Journal of Posthumanism

2025
Volume: 5, No: 5, pp. 3943–3963
ISSN: 2634-3576 (Print) | ISSN 2634-3584 (Online)
posthumanism.co.uk

DOI: https://doi.org/10.63332/joph.v5i5.1838

Risk Assessment, Worker Training, Personal Protective Equipment, and Safety Monitoring in Occupational Safety and Health: The Case of the Construction Sector in Bangladesh

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Abstract

This study intends to explore how risk assessments with training programs, personal protective equipment (PPE), and monitoring practices affect the occupational health and safety standards for construction workers in Bangladesh. The study uses quantitative methods with 291 participants to conduct hypothesis tests through SEM. Research results indicate that work health safety significantly benefits from risk determinations, training of employees, personal protective equipment (PPE), and rigid supervision systems. Yet, safety awareness acts as a middle link that binds these components. The research produces field-tested solutions available to be used by governmental agencies and other business partners in construction that enhance worker safety and alleviate on-the-job hazards. The study presents clear and actionable methods that help government officials and organizations within construction, combined with industry participants, defend workers and minimize workplace safety hazards.

Keywords: *Risk Assessment, Worker Training, Personal Protective Equipment (PPE), Safety Monitoring, Construction Sector in Bangladesh.*

Introduction

Occupational Safety and Health (OSH) in the construction sector remains a critical concern due to the inherently hazardous nature of the work environment, evolving technologies, and diverse regulatory practices across countries. Globally, construction industries grapple with persistent safety challenges, with developed and emerging economies emphasizing risk assessments, worker training, Personal Protective Equipment (PPE) use, and safety monitoring to mitigate risks (De Merich et al., 2022). In this context, Bangladesh's construction sector, valued at

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approximately US$ 12 billion and pivotal to national economic growth, presents a pressing case (BBS, 2023). Despite its economic importance, the sector recorded 149 fatalities and 72 injuries in 2023 alone, reflecting a dire OSH landscape (The Financial Express, 2024). With only 18% of firms implementing adequate safety training and risk assessments, the industry's OSH practices remain underdeveloped (Ahmed et al., 2021).

The problem lies in the lack of structured OSH practices in Bangladesh's construction industry, exacerbated by weak enforcement of safety laws, poor risk management, and insufficient training and monitoring systems (Ali et al., 2024). Although the Bangladesh Labour Act (2006) outlines safety provisions, its implementation is inconsistent and ineffective (Syed, 2024). Empirical evidence shows that nearly 60% of construction workers have suffered work-related injuries, while 35% report occupational illnesses due to substandard safety practices (BBS, 2023). Current literature reveals a notable gap in comprehensive, data-driven analyses of how core safety pillars - risk assessment, worker training, PPE, and safety monitoring - collectively impact OSH outcomes. Existing research often lacks a focused, contextual evaluation of these factors in developing countries like Bangladesh (Boadu et al., 2021), indicating the need for systematic investigation and locally informed strategies.

This study seeks to bridge the identified research and policy gaps by evaluating the impact of critical safety components - risk assessment, training, PPE, and monitoring - on OSH outcomes in Bangladesh's construction industry. The research contributes generally to the academic field by expanding knowledge on OSH in developing economies and socially by advocating for safer work environments aligned with SDGs 3 and 8. Practically, it offers actionable recommendations for policymakers, industry stakeholders, and construction firms to enhance worker safety and reduce occupational risks. By addressing systemic safety failures, this study aims to improve the well-being of workers and their families while fostering sustainable economic development.

Literature Review

Theoretical Underpinning

This study is grounded in several established theories that explain the determinants of OSH in the construction industry. The Swiss Cheese Model (Reason, 1990) highlights the role of risk assessment, where multiple safety defenses prevent accidents. The Experiential Learning Theory (Kolb, 2014) emphasizes the importance of worker training, suggesting that hands-on learning enhances risk identification and mitigation. PPE, framed within the Hierarchy of Controls Model (Manuele, 2005), is crucial when higher-level controls are unavailable, but its effectiveness relies on enforcement and compliance. Safety monitoring is informed by Behavior-Based Safety Theory (Cooper, 2000), advocating for continuous feedback to improve compliance. Safety awareness, mediating these relationships, aligns with the Theory of Planned Behavior (Ajzen, 1991), suggesting that awareness drives safer behavior. Globally, studies show the impact of PPE and training in improving safety, as seen in the Middle East (Alnuaimi, 2022). However, Bangladesh faces challenges like insufficient regulatory enforcement and worker non-compliance, underlining the need for culturally tailored safety initiatives (Sharar et al., 2024).

Determinants of OSH

Impact of Risk Assessment on OSH

OSH in construction hinges critically on effective risk assessment, which involves identifying,

evaluating, and controlling hazards to prevent workplace incidents. Frameworks like ISO 31000 and the Swiss Cheese Model emphasize their role in preventing systemic failures, with tools like HIRA and Bowtie Analysis promoting ongoing hazard mitigation (Wahab et al., 2021). In Bangladesh, where informal labor and weak regulation exist, risk assessment is especially vital (Ahmed et al., 2021). Validated risk identification methods significantly reduce incidents and improve worker engagement (Ozobu et al., 2022). Technological advancements like 4D BIM and IoT-based analytics enhance hazard detection (Numan, 2024), but gaps remain in longitudinal data and the adoption of digital tools for predictive risk management in resource-constrained settings.

H1: *Risk Assessment has significant impacts on OSH.*

Impact of Risk Assessment on Safety Awareness

Safety awareness, defined as workers' perception and proactive engagement with safety protocols, is vital in high-risk sectors like construction (Geller, 2001). Risk assessment enhances safety awareness by identifying hazards and fostering informed behavior, especially in Bangladesh, where low hazard perception and informal labor contribute to high accident rates (Almaskati et al., 2024). Studies show that participatory, localized risk assessments improve safety attitudes and situational awareness (Li et al., 2024). However, only 37% of construction firms in Bangladesh implement formal assessments, revealing a significant gap (Curran, 2025). Integrating digital tools and policy-driven training can help institutionalize safety practices and embed safety culture.

H2: *Risk Assessment has a significant impact on Safety Awareness.*

Impact of Worker Training on OSH

Worker training is essential for OSH, providing employees with the knowledge and skills to recognize hazards and practice safe behaviors, particularly in construction (Bęś & Strzałkowski, 2024). Theoretical models like Adult Learning Theory (Knowles, 1984) and Behavior-Based Safety (Cooper, 2000) emphasize the role of experiential training in driving safety improvements. In Bangladesh, where informal labor and weak regulation persist, only 40% of construction firms offer regular safety training (Ahmed et al., 2021). Studies from South Korea and India show that structured training significantly reduces accident rates (Kang et al., 2014; India Workplace Safety Report, 2023). Tailored strategies using local languages, pictograms, and mobile apps are crucial, though research gaps remain in digital interventions and longitudinal outcomes in low-resource settings.

H3: *Worker Training has significant impacts on OSH.*

Impact of Worker Training on Safety Awareness

Worker training is essential for enhancing safety awareness - workers' cognitive understanding and commitment to safety protocols, particularly in construction. In Bangladesh, where formal OSH systems are weak and accident rates remain high, training can improve hazard recognition and safe behavior (Hossain et al., 2023). Rooted in Kolb's Experiential Learning Model and behavior-based safety frameworks, participatory methods like drills and simulations foster better risk perception and behavioral change. Empirical evidence shows that training can increase safety awareness by over 71% (Islam et al., 2023). However, fewer than 40% of workers receive formal training (Ahmed et al., 2021), highlighting the need for localized programs with visual tools and mobile learning platforms to ensure broader impact.

H4: *Worker Training has significant impacts on Safety Awareness.*

Impact of PPE on OSH

PPE, including helmets, gloves, goggles, and protective clothing, is crucial for OSH in high-risk industries like construction, shielding workers from hazards (Malta et al., 2024). In Bangladesh, where regulatory enforcement is weak and PPE access is limited, its role is even more critical (Miah et al., 2024). The Hierarchy of Controls and Swiss Cheese Models position PPE as a last defense against safety system failures (Manuele, 2005). However, its effectiveness relies on proper usage and enforcement. Despite evidence that PPE reduces injuries by 20-40% (Zhang et al., 2019), challenges like cost, availability, and cultural resistance hinder its widespread use in Bangladesh's construction sector.

H5: *PPE has significant impacts on OSH.*

Impact of PPE on Safety Awareness

PPE serves as both a physical safeguard and a means to enhance safety awareness, particularly in high-risk sectors like construction. In developing economies like Bangladesh, where cultural resistance, low literacy, and weak safety infrastructure exist, PPE reinforces both protection and behavior (Ali et al., 2024). Behavioral Safety Models (Geller, 2001) suggest that PPE use improves hazard recognition and compliance, while the Human Factors Approach links it to heightened cognitive alertness (Reason, 1997; Akbarzadeh et al., 2025). Evidence from India shows a 35% reduction in incidents with proper PPE enforcement (Chellappa et al., 2019). In Bangladesh, localized training and subsidized PPE programs have improved awareness (Hossain et al., 2023), though long-term impacts and digital solutions remain underexplored.

H6: *PPE has a significant impact on Safety Awareness.*

Impact of Safety Monitoring on OSH

Safety monitoring is essential for detecting, assessing, and mitigating workplace hazards, particularly in high-risk sectors like construction (Basiru et al., 2023). In Bangladesh, where over 65% of sites lack adequate monitoring systems (Hossain & Ahmed, 2019), effective monitoring is crucial for improving compliance and reducing accidents. Rooted in Systems Theory (Reason, 1990) and proactive safety models, monitoring supports continuous risk assessment and fosters safety culture (Karanikas et al., 2022). Evidence links strong monitoring systems to improved compliance and up to 54% fewer incidents (Associated Builders and Contractors, 2024). Strategies like IoT integration, audits, and supervisor training are vital. However, longitudinal studies on the long-term impact of digital monitoring in developing economies are limited.

H7: *Safety Monitoring has a significant impact on OSH.*

Impact of Safety Monitoring on Safety Awareness

In high-risk sectors like construction, safety monitoring is crucial for enhancing safety awareness and workers' recognition of hazards. In Bangladesh, limited regulatory enforcement and resource constraints hinder effective monitoring (Ahmed et al., 2021). The Human Factors Approach and Safety Behavior Models suggest that continuous monitoring reinforces hazard perception and safe behavior through real-time feedback. Studies show that advanced monitoring tools, like wearable sensors and IoT systems, can reduce injuries by over 30% (Awolusi et al., 2019). However, challenges such as cultural resistance and lack of technology

persist. Strategies like mobile-based monitoring and regular audits can improve awareness (Hossain et al., 2023), though long-term behavioral impacts remain underexplored.

H8: *Safety Monitoring has a significant impact on Safety Awareness.*

Impact of Safety Awareness on OSH.

Safety awareness, defined as recognizing hazards and adhering to safety protocols, is critical for OSH in high-risk sectors like construction. In Bangladesh, where weak enforcement and inadequate safety practices prevail, promoting safety awareness is essential to reducing accidents (Ahmed et al., 2021). Behavioral Safety Models and Systems Theory emphasize that heightened awareness fosters safer behavior and is reinforced by a strong safety culture (Abubakar et al., 2022). Safety awareness programs can reduce injuries by up to 35% and improve compliance (Schoenfisch et al., 2016; Ajmal et al., 2022). Tailored strategies, such as visual training modules and mobile apps, can address literacy and cultural barriers (Datta et al., 2024). However, longitudinal and region-specific research, particularly in low-resource settings, remains limited.

H9: *Safety Awareness has a significant impact on OSH.*

Impact of Safety Awareness on the Relationship between Risk Assessment and OSH

This hypothesis proposes that safety awareness mediates the effectiveness of risk assessment in enhancing OSH outcomes. In Bangladesh, limited resources and infrastructure hinder effective risk assessment (Hasan et al., 2023). Systems Theory and Behavioral Safety Models highlight their complementary roles in risk reduction, while Cognitive Load Theory suggests awareness improves decision-making by reducing cognitive load (Sweller, 1988). Studies show that awareness enhances hazard recognition and compliance (Benson et al., 2024), though low literacy and cultural attitudes pose challenges. Targeted strategies like visual training, mobile apps (Hossain et al., 2021), and community campaigns can improve both awareness and risk assessment (Akter et al., 2022).

H10: *Safety Awareness has a significant impact on the relationship between Risk Assessment and OSH.*

Impact of Safety Awareness on the Relationship between Worker Training and OSH

Safety awareness enhances the impact of worker training on OSH, particularly in Bangladesh, where low literacy and limited resources hinder safety efforts (Anik et al., 2024). Behavioral safety models and Adult Learning Theories highlight that awareness improves hazard identification and compliance (Knowles, 1984; Dzah & Atianashie, 2023). Simulation-based training boosts hazard recognition (Zhang et al., 2019), while localized programs addressing cultural and literacy barriers enhance outcomes (Heydari et al., 2024). Integrating awareness into training fosters a proactive safety culture and OSH performance (Yazdi, 2025), though more longitudinal and digital-focused research is needed.

H11: *Safety Awareness has a significant impact on the relationship between Worker Training and OSH.*

Impact of Safety Awareness on the Relationship between PPE and OSH

This hypothesis posits that safety awareness enhances PPE effectiveness in improving OSH, especially in Bangladesh, where resource constraints and cultural barriers limit PPE use. The Hierarchy of Controls Model (NIOSH, 2023) and Behavioral Safety Models emphasize

awareness as key to proper PPE usage and compliance. Cognitive Load Theory supports that awareness improves decision-making in hazardous settings. Studies show PPE training with awareness reduces accidents (Zhang et al., 2019), but cost, availability, and attitudes remain challenges (Hossain et al., 2023). Subsidized PPE and localized training can boost compliance, though longitudinal and digital-focused research is needed.

H12: *Safety Awareness has a significant impact on the relationship between PPE and OSH.*

Impact of Safety Awareness on the Relationship between Safety Monitoring and OSH

Safety awareness mediates the impact of safety monitoring on OSH, especially where limited resources and cultural barriers hinder effective implementation. Behavioral Safety Models and Systems Theory highlight that awareness promotes proactive behaviors, enhancing monitoring effectiveness. Internet of Things (IoT) devices and wearable sensors improve hazard detection and awareness (Zhang et al., 2019), yet Bangladesh struggles with integration, and only 6.45% of workers receive formal training (Ali et al., 2023). Mobile apps, wearables, and localized training can strengthen outcomes, though long-term impacts remain underexplored (Adikwu et al., 2023).

H13: *Safety Awareness has a significant impact on the relationship between Safety Monitoring and OSH.*

Table 1 categorizes key OSH variables - risk assessment, worker training, PPE, and safety monitoring - defining each with references and linking them to survey items measuring perceptions of OSH. It also emphasizes the mediating role of safety awareness in influencing these perceptions.

Context	Definition	Code	Items	Reference
Risk Assessment	Risk Assessment involves identifying hazards, analyzing or evaluating the associated risks, and determining ways to eliminate or control the hazards (ISO, 2018). It includes stages such as Hazard Identification, Risk Analysis, Risk Evaluation, Control Measures, Monitoring, and Review.	RA1	A formal RA is conducted before starting new tasks or projects.	(Rahman & Ali, 2024)
		RA2	The company uses advanced digital tools, like real-time data analytics or IoT devices, to improve RA accuracy.	
		RA3	Systems are in place to monitor and report real-time risks as conditions change on-site.	
		RA4	I am well-informed about risks and hazards related to my tasks.	
		RA5	Actions taken after RA effectively reduce potential	

			hazards.	
Worker Training	Worker Training is the systematic development of the knowledge, skills, and attitudes required to perform a specific task or job effectively (Armstrong & Taylor, 2014). It includes Safety Induction, Skill Development Programs, Emergency Response Training, PPE Use, and Hazard Communication.	WT1	Safety training sessions are held frequently to keep workers informed and prepared.	(Hoque et al., 2024)
		WT2	Training content is regularly updated to include new regulations, procedures, and risks.	
		WT3	I feel confident applying safety knowledge from training in my daily work.	
		WT4	Safety training covers relevant hazards I may encounter at the worksite.	
		WT5	Training includes practical exercises for applying skills directly to my tasks.	
Personal Protective Equipment	PPE is equipment worn to minimize exposure to occupational hazards (Centers for Disease Control and Prevention, 2017). It includes Helmets, Safety Glasses, Gloves, High-Visibility Clothing, Safety Footwear, and Hearing Protection.	PPE1	PPE is readily available for all tasks at my worksite.	(Miah, Hossain, & Talukder, 2024)
		PPE2	The provided PPE is high-quality and suitable for the hazards in my environment.	
		PPE3	I have received adequate training on proper PPE use.	
		PPE4	PPE usage is strictly enforced by supervisors and management.	
		PPE5	I am encouraged to consistently use PPE, even when risks seem minimal.	
		PPE6	PPE is tailored to my specific tasks and risks, ensuring proper protection.	
Safety	Safety Monitoring	SM1	Regular safety inspections	(Al-

Monitoring	involves systematic data collection, analysis, and interpretation to identify and mitigate workplace risks (Health and Safety Executive, 2013). It includes Site Inspections, Safety Audits, Incident Reporting, Safety Metrics, and Hazard Observations.		effectively identify and mitigate site hazards.	Mohammad et al., 2024)
		SM2	Management actively communicates safety issues and inspection results to workers.	
		SM3	Adequate resources, like first aid kits and fire protection, are available for ongoing safety monitoring.	
		SM4	Digital devices, such as sensors or wearables, are used to monitor safety conditions effectively.	
Occupational Safety and Health	OSH refers to "the conditions and factors that affect the health and safety of employees or others in the workplace" (International Labour Organization, 2001). It includes Safety Policies, Risk Assessments, Emergency Procedures, Health Surveillance, Safety Training, and Signage.	OSH1	I am fully aware of the OSH policies at my worksite.	(Rahman & Ali, 2024)
		OSH2	Training on OSH is effective and comprehensive.	
		OSH3	Necessary resources and equipment for a safe work environment are readily available.	
		OSH4	Management is committed to implementing and maintaining safety standards.	
		OSH5	Safety protocols are consistently applied across tasks and locations.	
		OSH6	An adequate emergency response plan is in place, and employees are prepared.	
		OSH7	Safety measures have effectively reduced accidents and injuries at my worksite.	
Safety	Safety Awareness	SA1	I am aware of the potential	(Lohne &

Awareness	is the understanding of safety protocols and hazards, enabling safer decisions (Geller, 2001). It includes Hazard Recognition, Knowledge of Safety Protocols, and PPE use.		hazards related to my job tasks.	Drevland, 2024)
		SA2	I fully understand the on-site safety protocols for worker protection.	
		SA3	I am encouraged to report unsafe conditions without fear of reprisal.	
		SA4	I feel responsible for maintaining a safe environment and following protocols.	
		SA5	Safety programs promote a long-term commitment to safe practices.	

Table 1: Definition of Operational Variable and Measurement

Conceptual Framework

The figure illustrates a conceptual framework linking four key factors - Risk Assessment (H1), Worker Training (H2), PPE (H3), and Safety Monitoring (H4) - to OSH, demonstrating their direct influence. Additionally, Safety Awareness mediates these relationships (H5, H6, H7, H8), enhancing the impact of independent variables on occupational safety outcomes.

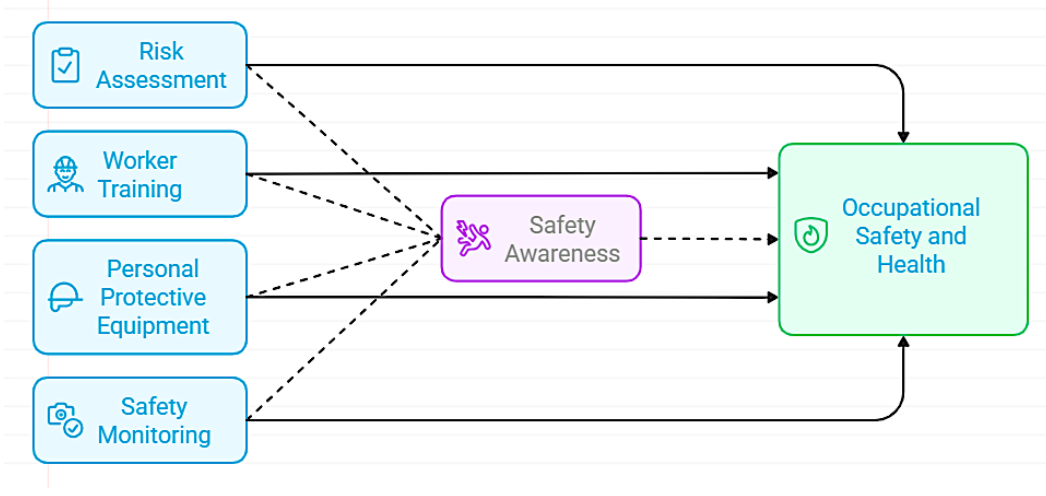

Figure 1: Risk Assessment, Worker Training, PPE, and Safety Monitoring impact OSH, mediated by Safety Awareness. (Source: Authors)

Methodology

Ethics Statement

The study received approval from the concern authority as it involves human participants. Participants' consent was confirmed physically, where participants were informed that each question was optional and no personally identifying information would be collected, ensuring strict anonymity.

Sample and Data Collection

This study was conducted among male and female employees in Bangladesh's construction industry across 31 sites in Dhaka, Gazipur, Feni, Khulna, and Jessore from January 23 to February 20, 2025. A total of 300 questionnaires were distributed, with 291 valid responses (97% response rate) after removing incomplete data. The study provides a strong foundation for analyzing the impact of risk assessment, worker training, PPE, and safety monitoring, with safety awareness as a mediating factor.

Characteristics		**Frequency**	**Percent**
Gender	Male	189	65%
	Female	102	35%
Age	15-25	91	31%
	26-35	79	27%
	36-45	53	18%
	46-55	47	16%
	56+	21	7%
Education	No Formal Education	67	23%
	Primary Level	196	67%
	Secondary Level	9	3%
	Others	19	7%
Working Experience	Less than 01 year	124	43%
	01-05 years	89	31%
	06-10 years	65	22%
	10+ years	13	4%

Table 2: Sample Characteristics

Source: Customized output of SPSS

Data Analysis

SEM was applied through Smart-PLS 4.0 for testing and analysis. This technique is appropriate and suitable for this study as it allows for the simultaneous analysis of multiple dependent relationships and includes latent variables (Byrne, 2016). PLS-SEM has greater statistical power than CB-SEM because of its efficiency in parameter estimation (Hair et al., 2017). It is a more reliable method of analysis, and it can be applied to data that does not follow a normal distribution (Hair et al., 2017). According to Kline (2023), a minimum of 100–150 respondents is required to obtain reliable results from structural equation modeling (SEM), indicating that the current study’s sample size is sufficient for robust analysis.

Common Method Bias

To assess common method bias (CMB), the authors conducted a full collinearity test using SmartPLS 4. The Variance Inflation Factors (VIFs) for all constructs were below 3.3, indicating that CMB is not a major concern (Kock & Lynn, 2012; Kock, 2015).

Testing Model Fit

Prior to testing the structural equation model (SEM), the model fit was assessed using two fit indices: the Standardized Root Mean Square Residual (SRMR) and the Normed Fit Index (NFI). The SRMR represents the discrepancy between the observed correlation matrix and the model-implied correlation matrix, where values below 0.08 indicate a good model fit (Hu & Bentler, 1999). Henseler et al. (2014) introduced the SRMR as a goodness-of-fit criterion for partial least squares SEM (PLS-SEM) to prevent model misspecification. The second index, the NFI, is an incremental fit measure that evaluates the Chi-square value of the proposed model against a baseline model, with values above 0.90 generally indicating an acceptable fit (Bentler & Bonett, 1980). Given that the model tested in this study was fully saturated, with no free parameters, the fit indices for the saturated (measurement) and estimated (structural) models were identical. In this study, the SRMR value of 0.064 (< 0.08) and the NFI value of 0.923 (> 0.90) suggest that the data provide an adequate fit to the model.

Result

Results of Measurement Model

To evaluate the construct reliability and validity, the research undertook a comprehensive examination of the measurement model, as presented in Table 3. The findings demonstrated robust indicators of reliability and internal consistency, with Cronbach's alpha coefficients exceeding the recommended threshold of 0.80, as outlined by Hair et al. (2021). This highlights the constructs' reliability and consistency. The study exhibited methodological rigor by adhering closely to the guidelines established by Hair et al. (2021), Shmueli et al. (2019), and Sarstedt et al. (2021). In addition to Cronbach's alpha, composite reliability (CR) was employed to further assess the internal consistency of the measuring scales. All the findings align with the recommendations of Hair et al. (2021) and Shmueli et al. (2019), emphasizing the reliability and robustness of the constructs.

The study also emphasized the importance of Average Variance Extracted (AVE) in measuring convergent validity. As described by Saunders et al. (2019) and supported by Sarstedt et al. (2014), AVE quantifies the variance explained by a construct relative to the variance attributed to measurement error. To ensure strong convergent validity, achieving an AVE of at least 0.50 is critical, as recommended by Hair et al. (2021), Shmueli et al. (2019), and Rahman et al. (2023). An AVE below 0.50 would suggest that measurement errors outweigh the variance explained by the construct, underscoring the need to meet this threshold for validity. In this study, all constructs exceeded the minimum AVE requirement of 0.50, with AVE values ranging above 0.594. This compliance demonstrates the rigorous validation process undertaken, ensuring the constructs' reliability and validity. By adhering to the methodological recommendations of Hair et al. (2021), Shmueli et al. (2019), Sarstedt et al. (2021), and Rahman et al. (2023), the research showcases a robust framework for evaluating construct validity and reliability.

Constructs	**Items**	**Loadings**	***α***	**CR**	**AVE**
Risk Assessment	RA1	0.761	0.782	0.850	0.659
	RA2	0.797			
	RA3	0.755			
	RA4	0.918			
	RA5	0.906			
Worker Training	WT1	0.827	0.809	0.718	0.611
	WT2	0.734			
	WT3	0.885			
	WT4	0.789			
	WT5	0.802			
Personal Protective Equipment	PPE1	0.827	0.866	0.898	0.597
	PPE2	0.785			
	PPE3	0.824			
	PPE4	0.784			
	PPE5	0.854			
	PPE6	0.740			
Safety Monitoring	SM1	0.786	0.796	0.868	0.624
	SM2	0.844			
	SM3	0.783			
	SM4	0.836			
Occupational Safety and Health	OSH 1	0.864	0.884	0.910	0.594
	OSH 2	0.855			
	OSH 3	0.751			
	OSH 4	0.842			
	OSH 5	0.710			
	OSH 6	0.791			
	OSH 7	0.756			
Safety Awareness	SA1	0.855	0.817	0.719	0.619
	SA2	0.758			
	SA3	0.870			
	SA4	0.775			

Constructs	**Items**	**Loadings**	***α***	**CR**	**AVE**
Risk Assessment	RA1	0.761	0.782	0.850	0.659
	RA2	0.797			
	RA3	0.755			
	RA4	0.918			
	RA5	0.906			
	SA5	0.866			

Table 3: Convergent Validity

*Abbreviations: CR = Composite Reliability, AVE = Average Variance Extracted, α = Cronbach's alpha. ***All indicators are significant at p < 0.001*

Source: Customized output of Smart-PLS

As emphasized by Shmueli et al. (2019), discriminant validity is a critical aspect of PLS-SEM path analysis, ensuring the statistical distinction between latent variables representing separate theoretical constructs. The results presented in Table 4 confirm the achievement of discriminant validity by satisfying the rigorous criteria of the Heterotrait-Monotrait Ratio (HTMT). According to Shmueli et al. (2019) and Hair et al. (2021), the HTMT metric is a reliable tool for assessing the degree of similarity between two latent variables. For discriminant validity to be established, HTMT values must fall below the threshold of 1. The findings in this study not only align with this requirement but also demonstrate compliance with the methodological standards, providing robust evidence of discriminant validity.

	1	2	3	4	5	6
1. Risk Assessment						
2. Worker Training	0.550					
3. PPE	0.686	0.569				
4. Safety Monitoring	0.563	0.623	0.711			
5. Occupational Health & Safety	0.723	0.722	0.641	0.558		
6. Safety Awareness	0.586	0.658	0.692	0.535	0.597	

Table 4: Discriminant Validity (HTMT Ratio)

Source: Smart-PLS output

Hypothesis Testing

The study examined multiple hypotheses to assess the relationships (in Table 5) between risk assessment, worker training, PPE, safety monitoring, safety awareness, and occupational safety and health. Additionally, mediation analysis confirmed the indirect effects (in Table 6) of several variables.

No.	Path	Original Sample	T-Statistics	*p*-values	Remarks
H1	Risk Assessment -> Occupational Health & Safety	0.284	4.748	0.000	Supported
H2	Risk Assessment -> Safety Awareness	0.001	3.950	0.000	Supported
H3	Worker Training -> Occupational Health & Safety	0.063	2.344	0.021	Supported
H4	Worker Training -> Safety Awareness	0.839	5.660	0.000	Supported
H5	Personal Protective Equipment -> Occupational Health & Safety	0.211	4.534	0.000	Supported
H6	Personal Protective Equipment -> Safety Awareness	0.098	2.275	0.025	Supported
H7	Safety Monitoring -> Occupational Health & Safety	0.710	11.668	0.000	Supported
H8	Safety Monitoring -> Safety Awareness	0.055	2.552	0.012	Supported
H9	Safety Awareness -> Occupational Health & Safety	0.634	13.021	0.000	Supported

Table 5: Direct Hypothesis Testing

Source: Customized output of Smart-PLS

No.	Path	Original Sample	T-Statistics	*p*-values	Remarks
H10	Risk Assessment -> Safety Awareness -> Occupational Health & Safety	0.001	3.891	0.000	Supported
H11	Worker Training -> Safety Awareness -> Occupational Health & Safety	0.532	4.105	0.000	Supported
H12	Personal Protective Equipment -> Safety Awareness -> Occupational Health & Safety	0.062	3.275	0.001	Supported
H13	Safety Monitoring -> Safety Awareness -> Occupational Health & Safety	0.035	2.309	0.023	Supported

Table 6: Mediating Effects

Source: Customized output of Smart-PLS

Discussion

The findings of this study highlight the significance of key safety interventions - risk assessment, worker training, PPE, and safety monitoring - in improving OSH in Bangladesh's construction sector. The strong relationship between risk assessment and OSH aligns with Reason's (1990) "Swiss Cheese Model," which posits that multiple layers of safety defenses can prevent workplace accidents by identifying and mitigating hazards before they lead to injury. Effective

risk assessment, as supported by previous research (Hale et al., 2015), provides construction firms with the necessary insights to implement proactive safety measures, ultimately reducing the likelihood of accidents.

Worker training also emerged as a significant predictor of both OSH and safety awareness. This finding reinforces Kolb's Experiential Learning Theory (2014), which emphasizes the importance of hands-on, experience-based learning in developing critical workplace skills. In hazardous environments like construction sites, practical safety training enhances workers' hazard perception, equipping them with the ability to recognize and respond to risks effectively. This result is consistent with Haslam et al. (2005), who found that skill-based training improves both cognitive and behavioral safety outcomes, reducing workplace injuries. Additionally, Gibb et al. (2014) argue that integrating safety training into professional development programs fosters a proactive safety culture, further supporting the necessity of structured training interventions. Similarly, the role of PPE in improving both OSH, and safety awareness aligns with the Hierarchy of Controls model (Manuele, 2005), which classifies PPE as a last-resort protective measure when hazard elimination, substitution, and engineering controls are infeasible. While PPE is widely acknowledged as an essential safety component, its effectiveness depends on proper usage, compliance, and enforcement. Research by Zhang et al. (2013) suggests that PPE compliance is influenced by workers' attitudes, organizational safety culture, and management enforcement, highlighting the need for targeted interventions to ensure consistent PPE usage.

The strong relationship between safety monitoring and OSH supports the Behavior-Based Safety (BBS) approach (Cooper, 2000), which emphasizes continuous observation, feedback, and reinforcement of safe behaviors. Construction safety studies (Choudhry et al., 2007) have demonstrated that structured safety monitoring programs reduce accident rates by creating an environment where workers are consistently reminded of and encouraged to follow safety protocols. The significant influence of safety monitoring on safety awareness further underscores the importance of managerial oversight and real-time hazard identification in preventing workplace incidents.

This study contributes to occupational safety literature by integrating multiple theoretical perspectives into a comprehensive framework. The significant mediating role of safety awareness suggests that direct interventions such as risk assessment, training, PPE, and safety monitoring alone may not be sufficient to ensure worker protection. Instead, safety awareness acts as a crucial bridge between these interventions and actual safety outcomes, reinforcing the notion that workers must first recognize and internalize safety principles before engaging in protective behaviors. This finding aligns with the Theory of Planned Behavior (Ajzen, 1991), which posits that awareness and intention are fundamental determinants of behavior. Workers who are more conscious of risks and knowledgeable about safety protocols are more likely to engage in self-protective actions. Similarly, Neal & Griffin's (2006) Safety Performance Model suggests that safety knowledge and safety motivation mediate the relationship between organizational interventions and actual safety performance. By demonstrating that safety awareness strengthens the impact of other safety measures, this study provides empirical support for these theoretical models and expands their applicability within the construction sector. Furthermore, these findings challenge the traditional assumption that safety training and monitoring alone are sufficient to improve workplace safety. Instead, the results suggest that fostering a culture of safety awareness is equally crucial in ensuring long-term compliance and behavioral change. This insight is particularly relevant in developing countries like Bangladesh,

where safety regulations are often inadequately enforced and informal labor markets dominate the construction sector. Previous research (Lingard & Rowlinson, 2004) has noted that without sustained efforts to build safety awareness, even well-designed interventions may fail to yield meaningful improvements in accident prevention.

Theoretical and Practical Contribution

This study advances the theoretical discourse on OSH by integrating risk assessment, worker training, PPE, and safety monitoring within Bangladesh's construction sector, where OSH challenges are compounded by weak regulation and informal labor. Extending the Swiss Cheese Model and enriching Experiential Learning Theory, it demonstrates that systematic hazard identification and hands-on training improve safety compliance and hazard perception. The research also refines the Hierarchy of Controls Model, showing that PPE effectiveness relies on regulatory reinforcement. A key theoretical contribution is identifying safety awareness as a mediator, aligning with the Theory of Planned Behavior (Ajzen, 1991), strengthening the relationship between OSH interventions and safety outcomes.

Practically, this study offers actionable insights for improving OSH in Bangladesh's construction sector, emphasizing risk assessment, training, PPE compliance, and safety monitoring. It underscores the importance of safety awareness and real-time monitoring, advocating for awareness campaigns, mandatory safety audits, and digital solutions to foster a proactive safety culture. These contributions provide a comprehensive framework for enhancing worker protection and ensuring sustainable development in high-risk industries globally.

Conclusion, Limitations, and Future Research Direction

This study provides critical insights into the impact of risk assessment, worker training, personal protective equipment (PPE), and safety monitoring on OSH within Bangladesh's construction sector. It emphasizes the need for comprehensive safety protocols to address high accident rates and inadequate safety measures. The research shows a strong correlation between risk assessment and reduced hazards, with worker training enhancing hazard perception and fostering safety compliance. PPE, while essential, requires proper usage, enforcement, and addressing cultural attitudes and cost barriers for effective implementation. Safety monitoring proves vital in reinforcing adherence to safety standards, with real-time oversight cultivating a safety-conscious workforce. The integration of safety awareness as a mediating factor amplifies the effectiveness of safety interventions, emphasizing the importance of awareness campaigns. The study contributes both theoretically and practically, offering a framework for OSH improvement in developing economies. Future research should explore long-term intervention effects, digital tools, and the impact of subcontracting and informal labor on safety compliance.

This study's cross-sectional design limits causal inference regarding the long-term impact of safety interventions. The sample, consisting of 31 construction sites from five districts, may not fully capture regional safety variations, and self-reported data introduces potential social desirability bias. Additionally, industry-wide organizational differences, such as firm size and subcontracting, were not explored. These factors may influence the effectiveness of safety protocols. Therefore, caution is needed when generalizing findings beyond the sampled sites.

Future research should employ longitudinal designs and broaden geographic and industry scope to include different economic zones and construction practices. Incorporating objective data, such as accident records and real-time monitoring, could address biases associated with self-reported data. Research should also investigate digital innovations like AI-driven risk

assessment tools, wearable devices, and mobile safety training modules to enhance compliance. Furthermore, exploring how subcontracting and informal labor dynamics affect OSH could provide critical insights into standardizing regulations and improving safety practices.

Conflict of Interest Statement

The authors affirm they have no conflict of interest.

Data Availability Statement

The data are available upon reasonable request.

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