Original Research Article

Open Access

Omniscient Pte.Ltd.

Visualization-Based Safety Training Framework for Foreign Workers Using F × S Risk Analysis and VR/BIM

Dayeon Song, Sungjin Ahn*

Department of Architectural Engineering, Keimyung University, Daegu, 42601, South Korea.

***Correspondence to:** Sungjin Ahn, Department of Architectural Engineering, Keimyung University, Daegu, 42601, South Korea; Email: sjahn@kmu.ac.kr

Published: 18 December 2025

Abstract: Foreign construction workers in Korea experience disproportionately high accident rates due to language barriers and ineffective text-based safety training. This study proposes a visualization-based safety education model tailored to their specific vulnerabilities and trade-specific accident risks. By analyzing accident statistics in high-risk trades such as scaffolding and lifting, the research develops an integrated framework that utilizes the Frequency-Severity (F×S) index to prioritize educational content. The model recommends a tiered application of visualization media, assigning high-immersion tools like Virtual Reality (VR) for critical risk scenarios and Building Information Modeling (BIM) animations for procedural training. This approach minimizes reliance on text and maximizes intuitive understanding, providing a practical, learner-centered framework to effectively reduce accident vulnerability in multicultural construction environments.

Keywords: Foreign construction workers; Visualization-based safety education; Vulnerability factors; VR/BIM

1. Introduction

1.1 Background and Objectives of the Study

The South Korean construction industry has long accounted for the highest proportion of accidents and fatalities across all industrial sectors. Statistics from the past five years indicate that the construction sector consistently accounts for approximately 25–30% of all industrial fatalities. This persistence demonstrates that the construction industry is a quintessential high-risk sector characterized by a complex interplay of structural and environmental risk factors[1]. These risks materialize specifically as serious accidents—including falls, collapses, falling objects, caught-in/between incidents, and electric shocks—which recur frequently in work types such as scaffolding and temporary structures, structural framework and shoring, lifting operations, and electrical/mechanical installation[2]. Meanwhile, although the employment of foreign workers at domestic construction sites has steadily increased, reports consistently indicate that these workers exhibit a higher accident rate compared to domestic workers[3]. Multiple studies emphasize that this disparity is not merely a result of nationality but stems from structural vulnerabilities compounded by language barriers, insufficient understanding of procedures, misinterpretation of signals and instructions, cultural differences regarding safety norms, and a lack of

work experience[4]. In particular, considering the phenomenon where foreign workers are concentrated in small-scale and high-risk work types, a structural environment is formed wherein they inevitably face a higher probability of accidents even under identical risk conditions. Despite these challenges, current safety education at construction sites remains predominantly Korean-language-centered, lecture-oriented, and reliant on text-based media. Consequently, there are significant limitations in sufficiently reflecting the risk structures specific to each work type and the cognitive and linguistic characteristics of foreign workers. While previous studies have confirmed that visualization-based education using technologies such as VR and BIM is effective in improving procedural understanding, spatial awareness, and judgment in hazardous situations[5][6], there is a lack of cases where these technologies are designed as an integrated educational system that encompasses both the learning characteristics of foreign workers and the risk patterns specific to each work type.

Therefore, to mitigate the accident vulnerability of foreign workers, a customized safety education model is required that integrally considers the risk characteristics of each work type (based on Frequency × Severity), the cognitive, linguistic, and experiential vulnerabilities of foreign workers, and the delivery effectiveness of visualization-based educational media. Based on this problem awareness, this study aims to propose a visualization-based safety education model customized for foreign workers that is risk-based, learner-centered, and media-optimized, suitable for the domestic construction environment.

1.2 Scope and Methodology of the Study

This study focuses on apartment complexes and general building construction projects, which exhibit a high deployment of foreign workers and high accident rates. The analysis centers on major construction work types where accident risks are concentrated: scaffolding and temporary structures; structural framework, formwork, and shoring; earthworks and foundations; lifting operations; electrical and mechanical installations; and finishing and fenestration works. While the primary target group of foreign workers consists of E-9 non-professional employment visa holders, the study comprehensively reviews the status of overall accidents and fatalities among foreign workers as available in recent statistics[1][3].

The research methodology is organized into the following four phases: First, in the literature review and statistical analysis phase, the conceptual foundation of the research was established by examining industrial accident statistics[1], studies on risk factor analysis by work type[2], research on the vulnerability of foreign workers[4], and studies on VR/BIM-based visualization education[5][6]. Second, in the phase of analyzing the current status and actual conditions the scale of accidents, accident types, and risk characteristics specific to work types among foreign workers were derived using recent accident statistics. Through this process, the structural risks faced by foreign workers and the inadequacies of the current safety education system were identified. Third, in the phase of designing the visualization-based education model, an integrated education model was proposed by synthesizing the accident mechanisms of each work type (Section 4.2) and the vulnerability factors of foreign workers (Section 4.3). This model consists of the following sequence: “Risk Factor Analysis → Procedural Modeling → Integration of Vulnerability Factors → Media Suitability Assessment → Education Module Design.” Fourth, in the phase of proposing application schemes based on risk levels by work type, educational priorities were established according to accident risk levels (Frequency × Severity ratings). Furthermore, practical application guidelines were presented for designing actual education modules by mapping suitable visualization media (e.g., VR, BIM) to specific work types, risk factors, and vulnerability factors.

Through this analysis and design, this study aims to establish a visualization-based, customized education system capable of substantially reducing the accident vulnerability of foreign workers at domestic construction sites.

2. Literature Review

2.1 Studies on Construction Industry Accidents and Work-Specific Risk Factors

Construction industry accidents account for a high proportion of total industrial disasters, with recurrent accidents primarily involving falls, falling objects, collapse, and caught-in/between incidents. According to domestic industrial accident statistics and Ministry

of Employment and Labor reports, more than half of all construction fatalities in recent years have resulted from fall and collapse accidents[1][4]. This suggests that construction accidents are not merely isolated events but rather require systematic management based on the inherent risk structure of specific work types (trades). Prior research analyzing work-specific risk levels has generally adopted standards from KOSHA CODE and OSHA (29 CFR 1926). These studies segment construction projects into detailed work unit activities and quantify the risk of each accident type based on Frequency (F) and Severity (S). Kim et al.[5] identified a high simultaneous presence of 'F' and 'S' in temporary works, structural works, lifting operations, and earthworks. Specifically, they classified high-risk activities—such as the installation and dismantling of formwork and shoring, scaffolding erection and removal, and lifting operations—as high-risk work groups that frequently lead to major accidents. Furthermore, case-based activity studies[9] reported that specific hazardous factors, including 'inadequate guarding of openings', 'failure to install scaffolding guardrails', 'shoring overload', and 'lifting signal errors,' repeatedly induce severe accidents. Hur. et al.[10], analyzed that construction phase management elements (planning, supervision, and procedural compliance) for assembly, dismantling, and lifting statistically have a significant impact on accident occurrence. These findings collectively provide: (1) identification of recurrent accident patterns, (2) designation of high-risk work trades, and (3) quantitative descriptions of accident-inducing process characteristics. They serve as critical evidence for this study in setting educational priorities by work type and determining risk levels based on the F x S model.

2.2 Current Status and Limitations of Safety Education for Construction Workers

Analyses of existing safety education operations consistently point out that current construction site training is Korean-centric, lecture-based, and text-oriented, often failing to adequately reflect work-specific risk factors, as well as the skill and language proficiency levels of the workers[4][6][7]. A report by the Occupational Safety and Health Research Institute[4] noted that statutory safety training is often conducted as a mere formality. Major issues cited include the failure to sufficiently integrate work-specific accident characteristics into the curriculum, a disconnect between the educational content and actual work procedures, and the absence of comprehension assessments or feedback. These limitations are reportedly exacerbated among foreign workers who face language and cultural barriers. Moreover, education relying on common KOSHA materials such as standard PPTs, photos, and general videos is cited as having poor instructional efficacy for high-risk tasks (e.g., scaffolding, shoring, lifting, electrical work) that require precise comprehension of spatial layouts, procedural steps, and specific hazards[6]. When educational content fails to accurately reflect the risk mechanisms and operational procedures of detailed process units, workers struggle to understand the cause-and-effect relationship between specific actions and the resulting accident. International research on job and safety training for multicultural workforces also indicates that single-language, text-centric teaching methods lead to cognitive load and reduced learning efficiency. Conversely, studies have shown that visual aids, simulation, and practice-based training strategies are more effective in enhancing comprehension and promoting the transfer of safe behavior to the job site[13]. These domestic and international findings underscore the necessity for a customized, visualization-focused education system that considers both work-specific risk characteristics and the linguistic and cultural background of the learners.

2.3 Research on Visualization-Based (BIM/VR) Construction Safety Education

Visualization-based education (VR, BIM, 3D) has been verified as effective in improving workers' spatial cognition, procedural understanding, and risk situation judgment capabilities. Domestic research on VR-based safety education[7] confirmed that VR training statistically significantly improves realism, learning engagement, and error reduction rates compared to traditional lecture-based education. The utility of VR simulation training was particularly emphasized for work types where on-site practice is difficult, such as work at heights and tasks with fall risks. Research on BIM-based safety education[8] showed that presenting process stages, structures, and danger points in 3D improves workers' understanding of work sequences,

ability to identify risk elements, and safety behavior intentions. 4D process visualization using BIM integrates time, space, and work sequences, holding significant value in enabling intuitive understanding of procedural risks that are difficult to convey via existing 2D drawings or text materials. Overseas, research applying VR to overall construction safety management has been accumulating. A recent review study[14] comprehensively analyzed cases of VR-based safety education, hazard recognition training, and site simulation, reporting that VR realistically reproduces actual fall risks and high-risk work environments, and is effective in enhancing learners' immersion, comprehension, and risk judgment abilities. This study emphasizes that VR is a particularly useful medium for improving learners' safety performance when designed to allow for repetitive learning by configuring hazardous situations into specific work scenarios, going beyond one-time experiences[14].

Research on BIM-based safety management is also actively progressing internationally, and a recent study[15] presents a systematic safety management framework that utilizes BIM to structure risk factors in design and construction phases and to preemptively review risks based on spatial/movement path conflicts and work sequences. Furthermore, a Digital Twin-based study[16] proposes a DTCS model that monitors worker, equipment, and process status and predicts and warns of risks by linking BIM models with real-time site data, emphasizing a closed-loop safety management system enabling continuous risk management and feedback learning throughout the entire design–construction–operation process. These studies demonstrate that visualization technologies such as VR, BIM, and Digital Twins are effective means to intuitively convey accident mechanisms and danger points and induce behavioral changes in learners, reinforcing the validity of the visualization-based safety education model for foreign workers in this study, as they are particularly useful for novices and foreign workers[7][8][14][15][16].

2.4 Research on Accident Characteristics and Safety Communication of Foreign Construction Workers

Foreign construction workers exhibit higher accident and fatality rates compared to domestic workers and possess structural accident vulnerabilities due to their tendency to be concentrated in high-risk work types and tasks. According to the Ministry of Employment and Labor White Paper[2] and Statistical Brief[3], the accident rate for foreign workers is higher than that of domestic workers. While the types of accidents—such as falls, falling objects, caught-in-between, and collapses—are similar to those of domestic workers, the incidence rate and severity are reported to be higher. Previous domestic studies have indicated that factors such as Korean language proficiency, tenure, safety education history, and assigned work type significantly influence the probability of accidents among foreign construction workers[11]. Research by Kim Jin-woo[12] identified "clarity of visual information," "peer communication," and "manager's communication style" as key factors affecting safety communication. Notably, this study demonstrated that visualized safety information and repetitive feedback from supervisors have a positive impact on the safety behavior of foreign workers. While existing research on education models for foreign workers[10] has suggested the necessity of image-based materials, multilingual support, and procedure/scenario-based learning, educational systems that integrate work-type-specific risk characteristics with the latest visualization technologies (VR, BIM, Digital Twin) remain relatively limited. Meanwhile, overseas research on job and safety training for a multicultural workforce[13] has raised concerns that workers with different linguistic and cultural backgrounds may be alienated by existing text-centered education, highlighting the need for content structures tailored to worker characteristics and visualization/experiential education strategies.

These domestic and international studies imply that the accident vulnerability of foreign construction workers is not merely an individual characteristic but a structural issue where language, procedure, signaling, and cultural factors overlap. To mitigate this, a customized education system combined with risk characteristics by work type is required.

2.5 Limitations of Previous Studies and Necessity of This Study

Prior studies have presented important grounds in respective areas through the analysis of accident risks by trade[5][9][10], improvement of safety education media and content[6][7], accident vulnerability and safety communication issues among foreign workers[11][12], and the verification of the effectiveness of VR/BIM-based visualization education[7][8][14][15]. Recently, approaches

attempting to preemptively predict and manage risk factors using digital twins have also emerged[16].

However, existing studies generally tend to be limited to specific trades or single educational media, or remain at the level of analyzing the behavioral and communication characteristics of foreign workers individually. Consequently, research that expands into an integrated education system combining trade-specific risk (F×S), foreign worker vulnerability, and the attributes of visualization-based educational media is lacking. Even in overseas research, while the technical application and educational effects of VR, BIM, and digital twins are actively discussed[14][15][16], cases presenting a model that simultaneously reflects the trade-specific risk structure and learner characteristics targeting foreign construction workers are very limited[13].

In particular, trade-specific visualization education strategies that comprehensively consider language constraints, procedural understanding, and signaling system issues in high-risk trades such as scaffolding, structure, and lifting—where the proportion of foreign workers is high—have not been sufficiently accumulated in domestic or international research. Furthermore, while factors regarding foreign workers' language, culture, and skill levels have been qualitatively presented in numerous studies, research that systematizes these into criteria for selecting educational strategies and media is rare.

Accordingly, this study aims to provide theoretical and practical grounds applicable to the design and operation of safety education at construction sites by proposing a visualization-based safety education model customized for foreign construction workers that integrally considers trade-specific accident risk (F×S), foreign worker vulnerability factors, and the delivery capabilities of visualization educational media.

3. Current Status and Analysis of Actual Conditions

3.1 Accident Status in the Domestic Construction Industry and Among Foreign Workers

According to domestic industrial accident statistics, over the past five years (2020–2024), the construction industry has accounted for an average of approximately 24% of all industrial accidents. In terms of fatal accidents, the construction sector accounts for roughly 25%, maintaining a proportion even higher than that of general injuries[1]. This indicates that the construction industry possesses the highest risk level across all industries, not only in terms of simple accident occurrence rates but also regarding major and fatal accidents. During the same period, the proportion of foreign workers among accident victims in the construction industry averaged around 10%, while their share of fatalities ranged between approximately 9% and 12%. Notably, approximately 40% of all foreign industrial accident victims work in the construction sector, confirming a structural tendency for foreign workers to be concentrated in this industry[3]. This suggests that the high assignment rate of foreign workers to high-risk work types, combined with limitations in language proficiency and procedural understanding, may lead to relatively higher vulnerability to accidents. This accident structure reinforces the need for an in-depth analysis of which accident types recur in specific work types within the construction industry (Section 3.2), and what cognitive and behavioral vulnerabilities characterize foreign workers (Section 3.3). Furthermore, this analysis of risks and vulnerabilities serves as a fundamental basis for designing the *Work-Type Risk-Based and Visualization-Based Customized Education Model for Foreign Workers* proposed in Chapter 4.

Table 1. Status of Foreign Worker Casualties and Fatalities in the Korean Construction Industry

Category	2020	2021	2022	2023	2024	Average
Total Casualties (persons)	26,799	29,943	31,245	32,353	34,370	30,942
Foreign Casualties (persons)	2,566	3,085	3,511	3,535	3,402	3,220
% of Foreign Casualties	9.6	10.3	11.2	10.9	9.9	10.3%
Total Fatalities (persons)	567	551	539	486	496	528
Foreign Fatalities (persons)	51	49	53	57	48	51.6
% of Foreign Fatalities	9.0	8.9	9.8	11.7	9.7	9.8%

Source: MOEL, Statistics on Fatal Accidents [1][4], Statistical Brief [3]

3.2 Risk Factors and Accident Type Characteristics by Work Activity

Domestic studies on accident characteristics by work type commonly indicate that accidents involving falls, collapses, falling objects, and being caught in between occur repeatedly in major work types such as temporary works, structural works, lifting, and earthworks. These studies suggest that such accident types stem from procedural errors during work stages and structural risks within the work environment. Kim et al. analyzed the risk levels of detailed tasks by work type by applying KOSHA CODE and OSHA standards. The results confirmed that tasks such as scaffolding installation/dismantling, formwork and shoring installation/dismantling, and lifting operations are high-risk activities with both high Frequency(F) and Severity(S)[2]. This implies a need to systematically understand "at which stage and by what mechanism accidents occur" for each work type. Research on construction safety accidents based on activity analysis revealed that specific accident-inducing activities—such as failure to install scaffold guardrails, unprotected openings, shoring overloads, and lifting signal errors—account for the majority of major accidents[4]. In other words, accidents do not result from a simple list of risk factors but rather from the accumulation of repeated procedural errors in specific work stages (Activities). Furthermore, the study *Analysis of Influential Factors by Site in Construction Safety Accidents* showed that compliance with planning, supervision, and procedures during construction stages (e.g., assembly, dismantling, lifting) has a statistically significant effect on accident occurrence. This highlights the importance of procedure-based risk management within the safety management system[5]. These risk characteristics by work type and stage serve as a critical basis for designing the visualization-based education model in this study. In particular, since the understanding of procedures and stages is directly linked to accident vulnerability for foreign workers, it is essential to clearly structure the accident mechanism for each work type and convert it into educational content.

3.3 Safety Vulnerability Factors of Foreign Construction Workers

The accident vulnerability of foreign construction workers is not defined by a single factor but possesses structural characteristics where linguistic, procedural, signal interpretation, skill, and cultural factors overlap. According to previous studies, foreign workers often exhibit low proficiency in understanding Korean and interpreting safety terminology. Consequently, cases where they fail to accurately perceive work instructions, warning signs, and safety rules are repeatedly reported[4]. This leads directly to a decline in the immediate risk judgment and response capabilities required in high-risk work types, becoming a primary factor that increases the likelihood of accidents compared to domestic workers, even in identical work environments. Additionally, foreign workers show a lack of understanding of work sequences in procedure-centered processes such as scaffolding, structural work, and lifting. This creates a high risk that procedural errors will lead to major disasters like falls, collapses, and caught-in accidents. This lack of procedural understanding is interpreted as the result of a combination of insufficient education, language barriers, and limitations in spatial cognition. Signals and communication are also significant vulnerability factors. In sites with mixed multinational crews, linguistic differences often lead to unclear transmission of lifting signals or situations where manager instructions are not fully understood. Empirical research has confirmed that signal transmission errors are representative risk factors that lead directly to falling objects and caught-in accidents[5]. In terms of skill level, the proportion of novices and unskilled individuals is higher among foreign workers compared to domestic workers. It has been repeatedly reported that low risk-prediction ability, poor adaptability to work environments, and low proficiency in equipment usage are directly linked to an increase in unsafe behaviors[11]. Cultural and normative factors are also critical elements explaining the accident vulnerability of foreign workers. When differences in the perception of safety regulations, risk tolerance, and adaptation to top-down work cultures are combined, there may be an increase in unsafe behaviors or a tendency to avoid requesting work stoppages in dangerous situations. Overseas research on multicultural education also analyzes that cultural and normative differences affect safety behavior, and education that does not account for these factors has low effectiveness in understanding and behavioral transfer[13]. As described, the accident

vulnerability of foreign construction workers has a structure where language, procedure, signal, skill, and cultural factors interact to cumulatively expand risk. Therefore, the visualization-based education model proposed in the following sections includes the minimization of text, visualization-centered information presentation, step-by-step procedure visualization, and the clarification of standard signals/behavior criteria as key strategies to resolve these vulnerabilities.

3.4 Operational Status and Limitations of Safety Education for Foreign Construction Workers

Safety education for foreign workers currently implemented at domestic construction sites possesses structural limitations, including being predominantly Korean-language-centered and lecture-based, relying on static text and PPTs, failing to reflect work-type characteristics, and lacking evaluation of educational performance[4][6]. It has been repeatedly pointed out that even the multilingual materials provided to foreign workers fail to sufficiently reflect work-type-specific procedures, risk factors, and the spatial structure of the work environment. Consequently, their low connectivity with actual work limits comprehension and behavioral transfer. Previous studies have reported that visualization-based education (VR, BIM 3D/4D, animation) is more effective than text-centered education, particularly for high-risk work types (e.g., scaffolding, formwork, shoring, lifting, electrical work). This is because capabilities such as procedural understanding, spatial cognition, and risk judgment directly influence accident occurrence in these fields[7][8]. Furthermore, given the limitations foreign workers face regarding language, culture, and procedural understanding, securing substantial comprehension through lecture-based education alone is difficult. Post-education evaluations are also often limited to formal quizzes, making it challenging to measure actual behavioral changes or levels of risk perception[4][8]. International research also suggests that for multicultural workforces, education strategies based on video, visual information, and simulation significantly improve learning efficiency. Conversely, text-centered education has been shown to reduce learning effectiveness due to linguistic and cognitive loads[13]. Collectively, these domestic and international studies demonstrate that existing safety education struggles to operate effectively when mismatches occur among work-type-specific risk factors, foreign worker vulnerabilities, and educational media characteristics. This finding supports the necessity of the work-type-based, learner-centered, and visualization-based education model proposed in this study.

4. Design of Visualization-Based Customized Safety Education Model for Foreign Construction Workers

4.1 Theoretical Basis for Model Development

The educational model proposed in this study is grounded in the accident risk levels by work type and the vulnerability factors of foreign construction workers derived in Chapter 3. It is constructed by integrating risk-based, learner-centered, and media-based approaches. Accident risk by work type is characterized by a combination of frequency and procedural errors. Multiple studies have confirmed that a lack of procedural and process understanding in high-risk work types—such as scaffolding, structural work, and lifting—leads directly to major accidents[2][4][5]. Furthermore, VR- and BIM-based visualization education has been reported to significantly improve learners' spatial cognition, procedural understanding, and risk perception capabilities. Domestic and international research consistently indicates that these methods are particularly effective for novices and foreign workers who experience difficulties with text-based learning[7][8][14][15]. It has been confirmed that foreign workers face a higher probability of accidents even under identical risk factors due to difficulties in understanding language, procedures, signals, and cultural nuances. To address this structural vulnerability, an education strategy centered on visualized procedural information, standardized signals, and repetitive feedback is essential[11][13].

Consequently, this study proposes an education model that integrates key risks by work type, procedure-based accident mechanisms, foreign worker vulnerability factors, and the suitability of visualization media.

4.2 Structuring Educational Content Based on Risk Factors by Work Type

Accident risk by work type manifests as a structure combining 'Accident Type – Accident Mechanism – Procedural/Spatial Elements – Behavioral Factors.' Previous studies[2][4][5] have indicated that major

construction work types (temporary works/scaffolding, structural works/formwork/shoring, earthworks/foundation, reinforced concrete, lifting, electrical/facilities, and finishing/windows) possess relatively clear accident mechanisms. This study reconstructs these findings from an instructional design perspective, organizing the accident mechanisms and essential procedural elements that must be understood for each work type. This structural framework serves as the criterion for the scope and composition of content to be applied in subsequent VR- and BIM-based visualization media.

Table 2. Structure of Visualization Training Content Based on Accident Types by Work Type (Synthesis of Previous Studies)

Work Type (Trade)	Major Accident	Accident Mechanism	Essential Training Content	Recommended Visualization Method
Temporary Works & Scaffolding	Fall, Collapse, Falling Objects	Poor scaffolding foundation → Deformation/Overturning / Missing platforms or guardrails / Detachment of members during dismantling	Scaffolding assembly/ disassembly sequence, Guardrail & toe board standards, Falling object prevention measures	VR High-altitude work experience, BIM 4D Sequence, Color coding of danger zones
Structure, Formwork & Shoring	Collapse, Fall, Falling Objects	Unsecured support conditions → Unbalanced load → Collapse / Insufficient opening protection	Understanding shoring support & load flow, Pouring procedure, Gang-form lifting & fixing	BIM 4D Pouring visualization, VR Collapse scenario
Earthworks & Foundations	Collapse, Caught-in	Instability of slopes/retaining walls / Collision within equipment swing radius	Retaining wall structure & slope standards, Equipment blind spots & signalman placement	3D Section animation, Aerial view movement path visualization
Reinforced Concrete (RC)	Impalement, Collapse, Falling Objects	Toppling of stacked rebar / Protruding rebar / Increased pouring pressure	Rebar stacking & binding, Moving work on scaffolding, Inspection before/after pouring	Rebar 3D Model, Pressure change animation
Lifting & Tower Crane	Falling Objects, Caught-in, Collision	Unbalanced load/Single-sling rigging / Misunderstood hand signals	Rigging standards, Standard signals, Setting danger radius	Repetitive hand signal video, VR Lifting scenario
Electrical & MEP	Electric Shock, Caught-in, Explosion	Live wire contact / Missing protective devices / Hazards from rotating bodies	LOTO (Lock Out, Tag Out), Grounding & insulation check, Installation of protective devices	Procedure animation, BIM MEP Model
Finishing (Painting, Windows, etc.)	Fall, Exposure, Breakage	Toppling of temporary platforms / Inhalation of organic solvents / Glass breakage	Platform installation & fixation, PPE & ventilation management, Glass handling	Photo/Diagram-based video

4.3. Educational Strategy Based on Vulnerability Factors of Foreign Construction Workers

The accident vulnerability of foreign construction workers is constituted by multi-layered factors, including language and literacy barriers, insufficient understanding of procedures, difficulties in signaling and communication, lack of skill proficiency, and differences in culture and norms. According to previous studies[11][13], these vulnerability factors do not merely increase the likelihood of accidents in isolation; rather, they form a structure in which risks are amplified when combined with the accident mechanisms specific to each work type. Therefore, to translate these vulnerability factors into educational strategies, this study proposes a response structure comprising Vulnerability Factors – Accident Impact – Educational Strategy – Visualization Method. This framework serves as a practical design criterion that clearly delineates 'what to emphasize and what to eliminate' in the instructional design process for foreign workers.

Table 3. Vulnerability Factors, Education Strategies, and Visualization Structure for Foreign Workers (Integrated Model)

Vulnerability Category	Detailed Vulnerability Factors	Accident Impact Mechanism	Educational Strategy	Visualization Method
Language & Literacy	Lack of Korean comprehension, Difficulty with safety terminology	Misunderstanding instructions/warnings → Direct accident	Minimize text, Multilingual labels, Pictogram-centered	Pictograms, Color coding, Keyword animation
Lack of Procedural Understanding	Lack of understanding of work sequence	Procedural error → Fall, Collapse, Caught-in	Procedure animation, Presentation of BIM 4D phases	BIM Sequence, Step-by-step animation

Continuation Table:

Vulnerability Category	Detailed Vulnerability Factors	Accident Impact Mechanism	Educational Strategy	Visualization Method
Signals & Communication	Misunderstanding hand signals/instructions, Poor communication in multinational teams	Signal error → Falling objects, Caught-in accidents	Repetitive training on standard hand signals, Visualization of danger radius	Looping signal video, 3D Overlay of danger radius
Lack of Skill & Experience	High ratio of unskilled/ novice workers	Failure in risk prediction → Unsafe behavior	VR-based hazard simulation experience, Case-based learning	VR Hazard simulation, Case replay
Cultural & Normative Differences	Differences in safety regulation awareness & behavioral norms	Non-compliance with regulations, Increased risk tolerance	Behavioral modeling video, Comparison of home country practice vs. domestic standards	Comparative video, Visualization of accident causes & results

4.4 Integrated Conceptual Structure of the Visualization-Based Safety Education Model

This section integrates the analysis of risk factors by work type presented in Section 4.2 with the vulnerability factors of foreign workers discussed in Section 4.3 to propose an integrated conceptual structure for a visualization-based safety education model. The model is constituted by a stepwise structure comprising: Risk Factor Analysis → Procedural Modeling → Reflection of Vulnerability Factors → Media Suitability Mapping → Educational Module Design → Evaluation and Feedback. This structure functions as a procedural framework for instructional designers to follow when developing actual visualization-based educational modules. In particular, visualization media based on VR and BIM can intuitively represent the accident mechanisms and procedural elements of each work type. Furthermore, they can effectively implement essential elements required to mitigate the vulnerabilities of foreign workers, such as the minimization of text, procedural animation, and the repetition of standard signals[7][8][14][15].

Table 4. Integrated Components of the Visualization-Based Safety Education Model for Foreign Workers.

Step	Component Model	Input	Process	Output
① Hazard Analysis	Derive Core Hazards by Construction Type	F/S (Feasibility Study) Index, Accident Cases	Hazard Extraction	List of Hazard Scenarios
② Procedure Modeling Analysis	Accident Mechanism Analysis	Work Steps, Process Flow	Structuring Procedure Errors / Hazard Points	Procedure-Based Educational Elements
③ Reflect Vulnerability Factors	Analyze Foreign Worker Learning Characteristics	Language, Procedure, Signal, Culture	Derive Strategy (Visualization-Centric)	Education Strategy Standards
④ Media Suitability Mapping & Comparison	VR/BIM/2D	Hazard by Construction Type + Vulnerability Factors	Media Suitability Assessment	Media Combination Decision
⑤ Education Model Design	Content Creation	Hazard, Procedure, Strategy, Media	Educational Structure Design	Education Model by Construction Type
⑥ Education Performance Evaluation & Feedback	Evaluate Educational Performance	Comprehension & Behavioral Data	Analysis & Improvement	Improved Education Model

5. Application Strategies for the Risk-Based Visualization Safety Education Model by Work Type

5.1 Design and Application Strategies for Educational Modules Based on Risk by Work Type

The analysis of accident risk by work type serves as a critical step in concretizing the visualization-based education model proposed in this study into actual educational content. As indicated in previous studies[2][4][5], high-risk work types in major construction projects can be identified using the F x S risk index, which is calculated by combining the Frequency (F) of accident occurrence and the Severity (S) of accident consequences. In particular, risk levels were reported to be relatively high in work types such as scaffolding/temporary works, structural works/

formwork/shoring, lifting, and roofing/electrical/facilities works. Furthermore, as presented in Chapter 4, accident mechanisms by work type are not merely a list of accident types; rather, they possess structural characteristics where errors occurring at specific procedural stages are combined with spatial risk factors. When the vulnerabilities of foreign workers—such as limitations in language, procedural understanding, and signal interpretation—are superimposed onto this, the likelihood that identical risk factors will lead to accidents increases significantly[11][13]. Therefore, it is necessary to adjust the difficulty of educational modules and the intensity of visualization media application by simultaneously considering the risk level by work type and the vulnerability factors of foreign workers. This study integrates educational objectives, key educational content, the intensity of visualization media application, and response strategies for foreign worker vulnerabilities into a single framework based on the F x S risk grade by work type. <**Table 5**> presents these criteria for constructing educational modules by risk grade. It is structured to apply high-immersion visualization media, such as VR, for high-risk work types, while selecting visualization media centered on BIM 3D/4D, photographs, and diagrams for medium- to low-risk work types.

Table 5. Visualization Education Model Configuration by Construction Type and Hazard Index (F×S)

Hazard Level	Representative Construction Type (Example)	Core Hazard Factors	Educational Goal	Suitable Media	Visualization for Foreign Workers: Countermeasures for Vulnerability Factors
A(Very High)	Civil Engineering, Painting, Electrical/ Equipment Installation	High places, Fall, Electrocution, Collapse, Fatal accidents, etc.	Immediate hazard recognition, Precise understanding of procedures to prevent severe accidents during and after work.	VR-based hazard experience, Detailed scenario of work procedures, BIM animation, 4D process visualization	Minimize reliance on language based on the technology, Supplement understanding by presenting clear procedures and actions using BIM animation.
B(High)	Scaffolding, Temporary Equipment, Waterproofing, Finishing (Interior)	Collapse of scaffolding/ temporary structures, Falls, Openings, Repeated accidents, etc.	Understanding the sequence of installation/ dismantling, Basic learning focusing on waterproofing measures.	BIM step-by-step model, Case videos, Photo-based comparative data	Enhance empathy and focus by presenting Standard Signal/Action Models and Signal/Instruction Models through case videos and comparative data.
C (Medium)	Structure, Masonry, Earthwork	Heavy load transfer, Collapse of slopes, Entrapment/Pinching by equipment, Accidents related to structural/foundation characteristics.	Understanding structure/cross-sections, Recognizing equipment routes and hazard zones.	3D animation, Cross-section/ equipment route visualization	Prevent behavioral errors caused by different cultural norms by clearly visualizing Danger Zones, Access Restriction Zones, and Equipment Routes in cross-sections.
D (Normal)	Foundation, Storage, Minor Finishing	Overturning, Damage, Minor Entrapment/ Pinching, Relatively minor accidents.	Hazard factor recognition, PPE (Personal Protective Equipment), Following basic rules.	Hazard Factor Checklist, Basic drawings/photos as educational materials	Support early adaptation by presenting safety rules from an objective perspective focusing on basic compliance.

5.2 Expected Effects and Limitations of the Study

The visualization-based safety education model based on risk by work type proposed in this study offers the following expected effects: First, by utilizing risk grades by work type based on F x S, educational subjects and resources can be prioritized and allocated to high-risk work types. This enables efficient educational operations centered on tasks with a high probability of accidents and severe consequences[2][4][5]. Second, by representing procedures, spaces, and risk factors in scenario form based on visualization media such as VR and BIM, higher comprehension and behavioral transfer can be expected for foreign workers with limited language and literacy skills compared to existing text-based education[7][8][14][15]. In particular, simulating accidents in procedure-centered processes

in advance offers the advantage of strengthening workers' risk perception capabilities. Third, educational strategies that account for the vulnerability factors of foreign workers (e.g., text minimization, utilization of pictograms and procedural animations, repetition of standard signals) are highly likely to bring about direct positive effects on signal interpretation, procedural compliance, and risk judgment during actual work[11] [13]. However, the limitations of this study are as follows: The correlation between risk grades by work type and educational effects, as well as differences in comprehension and behavioral transfer according to the level of visualization media application, need to be supplemented through future empirical research. Furthermore, designing segmented educational modules that reflect detailed characteristics such as the nationality, tenure, and language level of foreign workers is beyond the scope of this study and requires the development of more sophisticated models in follow-up research.

Nevertheless, this study is significant in that it presents the actual applicability of visualization-based educational modules by combining risk analysis by work type and the vulnerability factors of foreign workers, thereby providing a foundational framework for future site application and empirical research.

6. Conclusion

This study proposed a visualization-based safety education model that simultaneously reflects the risk structure by work type and the accident vulnerability of foreign workers. This was based on the premise that the proportion of accidents and fatalities among foreign workers at domestic construction sites is continuously increasing, and that accidents are concentrated in high-risk work types such as scaffolding/temporary works, formwork/shoring, lifting, and electrical/facilities works. First, as a result of analyzing accident mechanisms by work type from the perspective of F x S risk, it was confirmed that most accidents possess a structural pattern where errors in specific procedural stages are combined with spatial risk factors. Furthermore, it was identified that foreign workers possess structural vulnerabilities where the probability of accidents increases even when experiencing the same risk factors, due to language barriers, lack of understanding of procedures/signals, and cultural differences. VR-BIM-based visualization education is effective in improving comprehension and risk perception by intuitively presenting space, procedures, and risk elements. In particular, high educational effects can be expected for foreign workers who are vulnerable to text-centered education. Based on this, this study presented an integrated education model leading from risk factor analysis →procedural modeling → reflection of vulnerability factors → media suitability mapping → educational module design. Additionally, it proposed an educational strategy that differentially applies visualization media such as VR, BIM 4D, 3D sections, and photographs/diagrams according to the FxS risk grade by work type.

This study is significant in that it established a structural framework for a customized visualization-based education system by integrating risk characteristics by work type and foreign worker vulnerability factors. Future research requires empirical verification of learning effects and accident reduction effects through actual site application, as well as the development of segmented educational modules that reflect nationality, language level, and tenure.

Acknowledgement

This research was funded by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (RS-2025-16067924)

Conflict of Interest

The authors declare no conflict of interest.

References

[1] Ministry of Employment and Labor (MOEL). 2024 Industrial Accident Statistics. Sejong: Ministry of Employment and Labor, 2024. https://www.moel.go.kr/policy/policydata/view.do?bbs_seq=20240501485

[2] Ministry of Employment and Labor (MOEL), Division of Serious Industrial Accident Investigation. 2022 Status of Fatal Accidents Subject to Accident Investigation. Sejong: Ministry of Employment and Labor; 2023. https://www.moel.go.kr/news/enews/report/enewsView.do?news_seq=14546

[3] Lee, Y. Foreign Workers' Occupational Injury

Status Analysis. Migration Research & Training Centre Statistical Brief, 2025-05. Gwacheon: Migration Research & Training Centre; 2025. https://www.mrtc.re.kr/data/pop.php?file_name=%5B%ED%86%B5%EA%B3%84%EB%B8%8C%EB%A6%AC%ED%94%84%5D%EC%99%B8%EA%B5%AD%EC%9D%B8+%EA%B7%BC%EB%A1%9C%EC%9E%90+%EC%97%85%EB%AC%B4%EC%83%81%EC%9D%98+%EC%9E%AC%ED%95%B4+%ED%98%84%ED%99%A9+%EB%B6%84%EC%84%9D.pdf&save_file=b_202507081724570.pdf&down_cnt=2&b_no=971

[4] Occupational Safety and Health Research Institute (OSHRI). The 10th National Survey on Occupational Safety and Health: Final Report. Ulsan: OSHRI; 2023. https://oshri.kosha.or.kr/oshri/researchField/downTrendsSurveyReport.do

[5] Oh, M., Park, T., Park, Y., Son, K., Ahn, S., & Kim, T. An Assessment of Safety Education Contents Propriety Analyzing Accident Types by Work Classification in Construction Sites. *Journal of the Architectural Institute of Korea Structure & Construction*.2014; *30*(3), 131–139. https://doi.org/10.5659/JAIK_SC.2014.30.3.131

[6] Kim, T., Ahn, S., Lee, T., Kim, S., & Park, Y. Improvement of Educationa
l Contents to Enhance the Efficiency of Construction Worksite Safety Training. Journal of the Korea Institute of Building Construction. 2013;13(1): 75–82. https://doi.org/10.5345/JKIBC.2013.13.1.075

[7] Ahn, S., Park, Y. J., Park, T. H., & Kim, T. H. Development of safety training delivery method using 3D simulation technology for construction worker. *Journal of the Korea Institute of Building Construction*, 2015:*15*(6), 621-629. 10.5345/JKIBC.2015.15.6.621

[8] Ahn, S., Kim,T, Park, Y., & Kim, J. Improving effectiveness of safety training at construction worksite using 3D BIM simulation. *Advances in Civil Engineering*, 2020; *2020*(1), 2473138. https://doi.org/10.1155/2020/2473138

[9] Park, H., Lee, J., Seo, M., & Lee, S. Activity-Based Risk Analysis Using Case Studies of Building Construction Accidents. Journal of the Architectural Institute of Korea: Structure Division. 2024;40(1):287–297. http://dx.doi.org/10.5659/JAIK.2024.40.1.287

[10] Hur, Y., Lee, S., Yoo, W., & Song, T. Empirical Examination of Determinants Affecting Safety Incidents in Building Construction. *Journal of the Korea Institute of Building Construction*.2023;*23*(5), 583-593. 10.5345/JKIBC.2023.23.5.583

[11] Kim, J. M. The quantification of the safety accident of foreign workers in the construction sites. *Korean Journal of Construction Engineering and Management*, 2024; *25*(5), 25-31. https://doi.org/10.6106/KJCEM.2024.25.5.025

[12] Kim, J., Ishdorj, S., Jeon, J., & Kim, J. Identifying Vital Factors for Enhancing Safety Communication among Foreign Construction Field Workers. Buildings. 2024;14(6):1714. https://doi.org/10.3390/buildings14061714

[13] Perera,U., Jayadas A., Chandrasekera T., Nishan M., Efficiency in Occupational Skills and Safety Training for a Multicultural Workforce. KDU Journal of Built Environment. 2024:1(2):12-31. DOI:10.4038/kdujbe.v1i2.8

[14] Alzardah, A., Miller, M., Durham, L., & Chowdhury, S. Revolutionizing Construction Safety: Introducing a Cutting-Edge Virtual Reality Interactive System for Training US Construction Workers to Mitigate Fall Hazards. Frontiers in Built Environment. 2024. https://doi.org/10.3389/fbuil.2024.1320175

[15] Collinge, W., Farghaly, K., Mosleh, M., Manu, P., & Cheung, C. BIM-based Construction Safety Risk Library. Automation in Construction. 2022;141:104391. https://doi.org/10.1016/j.autcon.2022.104391

[16] Teizer, J., Johansen, K.W., & Schultz, C. The Concept of Digital Twin for Construction Safety. ASCE Construction Research Congress 2022. https://ascelibrary.org/doi/10.1061/9780784483961.121