedial action. A divergence between "those who investigate" and "those who implement" could be one reason for this lack of progress. The spider diagram below (**Figure 34**) visually indicates the weakest/ vulnerable phase among the other phases in the process of learning from previous incidents based on their mean scores.

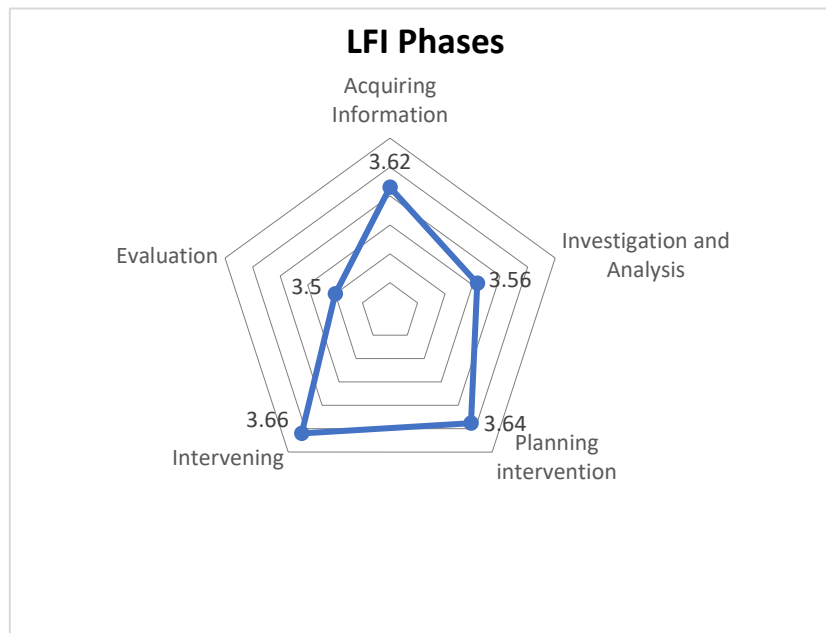


Figure 34: Spider diagram for LFI phases

Effective Knowledge Management (KM) techniques are essential for maintaining and sharing vital information on occurrences and accidents in the field of health and safety. In health and safety, knowledge management (KM) refers to a variety of activities that strive to acquire, organize, store, and share knowledge about incident prevention and mitigation techniques. The phases of LFI in health and safety can indicate certain KM inadequacies within organizations. Deficiencies in each phase such as insufficient data collection during the Acquiring Information phase, substandard analysis methods in the Investigation and Analysis phase, lack of evidence-based intervention planning, resistance to change during intervention implementation (Salas et al., 2012), and insufficient evaluation processes, may point to fundamental issues with the collection, synthesis, sharing, application, and retrieval of knowledge. To improve organizational resilience and safety performance, effective knowledge management techniques must be used to guarantee that incident learning processes are supported by robust channels for knowledge generation, sharing, and utilization.

4.2. BIM-based KDMS for construction accident/incident data development

Objective 2: To develop a BIM-based construction accident/incident knowledge database management system.

The developed system was implemented on real incidents published by the OSHA, and Alberta Occupational Health and Safety, as case studies for the experts to have an insight of the functionality of the system. Participants were presented with a novel construction accident/incident database plugin within Autodesk Revit. The plugin was created to help users manage and analyze construction-incidents related issues by offering access to a comprehensive database. Throughout the presentation, the purpose of every pushbutton in the plugin was explained, making it possible for attendees to easily move between different functionalities. Additionally, participants were shown 3D models of particular incident scenarios within Autodesk Revit, allowing them to comprehend the geographical context and complexities of each scenario. Moreover, the created database plugin's functionality was showcased, enabling participants to get incident reports and other relevant information related to every instance. To assist participants comprehend and engage, character animations portraying the chain of events for each incident were included within its corresponding incident record. This approach aimed to obtain feedback from the participants on the potential of the established system, along with animations, to improve learning outcomes and build a better knowledge of construction-related accidents/incidents. Following are the project models that were shown to the participants along with their detailed incident record from the database, and their recreated animations to visualize the chain of events.

4.2.1. Case Study 1: (Florida Formwork Table Collapse):

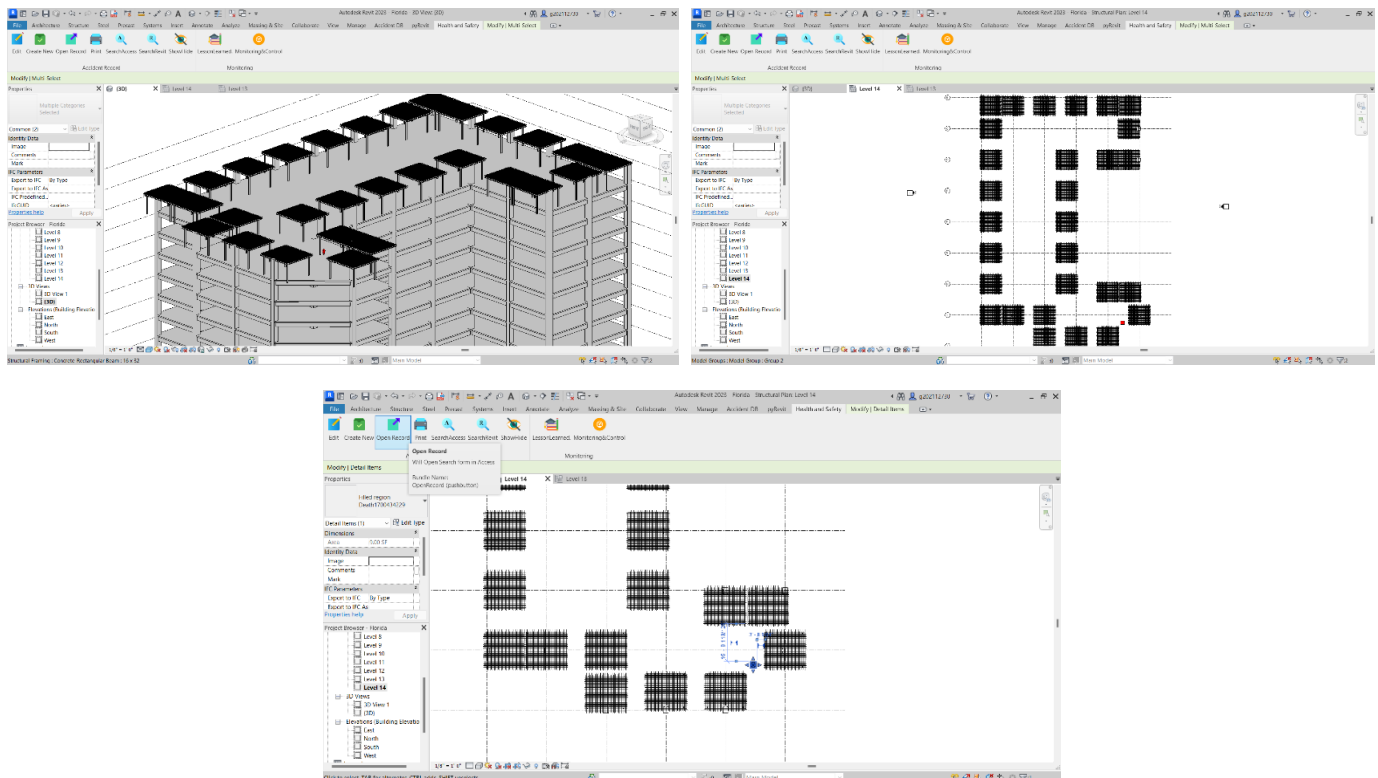


Figure 35: Incident record retrieval from the project model

Incident Report

Initials

Accident ID:

Employee Name:

Age:

Department:

Date of Incident:

Sex: ☒ Male ☐ Female

This is a report of a:

☒ Death ☐ Lost Time ☐ Dr Visit Only ☐ First Aid Only ☐ Near Miss

This report is made by:

☐ Employee ☐ Supervisor ☒ Team

Other:

Revit ID:

Nature of Injury

Job title at time of incident:

Nature of Injury: (most serious one)

☐ Abrasion, scrapes ☐ Amputation ☒ Broken bone ☐ Bruise ☐ Burn (heat) ☐ Burn (chemical)

☐ Concussion (to the head) ☐ Crushing Injury ☐ Cut, laceration, puncture ☐ Hernia

☐ Sprain, strain ☐ Illness ☒ Damage to a body system

This employee works:

☒ Regular full time ☐ Regular part time ☐ Seasonal ☐ Temporary

Months with this employer:

Months doing this job:

Incident Report

Incident Description

Exact location of the incident:

Exact time:

What part of employee's workday?

☐ Entering or leaving work ☒ Doing normal work activities ☐ During meal period ☐ Working overtime ☐ Other:

Name of witnesses:

What personal protective equipment was being used?:

Describe, step by step the events that led up to the injury:

Attachments

Written witness statements: Video: Photographs: Maps / Drawings:

Incident Causes

Unsafe Workplace Conditions (Check all that apply)

☐ Inadequate guard ☐ Unguarded hazard ☐ Safety device is defective

Figure 36: Incident record from the database



Figure 37: Incident recreated animation

Incident 1 Summary:

On the day of the incident, the table-setting personnel arrived at the scene about 6:30 a.m. They had a 30-minute planning discussion before beginning to put the tables on the 15th floor about 7 a.m. On the 15th level, there were around ten tables. Table T27 was the final table installed that day. Table T27's setting team consisted of a foreman and two additional workers. The crews used a Falcon MP20G-Z7/20FT personal fall arrest system (PFAS). Once Table T27 was on the floor, it needed to be leveled. The table-setting team leveled and finished securing the Table T27 legs. The foreman then indicated the crane's unhooking. Later in the afternoon, due to heavy winds, Table T27 bounced off the floor and collapsed to the ground. While the table tipped over, it became entangled with one of the employees' PFAS. The PFAS cracked, causing the employee to fall from the 15th floor to his death. The wind gust that afternoon was more than 30 mph.

4.2.2. Case Study 2 (Calgary Basement wall collapse):

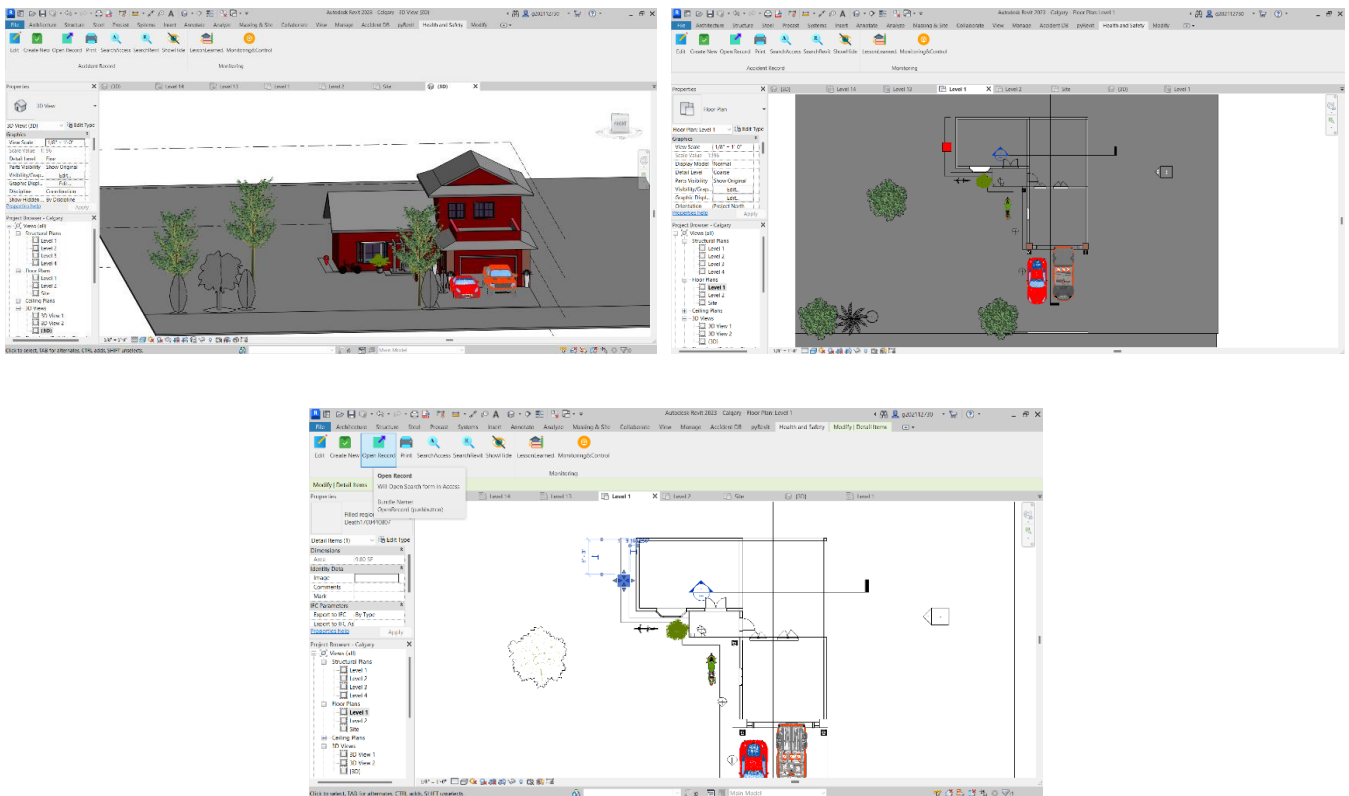


Figure 38: Incident record retrieval from the project model

Incident Report			
Initials			
Accident ID	This is a report of a:		This report is made by:
Employee Name	☒ Death	☐ Employee	
Age	☐ Lost Time	☐ Supervisor	
Department	☐ Dr Visit Only	☐ Team	
Date of Incident	☒ First Aid Only	Other	Site Officer
Sex:	☒ Male ☐ Female	☐ Near Miss	Revit ID 426451
Nature of Injury			
Job title at time of incident			
Nature of Injury: (most serious one)			
☐ Abrasion, scrapes ☐ Amputation ☐ Broken bone ☐ Bruise ☐ Burn (heat) ☐ Burn (chemical)			
☐ Concussion (to the head) ☒ Crushing Injury ☐ Cut, laceration, puncture ☐ Hernia			
☐ Sprain/strain ☐ Illness ☐ Damage to a body system ☐ Other			
This employee works:			
☒ Regular full time	☐ Regular part time	Months with this employer	0
☐ Seasonal	☐ Temporary	Months doing this job	0
Incident Description			
Exact location of the incident		15 Whiteram Way northeast (NE), Calgary, Alberta	
Exact time		8:40 am	
What part of employee's workday?		Name of witnesses	
☐ Entering or leaving work ☒ Doing normal work activities ☐ During meal period ☐ During break ☐ Working overtime ☐ Other		☐ Hard hat ☐ Describe, step by step the events that led up to the injury ☐ Worker 1 attended the work site to commence work as directed by the Contractor. Worker 1, using a small excavator, excavated an area at or near the	
Attachments			
Written witness statements		Video	Photographs
Incident Causes			
Unsafe Workplace Conditions (Check all that apply)			
☐ Inadequate guard ☐ Unguarded hazard ☐ Safety device is defective ☐ Tool or equipment ☐ Workstation layout is hazardous ☐ Unsafe behavior			

Figure 39: Incident record from the database



Figure 40: Incident recreated animation

Incident 2 Summary:

Worker 1 arrived at the construction site to begin work as ordered by the Contractor. Worker 1 used a small excavator to excavate an area at the southeast corner of the house, revealing the basement's south wall and footings. When the dig was finished, the concrete basement wall was cut to required dimensions. Worker 1 entered the excavation about 8:40 a.m. and used hand tools to begin moving the cut chunk of concrete at the base. During labor, the cut part began to shift and lean towards Worker 1. Worker 1 turned to leave the work area as the cut part dropped and hit the south wall of the excavation. The impact of the piece with the excavation wall resulted in a portion of the slab fracturing directly above Worker 1. The remaining length of concrete pinned Worker 1 against the excavation wall, inflicting fatal damage.

4.2.3. Case Study 3 (Athabasca Fall on Steel Rebar):

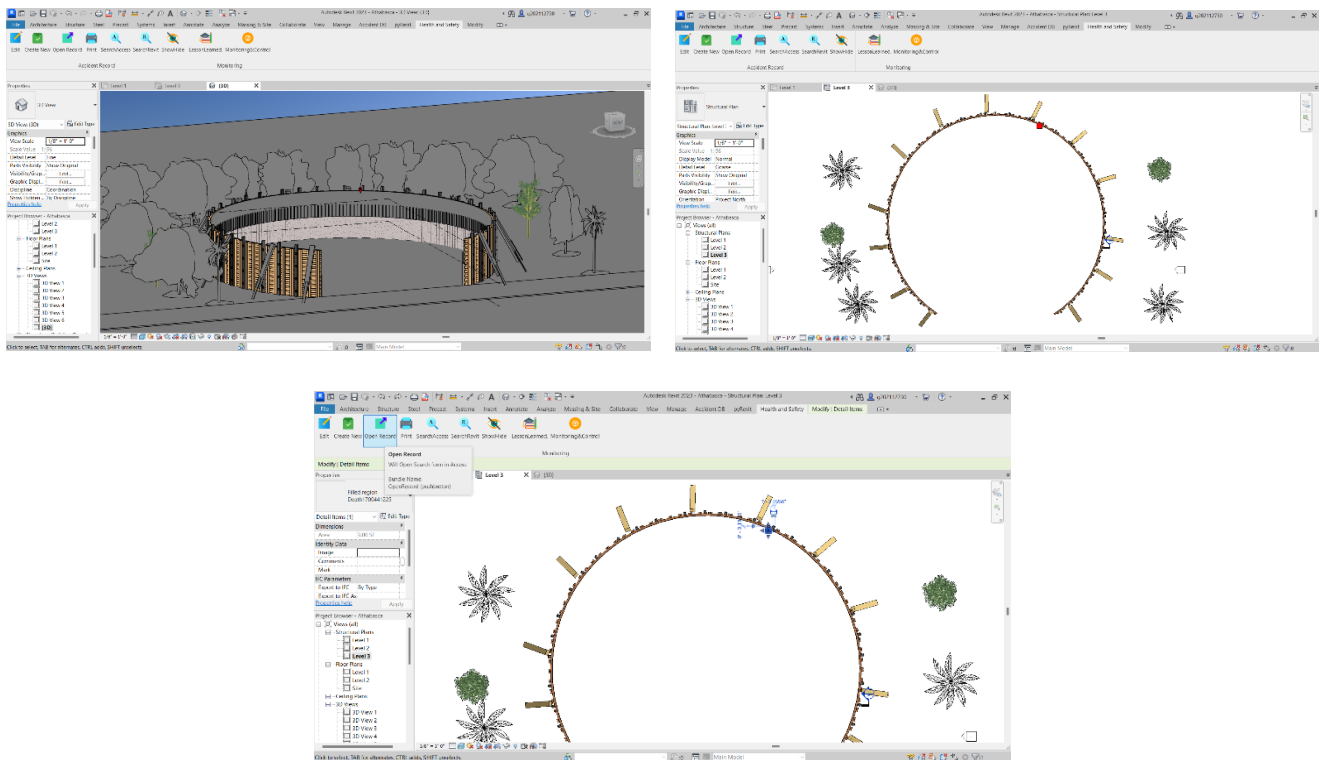


Figure 41: Incident record retrieval from the project model

Incident Report

Initials

Accident ID	1	This is a report of a:	☒ Death	This report is made by:	☐ Employee
Employee Name	Worker1	☐ Lost Time	☐ Supervisor	☒ Team	
Age		☐ Dr Visit Only	☐ Other		
Department	Formwork	☐ First Aid Only			
Date of Incident	27/07/2009	☐ Near Miss		Revit ID	471476
Sex:	☒ Male ☐ Female				

Nature of Injury

Job title at time of incident: Foreman

Nature of Injury: (most serious one)

☐ Abrasion, scrapes	☐ Amputation	☐ Broken bone	☐ Bruise	☐ Burn (heat)	☐ Burn (chemical)
☐ Concussion (to the head)	☐ Crushing Injury	☒ Cut, laceration, puncture	☐ Hernia		
☐ Sprain/strain	☐ Illness	☐ Damage to a body system	☐ Other		

This employee works:

☒ Regular full time	☐ Regular part time	Months with this employer	0
☐ Seasonal	☐ Temporary	Months doing this job	0

New Save Print

Incident Report

Incident Description

Exact location of the incident: Athabasca University in Athabasca, Alberta

Exact time: 7:00 am

What part of employee's workday?

☐ Entering or leaving work	Name of witnesses	
☒ Doing normal work activities	What personal protective equipment was being used?	No protective gear
☐ During meal period		
☐ During break		
☐ Working overtime		
Other		

Describe, step by step the events that led up to the injury

On July 27, 2009, workers were preparing to install strongbacks along a preformed wall at a construction facility. After conducting a safety meeting

Attachments

Written witness statements Video Photographs Maps / Drawings

Incident Causes

Unsafe Workplace Conditions (Check all that apply)

☐ Inadequate guard	☒ Unguarded hazard	☐ Safety device is defective
☐ Tool or equipment	☒ Worker error	☐ Unsafe behavior

New Save Print

Figure 42: Incident record retrieval from the project model



Figure 43: Incident recreated animation

Incident 3 Summary:

On July 27, 2009, workers were preparing to install strong backs along a preformed wall at a construction facility. After conducting a safety meeting, they entered the basement and installed the strongbacks. A co-worker assisted the general foreman, who then used a rope to lift the strong backs up the wall. When the second strongback was at the top, the general foreman untied the rope and tied it to another strongback. The rope fell, and the general foreman fell onto the exposed vertical rebar. Emergency medical services arrived and the general foreman was pronounced dead.

4.3. BIM-based KDMS for construction accident/incident data validation

Objective 3: To validate the feasibility of the proposed system for knowledge management of construction accidents/incidents data.

4.3.1. Semi-structured interview results

The table below (**Table 13**) shows the mean value, RII value, and ranking of the problems that can be successfully addressed and fixed using the created BIM-based knowledge management system for construction incidents. It is derived from the opinions of the experts, gathered on a 5-point Likert scale, where 1 denotes "strongly disagree" and 5 denotes "strongly agree."

Table 13: Effectiveness of BIM-CA/IKDMS in resolving KM issues in CA/IKM

No	KM issues in construction health and safety	Evaluation Scores for BIM-KMS		
		Mean Score	RII	Overall Rank
1	Disintegrated system, thereby increasing work repetition	4.5	0.9	1
2	Lack of visual insights	4.5	0.9	2
3	Lack of a database that serves as a "one-step shop" for accessing incidents/accidents data, lessons learned, and best practices.	4.4	0.88	3
4	Inaccessibility of information anytime and anywhere	4.3	0.86	4
5	Non-standardization of file directories, file plans, and document templates	4.3	0.86	5
6	Paper-based exchange of information (slow and efficient)	4.3	0.86	6
7	Lack of contextualizing	4.3	0.86	7
8	Limited quality of initial reports	4.1	0.82	8
9	Limited dissemination of findings	4.1	0.82	9
10	Non-existence of efficient interfaces between departmental systems to access information electronically.	4	0.8	10
11	No communication tool to share tacit knowledge	3.9	0.78	11
12	Complex reporting systems	3.9	0.78	12
13	Non-identification of systemic causes	3.7	0.74	13

The overall mean scores highlight that the majority of the experts rated positively (agreed or strongly agree), indicating that the proposed system substantially resolves the knowledge management issues in construction incident investigation. Ten of the thirteen knowledge management issues are deemed to have decreased by 80% or more in comparison to other issues based on RII values. Among all the highlighted KM problems from the literature ‘Disintegrated systems’ and ‘lack of visual insights’ were the top ranked issues that can be mitigated through the developed system, indicating that the BIM platform plays an essential role in terms of integrating the scattered information. Experts also suggested that this integration of incident information should also take place with the as-built construction drawings as well, whereas incident-recreated animations would provide a better insight to the users about the chain of events that caused the incident to occur. ‘Lack of database’, which includes all incident facts (description, evidence, statements, lessons learned, etc.), was listed as the second problem that the proposed system can solve, which suggests that with the use of BIM a central database for incidents or any other information related to the project can be effectively managed. As observed from **Table 13**, there is minimal difference in the mean scores of the KM issues that the proposed system can address. Obstacles such as ‘information inaccessibility,’ ‘non-standardization of files,’ ‘paper-based data sharing,’ and ‘lack of contextualizing’ have a similar average score and are very near to the average score of the top listed issues, emphasizing the fact that the developed tool is very likely to handle the majority of these concerns. On the other hand, ‘complex reporting systems’ and ‘non-identification of systematic causes’ remained troublesome and are placed second and last in terms of RII values. According to the respondents, their organizations use complex reporting strategies to record incident information in their databases. While the fields of the incident report of the developed system were compliant with OSHA, experts found these fields less informative and fairly basic when compared to the systems deployed within the enterprises.

4.3.2. Discussion

To develop a BIM-based accident/incident knowledge management system, as well as to enhance organizational learning from past incidents, the goal of this study was to enhance the knowledge management of construction incident data. Initially, a literature review was conducted to identify knowledge management (KM) challenges in the construction sector. Subsequently, a BIM-based knowledge management system was designed to efficiently handle construction incident data. In addition, three published incident case studies were turned into a video animation to exploit the visualization feature and enhance the learning element from the past occurrences as well as to aid in the effect incident investigation. The developed BIM-based knowledge management system was a central repository for all the incidents occurring in a project including all the necessary details of the incidents (date, time, description, etc.) along with the reconstructed incident film and additional visual proof. The specialists in construction health and safety assessed the developed system to determine whether the developed tool was feasible.

As the respondents pointed out, the suggested solution is expected to lessen the problems related to system disintegration, which means that tasks won't need to be repeated needlessly by generating something new or solving an issue that has been resolved. Research emphasizes the importance of teamwork in enhancing construction safety, that it promotes a culture of shared ownership and accountability for safety, with each team member actively contributing to ensuring a safe working environment (Hinze & Gambatese, 2003). According to Fargnoli et al., (2011), this collaborative approach supported by an integrated knowledge management system reduces the need for redundant communication efforts and ensures that ideas are communicated quickly.

The experts were also adamant that the problem of the incident's lack of visualization could be easily fixed with the help of the knowledge management system that has been put in place.

This system consists of photos, drawings, witness statements, and animations that have been constructed using the paper-based descriptive report. The use of visualization principles in the context of construction health and safety is critical for increasing comprehension, communication, and decision-making. According to Guo et al., (2017), visualization technology can enhance safety management by supporting safety training, job hazard area (JHA) identification, on-site safety monitoring, and alerts.

According to the experts, issues such as lack of database, inaccessibility of information, non-standardization of files, and paper-based exchange of information can be greatly solved by using the developed BIM-based knowledge management system, because it is a centralized repository where all the information regarding the incident have been stored and can be accessed and retrieved easily at anytime. Knowledge management consists of three techniques: preserving existing knowledge, disseminating and applying knowledge, and making knowledge usable (W. Kim & Park, 2003). Thomas & Keithley (2002) assert that knowledge management strategy implementation adds value and helps the company to foster greater employee collaboration, enhance access to lessons learned, and provide a "one stop shop" for all project-related matters that is open to all staff members at all times and locations. Lin & Tserng (2003) made the argument for how having the necessary knowledge at the appropriate time will work in favor of lean building, eliminating waste, decreasing mistakes, enhancing performance, and boosting productivity. This implies that efficient knowledge management can lessen the need on paper-based information sharing.

The experts also concurred that the system proposed would resolve problems such as inadequate information exchange and ineffective departmental system interfaces that prevented electronic information access. This makes sense since all of the incident's relevant information is under one umbrella, making it easier to convey all of the information at once and reducing the need to evaluate all of the material in a fragmented way. Through the sharing of information

about risks and risk management techniques, effective communication is essential to establish a secure working environment (Vecchio-Sadus, 2007). Dave & Koskela (2009) and Thomas & Keithley (2009) both discovered that using an integrated system improves information exchange and cooperation.

In addition to the survey, experts shared their thoughts on how the built system may be enhanced further by including other data analytics such as graphs and charts for the yearly number of incidents to examine the organization's safety performance. Additionally, some other query options were proposed, such as searching the occurrences by the kind of trainings, to indicate which safety trainings need to be addressed to prevent the occurrence of mishaps.

4.4. Assessment of learning potential using cognitive load measurement

Objective 4: To assess the potential of the proposed system for learning from past incidents based on cognitive load measurements.

The purpose of this experiment was to compare the possible impacts of visualization-based vs paper-based event comprehension on participants' CL. An in-depth understanding of the incidents is essential in various aspects of employee health and safety training and communication. Compared to conventional paper-based approaches, research has demonstrated that visualization aids, such as animations, and simulations, can improve learning and retention of knowledge (Mayer, 2016). Organizations may enhance safety communication by using visualization techniques to make complicated material more accessible and interesting. This will eventually lessen cognitive strain and increase employee knowledge retention (Trollip, Stanley R, Alessi, 2000).

4.4.1. CL and Task Performance measurement

Three incident case studies were chosen for this exercise, with the first incident report being lengthier and more complex than the others, the second being the moderately complex of the

three, and the third event being the simplest of the three. A thorough analysis of the NASA-TLX data average scores for each of the three occurrences was conducted. As can be seen from **Table 14**, for the first incident, paper-based comprehension was the most cognitively demanding in terms of mental demand, temporal demand, effort, and frustration levels except performance parameter. Participants' performance in the paper-based approach was marginally better than that of the visualization approach in terms of understanding the incidents based on their performance satisfaction level. The same pattern was observed for the other two events, where all of the CL characteristics proved to be more demanding except for the performance parameter, where the difference between paper-based comprehension and visualization-based comprehension of the incidents is quite small as similar to the case of first incident. As demonstrated in the **Table 14**, the difference between the other five characteristics (mental demand, temporal demand, effort, and frustration) was rather considerable.

Table 14: Cognitive load measurements of paper-based group and visual-based group

	Incident 1		Incident 2		Incident 3	
	Video Animations	Paper-based reports	Video Animations	Paper-based reports	Video Animations	Paper-based reports
Mental Demand	2.33	4	2.33	3.2	2.67	3.6
Temporal Demand	2.5	4.2	2.17	3.4	2.17	3.8
Performance	3.7	3.8	3.33	3.6	4.17	4.4
Effort	2.5	3.6	1.83	3	2.67	2.8
Frustration	2.5	3.4	1.67	2.4	2.33	2.4

As described in the previous section, the task involved participants divided into two groups, one using paper-based reports, other using character animation videos to assess and understand the details of the incident presented in their respective formats. Two metrics were used to evaluate task performance: the time it took participants to complete the activity, and the accuracy with which they grasped and summarized the chain of events as described in the reports. As indicated in the **Table 15**, which compares completion times of the participants for

all three instances as well as performance scores, for first instance, the paper-based group took 41 minutes to do the job, a considerable amount longer than the visualized-based group's 18 minutes. The group that understood the incident by seeing the incident video animations had the highest task score (6.08) out of the two groups. In the same way, the visual-based group finished the second incident case study incident in 11 minutes, which is 6 minutes faster than the paper-based group. They also scored higher than the paper-based group, with 6.2. However, both groups completed the third incident's work in the same amount of time, but the visual-based group received a higher task score 6.75, more than the other group.

In conclusion, there were considerable discrepancies among the paper-based and visual-based groups' completion durations and performance ratings across three event situations. The group that utilized visual aids demonstrated a constant ability to complete tasks more quickly and with higher scores, highlighting the value of visualization-based methods for improving task performance and incident comprehension.

Table 15: Task performance assessment of paper-based group and visual-based group

	Incident 1		Incident 2		Incident 3	
	Video Animations	Paper-based reports	Video Animations	Paper-based reports	Video Animations	Paper-based reports
Time Duration	18	41	11	17	12	12
Task Score	6.08	4.8	6.2	4.3	6.75	4.7

4.4.2. Discussion

Measuring cognitive load is one of the most significant components of evaluating the effectiveness of a system to improve learning, problem-solving, and decision-making. According to cognitive psychology research, cognitive load has a significant impact on people's capacity to absorb and comprehend information (Sweller, 1994). The cognitive load hypothesis

suggests that learning and problem-solving abilities may be compromised when cognitive resources are overworked due to unnecessary processing demands (Sweller, 2010). Therefore, assessing cognitive load is critical for verifying the notion that the developed system may greatly lower the cognitive load of comprehending the incident.

Our findings show that a visual-based method to understanding construction accidents requires much less cognitive burden than a typical paper-based approach. This conclusion is consistent with earlier research that have investigated the association between cognitive load and learning from experiences. Similarly, Mayer & Moreno, (2003) found that visual aids improve cognitive processing, increasing learning efficiency. Our findings support this notion, since individuals who used the visual-based strategy displayed faster understanding and memory of incident data. This implies that including visual features into incident reports can improve the learning process by reducing cognitive strain and allowing for more effective event analysis and memory (Mayer & Moreno, 2016 and Sweller, 2010).

CHAPTER 5

CONCLUSIONS

5.1. Summary of the Study

Despite advances in safety over the last 30 years, the construction sector's accident and sickness rate remains five times higher than the industry average globally due to its size, complexity, and dynamic nature. Construction-related incidents, such as accidents and near-misses, offer chances for learning, improving results, and preventing future occurrences. The recurrent occurrence of such occurrences shows that learning from incidents (LFI) is not being properly applied. Historical incidents can help detect prospective dangers, and a systematic framework based on knowledge management (KM) systems can make it easier to categorize and share event data across departments. However, present approaches rely on paper-based reporting, which lacks visual insights. BIM can improve KM by digitally portraying buildings and infrastructure and combining many data sources.

Firstly, his study aimed to enhance learning from previous accidents by first identifying major hurdles to LFI in the Saudi construction sector using a literature analysis and a pilot study with health and safety professionals. A poll was then conducted to rank these impediments in terms of importance.

Secondly, as highlighted in this study how improved knowledge management techniques are essential to enhance the learning process, the study identified and addressed KM issues in construction through literature and expert input, leading to the development of a BIM-based Construction Accident/Incident Knowledge and Data Management System (CA/IKDMS). This

system stores, analyzes, and visualizes accident data in 2D and 3D. Semi-structured interviews evaluated how this system addresses KM issues.

Finally, the study evaluated learning potential by cognitive load assessment. An experiment assessed cognitive load and task performance between groups, utilizing paper-based reports and visual-based incident recreations. The incident-recreated animations were developed by transferring the project model from the BIM platform to animation software, where the sequences of events before and after the incidents were animated according to the published incident reports utilized as case studies for this experiment.

5.2. Review of Research Objectives and Conclusions

Objective 1: To identify and analyze barriers that hinder the process of learning from past incidents in the construction industry (Saudi construction industry).

The purpose of this objective was to look at the significant impediments to LFI in the Saudi construction industry. To accomplish this goal, 22 barriers were identified after a thorough literature review and assistance from safety experts. Based on the response of 75 health and safety professionals, it was revealed that 14 out of 22 barriers were significant barriers to LFI, with the most important ones being poor quality of actions, lack of commitment by management, limited dissemination of findings, lack of understanding of how and what to report, and limited quality of reports. The findings further indicated that the intervening phase was the most prevalent of the five LFI stages. This implies that the lessons learned should be properly applied by selecting the right time, resource allocation, and activity conduct in the Saudi construction industry.

Furthermore, this outcome may serve as a foundation for a gap analysis that examines how the construction industry is presently addressing these barriers and what more can be done to enhance education and promote safety in the sector.

Objective 2&3: To create a BIM-based accident/incident knowledge database management system and validate its feasibility

To develop a BIM-based accident/incident knowledge management system, as well as to enhance organizational learning from past incidents, the goal of this study was to enhance the knowledge management of construction incident data. Initially, the literature review was conducted to identify knowledge management (KM) challenges in the construction sector. Subsequently, a BIM-based knowledge management system was designed to efficiently handle construction incident data.

The developed BIM-based knowledge database management system was a central repository for all the incidents occurring in a project including all the necessary details of the incidents (date, time, description, etc) along with the reconstructed incident film and additional visual proof. The specialists in construction health and safety assessed the developed system to determine whether the developed tool was feasible.

The developed system's results showed that problems like a disintegrated system, a lack of visual understanding, a lack of a database, non-standard file formats, paper-based information exchange, restricted information sharing, and limited accessibility could be mostly rectified.

Experts also shared their thoughts on how the built system may be enhanced further by including other data analytics such as graphs and charts for the yearly number of incidents to examine the organization's safety performance. Additionally, some other query options were proposed, such as searching the occurrences by the kind of training, to indicate which safety trainings need to be addressed to prevent the occurrence of mishaps.

Objective 4: To assess the potential of the proposed system for learning from past incidents based on cognitive load measurements

For this particular objective, three published incident case studies were turned into a video animation to exploit the visualization feature and enhance the learning element from past occurrences as well as to aid in effective incident investigation.

An experiment was carried out with 12 construction engineering management students to evaluate their knowledge and understanding of how the events happened. The students were separated into two groups: one group was responsible for paper-based comprehension of the incident, while the other group was responsible for visual comprehension. For both groups, task performance and cognitive load were assessed and compared.

According to the findings of the cognitive load and task performance evaluation, paper-based comprehension of the incident was the most cognitively demanding, time-consuming, and had a poor performance score in terms of the incident's correctness.

5.3. Future Work

1. The overall identification of critical barriers to LFI in the construction industry may serve as a foundation for a gap analysis that examines how the construction industry is presently addressing these barriers and what more can be done to enhance education and promote safety in the sector.
2. Experts suggested enhancing the system by incorporating additional data analytics, such as graphs and charts depicting the yearly number of incidents, to better assess the organization's safety performance.
3. Other query options were proposed, such as searching incidents by type of training, to identify which safety trainings need improvement to prevent future mishaps.

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APPENDIX A: QUESTIONNAIRE TO IDENTIFY CRITICAL BARRIERS TO LFI IN SAUDI CONSTRUCTION

Invitation to Participate in Master's Research Study

Dear Sir,

We write to humbly invite you to take part in an ongoing Master's study entitled **“Barriers to Learning from Incidents (LFI) in the Construction Industry”**. This study is being carried out under Assistant Professor Khwaja Mateen Mazhar's supervision. It primarily aims at highlighting the underlying major bottlenecks to learn from previous incidents, so as to adequately strategize to prevent recurrence of similar incidents in the future. This preliminary survey is core to achieving the research aims and objectives.

The survey questionnaire is attached to this letter and will take approximately 10-15 minutes to complete. **The aim of this survey is to understand the relevance and importance of the identified barriers to LFI, that have been extracted from published literature. Also, the preliminary survey aims to solicit health and safety experts' judgement to augment the list of barriers, should there be a need to add to/ modify/ and/or remove the identified barriers.** Be assured that all of the responses and information we collect will be kept in the strictest confidence and only used for academic purposes. We are willing to share the research outputs with you upon your request.

We would highly appreciate if you could also suggest other knowledgeable practitioners who would be willing to contribute to this research to us. Thank you for your invaluable time. If you have any questions, please email Waleed Imtiaz at g202112730@kfupm.edu.sa or Assistant Professor Khwaja Mateen at khwaja.mazher@kfupm.edu.sa

Yours sincerely,

Waleed Imtiaz Usman (Master's Candidate)

Department of Construction Engineering and Management,

King Fahd University of Petroleum and Minerals (KFUPM),

Dhahran, 31261, Saudi Arabia.

Barriers to Learning from Incidents in the Construction Industry

Instructions

1. Please draw upon your experience inside the health and safety department of your organization to complete this survey.
2. Please complete the questionnaire at your earliest convenience and preferably before **27 May 2023**, and the completed questionnaire will be collected in person by the researcher.
3. Your mobile number: _____ and email address: _____

Section One: Background Information of Respondent

Q1. What type of company do you work for?

Contractor ☐; Consultant ☐; Developer ☐; Subcontractor ☐;

Other(s) (specify): _____

Q2. Number of employees in your organization?

Less than 50 ☐; Between 100-500 ☐; Between 500-1000 ☐;

Between 1000-1500 ☐; 1500 or more ☐

Q3. What type of construction projects does your organization specialize in? (Check all that apply).

Residential ☐; Commercial/Office ☐; Educational ☐; Industrial ☐;

Public Utilities ☐; Other(s) (specify): _____

Q4. From how many years your organization is in business?

Less than 5 ☐; Between 5-10 ☐; Between 10-15 ☐; Between 15-20 ☐;

20 or more ☐

Q5. How many projects did your organization completed in last 5 years?

Less than 5 ☐; Between 5-15 ☐; Between 15-20 ☐; Between 20-30 ☐;

Between 30 or more ☐

Q6. What is your profession/job title?

Engineer ☐; Architect ☐; Project Manager ☐; Health and Safety Manager ☐;

Health and Safety Supervisor ☐; Other(s) (specify): _____

Q7. Your years of working experience in the construction industry:

1-5 yrs ☐; 6-10 yrs ☐; 11-15 yrs ☐; 16-20 yrs ☐; Over 20 yrs ☐

Q8. Your years of experience in health and safety:

1-5 yrs ☐; 6-10 yrs ☐; 11-15 yrs ☐; 16-20 yrs ☐; Over 20 yrs ☐

Section Two: Barriers to Learning from Incidents in the Construction

Industry

To what extent do you think accidents repeatedly occur due to inadequate learning from previous similar incidents?

0-20% ☐; 21-40% ☐; 41-60% ☐; 61-80% ☐; 81-100% ☐

Please indicate the level of importance of each of the following barriers to learning from incidents in the construction industry. Use the following scale: **1 = Not Important; 2 = Less Important; 3 = Neutral; 4 = Important; 5 = Very Important.**

LFI processes	Barriers	Description	Level of Importance
Acquiring Information	Limited quality of initial reports	Report contents are inadequate to determine relevance and to choose further actions.	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
	Under-reporting	Fear of being held accountable or humiliated or extra work.	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
	Complex reporting systems	Multiple systems overwhelm the reporter and demand too much of them.	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
	Lack of understanding of how and what to report	Non-recognition of the situation, lack of awareness about what is important, contradicting signals.	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
	<u>Any additional barriers:</u>		
Investigation and Analysis	Lack of structural feedback on follow-up reports	Only the person who reported the incident was aware of the follow-up.	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
	Limited dissemination of findings	Incidents are not shared across the departments/organization, making it difficult to identify them.	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
	Lengthy investigation reports	The investigative report is too detailed and lacks a brief overview.	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
	Non-identification of systematic causes	Proximal causes are highlighted rather than root cause identification.	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
	Selection of incidents to investigate	No criteria for selection based on the in-depth potential learning, and too many reports.	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
	Difficulty identifying broader lessons	Lack of technical review of investigations to identify broader lessons to be shared	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5

	<u>Any additional barriers:</u>		
Planning interventions	Lack of visual insights	Generated findings do not focus on connecting the audience to learning via visual aids.	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
	Lack of contextualizing	Workers fail to relate the reported incident knowledge to their work and decide its relevance to them.	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
	Difficulty in translating findings into recommendations	Inadequate presentation and communication of incident findings leads to difficulties in generating appropriate recommendations.	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
	Too many and vague recommendations	Recommendations are not feasible/practical and are outside the organization's control.	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
	Poor quality of actions	Employee involvement is limited in generating recommendations, focusing on quick fixes and technical actions.	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
	<u>Any additional barriers:</u>		
Intervening	Resistance to change	Recommendations not accepted by line managers and frontline personnel.	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
	Disparity of actions and recommendations	Actions focus on short-term improvements, leaving larger issues unattended.	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
	Inadequate monitoring	Insufficient management supervision and turnover leads to lack of historical knowledge by the person holding a supervisory role.	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
	Corporate amnesia	Due to corporate memory loss, it might be challenging to integrate change over the long term.	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
	Inadequate resources	Insufficient budget or time to implement corrective actions (production is prioritized over safety).	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5

	<u>Any additional barriers:</u>		
Evaluating	Lack of system evaluation	Lack of systematic monitoring and/ or an inadequate review system to evaluate the effectiveness of implemented actions/ recommendations/ lessons learned.	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
	Lack of structural feedback on follow-up reports	Only the person who reported the incident was aware of the follow-up.	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
	<u>Any additional barriers:</u>		

Any other comments:

**APPENDIX B: QUESTIONNAIRE FOR ASSESSMENT OF
BIM-BASED ACCIDENT/INCIDENT KNOWLEDGE
DATABASE MANAGEMENT SYSTEM**

Invitation to Participate in Master's Research Study

Dear Sir,

We write to humbly invite you to take part in an ongoing Master's study entitled “**BIM-based accidents/incidents knowledge database management system**”. This study is being carried out under Assistant Professor Khwaja Mateen Mazhar's supervision. The aim of this research is to exploit BIM technology to create a central repository for Accident/Incident investigation data to neutralize the knowledge management issues to improve the acquiring information and investigation processes which eventually would have an impact on effective learning as stated. Moreover, the visualization aspect of the system will provide awareness to the workers regarding the safety procedures needed to be implemented at the site. It would also allow the safety officers to conduct training sessions via accident simulations rather than exposing the workers to the site itself, providing zero risky environments.

The survey questionnaire is attached to this letter and will take approximately 10-15 minutes to complete. **The aim of this survey is to evaluate to what extent the developed system would resolve knowledge management issues of construction incidents.** Be assured that all of the responses and information we collect will be kept in the strictest confidence and only used for academic purposes. We are willing to share the research outputs with you upon your request.

Thank you for your invaluable time. If you have any questions, please email Waleed Imtiaz at g202112730@kfupm.edu.sa or Assistant Professor Khwaja Mateen at khwaja.mazher@kfupm.edu.sa

Yours sincerely,

Waleed Imtiaz Usman (Master's Candidate)

Department of Construction Engineering and Management,

King Fahd University of Petroleum and Minerals (KFUPM),

Dhahran, 31261, Saudi Arabia.

Barriers to Effective Knowledge Management of Construction Incidents

Instructions

1. Please draw upon your experience inside the health and safety department of your organization to complete this survey.
2. Please complete the questionnaire at your earliest convenience and preferably before **27 May 2023**, and the completed questionnaire will be collected in person by the researcher.
3. Your mobile number: _____ and email address: _____

Section One: Background Information of Respondent

Q1. What type of company do you work for?

Contractor ☐; Consultant ☐; Developer ☐; Subcontractor ☐;

Other(s) (specify): _____

Q2. Number of employees in your organization?

Less than 50 ☐; Between 100-500 ☐; Between 500-1000 ☐;

Between 1000-1500 ☐; 1500 or more ☐

Q3. What type of construction projects does your organization specialize in? (Check all that apply).

Residential ☐; Commercial/Office ☐; Educational ☐; Industrial ☐;

Public Utilities ☐; Other(s) (specify): _____

Q4. From how many years your organization is in business?

Less than 5 ☐; Between 5-10 ☐; Between 10-15 ☐; Between 15-20 ☐ ;
20 or more ☐

Q5. How many projects did your organization completed in last 5 years?

Less than 5 ☐; Between 5-15 ☐; Between 15-20 ☐; Between 20-30 ☐;
Between 30 or more ☐

Q6. What is your profession/job title?

Engineer ☐; Architect ☐; Project Manager ☐; Health and Safety Manager ☐;
Health and Safety Supervisor ☐; Other(s) (specify): _____

Q7. Your years of working experience in the construction industry:

1-5 yrs ☐; 6-10 yrs ☐; 11-15 yrs ☐; 16-20 yrs ☐; Over 20 yrs ☐

Q8. Your years of experience in health and safety:

1-5 yrs ☐; 6-10 yrs ☐; 11-15 yrs ☐; 16-20 yrs ☐; Over 20 yrs ☐

Section Two: Barriers to Effective Knowledge Management of Construction Incidents

To what extent, do you think the issues listed below will be solved by the proposed system?
These issues can be ranked based on their importance on a 5-point Likert scale: **1 = Strongly disagree; 2 = Disagree; 3 = Neutral; 4 Agree; 5 = Strongly agree.**

Problematic issues in KM of construction incidents	Level of Importance
Lack of a database that serves as a "one-stop shop" for accessing incidents/accidents data, lessons learned, and best practices	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
Disintegrated system, thereby increasing work repetition.	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
Inaccessibility of information anytime and anywhere	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
No communication tool to share tacit knowledge	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
Non standardization of file directories, file plans, and document templates	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
Paper based exchange of information (slow and inefficient)	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
Non-existence of efficient interfaces between departmental systems to access information electronically	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
Limited quality of initial reports	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
Complex reporting systems	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
Limited dissemination of findings	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
Non-identification of systemic causes	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
Lack of contextualizing	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
Lack of visual insights	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5

Any other comments:

APPENDIX C: QUESTIONNAIRE FOR COGNITIVE LOAD MEASUREMENT

Invitation to Participate in Master's Research Study

Dear Sir,

We write to humbly invite you to take part in an ongoing Master's study entitled “**BIM-based accidents/incidents knowledge database management system**”. This study is being carried out under Assistant Professor Khwaja Mateen Mazhar's supervision. The aim of this research is to exploit BIM technology to create a central repository for Accident/Incident investigation data to neutralize the knowledge management issues to improve the acquiring information and investigation processes which eventually would have an impact on effective learning as stated. Moreover, the visualization aspect of the system will provide awareness to the workers regarding the safety procedures needed to be implemented at the site. It would also allow the safety officers to conduct training sessions via accident simulations rather than exposing the workers to the site itself, providing zero risky environments.

The survey questionnaire is attached to this letter and will take approximately 8-12 minutes to complete. **The purpose of this survey is to compare the cognitive workload and task performance of the participants reading paper-based incident reports and visualizing the incidents recreated from those reports.** The questions in this questionnaire will ask you about your perceived mental load and how well you understood the incidents based on provided materials (i.e., paper-based, incident videos). Be assured that all of the responses and information we collect will be kept in the strictest confidence and only used for academic purposes.

Thank you for your invaluable time. If you have any questions, please email Waleed Imtiaz at g202112730@kfupm.edu.sa or Assistant Professor Khwaja Mateen at khwaja.mazher@kfupm.edu.sa

Yours sincerely,

Waleed Imtiaz Usman (Master's Candidate)

Department of Construction Engineering and Management,

King Fahd University of Petroleum and Minerals (KFUPM),

Dhahran, 31261, Saudi Arabia

Cognitive Load Measurement of Visual data against Paper-based data

Instructions

4. Please draw upon your experience inside the health and safety department of your organization to complete this survey.
5. Please complete the questionnaire at your earliest convenience and preferably before **27 May 2023**, and the completed questionnaire will be collected in person by the researcher.
6. Your mobile number: _____ and email address: _____

Section One: Background Information of Respondent

Q1. What type of company do you work for?

Contractor ☐; Consultant ☐; Developer ☐; Subcontractor ☐;

Other(s) (specify): _____

Q2. Number of employees in your organization?

Less than 50 ☐; Between 100-500 ☐; Between 500-1000 ☐;

Between 1000-1500 ☐; 1500 or more ☐

Q3. What type of construction projects does your organization specialize in? (Check all that apply).

Residential ☐; Commercial/Office ☐; Educational ☐; Industrial ☐;

Public Utilities ☐; Other(s) (specify): _____

Q4. From how many years your organization is in business?

Less than 5 ☐; Between 5-10 ☐; Between 10-15 ☐; Between 15-20 ☐;

20 or more ☐

Q5. How many projects did your organization completed in last 5 years?

Less than 5 ☐; Between 5-15 ☐; Between 15-20 ☐; Between 20-30 ☐;

Between 30 or more ☐

Q6. What is your profession/job title?

Engineer ☐; Architect ☐; Project Manager ☐; Health and Safety Manager ☐;

Health and Safety Supervisor ☐; Other(s) (specify): _____

Q7. Your years of working experience in the construction industry:

1-5 yrs ☐; 6-10 yrs ☐; 11-15 yrs ☐; 16-20 yrs ☐; Over 20 yrs ☐

Q8. Your years of experience in health and safety:

1-5 yrs ☐; 6-10 yrs ☐; 11-15 yrs ☐; 16-20 yrs ☐; Over 20 yrs ☐

Section Two: Task Performance

Please answer the following questions based on your understanding of the task.

1. In your words, please explain how the incident occurred.

2. *Based on your knowledge of the incident, in your opinion what can be done to avoid similar incidents in the future?*

Section Three: Cognitive Load Measurement

Please rate the cognitive load of the task based on a 5-point Likert scale: **1 = Very Low; 2 = Low; 3 = Neutral; 4 = High; 5 = Very High.**

Dimension	Question	Scale
Mental Demand	How mentally demanding was the task?	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
Temporal Demand	How temporally demanding was the task?	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
Performance	How successful were you in accomplishing what you were asked to do?	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
Effort	How hard did you have to work to achieve your level of performance?	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
Frustration	How insecure, discouraged, irritated, or stressed were you during the task?	☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5

What issues have you faced in understanding the incident case?

VITAE

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Date of Birth 2nd August, 1996
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Islamabad Pakistan

Academic Background

- Masters of Science (MS) in Construction Engineering and Management; King Fahd University of Petroleum and Minerals; Dharaan, Saudi Arabia.
- Bachelor of Science (BS) in Electrical Engineering (Electronics); Air University, Islamabad, Pakistan

Referred Journal

- Imtiaz, W., Khwaja, M., Tuffaha, F., A., Ghaithan, A. and Aziz, M (2024) Barriers to Learning from Incidents in the Construction Industry of Saudi Arabia

Papers Under Review