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Development of Knowledge Management Based on Safety Audit for Design-Build Contract in High-Rise Building Projects

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Abstract

Audits play a crucial role in construction safety management systems (CSMS) by identifying discrepancies and evaluating the effectiveness of safety implementation. Despite Indonesia's rapid infrastructure development, audit practices remain insufficient to prevent construction accidents. This research aims to formulate a conceptual framework for maturing a knowledge management-based CSMS audit to enhance the effectiveness of safety management implementation in construction projects. The study employed a quantitative approach using the least square method to test the significance of safety audit indicators, supported by descriptive analysis involving expert evaluations on three different construction projects. The findings revealed that the most influential safety audit elements are construction safety operations, followed by mastery and contribution to construction safety, safety planning, safety performance evaluation, and safety support. Expert assessments confirmed a high level of applicability of the proposed framework. The novelty of this study lies in the integration of knowledge management principles into the CSMS audit process, offering a more mature and structured approach to improving safety performance. This framework provides a practical tool to strengthen audit effectiveness and support continuous improvement in construction safety management within the Indonesian infrastructure sector.

Keywords: Safety Audit; Knowledge Management; Design-Build; CSMS; High-Rise.

1. Introduction

The construction sector plays a vital role in national development, serving as a strategic driver for economic growth and infrastructure enhancement. In Indonesia, infrastructure expansion has been accelerated through various government programs, including the relocation of the national capital city announced in early 2022 [1, 2]. To improve time and cost efficiency, many large-scale projects have adopted the design–build integrated contract method, which combines design and construction responsibilities under a single entity [3–5]. According to Ministerial Regulation No. 1 of 2020, this method assigns both design and construction accountability to one provider, aiming to streamline project execution and coordination [6, 7].

Despite these advances, the construction industry remains one of the most hazardous sectors worldwide, accounting for approximately one-third of all occupational fatalities [8, 9]. High-rise building projects, in particular, present

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significant safety risks due to their complex design, elevated work environments, and coordination challenges [10]. Previous studies have identified the main causes of construction accidents, including inadequate safety knowledge, unsafe working conditions, poor management practices, and human errors [11]. While the implementation of a Construction Safety Management System (CSMS) has been mandated to mitigate these risks, its effectiveness largely depends on the audit system that evaluates compliance and performance [12, 13]. However, existing evidence suggests that the application of safety audits in Indonesia's construction projects remains fragmented and inconsistent [14].

Recent studies have emphasized the importance of knowledge management (KM) in enhancing organizational learning and safety culture within the construction industry. KM facilitates the systematic collection, sharing, and utilization of safety-related data, enabling continuous improvement and reducing the recurrence of accidents [15–17]. Integrating KM into safety auditing processes has the potential to transform audits from mere compliance checks into dynamic tools for learning and improvement. Nevertheless, few studies have explored how knowledge management can be systematically incorporated into the CSMS audit framework, especially within design–build projects for high-rise buildings—projects characterized by complex coordination and overlapping design–construction phases. This gap highlights the need for a structured framework that links safety audits with knowledge management principles to enhance audit maturity and practical applicability.

Therefore, this research aims to develop and validate a conceptual framework for maturing a knowledge management-based CSMS audit within design–build high-rise building projects. By analyzing the relationships between key audit elements and their implementation levels, this study contributes to improving the effectiveness of safety management practices in Indonesia's construction industry. The paper is structured as follows: Section 2 reviews related literature, Section 3 outlines the research method, Section 4 presents the results, Section 5 discusses the findings, and Section 6 concludes the study.

2. Literature Review

Safety audits in the construction industry are fundamental tools for identifying potential hazards, ensuring compliance with safety regulations, and fostering a safety-oriented culture among workers. The construction sector is characterized by high accidents and fatality rates, which underscores the need for systematic and structured safety audits. These audits not only protect workers but also enhance project efficiency by preventing incidents that could cause schedule delays and financial losses [18]. According to Smallwood [19], regular safety audits reduce workplace injuries and ensure compliance with regulatory standards, while Gurmu [20] highlighted their contribution to construction productivity by minimizing disruptions.

Various methodologies are employed in safety audits, including checklists, observations, interviews, and advanced analytical tools such as Failure Mode and Effects Analysis (FMEA) and Hazard and Operability Study (HAZOP) [21]. In the Indonesian context, these tools are aligned with the Minister of Public Works and Housing Regulation No. 10 of 2021, which provides guidelines for implementing construction safety management systems [22]. Integrating risk management principles during the design and construction phases has been shown to enhance safety performance by enabling early hazard identification and control [23, 24]. However, as noted by Maliha et al. [25], many existing audit systems remain static and lack a learning mechanism that allows continuous improvement over time.

This gap forms the theoretical basis for the present research, which adopts a Knowledge-Based Safety Management (KBSM) approach. The KBSM approach integrates Knowledge Management (KM) principles into Safety Audit (SA) frameworks to create a dynamic system capable of capturing, sharing, and applying lessons learned from previous audits. Theoretically, this approach aligns with the Organizational Learning Theory (OLT) and the Knowledge-Based View (KBV) of the firm. The KBV argues that organizational knowledge is a strategic resource that drives performance improvement through effective acquisition, sharing, and utilization of information. Meanwhile, OLT emphasizes the importance of feedback loops and continuous learning processes that allow organizations to adapt and innovate over time.

Within the context of construction safety, this theoretical foundation implies that safety audits should evolve beyond compliance-check mechanisms into learning-oriented systems that actively promote knowledge creation and transfer. Previous models developed by Liu et al. [26], Dong et al. [27], and Harvey et al. [28] have partially addressed this by integrating KM concepts into safety management systems, but few studies have operationalized this integration within safety audits themselves. The present study builds upon and extends these models by formulating an integrated KM–Safety Audit framework that emphasizes dynamic knowledge flow across all audit stages.

Integrating KM with safety audits allows for systematic collection, analysis, and dissemination of safety-related knowledge, leading to better decision-making and proactive risk management [26, 29]. Liu et al. [26] emphasized that the availability and utilization of safety knowledge are vital in preventing workplace accidents and enhancing compliance. Developing centralized knowledge repositories or Knowledge Management Systems (KMS) further supports this process by enabling easy access to safety protocols, audit results, and training materials for all stakeholders [30]. Moreover, effective KM relies heavily on open communication and collaboration, which foster an environment where safety knowledge is continuously updated and applied [31].

Specifically, KM enhances audit effectiveness through three key mechanisms:

- Data sharing, which facilitates real-time dissemination of audit findings and hazard reports among stakeholders;
- Training and knowledge dissemination, which improve auditors' and workers' competencies in applying safety procedures and standards; and
- Knowledge-based decision-making, which enables project managers to identify risks earlier and implement evidence-driven corrective actions.
- These mechanisms transform safety audits from reactive compliance activities into proactive learning systems that support continuous safety improvement.

Applying this theoretical approach, safety audits are reconceptualized as knowledge-driven processes rather than routine inspections. This perspective emphasizes four key KM functions within safety auditing: (1) knowledge capture from incidents and audit results, (2) knowledge storage in organizational systems, (3) knowledge sharing through communication platforms and training, and (4) knowledge application in safety planning and daily operations [27, 28]. By embedding these KM principles, organizations can transform audits into continuous learning mechanisms that drive adaptive safety improvements and reinforce a proactive safety culture.

In conclusion, the integration of KM and safety audits forms the conceptual and theoretical foundation of this research. This study extends prior frameworks by positioning safety audits within the Knowledge-Based Safety Management paradigm, explicitly grounded in the Knowledge-Based View and Organizational Learning Theory. Through the mechanisms of data sharing, training, and knowledge-based decision-making, KM enhances audit effectiveness and promotes sustainable safety performance improvement. This theoretical lens not only addresses existing limitations in traditional audits but also aligns with modern trends in digital construction management and continuous safety improvement.

3. Methodology

3.1. Operational Framework

This article presents a research study that employs descriptive methods and survey techniques, using both qualitative and quantitative approaches. The research aims to describe a phenomenon, event, or occurrence that is currently happening. Data analysis involves processing available data using statistical methods to address research problems. The research methodology is Partial Least Squares (PLS). This second-generation multivariate analysis method allows the examination of complex relationships among variables to obtain a comprehensive understanding of the complete model. PLS is one of the alternative model estimation techniques for Structural Equation Modeling (SEM). It utilizes bootstrapping or random doubling methods, eliminating the need for normality assumptions and enabling the use of small sample sizes. This study demonstrates how PLS can be utilized as a practical analysis technique when sample sizes are limited or normality assumptions still need to be met. The operational framework of the research can be seen in Figure 1.

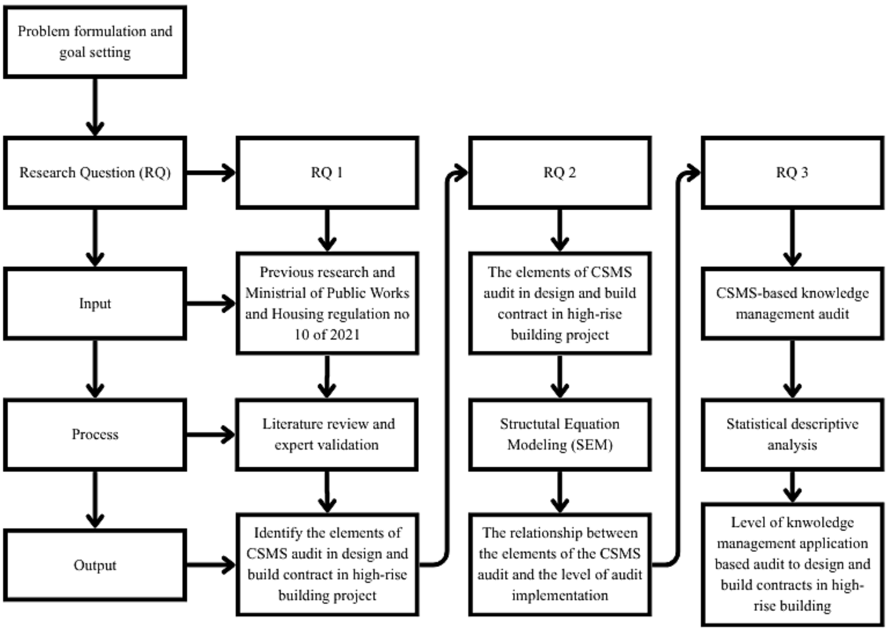

Figure 1. Research operational framework

3.2. Data Collection and Analysis

3.2.1. Phase 1 (Research Question – RQ1)

The data used to answer this study question includes a literature study, regulatory mapping based on the Minister of Public Works and Housing Regulation Number 10 of 2021, and expert validation. In answering RQ1, an archive analysis was carried out to obtain variables and indicators, which were then subjected to an expert validation questionnaire. The expert criteria that the author determines for validating the variables of this study are.

a. Minimum education of Bachelor or Diploma

b. Have work experience in the field of construction safety and building projects for at least 20 years

c. Have a certificate of construction safety expertise at least intermediate level

Respondents were selected using a purposive sampling technique, and respondents were selected based on their knowledge and experience in handling high-rise building project work. Expert validation was carried out by providing questionnaires related to the variables that have been compiled and conducting interviews related to these variables. Experts can revise, add and/or subtract variables compiled from the literature study.

3.2.2. Phase 2 (Research Question – RQ2)

The data required to address the second research question were obtained through a structured questionnaire distributed to respondents who met the following criteria:

a. Possess a minimum of a Diploma degree; and

b. Have professional experience in building projects, particularly those implemented under integrated design and build contract systems.

The questionnaire was developed based on indicators of the CSMS audit elements identified from the literature and utilized a Likert scale to capture respondents' perceptions. The instrument was distributed electronically using Google Forms after undergoing validation procedures.

The collected data were analyzed using the Partial Least Squares Structural Equation Modeling (PLS-SEM) technique with the assistance of SmartPLS 4 software. PLS-SEM was selected for its suitability in handling complex models involving multiple latent variables, especially when the research objective is predictive and exploratory rather than confirmatory. Moreover, it accommodates data that do not strictly meet normality assumptions and performs effectively with relatively small to moderate sample sizes, making it appropriate for the present study's context.

3.2.3. Phase 3 (Research Question – RQ3)

The data required to answer the third study question was through a stage two questionnaire using descriptive analysis. To answer RQ3, a stage 2 questionnaire was developed based on the elements of an audit using knowledge management. After that, the stage 2 questionnaire was validated by experts. The expert can add or subtract question points from the questionnaire list in the questionnaire validation process. After validation is carried out to experts, then distribution is carried out to the project to see the application of knowledge management-based CSMS audits in the project that is the target of the research. The expert criteria that the author determines for validating this study variable are the same as in Phase 1.

Expert validation is carried out by providing questionnaires related to the variables that have been compiled and conducting interviews related to these variables. Experts have the right to revise, add, and reduce the variables that have been compiled. After conducting expert validation and obtaining the results, questionnaires are distributed to the project. The data was handled using descriptive analysis after the questionnaire data was obtained. The descriptive analysis used in this study aims to summarize current issues.

4. Result

4.1. Identification of Research Variable

The factors influencing the effectiveness of contractor tender winner determination in Indonesia were obtained and subsequently mapped to identify the structure of key variables affecting the Construction Safety Management System (CSMS) audit. As summarized in Table 1, the study identified five main variables (X.1) Mastery and Contribution in Construction Safety, (X.2) Construction Safety Planning, (X.3) Construction Safety Support, (X.4) Construction Safety Operations, and (X.5). Table 1 provides a comprehensive reference to each variable, sub-variable, and indicator, along with their corresponding sources, serving as the foundation for the subsequent quantitative analysis and validation process.

Table 1. Research Variables

	Sub-Variable	Code	Indicator	Ref.
(X.1) Mastery and contribution in construction safety	(X1.1) Principal interest for internal and external issues	X1.1.1	The supplier determines matter that work on the approach of the safety management.	Nugroho et al. [9]
		X1.1.2	The Supplier establishes an CSMS management organisation based on regulatory requirements.	Machfudiyanto et al. [22]
		X1.1.3	The size of the CSMS management organisation is adjusted to the scale of construction work.	Machfudiyanto et al. [22]
		X1.1.4	Suppliers must appoint a person in charge of CSMS management has the capacity to be accountable for managing construction safety supervisions and operations.	Machfudiyanto et al. [22]
		X1.1.5	The arrangement, obligation, dominion and culpabilities of the safety management organization are intent on corresponding by the suppliers.	Machfudiyanto et al. [22]
	(X1.2) Construction Safety Commitment	X1.2.1	The supplier has a safety intention.	Machfudiyanto et al. [22]
		X1.2.2	The safety intention is validated by the favourable headship of the supplier.	Nugroho et al. [9]
		X1.2.3	The safety intention is communicated to all stakeholders, both internal stakeholders and external stakeholders.	Nugroho et al. [9]
		X1.2.4	Commitment to prevent and protect against threats and/or security disturbances in various forms, and protection of the safety of construction engineering, people, property, materials, equipment, the general public and the environment.	Nugroho et al. [9], Buniya et al. [32]
		X1.2.5	A safety devotes in pact sheet validated by the headship.	Nugroho et al. [9]
		X1.2.6	The supplier leader is involved in increasing contribution in the safety application.	Nugroho et al. [9]
		X1.2.7	The supplier ensures the approach of the safety management in accordance with the established objectives and programmes.	Nugroho et al. [9]
		X1.2.8	Suppliers must continuously consult with workers and/or workers' representatives/unions covering planning, implementation, performance evaluation and corrective action of the CSMS.	Nugroho et al. [9], Turkelson et al. [21]
(X.2) Construction Safety Planning	(X.2.1) Hazard Identification Risk Assessment, Control and Opportunity	X2.1.1	Supplier establishes Hazard Identification, Risk Assessment, Control, and Opportunities.	Rafindadi et al. [7], Nugroho et al. [9]
		X2.1.2	Supplier has data related to accidents both minor, moderate and severe accidents	Rafindadi et al. [7], Nugroho et al. [9]
		X2.1.3	Supplier conducts a review of hazard identification risk assessment, control and opportunities as a sequence of an accident whether minor, medium, or severe accidents.	Rafindadi et al. [7], Nugroho et al. [9]
		X2.1.4	Hazard identification and risk assessment, control, and construction safety opportunities as well as compliance with laws and regulations and others are well documented.	Rafindadi et al. [7], Nugroho et al. [9]
		X2.1.5	Provider has a construction safety analysis for moderate and safety high-risk, work is infrequently, work utilizes specific instrument, derived from work methods.	Rafindadi et al. [7], Nugroho et al. [9]
	(X.2.2) Action Plan (Goal and Programme)	X2.2.1	The supplier sets construction safety goals for each duty and phase of work.	Nugroho et al. [9], Mahulae [10]
		X2.2.2	Safety goals made must be strongest matches with the safety policy and can be steady.	Nugroho et al. [9]
		X2.2.3	Supplier in setting goals based on construction safety planning.	Nugroho et al. [9]
		X2.2.4	The supplier communicates to staffs and workers according to the official safety purpose.	Nugroho et al. [9]
		X2.2.5	The supplier conducts evaluations related to the safety goals that have been specified.	Nugroho et al. [9]
		X2.2.6	The Supplier establishes a construction safety programme based on its targets.	Nugroho et al. [9]
		X2.2.7	Supplier ensures construction is carried out	Nugroho et al. [9]
	(X.2.3) Standards and Regulation	X2.3.1	Suppliers identify and implement Construction Safety regulations and standards in implementing CSMS	Nugroho et al. [9], Smallwood [19], Buniya et al. [32]
		X2.3.2	The Supplier sets qualities referred to the sourcing of PPE in the form of safety body harnesses, safety shoes, safety helmets, safety googles, safety gloves, masks, ear plugs, safety vests and work protective equipment in the form of safety nets, safety ropes, fall arresters, safety fences, area barriers, fall protection, safety signage.	Smallwood [19], Buniya et al. [32]
		X2.3.3	The Supplier makes a list of expiration dates and extends permits, licences and certificates.	Nugroho et al. [9]
(X.3) Construction Safety Support	(X.3.1) Resources	X3.1.1	The supplier arranges the resources required for the application, preservation and constant enhancement of the safety management.	Nugroho et al. [9], Mahulae [10]
		X3.1.2	The Supplier prepares facilities and infrastructure in implementing CSMSs	Nugroho et al. [9]
		X3.1.3	The Supplier allocates CSMS costs to each construction activity.	Nugroho et al. [9], Machfudiyanto et al. [22]
	(X.3.2) Competence	X3.2.1	Supplier provides competent safety personnel	Nugroho & Tejamaya [33]
		X3.2.2	Supplier has a competent and certified safety officer/construction OHS expert.	Nugroho & Tejamaya [33]
		X3.2.3	Suppliers have Emergency Response Officers who have received training	Nugroho & Tejamaya [33]
		X3.2.4	Supplier has a First Aid Officer who has been given training and conducts training for workers	Machfudiyanto & Utomo [34]
		X3.2.5	Supplier employs workers who have a certificate of competence in their field	Nugroho et al. [9]
	(X.3.3) Care	X3.3.1	Supplier ensures workers are aware of construction safety policies and goals	Nugroho et al. [9]
		X3.3.2	Supplier analyses training plans related to workers' competency needs.	Nugroho et al. [9]
	(X.3.4) Communication	X3.4.1	Supplier has a Construction Safety communication procedure	Nugroho et al. [9], Machfudiyanto et al. [22]
		X3.4.2	Supplier makes a schedule for Construction Safety communication to all workers during construction activities.	Nugroho et al. [9]

	(X.3.5) Documented Information	X3.5.1	Supplier has non-automatic, strategy, drawings, instructions, and other necessary instruments in the workshop.	Smallwood [19]
(X.4) Construction Safety Operations	(X.4.1) Construction Safety Planning	X4.1.1	The supplier has a responsible individual for each point of the industry.	Smallwood [19]
		X4.1.2	The Supplier has documented strategy and work directions regarding safety performance.	Gurmu [20]
		X4.1.3	Supplier establishes, implements and maintains risk controls to eliminate hazards and reduce the risk of CSMS.	Smallwood [19], Gurmu [20]
		X4.1.4	Supplier controls safety likelihoods by get rid of hazards; putting processes back, actions, materials or non-hazardous appliances; performing engineering; executing authoritative oversights; and make use of suitable protective equipment.	Machfudiyanto et al. [22]
	(X.4.1) Operation Control (monitoring)	X4.2.1	Supplier performs operation control on communication management.	Alysha Fadli et al. [15]
		X4.2.2	Supplier performs operation control on special work permit management.	Gurmu [20]
		X4.2.3	Supplier conducts Construction Safety Analysis/CSA in carrying out large and medium risk work.	Gurmu [20]
		X4.2.4	Supplier has a tool operating procedure	Gurmu [20]
		X4.2.5	The Supplier has a lifting plan for lifting / transporting equipment / girder launchers.	Setiawan et al. [24]
		X4.2.6	The Supplier controls operations on the management of work protective equipment and personal protective equipment.	Setiawan et al. [24]
		X4.2.7	Supplier provides protection equipment according to hazardous shapes and the number of employees in the form of safety body harness, safety shoes, safety helmets, safety googles, safety gloves, masks, ear plugs, safety vests, safety networks, safety ropes, fall arrest, safety fences, area barriers, fall protection, safety signs.	Gurmu [20], Setiawan et al. [24]
		X4.2.8	Supplier places signs based on Construction Safety hazards and risk levels	Smallwood [19]
		X4.2.9	Supplier constructs safe and sturdy temporary constructions related to environmental hazard mitigation, such as scaffolding, temporary platforms, cargo lifts, temporary ladders, safety nets, fall protection devices, lightning rods, wind baffles, temporary roofs, etc.	Nugroho & Tejamaya [33]
		X4.2.10	The Supplier conducts operation control on work environment management.	Nugroho & Tejamaya [33]
		X4.2.11	Supplier provides conveniences for labor such as heckle, canteen, adequate lavatories based on rules and adjustment.	Buniya et al. [32]
		X4.2.12	The Supplier implements the 5R programme (Ringkas, Rapi, Resik, Rawat and Rajin).	Buniya et al. [32]
		X4.2.13	The Supplier has carried out work environment measurements.	Buniya et al. [32]
		X4.2.14	The Supplier plans and implements a programme to deal with construction work waste such as: garbage, concrete debris, demolition material, packaging material, used wood and boards, metal scraps, broken equipment, hazardous material scraps, chemical waste, plastic, electronic waste, etc.	Machfudiyanto & Utomo [34]
		X4.2.15	The Supplier makes procedures for receiving, storing, using and disposing of B3 materials by socialising them according to the Material Safety Data Sheet (MSDS).	Nugroho et al. [9]
		X4.2.16	Supplier makes temporary storage / disposal of waste in the field according to laws and regulations.	Nugroho et al. [9]
		X4.2.17	Supplier transports waste according to laws and regulations.	Nugroho et al. [9]
		X4.2.18	Supplier controls operations on occupational health management.	Nugroho et al. [9], Dobrucali et al. [11]
		X4.2.19	Supplier conducts operation control on labour social protection management.	Dobrucali et al. [11]
		X4.2.20	Supplier performs operation control on agency safety management.	Dobrucali et al. [11]
		X4.2.21	Suppliers carry out operational control on the maintenance of facilities, infrastructure and equipment.	Dobrucali et al. [11]
		X4.2.22	The Supplier provides a light fire extinguisher at the job site.	Nugroho & Tejamaya [33]
		X4.2.23	Suppliers in set earthmovers off have a license to operate and competent operators.	Manzoor et al. [6]
		X4.2.24	Suppliers carry out operational control on work environment security	Manzoor et al. [6], Nugroho & Tejamaya [33]
		X4.2.25	Supplier performs operation control on Construction Safety inspection	Manzoor et al. [6]
		X4.2.26	Supplier conducts periodic inspection and maintenance of equipment	Buniya et al. [32]
		X4.2.27	Supplier uses a check list when carrying out Construction Safety inspections.	Machfudiyanto et al. [22]
		X4.2.28	The Supplier controls operations on supply chain control.	Machfudiyanto et al. [22]
		X4.2.29	Supplier makes procedures for receiving and storing materials.	Nugroho et al. [9]
		X4.2.30	The Supplier makes procedures for the transfer and use of materials.	Nugroho et al. [9]
		X4.2.31	Supplier performs operation control on traffic engineering management.	Nugroho et al. [9]
		X4.2.32	Supplier plans and implements Emergency Response (floods, earthquakes and other natural disasters).	Nugroho et al. [9], Gurmu [20]
		X4.2.33	Supplier construct resuscitation in catastrophe and boxes.	Machfudiyanto & Utomo [34]
		X4.2.34	Suppliers in dealing with emergencies have to detail casualty, death occasion, and treacherous events.	Buniya et al. [32]

(X.5) Construction Safety Performance Evaluation	(X5.1) Monitoring, Measurement, and Evaluation	X5.1.1	Supplier conducts monitoring of safety implementation and auditing activities.	Smallwood [19]
		X5.1.2	Supplier makes certain the instrument which needs quantification correctness is gauged.	Machfudiyanto et al. [22]
		X5.1.3	Supplier ensures that safety performance is gauged by relevant caliber	Nugroho et al. [9]
		X5.1.4	Supplier records the observation and quantification results.	Nugroho et al. [9]
	(X5.2) Audit Internal	X5.2.1	Supplier run audits by the safety implementation.	Nugroho et al. [9]
		X5.2.2	Internal audit outcomes are documented	Buniya et al. [32]
	(X5.3) Management Review	X5.3.1	Supplier records safety management review for continuous development.	Buniya et al. [32]

4.2. Outer Model

Prior to the analysis, a total of 41 valid responses were obtained from professionals representing five building projects. The respondents were selected using purposive sampling, as they met specific criteria related to their educational background and experience in projects implemented under integrated design and build contract systems. Participation was voluntary, and informed consent was obtained from all respondents before completing the questionnaire. Ethical considerations were ensured by maintaining the anonymity and confidentiality of all participants. Subsequently, the collected data was subjected to validity and reliability testing to ensure the accuracy and consistency of the measurement model before proceeding with the PLS-SEM analysis. The sample size of 41 respondents met the minimum requirement for PLS-SEM analysis, following the "10-times rule," which suggests that the sample should be at least ten times the maximum number of inner or outer model paths directed at any latent variable in the model.

The validity test includes convergent validity and discriminant validity. Reliability tests include calculating composite reliability and Cronbach's alpha standards. Measurement model analysis is the first step before proceeding to the next stage, namely the analysis of the schema model (inner model). This analysis ensures that all measurement items used in the study represent valid and reliable latent constructs. The following are the results of testing the measurement model.

4.2.1. Measurement Model

Internal consistency reliability was evaluated to ensure that each construct consistently measures its corresponding indicators. The criteria commonly used to assess internal consistency are Cronbach's Alpha and Composite Reliability (CR), both of which indicate the internal coherence of the measurement instrument. According to the reliability standard, the acceptable threshold value for both Cronbach's Alpha and CR is ≥ 0.70, indicating satisfactory reliability. As summarized in Table 2, all constructs in this study—including the five main variables (X1–X5) and their sub-variables—exhibit Cronbach's Alpha and Composite Reliability values above 0.70, confirming that the measurement model meets the reliability requirements. Specifically, the CSMS components such as Construction Safety Planning (X2) and Construction Safety Operations (X4) show the highest internal consistency, reflecting their strong correlation with respective indicators.

Table 2. Cronbach's alpha

	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 next analytical stage evaluates convergent validity, which measures the degree to which multiple indicators of a construct are positively correlated and represent the same underlying concept. This validity is assessed using the Average Variance Extracted (AVE) and the loading factor of each indicator [25]. According to the general acceptance criteria, the loading factor value should exceed 0.70, and AVE values must be greater than 0.50 to confirm adequate convergent validity. As presented in Table 3, all constructs in this study meet the minimum threshold for convergent validity, with AVE values ranging from 0.50 to 1.00. These results indicate that each latent variable explains more than 50% of the variance of its respective indicators, demonstrating good representation of the underlying constructs. Among the constructs, Construction Safety Planning (X2) and Construction Safety Operation (X3) exhibit particularly high AVE values, reflecting strong indicator coherence and internal correlation.

Table 3. Convergent validity

	Average Variance Extracted (AVE)
X1	0.5070
X1.1	1.0000
X1.2	0.5110
X2	0.6073
X2.1	0.6552
X2.2	0.7965
X2.3	0.6546
X3	0.5964
X3.1	1.0000
X3.2	0.7173
X3.3	0.7851
X3.4	0.8144
X3.5	1.0000
X4	0.5544
X4.1	0.6097
X4.2	0.5626
X5	0.5403
X5.1	0.6067
X5.2	0.6767
Y	1.0000

The next stage is to evaluate convergent validity through the AVE value. If a model has an AVE value above 0.6, the model is categorized as having high convergent validity [9]. After elimination of the loading factor that is below 0.6, the model has an AVE standard which is obtained in Table 4.

Table 4. AVE value

	Rho A	Composite Reliability	Average Variance Extracted (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	0.8976	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

Based on the table above, it can be seen that the results of Rho A, Composite reliability, and Ave analyses have met the requirements, so it can be said that all indicators are relevant.

4.2.2. Discriminant Validity

The square root of the Average Variance Extracted (AVE) for each construct must be higher than the correlations between that construct and any other latent variables [22]. This criterion ensures that each construct is distinct and represents a unique concept within the model. To verify this, the Fornell–Larcker criterion and cross-loading analysis were employed. As presented in Table 5, the results indicate that all constructs fulfill the discriminant validity requirement, where the square root of each construct's AVE exceeds its inter-construct correlations. These findings confirm that the constructs are unique and effectively capture phenomena not represented by other variables within the model, thereby validating the distinctiveness of the measurement structure.

Table 5. Fornell Lacker criterion

	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

4.3. Inner Model

Structural model analysis is a set that explains and predicts the correspondence inter-variable in the Sudibjo research [25]. According to Furadatin, the coefficient of determination is a method to find out the expanse of the consequence of independent on dependent variables. The coefficient of determination can be a way to survey how much exogenous constructs can explain endogenous constructs. The expected value of the coefficient of determination is between 0 and 1. Table 6 is the estimation result using Smart PLS.

Table 6. R-square

Y	R Square Value
Intermediate Qualification	0.1017

The R-square value is a statistical metric that measures how well the independent variables explain the variation in the dependent variable. R-square values range between 0 and 1, where higher values indicate a stronger explanatory power of the independent variables over the dependent variable. In this study, the R-square value of 0.1017 indicates that approximately 10.17% of the variation in Intermediate Qualification can be explained by the independent variables used in the model. This suggests that, although the model provides a certain level of explanatory power, a substantial portion of the variation in Intermediate Qualification remains unexplained, implying that other influential factors may not have been included in the current model. The detailed R-square results can be seen in Figure 2, which visually illustrates the relationship and explanatory power of the model variables.

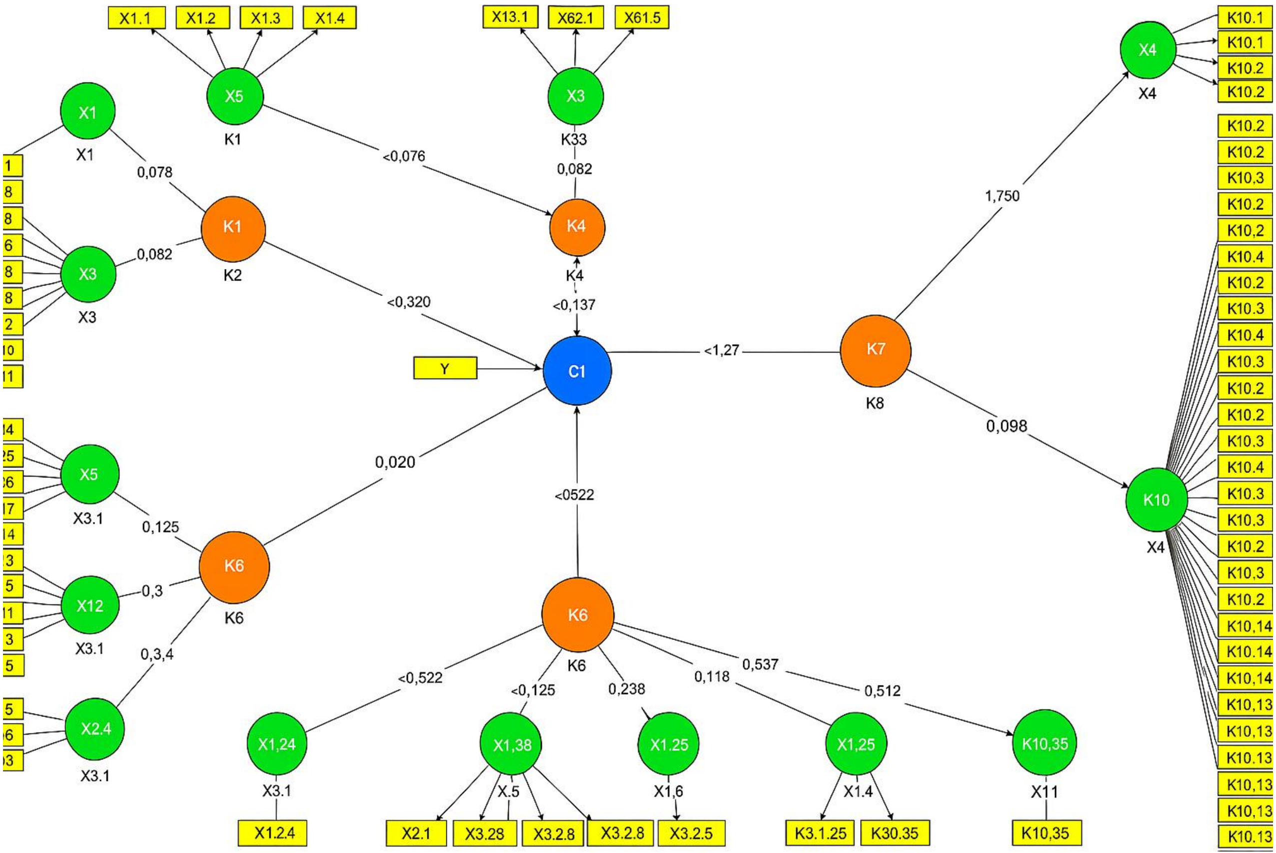

Figure 2. Qualification model

4.4. Hypothesis Test

Hypothesis testing in this study aims to conclude whether the hypotheses in this research are accepted or rejected. Hypothesis testing is conducted by comparing the values of t-statistic and p-value generated. According to Setiawan et al. [24], the t-statistic value must be greater than 1.96 at a significance level of 5%, and the p-value must be less than 0.05 for the hypothesis to be accepted. Table 7 is the structural model evaluation and hypothesis testing conducted result.

Table 7. Inner model test calculation

	Sample	T-Statistic	P-Values
X1 → Y	0.2518	1.3923	0.1645
X2 → Y	-0.0308	0.0580	0.9538
X3 → Y	-0.3523	0.8728	0.3832
X4 → Y	0.4188	1.0091	0.3134
X5 → Y	-0.0693	0.2168	0.8285

Testing the first hypothesis result show that the variables of mastery and contribution in construction safety have a path coefficient of 0.2518 and a T-Statistic of 1.3923. This finding shows that these elements have been well implemented and have a beneficial effect on improving the performance of the construction safety management system implementation. The second hypothesis shows that the Construction Safety Planning variable has a path coefficient of -0.0308 with a T-Statistic of 0.0580. This finding shows that the element still has a negative effect or still shows a downward trend in its application in improving the accomplishment of safety management system.

The third hypothesis shows that the Construction Safety Support variable has a path coefficient of -0.3523 with a T-Statistic of 0.8728. This result means that the application of Construction Safety Support has a negative and insignificant relationship with the Audit Implementation Level. The fourth hypothesis shows that the Construction Safety Operations variable has a path coefficient of 0.4188 with a T-Statistic of 1.0091. This finding indicates that the element has been well implemented and has a positive effect on improving the performance of the construction safety management system implementation. The fifth hypothesis shows that the Construction Safety Performance Evaluation variable has a path coefficient of -0.0693 with a T-Statistic of 0.2168. This result means that the application of Construction Safety Performance Evaluation has a negative and insignificant relationship with the Audit Implementation Level.

4.5. Critical Success Factor

Based on the results of the analysis using SmartPLS, the significant model of the application of the CSMS audit element is Construction Safety Operations, followed by Mastery and Contribution in Construction Safety, Construction Safety Planning, Construction Safety Performance Evaluation, and Construction Safety Support, as shown in Table 8.

Table 8. Critical success factor of safety audit implementation

Variable	Rank	Sub Variable	Analysis Value
X4. Construction Safety Operations	1	X4.2 Operation control	0.9982
		X4.1 Construction safety planning	0.9091
X1. Mastery and contribution in construction safety	2	X1.2 Construction safety commitment and labour participation	0.9881
		X1.1 Leadership awareness of external and internal issues.	0.7590
X2. Construction Safety Planning	3	X2.2 Action plan (objectives and programme)	0.9618
		X2.1 Hazard identification, risk assessment, control and opportunity (IBPRP)	0.9069
		X2.3 Standards and regulations	0.8134
X5. Construction Safety Performance Evaluation	4	X5.1 Monitoring, measurement and evaluation	0.9367
		X5.2 Internal audit	0.9067
X3. Construction Safety Support	5	X3.2 Competence	0.9316
		X3.3 Care	0.8789
		X3.4 Communication	0.8767
		X3.5 Documented information	0.7726
		X3.1 Resources	0.6336

4.6. Implementation Level of Safety Audit

At this stage, a questionnaire was distributed involving three high-rise building construction projects. Each project fills out a questionnaire related to the knowledge management-based CSMS audit that has been distributed. Where in each question in the questionnaire, if it is applied, it is given a value of one (1) and if it is not applied it is given a value of zero (0). In the descriptive analysis in this study, three grouping categories were used, namely low, medium, and high. On the results of the questionnaires from the three projects obtained a satisfactory value for each project. For the analysis result of the three projects can be seen in Table 9.

Table 9. Descriptive analysis based on grouping categories

Respondent	Value	Categories
Project 1	91%	High
Project 2	100%	High
Project 3	100%	High

After conducting descriptive analysis on the answers from the three projects, it can be seen that all projects fall into the high category of 66%-100% with a value of 91% obtained by project 1, project 2 and project 3 each 100%. Analysis of data processing related to the application of knowledge management-based CSMS audit development in high-rise building projects shows a significant picture. It can be summarized that the three projects studied obtained high ratings in the implementation of the audit. This indicates that the knowledge management approach integrated in the audit process makes a significant contribution to the quality and efficiency of project management.

5. Discussion

The significant value of the CSMS audit element lies in Construction Safety Operations, followed by Leadership and Employee Involvement in Construction Safety, Construction Safety Planning, Construction Safety Performance Evaluation, and Construction Safety Support. As shown in Table 8, these findings indicate that operational aspects and leadership engagement remain the primary drivers of safety performance within construction projects. Based on the distributed questionnaire involving three different building projects, it was also found that the level of CSMS audit implementation, particularly in design–build contract projects, demonstrates a relatively high degree of application. This success reflects an increasing understanding and application of best safety practices supported by effective knowledge management. The CSMS audit serves not only as a tool for identifying potential risks and promoting quality improvement but also as a mechanism for enhancing collaboration among stakeholders involved in construction projects.

When compared with previous studies, similar patterns can be observed. For instance, Alysha Fadli et al. [15] reported that implementing safety management systems significantly improves construction safety performance, aligning with the present study's finding that structured and consistent audits strengthen operational safety outcomes. Similarly, Eberhardt et al. [17] emphasized leadership commitment as a key determinant of safety management success, which corresponds with this study's identification of leadership and employee involvement as critical factors. Xu et al. [18] further confirmed that greater employee participation in safety practices contributes to measurable reductions in accident rates, supporting the finding that employee engagement is a significant element in the CSMS audit framework.

However, a more detailed examination reveals that Construction Safety Support shows a weak or even negative relationship with audit implementation. This pattern may arise because formal support mechanisms such as resource provision, top-down policy dissemination, or administrative oversight, are not always effectively connected to site-level operational realities. In some cases, safety support remains procedural or compliance-oriented rather than adaptive to the dynamic conditions of construction projects. Excessive bureaucracy, unclear feedback channels, or limited responsiveness to field challenges may weaken the perceived value of managerial support among site personnel. This suggests that while institutional support is necessary, it becomes effective only when translated into responsive actions, adequate resource allocation, and participatory communication structures that reinforce safety culture at the operational level.

The integration of Knowledge Management (KM) within the CSMS audit process further enhances its effectiveness by fostering real-time collaboration and learning. In practical terms, this integration is realized through digital platforms, shared databases, and centralized reporting systems that allow stakeholders to record, analyze, and disseminate safety-related information efficiently. For example, cloud-based audit systems or digital safety dashboards can store historical incident data, corrective actions, and lessons learned, enabling continuous feedback loops between management and field teams. Such systems help bridge organizational silos, ensuring that safety improvements are informed by accumulated project knowledge and accessible to all relevant parties. Through this mechanism, KM transforms audits from being periodic assessments into dynamic tools for organizational learning and proactive risk control.

Unlike earlier studies that primarily focused on leadership or employee engagement as isolated factors, the present research provides a novel contribution by emphasizing the unique effectiveness of CSMS audits within design–build contract frameworks. This contractual integration fosters better communication, accountability, and coordination—conditions that make the audit process more efficient and impactful. Thus, contract type emerges as an important contextual variable influencing the success of safety management implementation, a dimension often overlooked in previous studies. Furthermore, while studies such as Mourbas [35] focus mainly on accident prevention and risk minimization, the current research broadens the analytical scope by demonstrating that CSMS audits not only mitigate risks but also enhance teamwork, knowledge sharing, and stakeholder collaboration across project stages. This reinforces the understanding of safety audits as strategic management instruments that contribute to organizational learning and long-term performance improvement.

In summary, this study reaffirms the critical roles of leadership, employee participation, and structured safety systems as established in prior literature, while introducing contextual advancement through the integration of Knowledge Management and contractual mechanisms. The relatively weak relationship of Construction Safety Support emphasizes the importance of aligning top-level support with field-level realities. Future studies are encouraged to explore digital-based KM frameworks and adaptive support systems to strengthen the link between managerial policies and operational implementation in construction safety management.

6. Conclusion and Future Work

This study formulated and analyzed a framework for the Construction Safety Management System (CSMS) audit based on knowledge management principles, integrating indicators derived from both regulations and existing literature on construction safety. Five main variables and fifteen sub-variables were identified, comprising a total of eighty-six indicators. The analysis revealed that Construction Safety Operations exert the most significant influence on CSMS audit implementation, followed by Leadership and Employee Involvement, Construction Safety Planning, Construction Safety Performance Evaluation, and Construction Safety Support. These findings underscore the critical importance of operational execution and the knowledge competency of safety practitioners in ensuring effective audit outcomes.

The R Square result of 10.17% indicates a low causality model, this result shows that there are 89.83% of factors that must be explored and studied in future research.

The survey results, covering three design–build construction projects, indicate that the CSMS audit demonstrates a high level of application, with an average implementation score of 78%, categorized as "effective" according to the SmartPLS latent variable output classification. This reflects a growing awareness and commitment to safety management practices within Indonesia's construction sector, particularly under design–build contract structures that facilitate integrated planning, coordination, and knowledge sharing.

From a practical standpoint, construction firms are advised to institutionalize digital-based knowledge management platforms such as shared safety databases, audit tracking dashboards, and real-time feedback systems to capture and disseminate lessons learned across projects. These tools can improve audit consistency, promote transparency, and enhance interdepartmental collaboration. Government regulators, meanwhile, should develop standardized national guidelines for CSMS audits that incorporate knowledge management elements and require periodic digital reporting. This will help harmonize safety practices across project types and strengthen compliance monitoring mechanisms.

Despite the overall positive results, the study identifies remaining challenges in systematically embedding knowledge management into routine safety audit processes, particularly in translating managerial support into actionable field practices. Therefore, future research should focus on developing an integrated KM-based audit model applicable to various contract types and project complexities. Such integration will foster continuous learning, improve decision-making quality, and advance the maturity of safety culture in the construction industry.

Ultimately, this study contributes to both theoretical and practical understanding of CSMS audit systems by linking knowledge management integration with contractual frameworks, providing actionable insights for enhancing the sustainability, safety, and resilience of construction project management.

7. Declarations

7.1. Author Contributions

Conceptualization, R.A., Y.L., M.A.W., and D.B.N.; methodology, R.A. and Y.L.; software, R.A. and D.B.N.; validation, R.A., Y.L., and M.A.W.; formal analysis, R.A.; investigation, R.A., Y.L., and M.A.W.; resources, R.A., Y.L., M.A.W., and D.B.N.; data curation, R.A. and Y.L.; writing—original draft preparation, R.A., S.H., and M.R.F.; writing—review and editing, R.A. and S.H.; visualization, R.A. and A.A.I.M.; project administration, R.A. and A.A.I.M.; funding acquisition, R.A. All authors have read and agreed to the published version of the manuscript.

7.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy restrictions.

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7.4. Conflicts of Interest

The authors declare no conflict of interest.

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