An Audit System Causality Model for Construction Safety Management System Assessment in Building Projects using Integrated Design-Build

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ABSTRACT

Increasing the implementation of Construction Safety Management Systems (CSMSs) has proven to be an effective strategy for preventing construction accidents. Unfortunately, the current safety audit system is still not fully developed at each stage of the project life cycle, especially in integrated design-build contracts for construction projects. Based on this phenomenon, the objectives of the current research were developed, which include identifying the indicators and sub-indicators of the performance assessment audit system, and designing a causality model of the indicators and sub-indicators of the assessment audit system in each project life cycle, especially for the integrated design-build contract. The research method comprises a literature review and expert validation to obtain the indicators and sub-indicators for the safety system audit. In addition, a perception survey was conducted through with questionnaires being distributed to safety engineers and safety personnel in several construction projects. The questionnaire data were analyzed using Structural Equation Modeling (SEM) with Partial Least Squares (PLS) to develop a causality model for the safety indicators and sub-indicators. The study results obtained five indicators and eighty-six sub-indicators in the safety audit system that significantly influenced the performance of safety implementation in construction projects. Moreover, he causality model obtained Y1 = 0.2518X1 - 0.0308X2 - 0.3523X3 + 0.4188X4 - 0.0693X5 including: X1 leadership and worker participation in construction safety, X2 construction safety planning, X3 construction safety support, X4

construction safety operational, and X5 construction safety performance evaluation. The results of this study are expected to act as a reference, especially for service providers implementing the elements of the audit system.

Keywords-audit system; construction safety; building project; design-build; causality model

I. INTRODUCTION

The construction industry worldwide faces unique challenges in dealing with construction safety during the latter's implementation [1]. Certain construction industry characteristics, such as the dynamic work environment, use of heavy equipment, and interaction with hazardous work, are high accident causes compared to other industries [2]. In addition, many actors in the construction industry do not prioritize safety factors and thus are the cause of many cases of work accidents [3]. Time, cost, and quality are always the main parameters taken into account, while safety issues are often considered secondary, taking a back seat in the construction projects [4]. Many companies have yet to establish a comprehensive accident prevention policy, focusing instead on maximizing profits [5]. Data show that in some developed countries, construction workers are 3-4 times more likely to die from occupational accidents compared to workers in other industries, while in developing countries, the risks associated with construction work are 3-6 times greater. At least 108,000 construction workers die each year, accounting for 30% of all fatal work-related injuries [6]. The trend of high accident rates in the construction industry compared to other industries can be found in many countries, including Canada, the United Kingdom, New Zealand, India, the Republic of Korea, and Indonesia [7-11]. Construction is one of the riskiest occupations in Canada. In 2022, the former had the highest fatality rate. It was the industry with the third highest lost time injury rate out of the 19 industries surveyed in Canada. Meanwhile, in the Republic of Korea, although the overall occupational fatality rate decreased by ~1.22%, from 7.05% in 2009 to 5.83% in 2019, the occupational fatality rate in the construction industry increased by ~3.61%, from 6.55% in 2009 to 10.16% in 2019. Likewise, in Indonesia, the number of work accidents is also increasing every year. Data from the Indonesian Manpower Social Security Organizing Agency from 2019 to 2022 recorded an increase in work accidents, as shown in Figure 1.

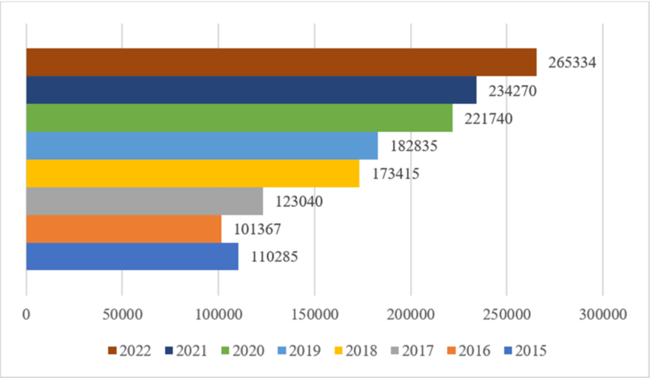

Fig. 1. Number of construction accidents in Indonesia.

An analysis of the accident case data reveals that the construction industry exhibits the highest work accident rate, accounting for 32% of the total of work accidents across all sectors. High-rise building projects are particularly susceptible to work accidents, with high-rise construction being considered more hazardous than low-rise construction. The inherent complexity of high-rise construction projects, characterized by the need for diverse expertise and technological integration, coupled with the execution of tasks at considerable heights, renders them particularly prone to work accidents [14]. Building construction sites, especially the high-rise ones, has consistently recorded the highest number of accidents annually [15]. Falling from heights while working remains a significant concern for construction workers [16]. In response, the Indonesian government has enacted a series of construction safety-related laws and regulations with the aim of enhancing safety performance and reducing the number of accidents on building projects [17]. These measures commenced with the promulgation of Law Number 1 of 1970 concerning Occupational Safety, which revoked the previous regulation of the Veiligheidsreglement of 1930. The most recent construction safety regulation is outlined in the Regulation of the Minister of Public Works and Housing of the Republic of Indonesia Number 10 of 2021 concerning Guidelines for CSMS. According to these regulations, CSMS implementation is mandatory during construction, as it is an integral component of project planning and control, while it also constitutes a component of the management system during construction work implementation, to ensure the realization of the construction safety objectives. Despite the existence of applicable regulations, data indicate that the incidents of work accidents in Indonesia remain high. Therefore, it is imperative to assess the extent to which construction safety regulations are implemented to ensure optimal construction safety performance [18]. The implementation of the CSMS regulation is inextricably linked to the safety audit system, which involves the assessment or measurement (rating tools) of the construction safety performance during project implementation. Auditing or measuring the construction safety performance is responsible for implementing appropriate corrective and preventive actions for work performance that are not up to standard [19]. The work safety audit process serves as the foundation for implementing appropriate corrective and preventive actions to address work safety performance that does not meet the established criteria [19, 20]. Auditing or measuring the construction safety performance must be carried out thoroughly in every project life cycle, from the feasibility study stage to the closing stage. However, the usage of rating tools for evaluating the efficacy of CSMS implementation in construction projects remains underdeveloped [21].

The present safety audit system, while significant for ensuring the proper execution of safety practices, possesses limitations that are seldom disclosed in research. These limitations include the tendency of safety audit systems to rely on qualitative and descriptive standards, which hinders their objectivity and reliability [22]. A multitude of studies have demonstrated that safety audits are often executed in a sporadic and irregular manner, failing to encompass the entirety of the project life cycle. This deficiency results in an absence of a systematic follow-up of the audit outcomes. Furthermore, studies have demonstrated that audit systems are not always tailored to the unique conditions and risks present at different construction sites, underscoring the limitations of a 'one-size-fits-all' approach [24-26]. Existing research has not extensively examined the direct impact of safety audit systems on accident reduction in construction projects. Although audits are widely regarded as a vital instrument for ensuring compliance with rules and regulations there is a paucity of empirical evidence to substantiate the extent to which they actually mitigate safety incidents in the field. In some cases, audits are merely perfunctory, failing to elicit tangible actions to address prevailing conditions. Consequently, even when audits are conducted, the implementation of their results is often ineffective or insufficient to make a significant impact [27]. The implementation of safety audit systems on construction projects has been developed and studied in several countries. However, the current implementation of safety audit systems remains confined to the construction stage, with a lack of comprehensive audits encompassing all project stages, from feasibility studies and design to closure. Consequently, there is an urgent need to comprehensively assess the evolution of CSMS indicators and sub-indicators by referencing the planning, do, check, and act management system. Additionally, safety audit systems are currently too general, necessitating the development of more specific audit systems for building projects, particularly those involving design-build contracts. The present study was thus developed to address this critical audit system gap by proposing a multifaceted approach. This approach entailed the development of novel elements and rating tools to assess specific construction safety performance on building projects under design-build contracts. The novel elements and tools were derived from the WBS approach, and their effectiveness was analyzed in measuring the cause-and-effect relationship of safety audit rating elements. The overarching objective of this research is to enhance the implementation of construction safety measures.

II. METHODOLOGY

An operational framework was developed to achieve the research objectives, as illustrated in Figure 2. The elements, sub-elements, and indicators of the safety audit system are obtained from CSMS regulations and previous related research. The research strategy for reducing potential biases is carried out by triangulating research with data collection techniques using two methods. Data collection for Research Question 1 (RQ1) entailed the procurement of risk data from various relevant journal references, followed by validation through an opinion survey and in-depth interviews with five experts who met the following criteria: minimum undergraduate engineering education, more than 10 years of experience in the CSMS field, and possession of a safety competency certificate. The results of the expert validation were processed using a binary "Yes" or "No" question, and then analyzed using descriptive analysis to obtain agreement on the validation of the existence of the elements, sub-elements, and indicators of the safety audit system. Research Question 2 (RQ2) concerned how to obtain causality quantification values for the application of elements, sub-elements, and indicators by improving the safety audit system. It encompassed a perception survey with a questionnaire form having been distributed to safety engineers, safety officers, and safety staff regarding the level of implementation of the elements, sub-elements, and indicators of the safety audit system that has been applied in their project. The distribution of the questionnaire occurred within ten building construction projects that were operating under design-build contracts. The Likert scale was used to assess the respondents' perceptions. Score "5": Completely implemented (100%), score "4": Implemented (75%), score "3": Less implemented (50%), score "2": Very little implemented (25%), score "1": Not implemented (0%). The data obtained from the questionnaire were then processed using the SEM analysis with PLS through SmartPLS 4. The operational model of the research is displayed in Figure 3.

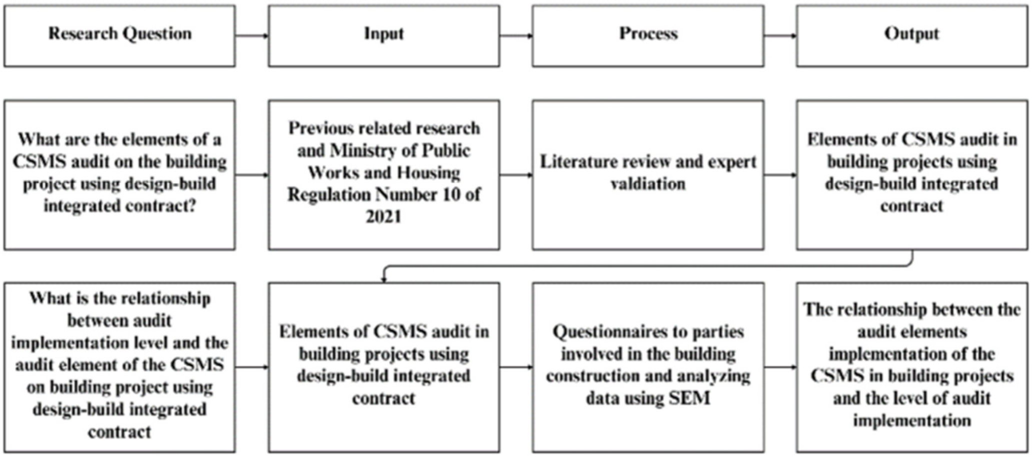

Fig. 2. Operational framework.

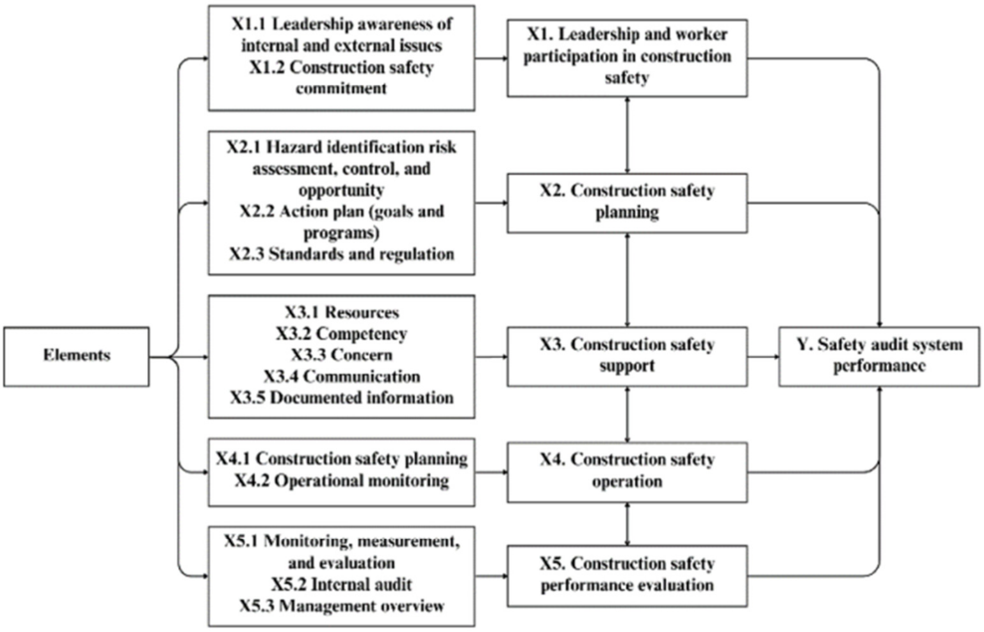

Fig. 3. Operational model of the research.

The data analysis for RQ2 was executed using SEM with PLS. This analysis included the following components: validity and reliability analysis tests, such as convergent validity, reliability analysis, and discriminate validity analysis, and structural model evaluation, such as the structural model (inner model), and the inner model test (path coefficients) and (significance t-statistic).

III. RESULTS AND DISCUSSION

A. *RQ1: Elements of A Construction Safety Management System Audit*

The results of regulatory studies, literature studies, and expert validation of the elements and indicators of the safety audit system yielded five primary elements, fifteen sub-elements, and 88 indicators, as detailed in Table I. The results of the expert validation process, which was conducted through in-depth interviews, yielded a mean value of 100%. This indicates that five experts validated five primary elements, fifteen sub-elements, and eighty-eight indicators that had a significant impact on enhancing the performance of the safety audit system. After the identification of the crucial elements through a comprehensive review of the extant literature, the subsequent phase of the research will entail the implementation of data collection through the utilization of questionnaires. These elements are typically grounded in extant theories, findings from prior research, or factors deemed pertinent to the research topic. The identification of elements from extant literature is instrumental in ensuring that the research is founded upon a robust and scientific foundation, with a focus placed on salient variables.

TABLE I. ELEMENTS, SUB-ELEMENTS, AND INDICATORS OF SAFETY AUDIT SYSTEM

Element	Sub-Elements	Indicators		References
X1	Leadership and Worker Participation in Construction Safety			
X1.1	Leadership awareness of internal and external issues	X1.1.1	The contractor understands internal and external issues that can affect the implementation of CSMS.	[19, 21]
		X1.1.2	The contractor establishes a construction safety organization based on regulatory requirements.	[19, 21, 22]
		X1.1.3	The contractor's CSMS management organization is adjusted to the scale of complexity of the construction work.	[19, 21, 22]
		X1.1.4	The contractor must prepare competent experts to manage the administration and operations of the CSMS.	[21]
		X1.1.5	The composition, duties, authority, and responsibilities of the CSMS organization are officially determined by the contractor's top management.	[21]
X1.2	Construction safety commitment	X1.2.1	The contractor has a construction safety policy at the design and construction stages.	[21]
		X1.2.2	The contractor top management signs construction safety policies and commitments.	[21]
		X1.2.3	The contractor's construction safety policy is communicated to all internal and external stakeholders.	[21]
		X1.2.4	The contractor is committed to preventing and protecting against security threats and disturbances in various forms, and protecting the safety of work methods, workforce, property, materials, equipment, the general public, and the environment.	[8, 19, 21, 23, 24]
		X1.2.5	Top contractor management signs safety commitment pact.	[21]
		X1.2.6	The contractor top management increases workforce participation in implementing construction safety in the design and construction stages.	[21]
		X1.2.7	The contractor ensures that the CSMS performance is in accordance with the stated objectives and	[21]

			programs.	
		X1.2.8	The contractor management continuously consults with workers and unions covering CSMS planning, implementation, evaluation, and corrective action.	[21, 25]
X2	Construction Safety Planning			
X2.1	Hazard identification, risk assessment, control, and opportunity	X2.1.1	The contractor prepares documents for hazard identification, risk assessment, construction safety control, and opportunities.	[8, 19, 21]
		X2.1.2	The contractor has construction accident data including near miss, moderate accidents, and fatality accidents.	[8, 19, 21]
		X2.1.3	The contractor reviews risk assessments, performs hazard identification, controls construction safety opportunities if an accident occurs, including near miss, moderate accidents, and fatality accidents.	[8, 19, 21]
		X2.1.4	The contractor identifies properly documented construction safety hazards and risks, controls and assesses opportunities, and complies with laws and regulations.	[8, 19, 21]
		X2.1.5	The contractor prepares Job Safety Analysis (JSA) specifically for jobs with moderate and high construction safety risks, or jobs with special equipment and work methods.	[8, 19, 21]
X2.2	Action plan (goals and programs)	X2.2.1	The contractor sets CSMS targets for each function from the design stage to the construction.	[19, 21, 23, 24]
		X2.2.2	The contractor sets measurable CSMS targets and consistently complies with the construction safety policies.	[13, 19, 21]
		X2.2.3	The contractor establishes CSMS objectives based on construction safety planning.	[19, 21]
		X2.2.4	The contractor communicates to all workers the CSMS objectives that have been set.	[19, 21]
		X2.2.5	The contractor monitors and evaluates the CSMS objectives that have been set.	[19, 21]
		X2.2.6	The contractor determines construction safety work programs based on CSMS objectives.	[19, 21]
		X2.2.7	The contractor ensures that the CSMS work programs are implemented.	[19, 21]
X2.3	Standards and regulations	X2.3.1	The contractor identifies and applies construction safety regulations and standards in CSMS implementation.	[19, 21, 23, 24]
		X2.3.2	The contractor sets standards regarding the procurement of personal protective equipment, such as safety body harnesses, safety shoes, safety helmets, safety glasses, safety gloves, masks, earplugs, and safety vests, as well as work protective equipment, such as safety nets, safety ropes, fall protection, safety fences, area dividers, and construction safety signs.	[19, 21, 23, 24]
		X2.3.3	The contractor places expiration dates and renews permits, licenses, and certificates on construction materials and equipment.	[21]
X3	Construction Safety Support			
X3.1	Resources	X3.1.1	The contractor provides resources to implement, maintain, and continually improve CSMS implementation.	[19, 21]
		X3.1.2	The contractor prepares facilities and infrastructure to implement CSMS.	[19, 21]
		X3.1.3	The contractor allocates funds for CSMS implementation activities.	[19, 21, 22]
X3.2	Competency	X3.2.1	The contractor provides/employs officers at the level of construction safety, who are competent and certified to supervise low risk work.	[13, 19, 21-24]
		X3.2.2	The contractor provides/employs officers at the level of construction safety, who are competent and certified to supervise moderate and high risk work.	[13, 19, 21-24]
		X3.2.3	The contractor provides/employs emergency response officers who have received training.	[13, 19, 21-24]
		X3.2.4	The contractor has trained personnel and medical equipment for injured workers.	[13, 19, 21-24]
		X3.2.5	The contractor ensures that all workers have competency certificates in their fields.	[13, 19, 21-24]
X3.3	Concern	X3.3.1	The contractor ensures that all workers are aware of CSMS policies and objectives.	[21]
		X3.3.2	The contractor analyzes training plans related to construction safety competency requirements for workers.	[21]
X3.4	Communication	X3.4.1	The contractor has/follows communication procedures in CSMS implementation.	[13, 19, 21]
		X3.4.2	The contractor creates a communication schedule for CSMS implementation addressing/being given to all workers during the design and construction activities.	[13, 19, 21]
X3.5	Documented Information	X3.5.1	The contractor has manuals, procedures, work drawings, work instructions, and construction safety documentation for all necessary construction activities.	[13, 19, 21]
X4	Construction Safety Operational			
X4.1	Construction Safety Planning	X4.1.1	The contractor has employed personnel who are responsible for implementing the CSMS at the design and construction stages.	[13, 21]
		X4.1.2	The contractor has documented the procedures and work instructions for CSMS implementation operations.	[21]
		X4.1.3	The contractor establishes, implements, and maintains risk controls to eliminate hazards and reduce risks to the CSMS.	[21]
		X4.1.4	The contractor controls construction safety risks by eliminating hazards, substituting non-hazardous processes, operations, materials, or equipment, performing engineering, implementing administrative controls, and using adequate personal protective equipment.	[21]
X4.2	Operational monitoring	X4.2.1	The contractor monitors and controls CSMS operations in communication management.	[21]
		X4.2.2	The contractor controls the operation of obtaining special work permits for high-risk work.	[21]
		X4.2.3	The contractor carries out construction safety analyses on moderate risk and high risk work.	[21]
		X4.2.4	The contractor has/follows construction equipment operating procedures.	[21, 25]
		X4.2.5	The contractor has a lifting plan for the lift/transport/slider girder work.	[21]

		X4.2.6	The contractor carries out operational control over the management of work protective equipment and personal protective equipment.	[21, 25, 26]
		X4.2.7	The contractor provides personal protective equipment and work protective equipment according to the hazardous conditions and number of workers, such as safety body harness, safety shoes, safety helmets, safety glasses, safety gloves, masks, earplugs, safety vests, safety nets, safety ropes, restraint falls, safety fences, area barriers, fall protection, and safety signs.	[21, 25, 26]
		X4.2.8	The contractor installs signs based on the construction safety hazards and risk levels.	[21]
		X4.2.9	The contractor prepares safe and sturdy equipment related to mitigating environmental hazards, such as scaffolding, temporary platforms, goods' lifts, temporary stairs, safety nets, fall protection equipment, lightning rods, wind barriers, and temporary roofs.	[21]
		X4.2.10	The contractor carries out control of work environment management operations.	[21]
		X4.2.11	The contractor provides workers with facilities, such as barracks, canteens, and adequate toilets, in accordance with rules and regulations.	[21]
		X4.2.12	The contractor implements a concise, neat, clean, careful, and diligent program.	[21]
		X4.2.13	The contractor has carried out work environment measurement.	[21]
		X4.2.14	The contractor plans and implements programs to address construction waste, such as garbage, concrete debris, demolition materials, packaging materials, scrap wood and boards, metal scraps, broken equipment, hazardous materials, chemical waste, plastics, and electronic waste.	[21, 25]
		X4.2.15	The contractor prepares material safety data sheets, procedures for receiving, storing, using, and destroying hazardous materials, and conducts outreach to all workers.	[21, 25]
		X4.2.16	The contractor performs temporary storage/disposal of waste in the field according to rules and regulations.	[21, 25, 28]
		X4.2.17	The contractor manages and controls construction waste in accordance with statutory regulations.	[21, 29]
		X4.2.18	The contractor carries out operational control over occupational health management.	[21, 30]
		X4.2.19	The contractor carries out control of labor social protection management operations.	[21]
		X4.2.20	The contractor carries out operational control and installation safety management.	[21]
		X4.2.21	The contractor controls the maintenance of facilities, infrastructure, and equipment.	[21]
		X4.2.22	The contractor provides a light fire extinguisher at the work site.	[21, 31]
		X4.2.23	The contractor operates heavy equipment in the field and is equipped with permits and competent operators.	[21]
		X4.2.24	The contractor controls the security operations of the work environment.	[21]
		X4.2.25	The contractor carries out operational control on construction safety.	[21]
		X4.2.26	The contractor carries out periodic inspections and maintenance of equipment.	[21]
		X4.2.27	The contractor uses checklists when conducting construction safety inspections.	[21]
		X4.2.28	The contractor carries out operational control in supply chain.	[21]
		X4.2.29	The contractor establishes procedures for receiving and storing materials.	[21]
		X4.2.30	The contractor establishes procedures for moving and using materials.	[21]
		X4.2.31	The contractor carries out operational control in traffic engineering management.	[21]
		X4.2.32	The contractor plans and implements emergency responses (floods, earthquakes, and other natural disasters).	[21, 32]
		X4.2.33	The contractor provides and prepares a first aid kit for accidents.	[21, 33]
		X4.2.34	The contractor is required to report fatal accidents, casualties, dangerous incidents, and emergency situations to the related parties.	[21, 34]
X5	Construction Safety Performance Evaluation			
X5.1	Monitoring, measurement, and evaluation	X5.1.1	The contractor monitors the implementation of the CSMS and evaluates compliance with regulations.	[13, 19, 21, 25, 26]
		X5.1.2	The contractor ensures that all equipment that requires precision in measurements is calibrated.	[13, 19, 21, 27]
		X5.1.3	The contractor ensures that CSMS performance is measured according to the applicable standards.	[13, 19, 21]
		X5.1.4	The contractor documents the results of CSMS monitoring and measurements.	[13, 19, 21, 27]
X5.2	Internal audit	X5.2.1	The contractor conducts internal audits related to CSMS implementation.	[13, 19, 21]
		X5.2.2	The contractor documents the results of the CSMS internal audit.	[13, 19, 21]
X5.3	Management overview	X5.3.1	The contractor conducts CSMS implementation reviews for continuous improvement.	[13, 19, 21]
Y1		Safety audit system performance		

Subsequent to the determination of these elements, a questionnaire is meticulously designed to quantitatively measure them. After the collection of the data from the aforementioned questionnaire, the data are analyzed using SEM, which is a statistical analysis method deployed to examine the relationship between the latent variables (variables that cannot be measured directly but are represented by several indicators) and measured variables. In this study, the elements identified from the extant literature function as latent variables, which are measured through items in the questionnaire. The subsequent sub-section will elaborate on this measurement process.

B. RQ2: Relationship between the Implementation of CSMS Audit System and the Level of Audit Performance

1) Convergent Validity Analysis

In order to execute a SEM analysis, it is necessary to establish the validity and relevance of the elements, sub-elements, and indicators. The criteria for determining the validity and relevance of an indicator include the following: an outer loading value of at least 0.70, indicating a high degree of relevance, an outer loading value between 0.40 and 0.70, indicating a moderate degree of relevance, or an outer loading value of less than 0.40, indicating a low degree of relevance or the potential for elimination. Convergent validity is defined as an analysis that measures the extent to which a measure is positively correlated with alternative measures of the same construct. A standard measure for establishing convergent validity at the construct level is the Average Variance Extracted (AVE). This criterion is the grand average value of the indicators associated with the construct (i.e., the sum of the squared charges divided by the number of indicators). The AVE measurement value must meet a value greater than 0.5. In this study, elimination was carried out on the elements' X1, X3, and X5 indicators. The indicators eliminated from element X1 are X1.1.1, X1.1.2, X1.1.3, X1.1.4, and X1.2.2, while from element X3, X3.1.1 and X3.1.3 and from element X5, X5.3.1. The elimination of these indicators is necessitated by the fact that the rho A value of the sub-variables X1, X3, and X5 does not meet the recommended limit, which is equal or greater than 0.70. Concurrently, indicators in elements X1 and X5 are eliminated because they have not met the minimum AVE requirement of 0.5. The data processing results subsequent to the elimination of these indicators are reflected in the AVE value of the elements and indicators of the safety audit system for improving construction safety performance on building projects with design-build contracts, as evidenced in Table II. The results of estimating the AVE value demonstrate that all calculated factors have a value greater than 0.5 and are declared valid. This finding suggests that, on average, the construct has accounted for more than half of the variability in its indicators.

2) Reliability Analysis

The most common criteria for measuring internal consistency reliability are Cronbach's alpha and composite reliability. The latter is defined as the instrument's ability to measure the indicator value, with the calculated reliability value having to be ≥ 0.70. The results of the reliability analysis of the elements, sub-elements, and safety management system indicators are presented in Table III. The findings of the data analysis demonstrate that the calculated value of reliability (composite reliability and Cronbach's alpha) exceeds 0.7. Consequently, it can be determined that the instrument is reliable and effective for usage in research endeavors.

3) Discriminate Validity Analysis

Discriminant validity analysis is defined as the extent to which a construct is genuinely distinct from other constructs according to empirical standards. Discriminant validity values are determined by calculating the Fornell-Lacker and cross-loading values. The Fornell-Lacker value is considered valid if the AVE square root value of each variable exceeds the value of the other variables. Meanwhile, the cross-loading value is deemed valid if the outer loading of an indicator and its variable is greater than the other variable indicators [15]. The outcomes of the Discriminant validity test are listed in Tables IV and V.

TABLE II. CONVERGENT VALIDITY

	rho_A	Composite Reliability	AVE
X1	0.8988	0.8985	0.5070
X1.1	1.0000	1.0000	1.0000
X1.2	0.8834	0.8891	0.5110
X2	0.9579	0.9576	0.6073
X2.1	0.8782	0.9046	0.6552
X2.2	0.9595	0.9647	0.7965
X2.3	0.7924	0.8463	0.6546
X3	0.9341	0.9418	0.5964
X3.1	1.0000	1.0000	1.0000
X3.2	0.9028	0.9267	0.7173
X3.3	0.7342	0.8796	0.7851
X3.4	0.7726	0.8977	0.8144
X3.5	1.0000	1.0000	1.0000
X4	0.9793	0.9790	0.5544
X4.1	0.8095	0.8586	0.6097
X4.2	0.9778	0.9774	0.5626
X5	0.8613	0.8911	0.5403
X5.1	0.7902	0.8596	0.6067
X5.2	0.7614	0.8625	0.6767
Y	1.0000	1.0000	1.0000

TABLE III. REALIBILITY ANALYSIS

	Cronbach's Alpha	Composite Reliability
X1	0.8707	0.8985
X1.1	1.0000	1.0000
X1.2	0.8548	0.8891
X2	0.9510	0.9576
X2.1	0.8694	0.9046
X2.2	0.9568	0.9647
X2.3	0.7249	0.8463
X3	0.9316	0.9418
X3.1	1.0000	1.0000
X3.2	0.9004	0.9267
X3.3	0.7272	0.8796
X3.4	0.7721	0.8977
X3.5	1.0000	1.0000
X4	0.9776	0.9790
X4.1	0.7747	0.8586
X4.2	0.9758	0.9774
X5	0.8567	0.8911
X5.1	0.7810	0.8596
X5.2	0.7610	0.8625
Y	1.0000	1.0000

The findings of the discriminant validity analysis (Fornell, Lacker, and cross-loading) suggest that the majority of the constructs are distinct and capture phenomena that are not represented by other constructs in the model.

4) Structural Model (Inner Model)

The process of inner model testing is initiated by the examination of the R-squared value of the dependent latent variable. The R-square coefficient is a measure of the extent to which the variable X exerts influence over variable Y in the study, particularly in the context of exogenous latent variables affecting endogenous latent variables. The coefficient of determination serves to ascertain whether the variables employed are capable of elucidating the model that has been developed. The outcomes of the data testing process are presented by the R-square value shown in Table VI. The R-Square value is 0.1017, which corresponds to 10.17% of the total variation in the dependent variable. This indicates that the independent variable can explain or predict 10.17% of the dependent variable. It is noteworthy that an R-Square value of 0.10 or higher is generally regarded as sufficient to explain the dependent variable. This finding aligns with the conclusions that an R-Square value of at least 0.10 can be considered significant in explaining the dependent variable. Although the R-Square value of 10.17% is relatively low, it offers preliminary insights into the relationship between the measured variables and the safety and audit performance on construction projects. This observation underscores the need for further research, as it highlights the model's ability to capture only a fraction of the variability in safety, emphasizing the necessity for a more comprehensive understanding of the factors influencing this relationship. Further deliberations on the limitations of this model and recommendations for future research will facilitate a more profound comprehension of the factors that influence the relationship between the construction audit and safety and how they can be more accurately measured in the future.

TABLE IV. FORNELL LACKER

	X1.1	**X1.2**	**X2.1**	**X2.2**	**X2.3**	**X3.1**	**X3.2**	**X3.3**	**X3.4**	**X3.5**	**X4.1**	**X4.2**	**X5.1**	**X5.2**	**Y**
X1.1.5	1.000	0.649	0.575	0.620	0.613	0.515	0.489	0.554	0.596	0.548	0.457	0.528	0.499	0.445	0.054
X1.2.1	0.435	0.775	0.371	0.316	0.423	0.323	0.310	0.266	0.481	0.363	0.369	0.462	0.387	0.330	0.121
X1.2.2	0.291	0.469	0.383	0.197	0.266	0.160	0.347	0.304	0.381	0.249	0.469	0.410	0.594	0.475	0.107
X1.2.3	0.343	0.768	0.649	0.481	0.623	0.355	0.633	0.542	0.610	0.336	0.533	0.619	0.591	0.343	0.145
X1.2.4	0.665	0.844	0.503	0.523	0.498	0.494	0.481	0.454	0.609	0.524	0.524	0.556	0.513	0.450	0.229
X1.2.5	0.184	0.477	0.509	0.554	0.498	0.279	0.599	0.631	0.523	0.340	0.523	0.506	0.490	0.439	0.082
X1.2.6	0.648	0.829	0.555	0.517	0.593	0.686	0.439	0.523	0.562	0.309	0.560	0.601	0.433	0.424	0.189
X1.2.7	0.581	0.797	0.533	0.542	0.563	0.225	0.502	0.419	0.530	0.515	0.359	0.482	0.571	0.355	0.281
X1.2.8	0.393	0.646	0.538	0.384	0.405	0.425	0.327	0.382	0.415	0.281	0.471	0.594	0.316	0.368	0.253
X2.1.1	0.277	0.508	0.795	0.521	0.419	0.384	0.566	0.637	0.691	0.377	0.646	0.727	0.647	0.589	0.093
X2.1.2	0.397	0.550	0.783	0.557	0.497	0.501	0.359	0.524	0.705	0.176	0.575	0.715	0.602	0.441	0.047
X2.1.3	0.265	0.561	0.810	0.514	0.393	0.354	0.489	0.566	0.614	0.247	0.683	0.818	0.616	0.553	0.211
X2.1.4	0.574	0.571	0.869	0.747	0.649	0.279	0.650	0.667	0.633	0.522	0.620	0.755	0.684	0.585	-0.018
X2.1.5	0.709	0.623	0.787	0.785	0.719	0.499	0.600	0.606	0.600	0.615	0.514	0.655	0.535	0.436	0.070
X2.2.1	0.614	0.497	0.641	0.794	0.479	0.483	0.667	0.764	0.816	0.668	0.738	0.648	0.570	0.636	0.033
X2.2.2	0.614	0.572	0.803	0.954	0.657	0.457	0.555	0.795	0.683	0.485	0.670	0.749	0.566	0.543	0.119
X2.2.3	0.573	0.549	0.729	0.913	0.631	0.414	0.521	0.739	0.630	0.470	0.652	0.705	0.509	0.550	0.156
X2.2.4	0.475	0.570	0.689	0.894	0.574	0.189	0.513	0.607	0.696	0.582	0.548	0.616	0.601	0.492	0.221
X2.2.5	0.587	0.557	0.722	0.905	0.724	0.380	0.471	0.634	0.655	0.524	0.554	0.660	0.565	0.478	0.129
X2.2.6	0.496	0.544	0.703	0.927	0.515	0.255	0.540	0.746	0.624	0.437	0.577	0.640	0.550	0.509	0.211
X2.2.7	0.516	0.556	0.636	0.851	0.785	0.457	0.568	0.609	0.586	0.511	0.549	0.659	0.569	0.429	0.281
X2.3.1	0.675	0.681	0.582	0.672	0.896	0.575	0.466	0.460	0.632	0.593	0.528	0.658	0.574	0.488	0.179

TABLE V. CROSS LOADING

	X1.1	**X1.2**	**X2.1**	**X2.2**	**X2.3**	**X3.1**	**X3.2**	**X3.3**	**X3.4**	**X3.5**	**X4.1**	**X4.2**	**X5.1**	**X5.2**	**Y**
X1.1	1.000														
X1.2	0.649	0.715													
X2.1	0.575	0.699	0.809												
X2.2	0.620	0.616	0.790	0.892											
X2.3	0.613	0.681	0.681	0.701	0.809										
X3.1	0.515	0.532	0.497	0.421	0.627	1.000									
X3.2	0.489	0.622	0.668	0.610	0.568	0.458	0.847								
X3.3	0.554	0.600	0.744	0.782	0.549	0.493	0.758	0.886							
X3.4	0.596	0.718	0.796	0.747	0.659	0.637	0.680	0.796	0.902						
X3.5	0.548	0.516	0.501	0.584	0.605	0.421	0.689	0.534	0.667	1.000					
X4.1	0.457	0.649	0.743	0.684	0.588	0.576	0.736	0.776	0.844	0.639	0.781				
X4.2	0.528	0.733	0.901	0.749	0.711	0.601	0.661	0.738	0.853	0.606	0.882	0.750			
X5.1	0.499	0.662	0.759	0.628	0.623	0.420	0.676	0.610	0.796	0.659	0.806	0.802	0.779		
X5.2	0.445	0.538	0.640	0.580	0.438	0.336	0.536	0.648	0.717	0.585	0.771	0.732	0.702	0.823	
Y	0.054	0.253	0.091	0.185	0.207	0.063	0.054	0.084	0.142	0.118	0.214	0.222	0.160	0.122	1.000

5) Inner Model Test (Path Coefficients)

The Inner Model test value is indicative of the direction of the positive or negative variable relationship. The outcomes of this calculation demonstrate the direction of the influence of each variable "X" on the variable "Y." The closer the value is to "+1," the stronger is the relationship between the two constructs. Conversely, a value closer to "-1" signifies a negative relationship [15]. The results of the Inner Model test, as portrayed in Table VII, provide a quantitative representation of these relationships.

6) Inner Model Test (Significancy T-Stastistic)

The results of the analysis of the Inner Model test evaluation parameters (significancy T-statistic) are calculation results that show the significance value of a variable, as depicted in Figure 4. This value is evident in the T-statistic calculation results, which demonstrate the impact of the variables on variable "Y," specifically enhancing the efficacy of the safety audit system. The significance acceptance value is determined by the following criteria: if the *P* values are equal to or greater than 0.05 or the T-statistic value is greater than 1.96, then the variable is considered significant. The results of the analysis employing the SmartPLS tool are presented in Table VIII. The equation obtained from the data analysis results is:

$$Y1 = 0.2518X1 - 0.0308X2 - 0.3523X3 + 0.4188X4 - 0.0693X5 \quad (1)$$

TABLE VI. R-SQUARE

	R Square
Y	0.1017

TABLE VII. INNER MODEL RESULTS

	X1	**X2**	**X3**	**X4**	**X5**	**Y**
X1						0.252
X2						-0.031
X3						-0.352
X4						0.419
X5						-0.069
Y						

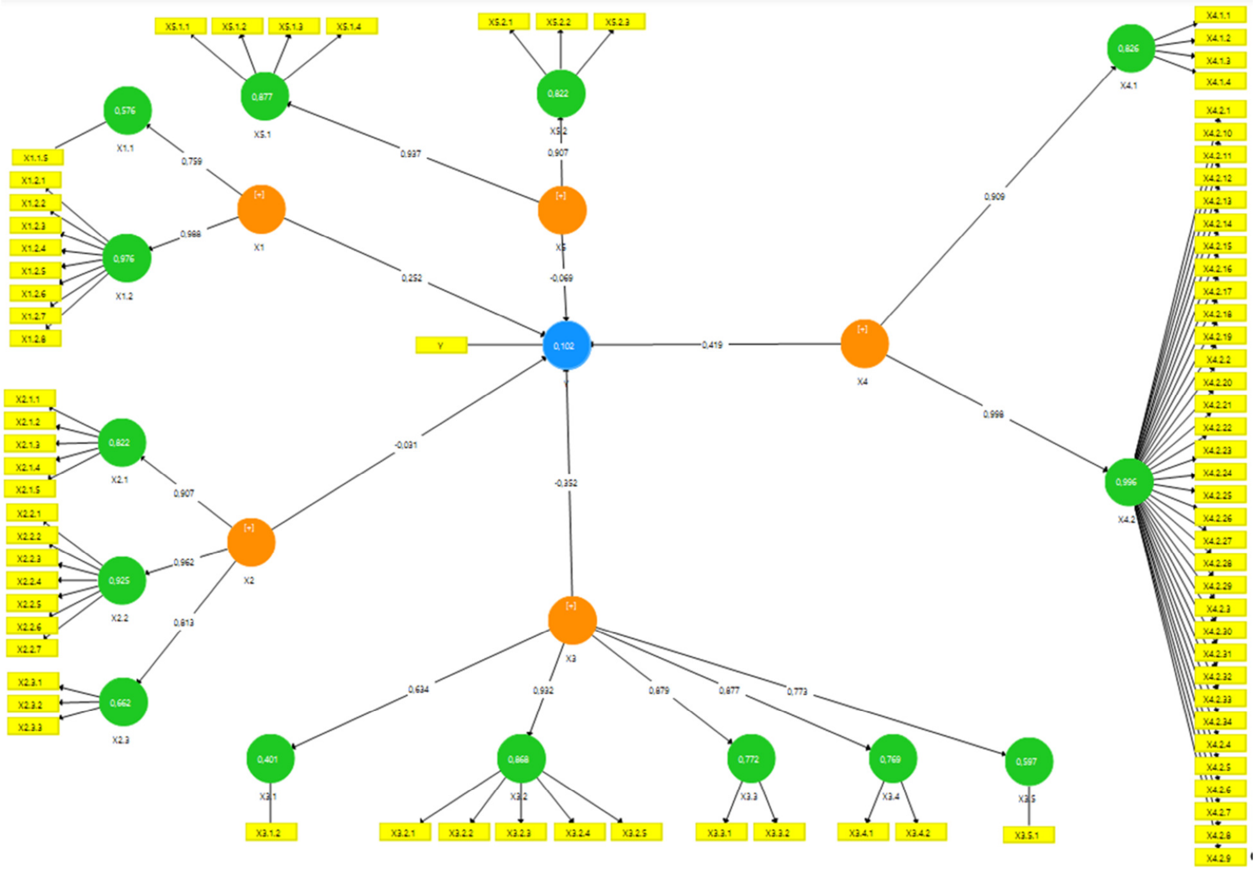

Fig. 4. Inner model test

TABLE VIII. P-VALUES

	Deviation Standard (STDEV)	T-Statistical (| O/STDEV |)	*P*-Values
X1 → Y	0.1809	1.3923	0.1645
X2 → Y	0.5304	0.0580	0.9538
X3 → Y	0.4036	0.8728	0.3832
X4 → Y	0.4151	1.0091	0.3134
X5 → Y	0.3196	0.2168	0.8285

The statistical test for each proposed relationship is performed by simulation. The bootstrapping method is applied to the sample to test the hypothesis, aiming to overcome the problem of non-normality in research data. The following are the results of hypothesis testing using the bootstrapping method of PLS analysis:

- The results of testing the first hypothesis show that the variable leadership and worker participation in construction safety has a path coefficient value of 0.2518 and a T-statistic value of 1.3923. This result reveals that these elements are well implemented and have a positive effect on the performance of construction safety implementation. Previous research shows that organizational commitment and stakeholder involvement play an essential role in construction safety policy implementation [8, 19, 22].

- The results of the second hypothesis test exhibit that the construction safety planning variable has a path coefficient value of -0.308 and a T-statistic value of 0.0580. This result suggests that this element still has a negative effect or a downward trend when applied to improve the performance of the CSMS.

- The results of testing the third hypothesis demonstrate that the construction safety support variable has a path coefficient value of -0.3523 with a T-statistic value of 0.8728. This result means that the use of construction safety support has a negative and insignificant relationship with the level of audit implementation. It is exhibited that this element still has a negative effect or still shows a downward trend when applied to improve the performance of the CSMS.

- The results of the fourth hypothesis test display that the construction safety operations variable has a path coefficient value of 0.4188 with a T-statistic value of 1.0091. This result indicates that this element has been adequately implemented and has a positive impact on the performance of the CSMS. Previous research shows that the construction safety operations are essential to the implementation of construction safety [13, 19, 23].

The results of the fifth hypothesis test show that the safety performance evaluation variable has a path coefficient value of -0.0693 with a T-statistic value of 0.2168. This result means that the application of safety performance evaluation has a negative and insignificant relationship with the level of audit implementation. The former suggests that this element still has a negative effect or still shows a downward trend when applied to improve the performance of the CSMS.

IV. DISCUSSION

The results of the audit system causality model for the assessment of the CSMCs in building projects using the integrated design-build method demonstrate noteworthy discrepancies in the impact of various key elements in construction safety management. Specifically, leadership and worker participation in construction safety and construction safety operations exhibit positive path coefficients, while the construction safety planning, construction safety support, and construction safety performance evaluation demonstrate negative path coefficients. Prior research consistently indicates that leadership in construction safety and worker participation frequently exert a substantial positive influence on safety performance. Authors in [23, 26] demonstrate that strong leadership in safety, characterized by management's active involvement in promoting a safety culture, leads to increased safety commitment among workers. Proactive leadership in safety ensures the integration of safety practices into all aspects of work, thereby fostering a safety-oriented work environment. Worker participation in safety activities also strengthens compliance with safety procedures, as workers feel more responsible and directly involved in accident prevention. This finding aligns with the results of the present study, wherein leadership and worker participation exhibited positive path coefficients, signifying their substantial contribution to enhancing safety in construction projects employing the integrated design-build method. The active engagement of workers and the explicit demonstration of leadership support ensure that safety policies are not only comprehended, but also effectively executed in the field. Contrary to the findings of previous studies, the results of this study contradict those of previous studies on safety planning, safety support, and safety performance evaluation. Authors in [5, 9] demonstrate that comprehensive safety planning, management support, and effective safety performance evaluation are crucial factors in enhancing safety in construction projects. The negative coefficient observed in this study suggests that these factors might not be implemented effectively enough in the context of integrated design-build projects. The positive path coefficients for leadership and worker participation can be attributed to an integrated approach that facilitates more extensive communication and involvement between management and workers. The design-build method fosters enhanced collaboration among the involved parties, hence facilitating an increased worker participation in safety-related matters. With an active involvement from workers and visible support from the leadership, safety regulations can be consistently and effectively implemented in the field. It is noteworthy that workers who feel heard and involved in the decision-making process are more likely to comply with the safety procedures.

Conversely, the negative path coefficient in construction safety planning may be indicative of limitations in the safety planning stage of the integrated design-build method. This approach integrates planning and execution into a single stage, therefore placing a greater emphasis on time and cost efficiency than on meticulous safety planning. This tendency can potentially lead to deficient or marginalized safety planning, which in turn can adversely impact the on-site safety performance. The presence of negative construction safety support suggests that, despite the existence of formal support from the management, the practical implementation of that support is inadequate. The absence of tangible follow-up on the ground can lead to ineffective supervision and noncompliance with the established safety standards. This underscores the notion that the mere existence of a safety policy is insufficient to ensure significant improvements in safety, underscoring the necessity of robust supervision and support to complement such policies. The negative construction safety performance evaluation also reflects implementation issues. Evaluations that are conducted solely in a formal manner, or which are not followed by effective corrective actions, may not have the anticipated impact on safety. In integrated design-build projects, where there is significant pressure to complete the project expeditiously, safety evaluations may be conducted in haste or solely as an administrative requirement, resulting in no tangible enhancement in practice. These findings underscore the pivotal role of worker leadership and participation in enhancing safety on construction projects. Consequently, it is imperative for construction companies to ensure that the management is actively involved in safety activities and that workers are involved in safety-related planning and decision-making processes. The integration of active participation into the fabric of construction companies' operations fosters the development of a robust safety culture, which, in turn, has been shown to lead to significant improvements in the on-site safety performance. Conversely, the negative coefficients on safety planning, safety support, and safety performance evaluation suggest the necessity for enhancement in the implementation of these components. Further research is necessary to elucidate the reasons behind the observed discrepancy between the anticipated and actual positive impacts of these elements. A promising avenue for future research lies in the exploration of methodologies to adapt integrated design-build methods in a way that ensures safety, which will be a priority without compromising critical factors, such as time and cost efficiency. Future research should also focus on developing more adaptive and dynamic safety management models that suit the characteristics of integrated design-build projects. For instance, a more interactive safety performance evaluation, incorporating real-time reporting and prompt follow-up, may prove more efficacious in enhancing safety than a formalized audit system that is isolated from day-to-day operational processes.

V. CONCLUSIONS

A safety audit system for building projects with integrated design-build contracts was developed, and its effectiveness was evaluated. The development process involved a thorough literature review and expert validation, leading to the identification of five primary elements, 15 sub-elements, and 88 indicators. These elements and indicators are: X1 Leadership and labor participation in construction safety, X2 construction safety planning, X3 construction safety support, X4 construction safety operations, and X5 construction safety performance evaluation. The SmartPLS processing yielded insights into the relationship between the audit system elements and the level of audit implementation. Element X1 and element X4 have been shown to exert a positive influence on the level of audit implementation. This suggests that these elements have been effectively incorporated into the design-build contract, while concurrently exhibiting an inverse relationship with the other three elements, namely X2, X3, and X5, which have a negative effect, meaning that the implementation is still lacking in the integrated design-build contract. This suggests that in the future, these elements can be developed and applied to other projects as a reference. The results of this study offer significant insights into the implementation of the audit system causality model for the assessment of Construction Safety Management Systems (CSMSs) in building projects that use the integrated design-build method. The findings underscore the need for stakeholders in the construction industry to prioritize aspects of safety planning and performance evaluation, ensuring that management support for safety is not merely a formality but is integrated into every stage of the project implementation. Project management must prioritize the balance between time efficiency and safety by ensuring that safety is not neglected in the project planning and execution process. Moreover, these results underscore the significance of formulating policies that not only regulate safety aspects in a theoretical framework, but also necessitate tangible and sustainable implementation. Policies that promote comprehensive safety planning, facilitate worker participation, and incorporate continuous performance evaluation are likely to yield a more substantial positive impact on safety in construction projects.

Even though this study provides important insights into the application of the audit system causality model for the assessment of CSMSs on integrated design-build projects, some limitations must be noted. It is possible that this study may only cover a limited number of projects with similar characteristics. The limited sample size may restrict the generalizability of the findings. Projects of varying sizes, diverse construction types, or other implementation methods may yield different findings. The identification of key elements affecting safety is a notable achievement. Nevertheless, it is plausible that other factors, such as government policies, advancements in safety technology, or variations in worker knowledge, have not been fully considered within the model applied. To address these limitations, future research should consider expanding the geographical coverage and diversifying the types of projects studied. The employment of a mixed method approach, integrating quantitative and qualitative data, promises to offer a more comprehensive understanding of the factors influencing construction safety. The integration of advanced technologies, such as the Internet of Things (IoT), Artificial Intelligence (AI), and big data, in safety audit systems presents significant opportunities for research, while holding a great potential for enhancing the accuracy and efficiency of safety audit systems through real-time safety monitoring and safety performance evaluation.

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