Transforming Construction with Off-site Methods and Technologies - TCOT 2026 Conference

August 18-20, 2026, Newcastle upon Tyne, UK

VR AND BIM INTEGRATION FRAMEWORK FOR H&S MANAGEMENT DURING DESIGN PHASE

Sanal Kumar Sindhujadevi, Anurag[1,*], Suliman, Alaeldin[1], and Razavialavi, Seyedreza[2]
[1] School of Architecture and Built Environment, Northumbria University, UK
[2] Arcadis Ltd., Canada
[*] anuragofficial101@gmail.com

Abstract: The construction industry faces high rates of accidents and injuries due to traditional risk identification methods, such as 2D drawings, manual inspections, and reactive assessments during construction, which hinder early hazard detection and multi-disciplinary collaboration. Despite the potential of Building Information Modelling (BIM) and Virtual Reality (VR) to improve health and safety (H&S) management, their integration for proactive design-phase applications remains underexplored. This study develops and validates a BIM–VR workflow for early H&S hazard identification and management. Adopting a pragmatic philosophy and abductive mixed-methods approach, a literature review identified gaps in existing frameworks, informing workflow design using tools like Revit, Enscape, Navisworks, Vrex, and Autodesk Construction Cloud. The workflow was implemented on an anonymized real-project BIM model. Quantitative validation against the construction-phase risk register showed over 80% of hazards were identified proactively. Qualitative assessment confirmed enhanced clarity and coordination in safety information. The BIM-VR workflow advances design-phase H&S by enabling immersive hazard review, metadata integration, and collaborative issue resolution, offering a replicable solution aligned with digital construction practices.

Keywords: VR; BIM; Health AND Safety

1 INTRODUCTION

The construction industry is a major contributor to economic development but remains one of the most hazardous sectors due to the complexity of projects and the involvement of multiple stakeholders. Construction activities continue to experience a high number of accidents, injuries, and fatalities worldwide, highlighting the importance of effective health and safety (H&S) management practices (Sidani et al. 2022). In Great Britain, construction accounts for a considerable number of work-related deaths each year, with common causes including falls from height, being struck by moving objects, and structural collapses (HSE, 2025). Many of these incidents are associated with insufficient planning, poor visualisation of site conditions, and limited coordination among project stakeholders; traditionally, safety planning relies on manual assessments, fragmented documentation, and two-dimensional drawings, which limit the ability of project teams to visualise hazards and coordinate safety planning effectively (Sidani et al. 2022). Although BIM improves design coordination and information management, identifying hazards from static 3D models alone remains challenging because safety risks often depend on spatial awareness and contextual understanding of construction processes. As a result, safety management in many projects remains reactive, with hazards identified during construction rather than addressed proactively during design.

In recent years, several digital technologies have been introduced to improve construction safety performance, including Virtual Reality (VR), Building Information Modelling (BIM), unmanned aerial vehicles (UAV), laser scanning, and sensor-based systems (Haupt et al. 2019). Among these, BIM has become widely adopted as a digital representation of the physical and functional characteristics of a facility, enabling improved collaboration, information management, and decision-making throughout the project lifecycle (NBIMS, 2013). However, its application for health and safety management (8D BIM) remains comparatively underexplored (Getuli et al. 2020). At the same time, immersive technologies such as VR are increasingly used in the Architecture, Engineering, and Construction (AEC) industries for design review (Zhang et al. 2020). This technology allows stakeholders to explore virtual construction environments and gain improved spatial understanding of projects before construction begins. Despite these advancements, the integration of BIM and VR specifically for proactive H&S management during the design phase remains limited (Getuli et al. 2022).

Integrating VR with BIM provides an opportunity to overcome these limitations by enabling immersive interaction with digital models and improved visualisation of potential hazards. Furthermore, once hazards are identified, current practices often lack systematic frameworks for assigning, tracking, and resolving these issues collaboratively among stakeholders (Hoeft and Trask 2022). The absence of frameworks and standardised processes for integrating safety information across disciplines can therefore result in fragmented communication and delayed risk mitigation (Amiri 2022).

Recent research has explored the use of digital technologies such as BIM, VR, augmented reality, and visualisation tools to enhance H&S management. BIM provides a model-centric platform capable of storing geometric and non-geometric information; enabling the transfer of safety-related knowledge across project phases (Hoeft and Trask 2022). Model-based analysis and rule-based safety checking have also been proposed to support hazard identification during design (Getuli et al. 2021). Meanwhile, VR enhances spatial awareness and allows stakeholders to explore construction environments virtually, improving the identification of safety risks (Zhang et al. 2020). However, their practical implementation remains limited, with applications often restricted to safety training or construction-phase monitoring rather than systematic safety planning (Akinlolu et al. 2022).

BIM-VR applications such as design review, workspace planning, and safety training simulations have demonstrated improved visualisation and stakeholder understanding of construction environments (Getuli et al. 2020). Nevertheless, most frameworks focus on construction-phase activities and rarely address proactive hazard identification during the design stage. In addition, many VR platforms primarily utilise geometric BIM models and do not fully exploit safety-related metadata embedded within BIM environments (Sidani et al. 2020). Consequently, despite the recognised potential of BIM and VR technologies, there remains limited evidence of structured workflows that integrate immersive visualisation with model-based information management for early hazard identification and collaborative issue management.

Therefore, this research aims to develop and validate a structured framework that integrates BIM and VR to support proactive H&S management during the design phase of construction projects. Accordingly, the study seeks to (1) review existing H&S management frameworks and identify their limitations; (2) analyse current BIM and VR technologies that support safety management; and (3) develop and validate a BIM-VR integrated framework for early hazard identification and collaborative issue management.

This paper is structured as follows: Section 2 presents the BIM-VR framework development; Section 3 reports results from verification and validation using a real project BIM model; Section 4 discusses findings in relation to existing literature; and Section 5 concludes with contributions and future research directions. The framework was evaluated using construction risk register data, expecting to demonstrate improved early hazard identification and multidisciplinary coordination.

2 BIM–VR FRAMEWORK DEVELOPMENT AND VALIDATION

This study adopts a pragmatic research philosophy and abductive mixed-methods approach, using literature review to identify H&S framework gaps and inform workflow design. The framework was developed and tested using an anonymized real construction project featuring a mature federated BIM model (LOD 400) and diverse stakeholders including designers, safety officers, and contractors. Five VR review sessions were conducted with 12 participants to identify hazards, which were then compared quantitatively against the project's construction-phase risk register (n=34 hazards) and assessed qualitatively for issue clarity and coordination improvements. This approach ensures both theoretical grounding and practical replicability across digital construction workflows. The following sections provide more details.

2.1 Five-Stage BIM–VR Workflow

The BIM–VR framework integrates design-phase H&S management through five stages: (1) Model preparation, (2) VR hazard identification and metadata, (3) Issue creation, and (4) Collaborative review/resolution. The proposed BIM–VR integration workflow is illustrated in Figure 1.

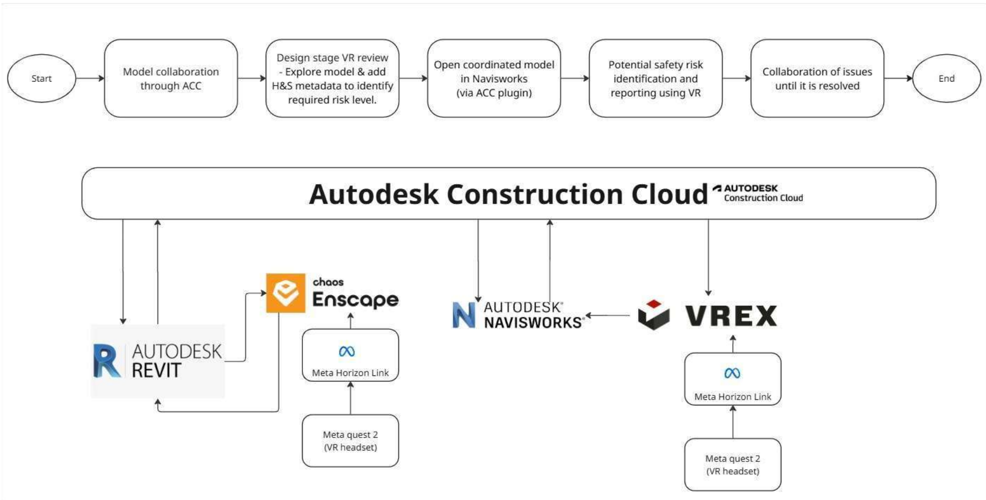


Figure 1. Proposed workflow

2.2 Model Preparation

The process starts with model collaboration via Autodesk Construction Cloud (ACC), acting as the Common Data Environment (CDE) for project information sharing, issue tracking, and reporting (Bello and Moreno, 2020). Revit models from all trades are synchronized into ACC, enabling coordinated model access across platforms such as Navisworks and Vrex. Version control, permissions, and metadata alignment ensure traceability and support communication of hazards, countermeasures, and design decisions from design to construction stage. ACC provides a structured ecosystem to maintain the VR–BIM workflow as part of formal H&S processes.

2.3 VR Hazard Identification and metadata

Revit and Enscape, coupled with the Meta Quest 2 VR headset, enable immersive hazard identification. Revit allows incorporation of geometric and non-geometric metadata, while Enscape converts the model into a navigable VR environment. Project-specific hazards such as fall protection, fire risks, and maintenance requirements are tagged and differentiated based on severity using metadata, and spatial configurations, access routes, and lifting paths are reviewed. Immersive VR walkthroughs allow H&S professionals to prioritize hazards, ensuring proactive mitigation during design rather than reactive identification during construction (Balin et al. 2024).

2.4 Issue Creation

Navisworks integrates multidisciplinary models for consolidated analysis of hazards. Federated models imported via ACC enable creation of filtered views, section cuts, and hazard-based colour coding (high, medium, low) using metadata. This structured preparation links VR-identified hazards to digital records, enhancing traceability and enabling focused risk review.

Vrex, a multi-user VR platform, enables collaborative hazard review and reporting. Models exported from Navisworks to ACC are accessed in Vrex, where hazards are identified, annotated with screenshots and positional coordinates, and discussed by multiple stakeholders. Issues created in VR are synchronized back to ACC and Navisworks, embedding the immersive review within the formal H&S management workflow.

2.5 Collaborative Review and Resolution

ACC facilitates assignment, tracking, and resolution of hazards. Issues are filtered by location, responsible party, priority, or status. Designers update models to mitigate hazards, resynchronize with ACC, and re-review. Issues are closed once mitigation is confirmed, ensuring transparency, accountability, and traceability throughout the design-phase hazard management cycle.

2.6 Workflow Implementation and Validation

The workflow was tested using a live construction BIM model. Shared Revit parameters (Table 2) covered major H&S risks. The model was federated in Navisworks, reviewed in Vrex, and tracked in ACC, demonstrating the complete digital loop. Issues were monitored, updated, and closed following mitigation, completing the digital loop from identification to resolution. The risk and its associated Revit parameters and assigned categories are shown in Table 1.

Table 1: H&S hazards & Shared parameters

No.	H&S risk	Revit parameters	Assigned categories
1	Fall Protection	Fall_Risk_Level, Work_At_Height_Required, Safe_Access_Method, Edge_Protection_Required, Installation_Height_m	Floors. Roofs, Stairs, Ramps, Railings, Structural Framing, Structural Foundation
2	Slips Trips	Temporary_Surface_Hazard, Drainage_Requirement, Pedestrian_Route_Impact, Surface_Finish_SlipRating	Floors, Ramps, Stairs, Topography, Roofs (walkable roofs)
3	Manual Handling	Component_Weight_kg, Team_Lift_Required, Mechanical_Lift_Necessary	Structural Framing, Structural Foundations, Mechanical Equipment, Plumbing Fixtures, Electrical Equipment, Generic Models
4	Hazardous Substances	Hazardous_Material_Flag, COSHH_Category, Cutting_or_Sanding_Required, Extraction_Needed, Respiratory_PPE_Level	Walls, Floors, Roofs, Ceilings, Generic Models, Mechanical Equipment
5	Struck By Moving Objects	Overhead_Work_Risk, Hoisting_Required, Critical_Lift_Component	Structural Framing, Structural Foundations, Mechanical Equipment, Electrical Equipment, Generic Models
6	Long Term Health	Noise_Emission_Level_dB, Vibration_Level_ms2, Safe_Maintenance_Clearance_mm	Mechanical Equipment, Electrical Equipment, Plumbing Equipment, Duct Accessories, Pipe Accessories
7	Coordination Design Quality	Design_Clarity_Level, Coordination_Risk_Index, Information_Complete	Generic Models, Structural Framing, Walls, Floors, Mechanical Equipment
8	Existing Building Renovation	Existing_Building_Present, Hidden_Services_Risk, Asbestos_Likelihood	Walls, Floors, Ceilings, Structural Framing, Structural Foundations
10	Periodic Replacement	Periodic_Replacement_Required, Replacement_Interval_Years	Mechanical Equipment, Electrical Equipment, Plumbing Equipment, Lighting Fixtures, Specialty Equipment
11	Periodic cleaning	Periodic_Cleaning_Required, Cleaning_Access_Method	Windows, Curtain Panels, Roofs
12	Flooding Risk	Flooding_Risk_General. Roof_Flooding_Risk	Roofs, Floors, Topography, Site, Structural Foundations
14	Structural Protection	Structural_Protection_Required	Structural Framing, Structural Foundations, Walls, Floors
15	Access Protection	Access_Protection_Required, Suicide_Mitigation_Considered	Floors, Railings, Walls, Curtain Panels, Windows

16	Ground Conditions	Ground_Gas_Risk, Piling_Gas_Release_Risk	Structural Foundations, Topography, Site, Generic Models
18	Temporary Works Equipment	Temporary_Works_Required, Temporary_Equipment_Stability_Critical	Generic Models, Structural Framing, Structural Foundations, Site

3 RESULTS

The BIM–VR workflow was implemented on a live construction project BIM model (LOD 400) and validated The BIM–VR workflow was implemented and evaluated on a live construction project BIM model (LOD 400), directly testing the five-stage framework from Section 2 against the construction-phase risk register (n=34 hazards). Results are organized by verification (technical functionality) and validation (hazard identification effectiveness), confirming all three research objectives.

3.1 Verification: Technical Integration

Verification confirmed the workflow operates as intended without interoperability issues, as designed in Section 2. 3D models and metadata transferred seamlessly from Revit to ACC, Navisworks, and VR platforms. Safety data remained visible in VR and Navisworks, supporting risk identification across all stages. Issue creation and management through Vrex, Navisworks, and ACC functioned seamlessly. The Meta Quest 2 headset provided stable immersive navigation, and Enscape and Vrex operated reliably. This demonstrates the workflow functions as an integrated system rather than fragmented components.

3.2 Validation: Hazard Identification Effectiveness

Validation assessed the workflow's ability to identify design-phase hazards compared to the construction-phase risk register (see Table 3). The register documented 34 hazards identified during construction, of which 28 were identified proactively through the VR-BIM workflow, yielding an **82.35% identification rate.

Table 3: validation results

Performance Metric	Result	Details
Total register hazards	34	Construction-phase ground truth
VR-BIM identified	28	Design-phase proactive detection
Identification rate	82.35%	High success rate
Missed hazards	6	Ground conditions (n=3), logistics (n=3)

Some hazards, such as unforeseen ground conditions and construction delivery risks, were not captured. Quantitatively, the workflow successfully identified the majority of hazards, and qualitatively, the issues contained more detailed information than the risk register, supporting clearer coordination and resolution. The results confirm the workflow is practically applicable for real projects, enhancing early hazard identification and improving H&S information clarity and collaboration.

Qualitative improvements confirmed enhanced clarity and coordination: (1) VR issues included screenshots, 3D coordinates, and element links (vs. register's text-only format). (2) Multidisciplinary assignment via ACC reduced coordination delays. (3) Design mitigations implemented pre-construction, avoiding costly change orders.

3.3 Key Workflow Outputs

The results directly confirm the three objectives from the Introduction: (1) Existing frameworks are limited as they demonstrate limitations of reactive frameworks vs. proactive digital approach. (2) BIM/VR underutilized for H&S; the workflow demonstrates full integration potential. (3) The developed framework validates at 82.35% effectiveness with superior issue management.

Figures 2-5 illustrate workflow execution across stages. Table 2 documents shared parameters enabling metadata persistence. The workflow demonstrated proactive, collaborative, and traceable design-stage H&S management, confirming practical applicability for real projects.

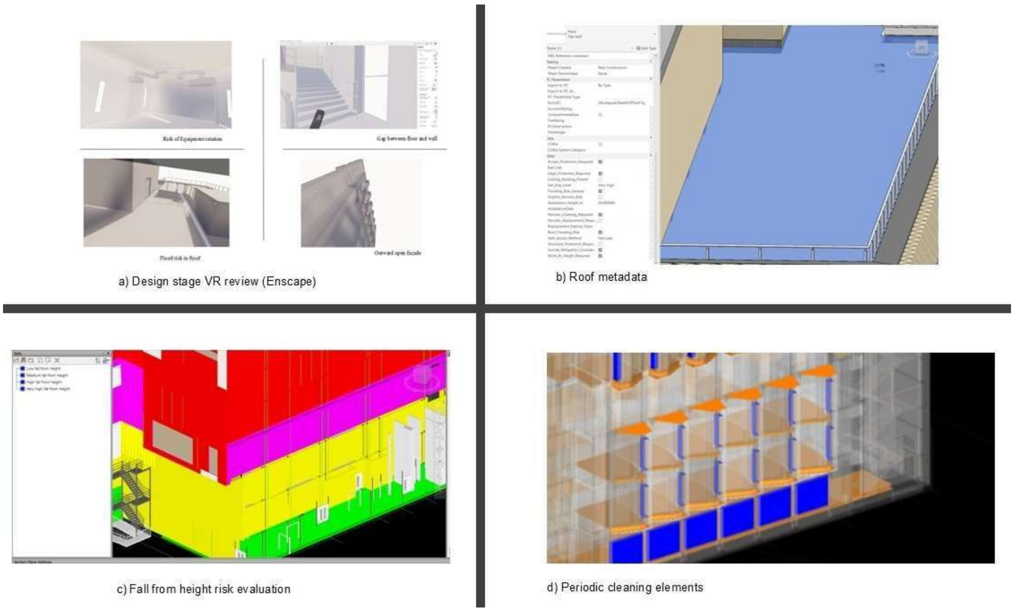


Figure 2. Setting up of model for Hazard identification

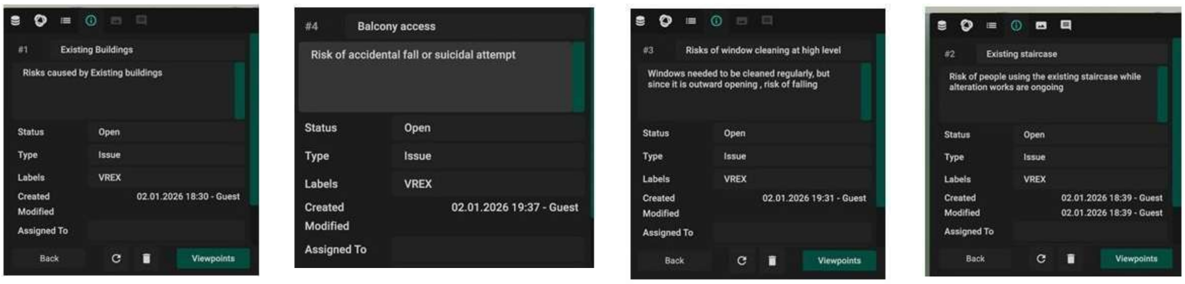


Figure 3. Hazards identified in Vrex and details

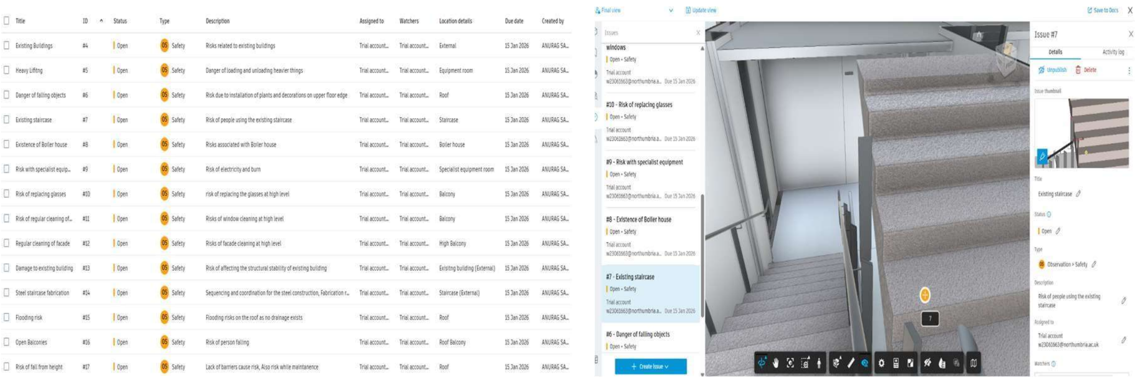
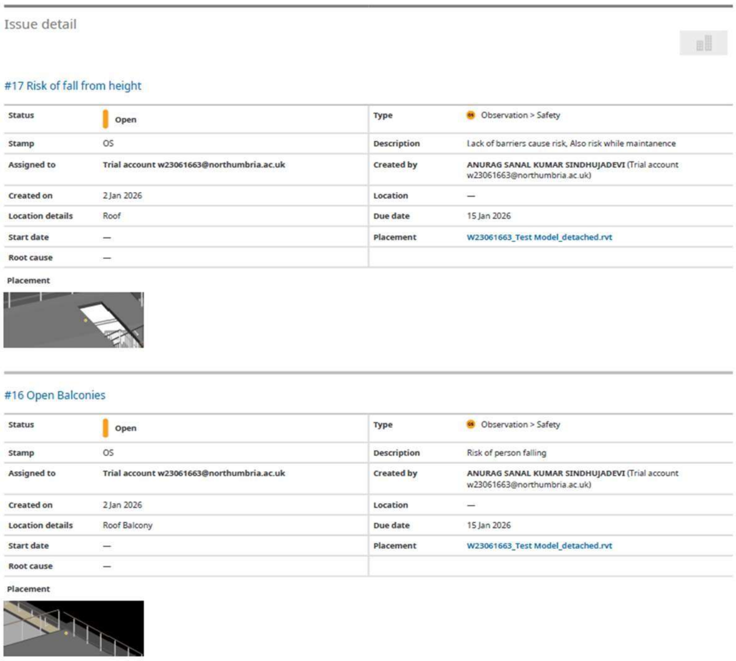


Figure 4. Generated issues in ACC



Issue detail

#17 Risk of fall from height

Status	Open	Type	Observation > Safety
Stamp	OS	Description	Lack of barriers cause risk, Also risk while maintanence
Assigned to	Trial account w23061663@northumbria.ac.uk	Created by	ANURAG SANAL KUMAR SINDHUJADEVI (Trial account w23061663@northumbria.ac.uk)
Created on	2 Jan 2026	Location	—
Location details	Roof	Due date	15 Jan 2026
Start date	—	Placement	W23061663_Test Model_detached.rvt
Root cause	—		

Placement

#16 Open Balconies

Status	Open	Type	Observation > Safety
Stamp	OS	Description	Risk of person falling
Assigned to	Trial account w23061663@northumbria.ac.uk	Created by	ANURAG SANAL KUMAR SINDHUJADEVI (Trial account w23061663@northumbria.ac.uk)
Created on	2 Jan 2026	Location	—
Location details	Roof Balcony	Due date	15 Jan 2026
Start date	—	Placement	W23061663_Test Model_detached.rvt
Root cause	—		

Placement

Figure 5. ACC issue report screenshot

4. DISCUSSION

The results (as in Section 3) confirm the three research objectives. This discussion analyses their implications for H&S practice and positions the workflow against existing frameworks and tools.

4.1 Limitations of current frameworks

Current frameworks rely on individual experience and 2D drawings for hazard identification, creating inconsistencies and limiting spatial visualisation. Although regulatory standards define stakeholder responsibilities, they lack operational guidance for design-stage proactive risk assessment. Trade-separated safety management causes fragmented communication, duplicated assessments, and overlooked hazards in complex projects.

The findings confirm frameworks prioritise compliance over proactive planning. Manual inspections and poor collaboration restrict early hazard detection, with many risks discovered during construction when mitigation is costlier. The construction phase risk register is presented in Table 4.

4.2 BIM and VR Tools for H&S Management

BIM adoption focuses mainly on scheduling, design coordination, and clash detection, with safety applications limited despite capabilities for structured H&S metadata and information transfer across phases. The key limitation is absent safety parameters, underutilising BIM models for proactive hazard identification.

VR provides complementary immersive spatial awareness, enabling full-scale hazard detection beyond 2D drawings and improving communication for non-BIM experts. However, VR remains confined to training and presentations, lacking BIM metadata integration for systematic analysis.

The findings confirm BIM (structured data) + VR (spatial understanding) integration overcomes individual limitations, enabling effective early hazard identification and management as demonstrated by the 82.35% validation rate (Section 3).

4.3 BIM–VR Integrated Workflow

The proposed BIM–VR workflow addresses limitations of existing frameworks and tools through structured digital processes. By embedding hazard-related metadata within BIM models and enabling immersive VR exploration, it supports proactive hazard identification during the design phase rather than reactive detection during construction. A key contribution is shifting safety decision-making from construction sites—where simultaneous activities complicate mitigation—to the design stage, enabling safer adjustments that reduce delays and costs.

VR walkthroughs simulate site visits, with two review cycles enhancing effectiveness: the first supports trade-specific metadata population, while the second enables multidisciplinary evaluation of combined risks. Integration with Autodesk Construction Cloud (ACC) centralises coordination, reducing fragmented trade communication through controlled model and issue sharing. Navisworks enables metadata-based filtering for hazard-specific analysis beyond geometric VR visualisation, while the Meta Quest 2 headset provided stable immersive navigation. Collaborative VR reviews improved communication for non-BIM experts, facilitating mitigation discussions.

Importantly, the framework leverages existing industry-standard tools (Revit, Navisworks, ACC), ensuring immediate practicality and adoption potential within current construction practices.

4.4 Verification and Validation Outcomes

The verification confirms the technical integration promised in Section 2, with model geometry and safety metadata transferring seamlessly across Revit, VR, and ACC platforms without interoperability issues—addressing the framework fragmentation identified in 4.1.

Validation provides empirical proof of the workflow's effectiveness (4.3), detecting 28/34 hazards (82.35%) from the construction-phase risk register. Three missed hazards (ground conditions, logistics) highlight model scope limitations, suggesting site context integration as future enhancement.

Qualitative benefits validate the BIM-VR synergy from 4.2: workflow issues included images, 3D coordinates, responsible parties, and due dates—far richer than traditional registers. This enhanced detail improves traceability and communication, directly overcoming the siloed trade practices noted in 4.1. The results demonstrate practical superiority for proactive design-stage H&S management.

5. CONCLUSION

This study addressed the H&S framework limitations (Section 4.1) and BIM/VR underutilisation (4.2) through the five-stage BIM–VR workflow developed in Section 2. Validated on a live project (Section 3), the workflow achieved 82.35% hazard identification during design, confirming its effectiveness for proactive risk prevention over reactive construction-phase detection. The workflow contributions (4.3) demonstrate how BIM metadata + VR immersion within Autodesk Construction Cloud overcomes fragmented trade communication and 2D drawing limitations. Verification (4.4) confirmed seamless technical integration, while qualitative improvements—richer issues with screenshots, coordinates, and assignments—enhance transparency and collaboration beyond traditional risk registers. The study advances digital construction safety by providing an industry-practical, empirically validated framework using existing tools (Revit, Navisworks, ACC). Limitations include single-project scope, model scope (missed site logistics) and not considering the dynamic changes of site condition. Future work should validate across multiple projects and integrate site context, mixed reality, and AI-driven hazard detection.

Table 4. Construction phase risk register

Design Element	Hazard	Risk	Risk Level	Controls / mitigation / action
Ground Conditions	Unforeseen ground conditions prior to receiving surveys	Risk of discovery of hazardous materials such as asbestos or others	H	Complete all ground conditions surveys prior to commencing relevant packages
Existing Buildings	Unforeseen problems with existing building/s fabric, upgrades, layout etc	Risk of discovery of hazardous materials such as asbestos or others	H	Complete all surveys prior to commencing relevant packages
Site	Problems working on constraint site within busy city environment and surroundings	Risk of injury and danger to people working or passing by the site	M	Plan and program activities in great detail and include the necessary fallback positions
Site	Danger of construction deliveries during enabling works and main works	Risk of injury and danger to people working or passing by the site	M	Ensure clear separation between construction activities and day to day hospital operations using hoardings/access restriction/clear signage/regular briefings to personnel, etc
Loading risk	Danger of loading and unloading	Risk of injury and danger to people working	M	-
Falling object	Danger of installing plant on upper floors and roof levels	Risk of injury and danger to people working or passing by the site	M	Façade protection and crash decks to be used to mitigate danger from falling objects.
Existing Staircase	Risk of people using the existing staircase while alteration works are ongoing	Risk of people using the staircase while work is ongoing.	M	Stair to be taken out of commission, if possible, otherwise use of crash deck to safeguard lower levels.
Boiler House	Danger of working with live and existing Boiler House	There is a risk electrocution, burns and scalds, a risk of interruption of heating or power.	H	Aim to design out Boiler House interface or ensure isolation of services prior to removal/alteration/ commissioning.
Specialist Equipment	Risk with installing new hospital specialist equipment such as scanners	There is a risk electrocution, burns and scalds.	M	Ensure isolation of services prior to removal/alteration/ commissioning.
Glazing	Risk with replacing existing façade glazing	Risk of injury and danger to people working or passing by the site	M	Façade protection and crash decks to be used to mitigate danger from falling objects. Street closures/out of hours unloading/operations where necessary.
Roof	Flood hazards associated with the use of a blue roof on main roof level	Risk and danger of flooding to new building and existing surroundings	M	Ensure design allows for future levels of potential flood water to escape through roof drainage. Ensure regular maintenance of roof outlets.
Access and Maintenance	Hazards of window cleaning at high level	Risk of working at height	M	All windows on upper floors are inward opening so they can be cleaned from the inside
Access and Maintenance	Hazards of facade cleaning at high level	Risk of working at height	M	Specified materials to be chosen to be long lasting and with little cleaning and maintenance required
Balconies	Access to terraces and balconies on upper floors	Risk of persons falling from either deliberately (suicide) or accidentally from terraces or balconies.	H	Height of balustrade to be specified in line with regulations.
Steel Staircase	Construction of the steel staircase	Sequencing and construction methodology for this area coordinated with RC frame and precast stair flights	M	Continued design development and consultation with contractor at the appropriate stage. Option to omit steel frame all together.
Roof access for cleaning and maintenance	Falls from height	-	H	-
Damage to existing buildings	Structural stability, resulting in accidents	-	H	-

References

Akinlolu, M., Haupt, T.C., Edwards, D.J., and Simpeh, F. 2022. A bibliometric review of the status and emerging research trends in construction safety management technologies. International Journal of Construction Management, **22**(14): 2699–2711. Taylor and Francis Ltd.

Amiri, Z. 2022. Universidade do Minho Escola de Engenharia Mixed Reality and BIM applied to Construction Health and Safety.

Balin, S., Bolognesi, C.M., and Borin, P. 2024. Enhancing Immersive Representation in Building Information Modelling: Towards a Framework for Effective Integration of Immersive Technology in the AEC Sector. 2024 10th International Conference on Virtual Reality, ICVR 2024,: 106–112. Institute of Electrical and Electronics Engineers Inc. doi:10.1109/ICVR62393.2024.10867852.

Bello luis vidal, F., and Sara Moreno luis vidal, architects. (n.d.). To Autodesk Construction Cloud and Beyond: 100 Projects, 500 Million Square Meters, and 1,200 Stakeholders.

Getuli, V., Capone, P., and Bruttini, A. 2021. Planning, management and administration of HS contents with BIM and VR in construction: an implementation protocol. Engineering, Construction and Architectural Management, **28**(2): 603–623. Emerald Publishing. doi:10.1108/ECAM-11-2019-0647.

Getuli, V., Capone, P., Bruttini, A., and Isaac, S. 2020. BIM-based immersive Virtual Reality for construction workspace planning: A safety-oriented approach. Automation in Construction, **114**: 103160. Elsevier. doi:10.1016/J.AUTCON.2020.103160.

Getuli, V., Capone, P., Bruttini, A., and Sorbi, T. 2022. A smart objects library for BIM-based construction site and emergency management to support mobile VR safety training experiences. Construction Innovation, **22**(3): 504–530. Emerald Publishing. doi:10.1108/CI-04-2021-0062.

Haupt, T.C., Akinlolu, M., and Raliile, M.T. 2019. Applications of digital technologies for health and safety management in construction. : 88–97. doi:10.31705/WCS.2019.9.

Hoeft, M., and Trask, C. 2022. Safety Built Right in: Exploring the Occupational Health and Safety Potential of BIM-Based Platforms throughout the Building Lifecycle. Sustainability (Switzerland), **14**(10): 6104. MDPI. doi:10.3390/SU14106104/S1.

Sidani, A., Duarte, J., Dinis, F., Sanhudo, L., Santos Baptista, J., Poças Martins, J., and Soeiro, A. 2020. Virtual Reality and the future of construction. University of Porto. pp. 46–50.

Sidani, A., Martins, J.P., and Soeiro, A. 2022. BIM approaches for enhanced health and safety status in construction - protocol for a systematic review: Protocol. International Journal of Occupational and Environmental Safety, **6**(1): 1–8. University of Porto. doi:10.24840/2184-0954_006.001_0001.

Zhang, Y., Liu, H., Kang, S.-C., and Al-Hussein, M. 2020. Virtual reality applications for the built environment: Research trends and opportunities. Automation in Construction, **118**: 103311. doi:10.1016/j.autcon.2020.103311.