

Development of Construction Safety Audit System Based on Mobile Application in High-Rise Design and Build Projects to Improve Construction Safety Performance

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ABSTRACT: *The Indonesian construction industry, particularly high-rise design and build projects, faces increasing complexity and safety risks, while conventional paper-based audits remain slow, fragmented, and limited in traceability. These shortcomings often delay corrective actions and weaken compliance with national regulations. To address this gap, this study develops a mobile application-based construction safety audit system aimed at enabling real-time monitoring, systematic risk identification, and rapid reporting. The research was conducted through literature review, expert validation, and analysis of current safety audit practices to design and evaluate a prototype system. The mobile application incorporates essential features such as digital checklists, photo documentation, automated reporting, data security, and a user-friendly interface. Validation by experts confirmed the feasibility of the proposed model, with transparency identified as the most influential factor in strengthening compliance with the Construction Safety Management System (SMKK). Furthermore, a quantitative validation using Structural Equation Modeling – Partial Least Squares (SEM-PLS) with 90 respondents demonstrated that both conventional audits ($\beta = 0.229$, $p = 0.008$) and mobile-based audits ($\beta = 0.836$, $p < 0.001$) significantly influence construction safety performance. The model explained 86.1% of the variance in safety outcomes, confirming the strong explanatory power of the proposed framework. The findings emphasize a paradigm shift, while conventional audits remain relevant with moderate contribution, mobile-based audits provide a dominant effect by enabling higher accuracy, faster reporting, and broader stakeholder engagement. The developed mobile application thus offers a practical and scalable solution to improve occupational safety performance in high-rise projects and can serve as a reference for broader implementation within the Indonesian construction industry.*

KEYWORDS - *Construction Safety Audit, Mobile Application, High-Rise Construction, Design and Build, Safety Performance, Digital Technology*

I. INTRODUCTION

The construction industry is globally recognized as one of the sectors with the highest accident rates due to its complex processes, hazardous environments, and diverse workforce. High-rise projects, particularly those implemented under design and build contracts, carry even greater safety challenges because design and execution are integrated, increasing the risk of overlooked

hazards during early planning stages. Effective safety management therefore requires not only compliance with regulatory frameworks but also systematic, proactive monitoring and auditing mechanisms [1].

In Indonesia, the construction sector continues to expand rapidly, driven by large-scale infrastructure and urban development projects. However, this growth has been accompanied by persistently high accident rates. Data from the Social Security Agency for Employment (BPJS Ketenagakerjaan) recorded more than 234,000 workplace accidents in 2021, an increase compared to the previous year [2]. Most incidents occurred during working hours on project sites, underscoring the urgent need for stronger safety systems. The rate of construction accidents in Indonesia during 2017–2021 is shown in Figure 1.

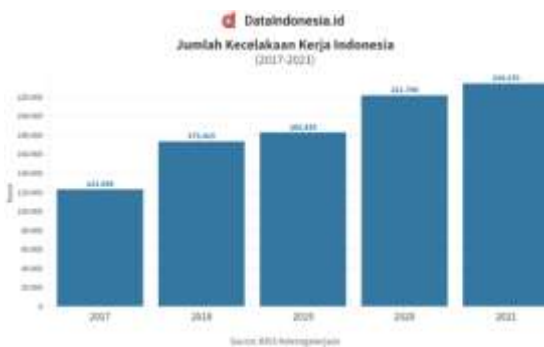


Fig 1. Rate of construction accidents in Indonesia, 2017–2021

Despite the existence of regulations such as Law No. 1/1970 on Occupational Safety, Government Regulation No. 50/2012 on Occupational Health and Safety Management Systems (SMK3), and the Ministry of Public Works and Public Housing (PUPR) Regulation No. 10/2021 on the Construction Safety Management System (SMKK), implementation remains limited [3]. Conventional safety audits in Indonesia are often paper-based, fragmented, and reactive, typically conducted after construction has commenced or even following accidents. This approach delays corrective actions and weakens compliance with safety standards. The multi-level consequences of construction accidents are presented in Figure 2.



Fig 2. Consequences of construction accidents at micro, meso, and macro levels

Several studies indicate that unsafe design contributes to up to 42% of fatal accidents in construction, highlighting the importance of integrating safety into both planning and execution phases [4]. While international research has explored digital solutions such as Building Information Modeling (BIM), sensor-based monitoring, and wearable technologies, mobile applications have emerged as practical tools to support real-time auditing and risk management [5].

Against this background, this study develops a mobile application–based construction safety audit system tailored to high-rise design and build projects. The proposed system aims to enhance efficiency, accuracy, and responsiveness in safety auditing, thereby improving overall construction safety performance. The research contributes both theoretically, by addressing gaps in safety audit practices, and practically, by providing a scalable digital solution that can be applied across the Indonesian construction industry.

II. LITERATURE REVIEW

2.1. Construction Industry Context

Construction work encompasses a wide range of activities, including building, maintenance, operation, and demolition, each requiring effective project management strategies [6].

High-rise projects, particularly under design and build contracts, are characterized by compressed schedules, overlapping phases, and limited land availability, which increase safety challenges [7]. Compared with conventional contracts, design and build projects integrate planning and execution, providing opportunities for efficiency but also raising safety risks when hazards are not addressed during early design stages.

2.2. Construction Safety Performances

Construction safety refers to engineering practices aimed at protecting workers, the public, property, materials, and the environment during project execution [8]. The sector remains among the most hazardous industries, with accident rates surpassing many other sectors worldwide. In Indonesia, construction accidents have shown a steady increase, reaching 234,270 reported cases in 2021 [2]. The consequences of accidents extend beyond workers, affecting project costs, schedules, company performance, and even national competitiveness [9].

These instruments play a crucial role in reducing workplace accidents and enhancing construction safety performance in Indonesia. The implementation of these methods aligns with government efforts to improve occupational health and safety (OHS) standards in construction. These instruments serve as the realization of SMKK, as regulated in Permen PUPR No. 10 of 2021.

2.3. Conventional Construction Safety Audits

Audits play a central role in safety management systems, serving to evaluate compliance, effectiveness, and potential risks. Conventional audits in Indonesia rely heavily on paper-based records, fragmented checklists, and manual inspections [3]. These methods often delay corrective actions, reduce transparency, and limit traceability. Furthermore, audits are frequently reactive, conducted after construction has begun or accidents have occurred, rather than during early planning and design stages [10].

2.4. Digital and Mobile Technology in Construction Safety

Advancements in digital technologies have enabled new approaches to safety monitoring and auditing. Global research has explored the application of Building Information Modeling (BIM), sensor-based systems, wearable devices, and augmented or virtual reality to improve hazard identification and training [11][12]. Mobile technology has gained traction due to its

accessibility and ability to provide real-time data capture, automated reporting, and rapid risk communication [13]. Despite these advancements, adoption in Indonesia remains limited, with most companies still relying on manual methods [14].

2.5. Research Gap and State of the Art

Existing studies highlight the importance of integrating safety considerations into both design and execution phases [4][11]. However, in the Indonesian context, conventional audits remain inadequate, and digital solutions are not yet widely implemented. Limited research has specifically addressed the development of mobile application-based safety audit systems tailored for high-rise design and build projects. This study seeks to fill that gap by designing and validating a mobile application that enhances efficiency, transparency, and effectiveness in construction safety audits.

Table 1. Selected studies on construction safety and digital innovation

Author(s) & Year	Location	Focus	Key Findings
Sattineni & Schmidt (2015) [13]	USA	Mobile device adoption on construction sites	Mobile technology improves efficiency and reduces paperwork, but challenges remain in training and data security.
Afzal et al. (2021) [11]	UAE	Virtual Design and Construction (VDC) for safety	VDC technologies such as BIM, VR, and AR enhance safety but lack direct implementation evidence on site.
Lee et al. (2008) [12]	Korea	Mobile-based safety monitoring system	Demonstrated reduction of fall accidents via sensor and mobile warning system.
More & Waghmare (2019) [10]	India	Safety management and audit in infrastructure projects	Effective safety audits significantly reduce accidents; strong management commitment is essential.

III. RESEARCH METHODOLOGY

3.1 Research Design

This study employed a mixed-method research design, combining qualitative and quantitative approaches to develop and evaluate a mobile application-based construction safety audit system. The research began with a literature review to

identify gaps in current safety audit practices and to establish a theoretical foundation. Expert validation and comparative analysis of conventional audit processes were then conducted to ensure the applicability of the proposed model. The developed prototype was tested for feasibility in terms of features, usability, and its potential contribution to safety performance in high-rise construction projects. Finally, the quantitative stage applied Structural Equation Modeling – Partial Least Squares (SEM-PLS) to statistically test the relationship between conventional audits (X1), mobile-based audits (X2), and construction safety performance (Y). The overall research methodology is illustrated in Figure 3.

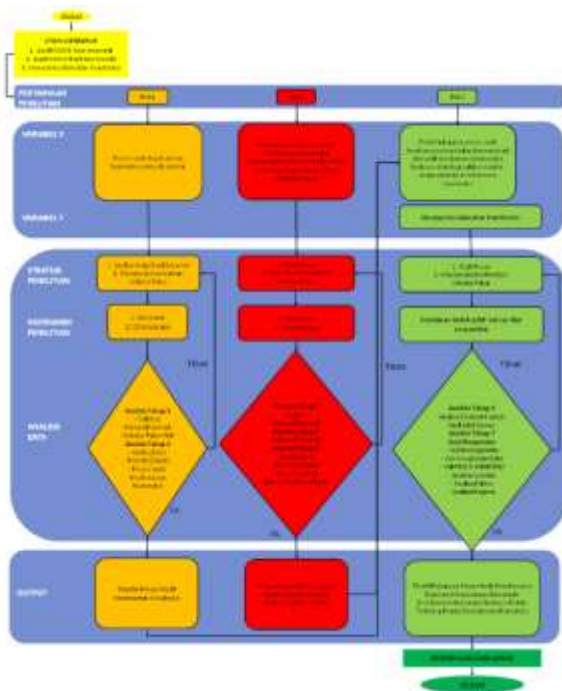


Fig 3. Research methodology framework

3.2 Data Collection Methods

Data collection involved three main techniques. First, archival analysis was conducted by reviewing regulatory documents, audit standards, and best practices in construction safety management. Second, expert judgment was obtained through structured discussions with professionals experienced in safety management and construction audits. Third, prototype testing was carried out using digital checklists, photo documentation, and automated reporting

functions, which were designed to replicate practical safety audit conditions. Lastly, a structured questionnaire was distributed to 90 construction professionals involved in high-rise building projects. The questionnaire consisted of items measuring perceptions of conventional audit practices (X1), mobile-based audit practices (X2), and construction safety performance (Y), with sub-dimensions including worker safety, equipment safety, material safety, and public/environmental safety. Responses were measured using a five-point Likert scale.

3.3 Data Analysis Methods

The data analysis consisted of two main approaches:

1. Qualitative Analysis

- Literature review, regulatory review, and expert judgment were conducted to identify audit elements and indicators.
- Expert input was used to refine the questionnaire items and validate content validity.

2. Quantitative Analysis (SEM-PLS)

- To statistically validate the relationships between constructs, SEM-PLS was applied using SmartPLS software.
- This method was selected because it is suitable for exploratory research, can handle relatively small sample sizes, and is effective in testing complex models with latent variables.
- The SEM-PLS analysis evaluated:
 - a) Measurement Model, assessing construct reliability and validity using Cronbach's Alpha, Composite Reliability (CR), and Average Variance Extracted (AVE).
 - b) Structural Model, testing the hypothesized relationships between X1, X2, and Y through path coefficients, t-statistics, and p-values.
 - c) Coefficient of Determination (R^2), measuring the explanatory power of the model for construction safety performance.

3.4 Validation

Validation was achieved through expert evaluation, where safety practitioners assessed the usability, practicality, and compliance of the mobile application features with regulatory standards, including the Construction Safety Management System (SMKK). The validation process ensured that the system was not only theoretically grounded but also practically feasible for implementation in the Indonesian construction context. SEM-PLS model provided statistical evidence of the model's robustness, confirming the significance of the relationships between conventional audits, mobile-based audits, and construction safety performance.

IV. RESULT AND DISCUSSION

4.1 Limitations of Conventional Safety Audits (RQ-1)

The investigation into current safety audit practices revealed significant limitations in the Indonesian construction industry. Safety audits remain predominantly conventional, relying on paper-based checklists, manual documentation, and fragmented reporting mechanisms. This approach results in lengthy processing times, difficulties in data storage, and limited traceability of audit findings. Furthermore, corrective actions are often delayed because the reporting process requires manual consolidation before reaching decision-makers. These shortcomings weaken compliance with the Construction Safety Management System (SMKK) and hinder the effectiveness of preventive measures [2][3][10].

The findings are consistent with prior studies indicating that conventional audits tend to be reactive rather than proactive [10], and that unsafe design decisions can contribute to up to 42% of fatal construction accidents [4]. This underscores the need for an audit system capable of integrating safety monitoring into the early design and planning stages. In Indonesia, where high-rise projects under design and build contracts continue to increase, the reliance on conventional audits poses substantial risks in terms of both project performance and worker safety.

4.2 Development of a Mobile Application Based Audit System (RQ-2)

To address the identified gaps, this study developed a mobile application prototype designed specifically for construction safety audits in high-rise design and build projects. The application integrates five essential features:

- Digital checklists aligned with national safety regulations to ensure compliance.
- Photo documentation to capture on-site conditions and provide visual evidence.
- Automated reporting to support rapid dissemination of audit findings.
- Secure data storage to maintain reliability and prevent data loss.
- User-friendly interface to enable adoption by diverse stakeholders, including safety officers, project managers, and regulatory bodies.

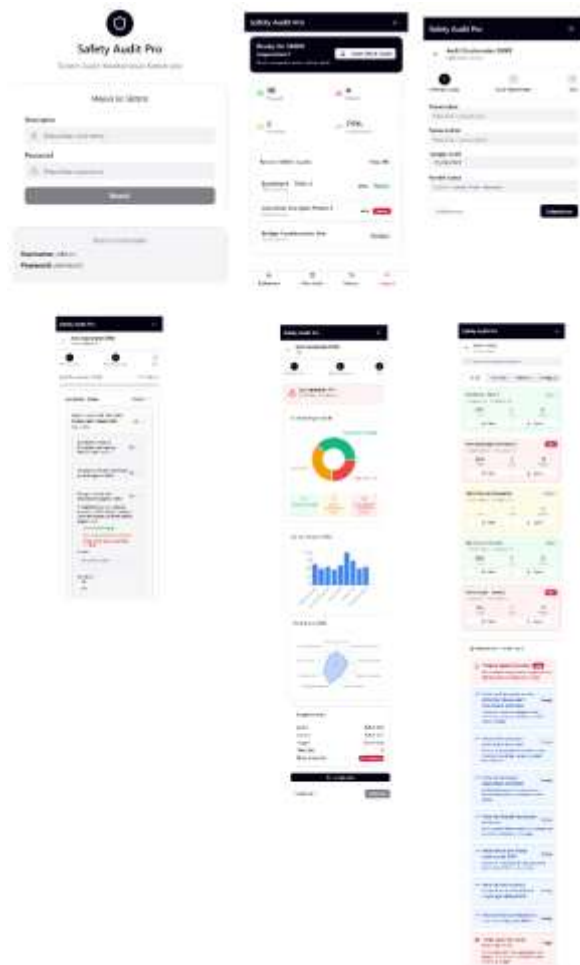


Figure 4. Prototype interface of the mobile application for safety audits

4.3 Expert Validation and Feasibility Assessment (RQ-3)

Validation was carried out through structured expert reviews involving professionals with extensive experience in construction safety management. The experts evaluated the application based on usability, compliance with regulations, and potential impact on safety performance.

The validation results confirmed that the application is feasible for practical use. Experts highlighted several improvements compared to conventional audits:

- Speed, audit results can be compiled and disseminated in real time, reducing delays in reporting.
- Accuracy, the digital format minimizes transcription errors and ensures more consistent data capture.
- Transparency, audit findings are documented systematically, enabling easier verification and accountability.
- Effectiveness, corrective measures can be implemented more promptly, reducing exposure to risks.

Notably, transparency emerged as the most influential factor, as it significantly enhances compliance with SMKK standards and strengthens organizational accountability. These findings resonate with earlier research suggesting that management commitment and system reliability are critical for improving safety performance [9][10].

To complement the expert validation, a quantitative analysis was carried out using Structural Equation Modeling – Partial Least Squares (SEM-PLS). The survey involved 90 respondents working on high-rise building projects in Indonesia. The demographic characteristics of respondents include gender, age, education level, years of work experience, and job position. The majority were male professionals with more than five years of experience in construction projects, ensuring that the responses reflected adequate field knowledge.

Table 2. Descriptive Statistics of Variables

Variable	N	Minimum	Maximum	Mean	Std. Deviation
Audit Conventional (X1)	90	1,000	5,000	3,76889	1,073024
Audit Mobile (X2)	90	2,000	5,000	4,49111	0,568191
Safety Performance (Y)	90	2,333	5,000	4,42315	0,568255
Valid N (listwise)	90				

Respondents perceived mobile-based audits (X2) more positively compared to conventional audits (X1), while safety performance (Y) was generally rated high.

Table 3. Construct Reliability and Validity

Variable	Cronbach's Alpha	rho_A	Composite Reliability	Average Variance Extracted (AVE)
Mobile Application-Based SMKK Audit (X2)	0,878	0,880	0,912	0,674
Conventional SMKK Audit (X1)	0,913	0,933	0,933	0,737
Safety Performance (Y)	0,946	0,947	0,953	0,627

All constructs exceeded the recommended thresholds ($\alpha > 0.7$, CR > 0.7 , AVE > 0.5), confirming that the indicators reliably measure their respective latent variables.

Table 4. Path Coefficients

Variable Relation	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (O/STDEV)	P Values
Mobile Application-Based SMKK Audit (X2) ----> Safety Performance (Y)	0,836	0,837	0,058	14,434	0,000
Conventional SMKK Audit (X1) ----> Safety Performance(Y)	0,229	0,232	0,086	2,654	0,008

Both conventional (X1) and mobile-based audits (X2) significantly influence safety performance (Y).

Table 5. Coefficient of Determination (R^2)

Dependent Variable	R Square	R Square Adjusted
Safety Performance (Y)	0,861	0,858

The model explains 86.1% of the variance in construction safety performance, which indicates a very strong explanatory capability.

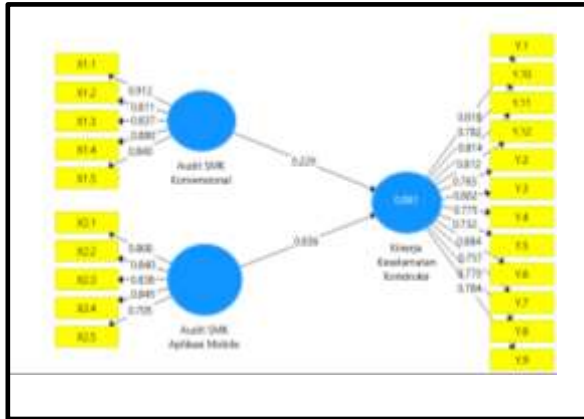


Figure 5. SEM-PLS Path Diagram

The SEM-PLS results demonstrate that both audit approaches significantly affect construction safety performance. Conventional audits ($\beta=0.229$, $p=0.008$) provide a moderate but meaningful contribution, while mobile-based audits ($\beta=0.836$, $p<0.001$) exert a very strong influence. The model explains 86.1% of the variance in safety performance, showing that the combination of both audit methods is highly effective in predicting safety outcomes.

These findings highlight a paradigm shift, although conventional audits remain relevant, their role is supplementary compared to the dominant contribution of mobile-based audits. Mobile applications offer higher accuracy, real-time reporting, and broader stakeholder involvement, aligning with literature emphasizing the importance of digital transformation in safety management [14][15][16].

4.4 Comparative Analysis: Conventional and Mobile Audit

To highlight the improvements offered by the mobile application, Table 2 presents a comparison between conventional audits and the proposed mobile system.

Table 6. Comparison of conventional and mobile-based safety audits

Criteria	Conventional Audit	Mobile Application Audit
Data Collection	Paper-based, manual entry	Digital checklist with photo documentation
Reporting	Delayed, requires manual compilation	Automated, real-time report generation
Traceability	Limited, records often fragmented	Centralized, easily accessible digital records
Transparency	Low, prone to manipulation	High, systematic and verifiable documentation
Corrective Action	Reactive, often after incidents	Proactive, supported by immediate risk alerts
Efficiency	Time-consuming, labor-intensive	Fast, user-friendly, reduces administrative load

The comparative analysis clearly demonstrates that the mobile application provides substantial improvements in speed, transparency, and overall effectiveness of safety audits, supporting a proactive rather than reactive approach.

4.5 Hypothesis Testing and Discussion

The hypothesis of this study posited that a mobile application-based audit system would improve the performance of construction safety audits compared to conventional methods. The empirical findings strongly support this hypothesis. The developed system was validated by experts as being more efficient, transparent, and reliable.

Theoretically, the findings contribute to the growing body of literature on digital transformation in construction safety. While prior research has emphasized the role of BIM, sensors, and wearable devices in enhancing safety [5][11][12], this study demonstrates that mobile applications offer a practical and scalable alternative, particularly in developing countries where resource limitations constrain the adoption of more complex technologies.

Practically, the application provides a feasible solution for construction companies in Indonesia to strengthen compliance with SMKK and improve safety outcomes. By integrating mobile technology into the audit process, firms can reduce delays, increase accountability, and improve decision-making at both project and organizational levels.

4.6 Broader Implications

The adoption of mobile-based safety audits has implications beyond individual projects. At the industry level, digital audits can contribute to more accurate national safety data, supporting evidence-based policymaking. For companies, the system enhances corporate image and competitiveness by demonstrating commitment to safety. At the worker level, improved audits translate into safer environments, reducing accident rates and associated socioeconomic costs.

These broader implications suggest that the proposed system is not merely a technological innovation but also a strategic tool to advance occupational safety culture in Indonesia's construction sector.

V. CONCLUSION

This study aimed to overcome the limitations of conventional construction safety audits in Indonesia's high-rise design and build projects by developing a mobile application-based system. Conventional audits were found to be slow, fragmented, and reactive, resulting in delays and weak compliance with national regulations. The proposed mobile system was designed, validated, and assessed to provide a more efficient and transparent approach.

The key findings of this research can be summarized as follows:

- Conventional audits are limited by paperwork, manual reporting, and low transparency, which hinder timely corrective actions.
- The mobile application prototype integrates digital checklists, photo documentation, automated reporting, data security, and user-friendly design, offering a practical solution for real-time audits.
- Expert validation confirmed the feasibility of the system, highlighting improvements in speed, accuracy, and especially transparency, which strengthens accountability and compliance with SMKK.
- Safety performance contributions extend across four areas: protecting workers, safeguarding the public and environment,

minimizing equipment risks, and ensuring secure material management.

- Hypothesis testing supports the idea that mobile-based audits are superior to conventional methods in terms of efficiency, responsiveness, and reliability.
- The SEM-PLS analysis with 90 respondents confirmed that both conventional and mobile-based audits significantly affect construction safety performance. Mobile-based audits ($\beta=0.836$, $p<0.001$) provide the strongest contribution, while conventional audits ($\beta=0.229$, $p=0.008$) remain supportive with a moderate influence. Together, these factors explain 86.1% of the variance in safety performance, underscoring the effectiveness of integrating mobile technology into construction safety audits.

There are 2 implications from this research:

1. Theoretically, expands literature on digital transformation in construction safety by showing the role of mobile applications as feasible and scalable audit tools.
2. Practically, Provides the construction industry with an adaptable solution to enhance audit efficiency, transparency, and compliance, directly supporting national safety regulations.

While this study offers promising results, its scope is limited to prototype validation and expert assessment. Future research is recommended to:

- Conduct large-scale, long-term testing across diverse projects.
- Measure quantitative impacts such as reductions in accident rates.
- Explore integration with BIM, sensors, and wearable technologies.
- Investigate user adoption behavior and organizational readiness for digital safety audits.

In conclusion, this research demonstrates that mobile application-based audits can transform construction safety practices, providing a practical and scalable tool to improve safety performance in Indonesia and potentially in broader international contexts.

VI. Acknowledgements

The authors are grateful to all construction safety audit research group members who assisted, advised or provided suggestions and responses throughout the drafting and completion of this study and to construction safety experts and the construction safety committee who helped the author validate this research process.

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