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Reducing Falls from Heights through BIM: A Dedicated System for Visualizing Safety Standards

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Abstract: Falls from height (FFH) are common safety hazards on construction sites causing monetary and human loss. Accordingly, ensuring safety at heights is a prerequisite for implementing a strong safety culture in the construction industry. However, despite multiple safety management systems, FFH are still rising, indicating that compliance with safety standards and rules remains low or neglected. Building information modelling (BIM) is used in this study to develop a safety clauses visualization system using Autodesk Revit's application programming interface (API). The prototype digitally stores and views clauses of safety standards, such as the Operational Health and Safety Rules 2022 and Introduction to Health and Safety in Construction by NEBOSH 2008, in the BIM environment. This facilitates the safety manager's ability to ensure that the precautionary measures needed to work at different heights are observed. The developed prototype underwent a focus group evaluation involving nine experts to assess its effectiveness in preventing FFH. It successfully created a comprehensive safety clause library that allows safety managers to provide relevant safety equipment to workers before work execution. It also enhances the awareness of construction workers of all safety requirements vis-à-vis heights. Moreover, it creates a database of safety standards that can be viewed and expanded in future by adding more safety standards to ensure wider applicability.

Keywords: falls from height; OSHA; health and safety in construction; BIM; application programming interface; safety clause

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1. Introduction

Despite having the potential for high financial returns, construction is one of the most hazardous industries. Falls from height (FFH) are a prevalent cause of serious injuries and fatalities to workers in construction [1]. Different practices, such as work-at-level (WaH) principles and other rules, have been created to oversee FFH incidents. However, such injuries are still occurring, highlighting the potential lack of implementation or negligence of such systems on construction sites [2]. According to Construction Fatality Assessment and Control Evaluation (FACE) database [3], between 1982 and 2015, 42% of deaths in the construction industry were related to falls. Similarly, in Great Britain alone, between 2013 and 2017, 49% of serious injuries were caused by FFH [4]. Such accidents were also responsible for 35% of fatal injuries in the United States (US) construction industry between 2010 and 2015 [5].

Fractures, trauma, contusions, concussions, and other short and long-term issues are some of the many physical and psychological injuries associated with FFH. Most injuries directly impact a worker's body, but a persistent impairment can also result in psychological issues. Such psychological concerns and stress are key reasons for the high suicide rate among construction workers [6]. Accordingly, it is no surprise that FFH is an area of serious concern for construction safety management professionals and researchers.

The traditional approach and conventional practices of the construction industry provide leniency towards safety practices on site where negligence takes the life of many. Recent research has focused on curbing the occurrence of FFH accidents by proposing prevention through design (PtD) [7] and collective protection equipment (CPE) [8]. Similarly, several safety practices have been adopted on construction projects, such as using railings, safety nets, scaffoldings, hole coverings, personal protection equipment (PPE), safety harnesses, helmets, etc. However, awareness regarding their usage remains minimal [9]. This must change in line with the ambitious goals of construction organizations, such as zero tolerance for safety negligence and zero injuries. Different techniques, such as encouraging safety culture in construction industry, transparency about accident numbers, emotional commitment, focusing on the workers' needs, feedback, awareness about the safety gear, and triggering collective behavior and responsibility are pivotal to realizing the zero injury goals [10,11].

The use of fall protection equipment is instrumental in tackling FFH concerns. Generally, such equipment is regulated by national laws and international safety standards. For instance, according to Occupational Safety and Health Administration (OSHA), all workers working at a height above two meters are prone to falls and must use PPE [12]. Regrettably, despite the legal stipulations in the national laws and international standards, workers rarely use PPE at heights mainly because of low safety awareness or discomfort while wearing the safety gear [2]. This trend is more pronounced in developing countries. Awareness and training can make the workers more comfortable and well-informed about using safety equipment at heights. However, in line with the essence of a genuine safety culture, safety must be prioritized and acted upon by everyone in the organization (from top to bottom). Therefore, it is essential to create a mechanism for the health and safety (H&S) managers to access international standards on safety at heights while visually monitoring all the workers' needs on the construction site through a dedicated system.

Accordingly, the proposed dedicated system aims to prevent FFH accidents by improving compliance with safety standards by making safety clauses visible in a digital and visual environment. The main aim of this study is to observe how the developed system can facilitate safety through BIM in preventing FFH. The study also analyzes if technology-based solutions can promote a safety culture and help H&S managers proactively manage CPE and PPE before work execution. Accordingly, when the safety standards are correctly understood and implemented, an industry-wide safety culture can be developed to prevent FFH accidents in the construction industry.

2. Theoretical Background and Research Gap

Despite the well-known importance of safety, construction worksite accidents are still prevalent, and the industry is far from achieving a zero-injury goal. Research has provided nuances in solving the issue of FFH, but it remains limited [13,14]. The existing body of research on FFH has mainly focused on its causal factors; however, no research has been conducted to digitalize safety standards and their clauses. Most researchers have developed new systems for FFH prevention (as shown later in the section). Still, the basics of complying with the already existing safety/clauses have been given little attention. Increasing the efficiency in understanding and implementing safety standards holds tremendous potential to prevent FFH and develop a holistic safety culture.

Research on FFH prevention and monitoring has been conducted by Zhang et al. [15], who developed an automated rule-checking framework that integrates safety into BIM and allows preventive detection of fall-related hazards to prevent falls, near-misses, and accidents. Tanvi et al. [2] identified technologies that ensured safety at heights and their application in the construction industry. The authors provided an in-depth understanding of how technology can prevent fall accidents. Another study conducted by Fang et al. [16] developed a computer vision-based approach for safety harness detection for workers at heights, ensuring on-site safety rules compliance and improving the safety culture.

Similarly, Chi et al. [17], through their coding system, classified fatal falls based on individual forces, work location, and other related factors to identify the major causes of increasing FFH accidents on construction sites. Huang and Hinze [18] used the OSHA database to investigate the prevalent causes of FFH and found human error and lack of safety measures as the leading causes [12]. Duncan and Bennett [19] suggested using both active and passive methods for safety at heights to control FFH proactively. Other researchers have explored numerous domains of construction safety management at heights, such as the safety behavior of workers [20], safety programs related to FFH [21], and the prevalence of safety culture [22].

Recently, the digitalization of construction safety has received greater attention. This is because the construction industry and the number of its workers have expanded. Therefore, the traditional form of safety management seems incapable and inadequate [23]. To cope with this expansion, the focus has shifted to the application of digital technologies for improving construction safety. Some of the research in this domain includes the use of computer and information technology (CIT), virtual reality (VR), BIM [24], knowledge-based systems [25], BIM-based hazard recognition and risk indicating system to prevent FFH [26].

Rey-Merchán et al. [9] used technology as a solution for preventing FFH. For this purpose, the authors proposed that technologies such as Bluetooth low energy devices (BLE) integrated with BIM, radio frequency identification (RFID), or the Global Positioning System (GPS) can drastically improve the effectiveness of monitoring approaches for reducing FFH. Similarly, RFIDs have been used to identify whether the workers are using adequate PPE [27], and ultra-wide band (UWB) technology has been applied to locate individuals and materials on site [28]. Similarly, the global navigation satellite system (GNSS) has been used to identify risk zones and the workers' location [29]. More recently, Gómez-de-Gabriel et al. [30] presented a sensor system based on BLE to detect the proper use of safety harnesses in workers.

The abovementioned studies have attempted to address the problem of FFH by developing proactive detection and monitoring mechanisms that can identify and locate safety mishaps at heights. New technologies such as computer vision-based approaches [16], RFIDs [27], and UWB [28], etc., relating to the detection and monitoring of workers for PPE, locating hazardous locations on site, and creating hazard recognition and risk indicating systems on construction sites have been introduced. In this context, the proposed study goes a step further and examines the safety standards perspective that has not been incorporated in previous studies. The proposed system can be a valuable plug-in to all the developed systems and will ease the process of determining what safety prerequisites are to be followed at any given height on a construction site. It will be displayed in a visual environment of BIM.

Despite the increase in studies on construction safety and the associated burden of fall accidents, the research on developing a BIM-based safety clause repository remains sparse [31,32]. Although different technologies have been used in many domains of safety management, limited work can be found on systems where safety clauses are visually accessible, easy to understand, and more functional. This gap is humbly targeted in the current study.

The system proposed in this study will have widespread applications. Firstly, the system can be used as a plug-in with other monitoring and detection systems for highlighting risk zones and relevant safety harnesses. In this case, the proposed system will assist H&S managers in highlighting the required PPE and CPE needed at a particular height as per selected safety clauses. Secondly, this technology, through its ability to make the safety clauses available by merely clicking on the required area of the model building, will further facilitate the understanding of safety clauses within an operational environment.

This study, therefore, aims to develop a system named Safety Clause Visualization System prototype (SafeCl) with the following key goals:

1. Creating an integrated visual platform where FFH risk zones can be marked and monitored.
2. Creating a visual repository for highlighting the corresponding safety measures at different heights as per OSHA and NEBOSH standards. This will ease the process of consulting safety clauses for heights by making it visually understandable and interactive.
3. Enabling H&S managers to determine the safety practices and training necessary for workers to work at heights. Against this aim, this research utilizes BIM as a decision support system (DSS) for safety managers on construction sites to make safety-related decisions.

To achieve these goals, the current study has the following objectives:

1. To enable H&S managers to ensure compliance with safety standards and prevent FFH by making all the relevant safety clauses of the selected safety standard available in a visual environment.
2. To digitalize safety standards information on a visual platform that is easy to understand and implement.
3. To enable the H&S manager to take proactive measures of making all the CPE and PPE required available to be used while working at a particular height on a day-to-day basis.

In this study, a comprehensive technology review was undertaken, and BIM was selected as a digitalization and visualization medium due to the following reasons:

- BIM is the most thriving technology within the construction industry, requiring beginner-level competency for its usage [33].
- BIM provides a virtual prototype giving 3D models of the building, which makes visualization of different areas of the building easy and viable.
- BIM aids in accumulating construction information and is viewed as a potential technology to improve construction safety management.

3. Materials and Methods

This research has adopted the methodology used by Ali et al. [31] as illustrated in Figure 1. Accordingly, the research was conducted in three steps.

1. A detailed literature review was conducted on construction safety and BIM through diverse literary databases (Scopus, Web of Science, Google Scholar, Refseek, Institute of Educational Sciences) from 1995 to 2022. Afterwards, official safety guides of two internationally used standards OSHA 2022 and Introduction to Health and Safety in Construction by NEBOSH 2008 [12,34 were consulted.
2. The next stage was based on the idea that BIM technology is the 'digital repository solution' that provides an API for developing plug-ins. Accordingly, this research used it to develop the plug-in of the proposed system named "SafeCl". The environment used to develop the plug-in consisted of Autodesk Revit Architecture (BIM Software), Visual Studio.net (Environment for Software Development), and Structured Query Language (SQL) (Database Management System). In addition, in the developed system, safety clauses from two safety standards OSHA 2022 [12] and Introduction to Health and Safety in Construction by NEBOSH 2008 [34], were integrated into a BIM environment by creating a library of standards using the SQL database. This database is linked with an FFH API to digitally show the safety

prerequisites at a defined height. The safety clause library can be expanded further in future by adding more safety standards.

3. Lastly, the proposed system (SafeCl) was evaluated and validated through an expert evaluation. It included nine experts from academia and industry. This step helped determine the effectiveness, compliance, limitations, and barriers to implementing the proposed system. This section explains the SafeCl from a user's perspective, which considers the role of the H&S manager, as shown in Figure 2.

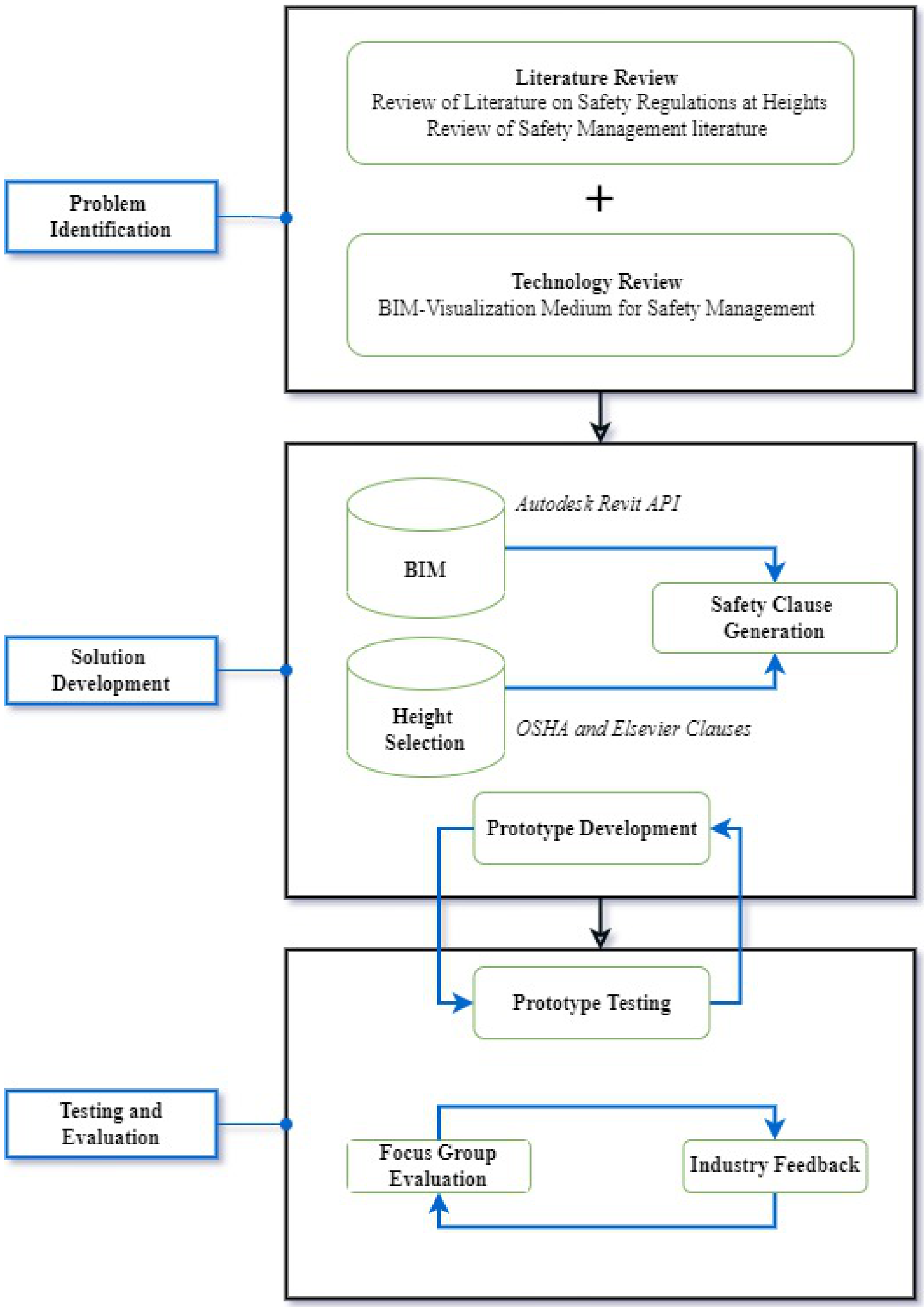

Figure 1. Research Design.

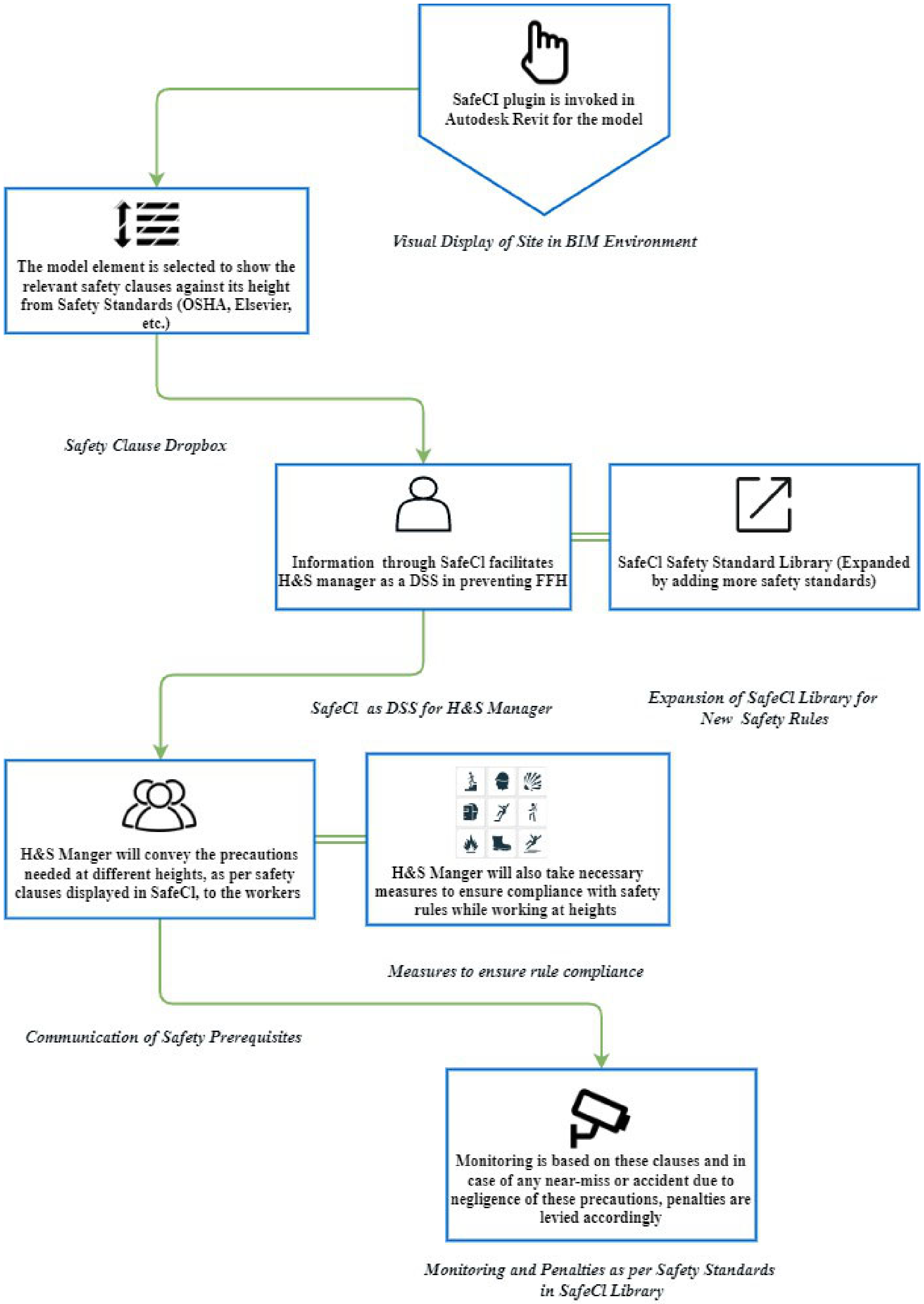

Figure 2. Working of SafeCl.

1. The H&S manager/user launches the SafeCl plug-in from Autodesk Revit User Interface (UI) to determine the safety equipment and arrangements needed at relevant heights for the project model.
2. On launching the SafeCl tab, a ribbon appears, displaying a library of different safety standards (OSHA and NEBOSH in this case), guidelines and clauses for working at a particular height. The safety standards library can also be expanded by adding

different safety standards in the library. This will enable the use of the proposed system across the board, where different safety standards are followed.

3. The H&S manager selects the model element (height from ground level), where the workers are supposed to work on the building model in BIM.
4. Based on the selected height, the SafeCl plug-in as a DSS suggests the detailed requirements of working at the desired height according to the chosen safety standard (OSHA or NEBOSH).
5. The H&S manager can then communicate the safety clauses to the workers and supervisors and ensure on-site compliance.

4. SafeCl Demonstration

The functionalities of the SafeCl are demonstrated in this section on a sample construction site. For this purpose, the built-in sample house model of Autodesk Revit Architecture is used. The ribbon in Figure 3 shows the SafeCl plug-in added in to Autodesk Revit. Figure 4 shows the selection of height elements by clicking on the wall. In this case, the wall is a first-level curtain wall. BIM model automatically detects the height of the wall due to its built-in attributes.

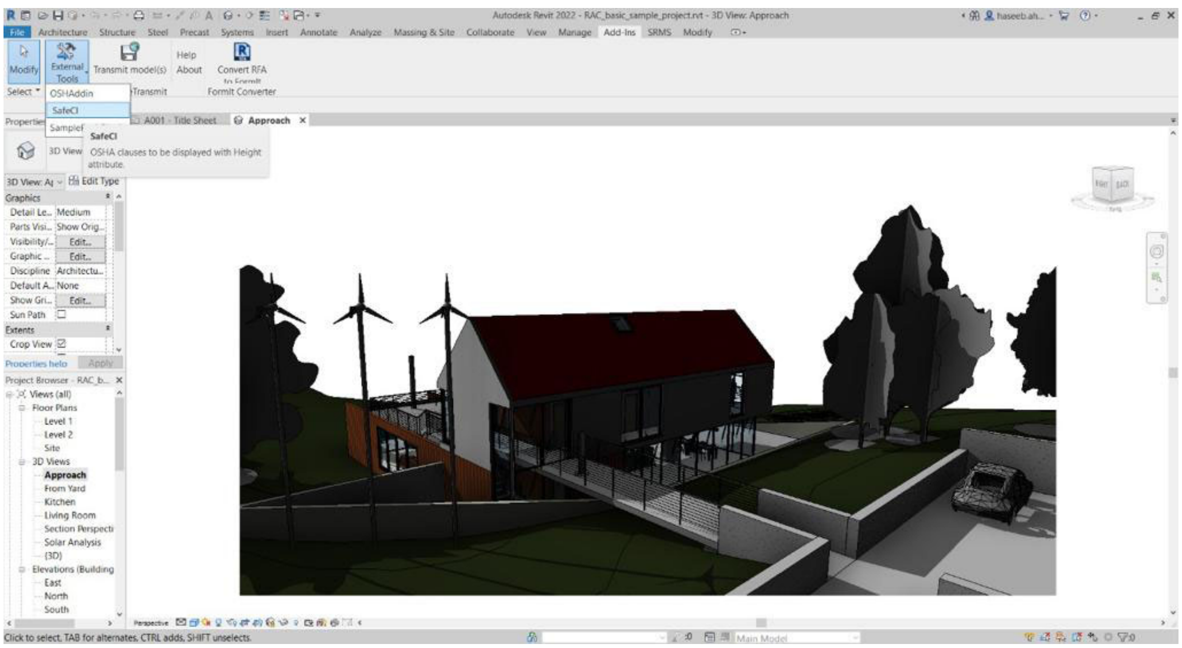

Figure 3. Plug-in in Autodesk Revit to Activate SafeCl Visualization System.

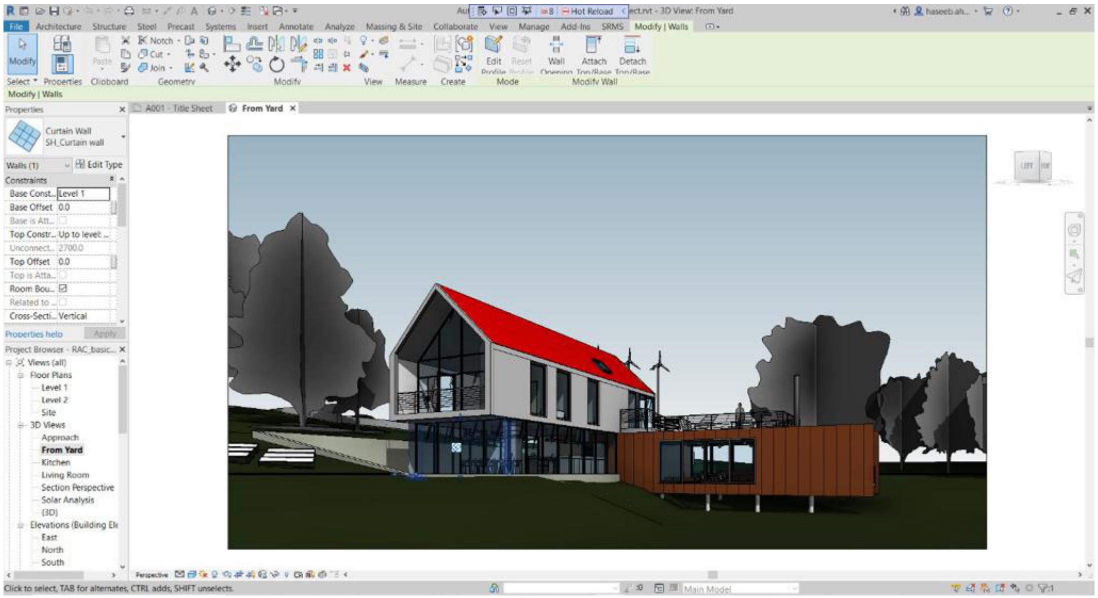

Figure 4. Selection of wall element along whose height the safety clauses are needed.

Figures 5–7 indicate safety clauses when different heights are selected. For example, to display the safety clauses from safety standards at the selected height, three random elements in the BIM model with different heights, i.e., more than 10 ft, more than 20 ft, and more than 25 ft, are selected (as shown in the selection of a wall in Figure 4). Corresponding outputs are shown in Figures 5–7. The displayed safety clauses include a combined result from the two selected standards (OSHA and NEBOSH).

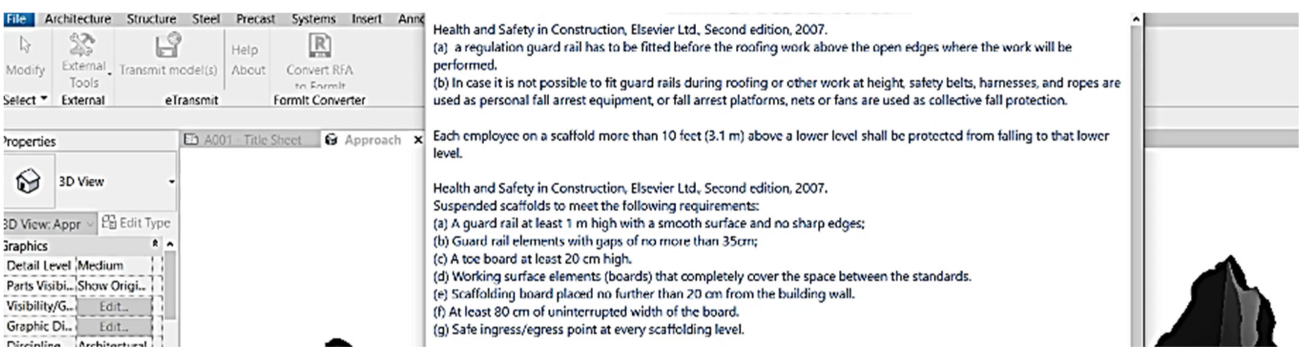

Figure 5. Display of OSHA and NEBOSH safety clause on more than 10 ft selected height.

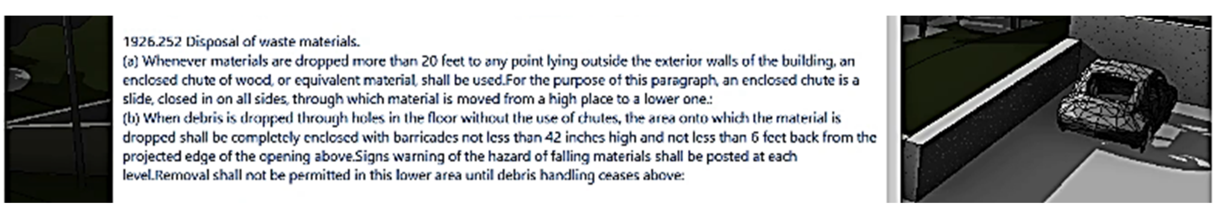

Figure 6. Display of OSHA and NEBOSH safety clauses on more than 20 ft Selected height.

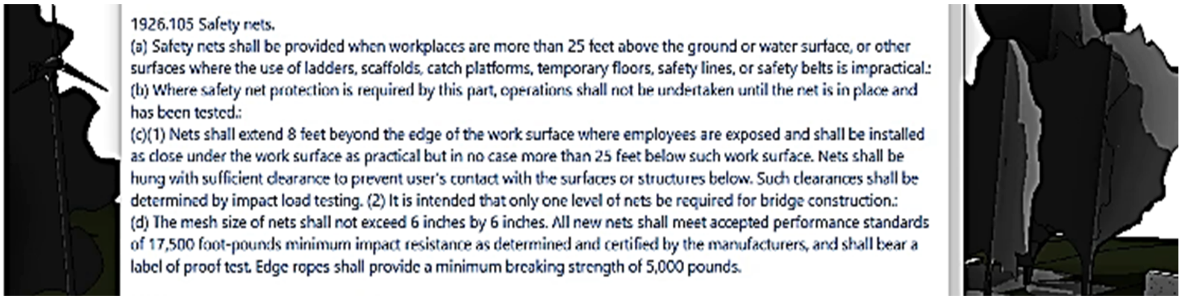

Figure 7. Display of OSHA and NEBOSH safety clauses on more than 25 ft selected height.

At more than 10 ft height, the drop box in Figure 5 suggests the relevant safety guidelines as per OSHA and NEBOSH. OSHA safety clauses suggest using safety nets and barricades. In comparison, NEBOSH safety clauses require suspended scaffolds with at least 1 m railing. In addition, the sub-clauses highlight other relevant requirements while working at a height of more than 10 ft. Similarly, as per the safety clauses at the height of more than 20 ft, NEBOSH suggests using guard rails/safety harnesses/ropes/belts, suspended scaffolds, and other personal and collective PPEs to tackle FFH (Figure 6).

Figure 7 shows the safety clauses regarding work at the height of more than 25 ft. At this height, NEBOSH clauses suggest using PPE and CPE, such guard rails, belts, harnesses, suspended scaffolds, and safety nets. OSHA standards require the use of temporary floors or safety lines. If installation of the floors is impractical, safety nets should be installed. The sub-clauses suggest the type of net to be used. Moreover, it suggests using temporary barricades if waste material is thrown from such a height. Collectively both standards provide best practices to tackle any FFH incident proactively.

This tool can be used in day-to-day task allocation in the construction industry so that the safety managers are abreast of all the safety requirements on site beforehand. As a result, the safety management team can use and recommend both CPE and PPE on the construction site to prevent injuries associated with FFH.

5. SafeCl Evaluation

The proposed SafeCl prototype was evaluated using a focus group. Focus groups are formulated in a qualitative research technique where a trained moderator interviews experts (six to eight generally) with similar subject backgrounds, demographics, or both [35]. This interview methodology was employed in this research because it fosters open communication among the participants and thus provides better insight into the thoughts and perspectives on projects and policies via dynamic interaction [35]. This, however, is unlikely in other types of interview techniques such as one-on-one interactions. The focus group technique provided our research with numerous outcomes; first, the relaxed environment allowed one participant's opinion to bring forth opinions from other participants; secondly, it enabled our research to gauge the opinions of our target market in several construction industries; and thirdly, the focus group allowed for the open discussion on issues that are not very common in other formal, structured interviews.

A focus group of nine safety experts was organized in this study to evaluate the developed system (SafeCl). A purposive sampling method was used to select the evaluating experts. The criterion for choosing the experts involved a minimum of ten years of experience in the construction industry or academia and being well versed with construction site safety, BIM, and safety clauses. Accordingly, six of the involved experts were from the industry, whereas three had a Ph.D. degree in construction safety management. There were two experts from Italy, Australia, and Pakistan, and three experts from Saudi Arabia. Because of COVID-19, the focus group session was conducted virtually using a zoom meeting that was not time bound and ended when consensus was reached. The following format was adopted for this focus group:

1. The proposed system was demonstrated to the participants with all the instructions and available functions.
2. A few safety clauses on different heights were randomly generated using a sample model in BIM to understand and visualize the clauses.
3. After the demonstration, the first author initiated and moderated the discussion to obtain the experts' feedback. Initially, the experts were asked about the benefits and effectiveness, barriers to implementation, and future improvements to the proposed system.

The experts' responses were recorded on a survey questionnaire that was shared with them before the evaluation session. These survey questionnaires had two primary purposes. First, to evaluate whether this proposed prototype provides a novel and feasible approach to solving issues of FFH on construction sites. Second, to analyze the effectiveness, limitations, and barriers to its implementation and how to overcome these barriers.

6. Results and Discussion

The focus group discussions were gauged on various parameters of the proposed prototype. These are discussed in the following sub-sections.

6.1. Potential of SafeCl System in Safety Management to Prevent FFH

After filling out the survey questionnaires, a focus group open-ended discussion was conducted where individual participants indicated their responses to the prototype under discussion, its novelty, and potential. The questions are listed in Table 1. The responses were scaled on a 5-point Likert scale. The responders specified their level of agreement to the given statements in five points: (1) Strongly disagree; (2) Disagree; (3) Neutral; (4) Agree; (5) Strongly agree.

Table 1. Experts' Opinions on the Novelty and Potential of SafeCl tool.

Posed Statement Description	Average Scores
Is the current/traditional form of safety standard information on FFH accidents in an understandable and integrated format?	2.1
Does the lack of understanding of safety clauses or guidelines adversely affect construction safety management in preventing FFH?	4.5
Should the safety standards' clauses be digitalized to improve construction safety management?	4.6
Will SafeCl improve the implementation of safety standards in construction projects?	4

The responses of the focus group to each statement were analyzed, and the average score, as shown in Table 1, was calculated. The results show a wider agreement on the issue of flawed safety management tools that have hampered safety, resulting in increased FFH incidents on construction sites. Most of the respondents agree that the safety standards and their information is not in an understandable format, indicating the need for an improved system to enable H&S managers to analyze and understand safety clauses. With an average score of 4.5, a wider agreement was observed on the lack of understanding of safety clauses that negatively impact safety management, leading to its failure to prevent FFH. Follow-up discussions suggest that this might arise due to traditional methods of keeping and analyzing all safety records in hard copies [36]. This results in a lack of, or a flawed, understanding of safety prerequisites to prevent FFH. To prevent this, Guo et al. [25] proposed that the visual safety data can be used as safety-related knowledge for future safety management. In line with the same argument, all the respondents strongly agreed that safety clauses must be digitalized to make them more accessible, understandable, and practical. Considering that FFH is a major cause of safety mishaps on construction sites, the focus group agreed that SafeCl could play a significant role in implementing safety rules on construction sites. The developed prototype was declared a useful digital platform that could aid safety managers in day-to-day activities where they have to make all necessary safety equipment available before task execution.

6.2. Effectiveness of SafeCl in Addressing Safety at Heights

The focus group's opinions were also gauged to assess the effectiveness of the SafeCl system in solving FFH issues, as indicated in Table 2. Research on safety management and FFH was consulted to show key issues in safety management to prevent FFH in construction. The opinions of focus group participants on how SafeCl can address these issues were captured accordingly. Table 2 indicates the average score assigned by focus group members to SafeCl on its effectiveness in solving the selected issues.

Table 2. Effectiveness of SafeCl system in solving problematic issues of safety management for FFH.

No.	Problematic Issues of Safety Management for FFH	Reference	Effectiveness Score for SafeCl
1	Flawed risk perception normalizing risk and forfeiting PPE	Areosa [37]	4.8
2	The social contagion effect of a supervisor's violation of safety rules on workers	Liang et al. [38]	4
3	No visualization tool for safety rules on heights	Rodrigues et al.[39]	4.9
4	Lack of safety training	Dawood et al.[40]	4
5	Inaccessibility of safety documents when needed	Martínez-Rojas et al.[41]	5
6	Poor communication of safety rules	MC Rey-Merchán et al. [9]	4.5
7	Lack of available safety utilities on site	Zou et al.[42]	4.8
8	Poor safety practices	Vitharana et al.[43]	5

As per the responses, the SafeCl can effectively end the trend of forfeiting PPE while working at heights. Often PPE is avoided by workers due to the inconvenience of wearing it while working at heights [44]. Moreover, the safety supervisors' negligence in terms of compliance with safety rules and prerequisites while working at heights is also a major problem resulting in FFH. The SafeCl tool mandates the need to comply with the safety rules to prevent FFH. It also makes the supervisor accountable by indicating the necessary equipment needed to ensure safety at height against each construction activity before its execution.

According to experts, if supervisors neglect the rules, it should lead to a penalty. The problem of social contagion also leads to violation of safety rules if the supervisor forsakes it. The clauses allocate roles and responsibilities to the manager and the workers through the proposed SafeCl system. With an average score of 4.9, the SafeCl system also meets the requirement for a safety standards visualization system that can make safety documents promptly accessible when needed. This tool will help eliminate the traditional pattern of neglecting or forsaking safety rules while working at heights. It will enable H&S managers/supervisors to ensure that all safety prerequisites such as CPE and PPE are in place before initiating work at heights. As per the focus group's reviews, this proactive approach will optimize safety management at heights [45]. Accordingly, the proposed SafeCl DSS was positively received by the focus group to solve some of the pressing issues of safety while working at heights [46].

6.3. Barriers to the Implementation of SafeCl System

The focus group also highlighted some barriers to implementing the developed SafeCl system that must be addressed before its industry-wide use to facilitate its holistic adoption. The hurdles included affordability, poor network availability/coverage, lack of adaptation to new technology in the construction industry, and lacking seriousness about safety culture on construction sites (Table 3). These concerns were particularly highlighted by the industry experts who had relevant experience of the construction site working environment. The respondents highlighted that as most sites are in remote areas, internet accessibility is a problem. More so, a high number of respondents also showed the attitude of construction workers toward safety which often becomes a hurdle in the true implementation of any safety system. Similarly, the problem of affordability of the system was brought up, along with the training needed for the H&S managers, the lack of adaptability in the industry [47], and the lack of BIM knowledge [48,49].

Table 3. Barriers to Implementing SafeCl.

Barriers	Key Comments	Number of Respondents
Affordability	"Proper training would be required to use SafeCl that may require an organization to invest significantly in PPEs, CPEs and training of the workers."	3
Network Availability/Coverage	"Network would be required all the time to view the safety clauses on BIM environment that would aid H&S managers in creating a safe working environment at heights."	4
Adopting a New System	"The construction industry is highly resistant to adopting new technologies and changes."	3
Lack of BIM Knowledge	"It is difficult to convince each worker to learn BIM, associated technologies and report every event, especially on large construction projects."	4
Attitude Towards Safety	"Construction industries (especially in developing world) have a very casual attitude towards safety culture and do not consider it as something important."	5

The highlighted barrier to affordability can be addressed on the premise that damage after a safety incident due to FFH takes more human and material resources following the concept of "a dollar spent now on compliance saves 10 in discovering the issues and 100 in addressing them a later stage". The training cost for the workers to use safety tools while working at heights is less than the post-accident medical expenses and impacts on organizational reputation. This is the era of proactive decision-making where resource management and its proper distribution in the safety training domain have numerous payoffs in the form of reduced human and material loss on the worksite [50,51]. More so, each construction company allocates a significant budget to the H&S department to proactively manage and prevent safety mishaps [52] and FFH accidents. Therefore, the proposed SafeCl can provide a viable instrument to ensure the best safety practices and rule adoption while working at heights.

Regarding the second concern "lack of network availability/coverage", most construction companies have 24/7 access to the internet to view applications such as SafeCl. Therefore, if there is a problem with the network, construction companies can allocate budget for it to keep the network running, at least when the H&S manager views the day task and its related safety clauses.

The issue of lack of adaptability of the new system and lack of knowledge of BIM can be addressed by training the personnel dealing with the SafeCl tool and modifying it as per the organization's needs to enhance implementation. Further, the developed SafeCl system requires beginner-level skills to operate and execute, and no excessive expertise or programming experience is needed. Although the construction industry lacks an attitude toward a safety culture, this implementation will materialize with time and concentrated efforts. Nevertheless, systems such as SafeCl will compositely develop a safety culture in the industry in the long run if they are properly implemented. This will help facilitate and encourage a robust safety culture in the construction industry.

SafeCl can be used widely in the construction industry's H&S department. It will assist the H&S manager in understanding and implementing safety guidelines within construction setups. Additionally, it will also aid the workers in understanding the safety requirements while working at a particular height by merely clicking at that height in the absence of the H&S manager. Hence, it will simplify the understanding and adoption of safety clauses while working at heights and help implement a holistic safety culture across organizations.

7. Conclusions and Recommendations

This research proposed and explored the benefits of a digitalized safety management system to curb the increasing number of safety incidents, especially FFH, due to poor safety practices and a lack of usage of both CPE and PPE. This research addresses safety concerns in various ways. Firstly, it digitalizes safety management standards that will reduce the overlapping of information by creating a permanent repository accessible anywhere and anytime to the supervisors, H&S managers, and other relevant personnel. Secondly, it enables the decision-makers to grasp the long safety reports based on various standards. Such standards that are too diverse and vague are simplified through digitalization in BIM, so that only height-relevant clauses of the selected safety standard are shown. Finally, SafeCl database can be created within the BIM environment in an organized and updated format, unlike the traditional manual safety management format where standards are present in the shape of long reports in hard copies and often not followed meticulously. SafeCl's visual interface provides a prototype for viewing the safety standards necessary while working at different heights. It addresses the issues of traditional safety management through digitalizing and invigorating the safety management process at heights by proactively tackling the issue of FFH.

An additional positive spillover of the SafeCl system is embedded in the way it sensitizes safety management within the construction hierarchy. Moreover, it is observed that the development of a BIM-based API empowers key stakeholders to implement the safety rules and make effective and timely decisions. Also of significance is that human and material resources can be efficiently utilized. The developed BIM-based safety clause visualization system (SafeCl) improves safety management by making it easy to understand and implement international and national safety rules and standard operating procedures through digitalization. To enrich the substance and results of the SafeCl, some future improvements as shown in Table 4.

Table 4. Future improvements in SafeCl.

Area	Recommendations Suggested
Integrating SafeCl with other plug-ins	This system provides rich information and management of safety clauses for working at different heights. It will be interesting to integrate it with other systems that promote a safety culture to prevent FFH.
Safety best practices forums	The system can, side by side with safety standards, include safety best practices while working at heights, enriching the safety management guidelines for different construction industries across the board.
Diverse safety standards	The system can use different safety standards making it feasible to be used by any country or construction industry.

In future, this work can be expanded further to include the prescribed dimensions of the SafeCl system. The integration of SafeCl with other plug-ins in BIM concerning safety management can improve the safety management regime in construction management. Further, including best practices alongside safety standards can strengthen safety measures required at heights to prevent FFH. The proposed SafeCl system's library can be expanded to include as many safety standards as needed. These can be a departure point for future work on the SafeCl visualization system.

Moreover, spatial location-tracking technology can be integrated with BIM to obtain better location-based information virtually to see if there is any violation of the safety clauses while the workers are at heights. The prototype can also be enhanced and developed into a knowledge-based DSS that can be more effective and supportive for the decision-makers to decide on the critical safety violation situations in augmented realities or metaverse environments. This will help safety personnel visualize hazardous events and proactively tackle them by taking relevant corrective actions, minimizing the odds of future occurrences.

SafeCl is not colossal or a perfect solution, thus it has certain limitations. One major limitation is that it does not ensure compliance with the safety clauses by monitoring safety violations on site. Further modification of this study can include monitoring mechanisms that can visually indicate the violation of the safety clauses by the construction workers. Moreover, the recommendations from the prototype evaluation, as given in Table 4, can be realized to enhance the effectiveness of SafeCl. In the next phase of this study, the application of SafeCl will be carried out on a real construction project, and additions/modifications proposed by industry experts will be incorporated to develop an improved plug-in that addresses any further lacunae in the prevention of FFH.

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