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Development of the Knowledge Base Information System for Integrated Risk-Based Audit of High-Rise Buildings Through Design-Build Method to Improve Construction Safety Performance

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ABSTRACT

The construction safety audit carried out is still ineffective in preventing accidents. This shows that the undistributed and inaccurate information obtained hinders the audit outputs from being learned for continuous improvement. To address this issue, this study aimed to develop a knowledge base information system to support an integrated audit process during both the design and construction phases. The objective was to improve construction safety performance by emphasizing risk and enabling continuous improvement. The study employed experimental methods including a literature review and expert validation to combine the ordinary and risk audit processes with knowledge management, resulting in a comprehensive website-based information system. The results show that the system can effectively support a risk-based audit process for the design-build method of high-rise buildings, leading to an enhancement of construction safety performance. This system enables the construction safety audit process to run effectively, in order to organize a continuous improvement in construction safety performance.

1. INTRODUCTION

The construction of state buildings is one of the National Strategy Projects (PSN) currently being intensified by the government to boost the economy. In line with the ongoing infrastructure development, the government has announced plans to relocate Indonesia's National Capital in early 2022 through Law No. 3 of 2022 concerning the State Capital [1]. This indicates that the initial phase of relocation to the State Capital Region (IKN) is scheduled to begin between 2022 and 2024. In this context, infrastructure development has been intensive in the last seven years, as evidenced by the increasing budgets and volumes, accompanied by demands for faster execution times. To support the IKN, high-rise buildings are being constructed using the design-build method. This approach takes into account the high risks, complexity, and uncertainty of the project [2]. To achieve this goal, construction implementation mostly employs design-build methods, which involve work construction contracts related to building development. In this case, the provider has a single unit of responsibility for the design and implementation of construction [3]. However, the construction sector in Indonesia often experiences increased work accidents.

According to BPJS Employment (Indonesia's Worker Insurance), the number of construction accidents at work sites has been increasing in the country, with 123,040 occurring in 2017 and 234,270 in 2021. This indicates that work site accidents in high-rise buildings carry greater risks than those in low-rise buildings. The most fatal or frequent accident in high-rise construction projects is a fall from heights, which often results in fatal injuries and even death [4]. Therefore, conducting an audit on construction safety is essential to ensure appropriate and precautionary performance. The safety audit process is responsible for implementing appropriate corrective and preventive measures for non-standardized work performance. Companies develop the outputs of occupational safety and health (OHS) audits to become standard checklists, improve recommendations, enhance environmental, health, and safety performance, as well as reduce accidents [5].

Despite the valuable lessons that can be learned from the audit process outputs, they are not well-documented or integrated into knowledge management. This knowledge could be used to improve the future projects of construction service providers, given the diverse and different risks involved [6, 7]. However, due to limited manpower and time, a solution is needed to overcome these limitations in the knowledge management audit process [8]. Currently, the existing work safety audit process has not been compiled into a regularly updated database of lessons learned. Therefore, it is necessary to develop a knowledge base for proficiency management in the audit process and establish a scientific platform specifically for high-rise buildings with design-build methods. This will facilitate learning and improve the effectiveness and efficiency of the audit process [9].

The knowledge base management system has problem-solving characteristics that aid in decision-making processes using an if-then approach. This system is highly structured and used to address specific problems, while also containing activities that facilitate effective knowledge management [10]. To improve construction safety performance, the operational

pattern of the knowledge management system emphasizes an approach that facilitates the development of data-oriented decision-making processes rather than assumptions. This approach helps to identify the sources of problems and develop long-term, comprehensive solutions [11].

According to the study [12], the main advantages of using organizational information system were based on the following, (1) storing large amounts of information and data at low cost, (2) enabling effective collaboration regardless of distance, time, language, and culture, as well as (3) increasing the effectiveness and efficiency of people working in the same group and different locations. This statement explains that the development of an information system is expected to facilitate the implementation of knowledge management in buildings and to improve control over critical safety variables in high-rise building projects. The knowledge map also needs to be structured according to the specific conditions of the company, regarding previous experiences [13]. Therefore, this study aims to develop a knowledge management information system for an integrated audit process at the design and construction phase.

This management system is also known as the knowledge base, a representation of the proficiency needed to understand, formulate, and solve problems. From this context, every problem-solving activity is often documented and becomes a guide or reference for integrated service standards. Moreover, documentation increases the efficiency and effectiveness of organizational duties and responsibilities. The knowledge base outputs are also a collection of documented problem formulation and solution proficiency. This study is expected to contribute to the improvement of the construction safety audit process, thereby enhancing accident prevention during the design phase. This, in turn, will help to mitigate infrastructure catastrophes during the construction phase in Indonesia's accelerated development era [14, 15].

2. METHODOLOGY

The case study method was used to comprehensively answer research questions and observe related phenomena [16]. In this case, the experimental stages were divided into two, namely (1) the formulation of a knowledge base for the construction safety audit process, and (2) the design of a web-based information system.

2.1 Knowledge base of the construction safety audit process

In this study, data sources from [17-20] were employed. This study provided adequate data on the audit process and activities performed, as well as risk controls. The characteristics of the data collected are data consisting of audit processes, audit activities, objectives, targets, risks, causes, impacts, preventive actions, and corrective actions, which were obtained based on previous research. Researchers get data through three stages. The first stage is data reduction, the writer must identify abstract data or raw data. The second stage, the researcher combines the appropriate data to become a single unit of information. Finally, data interpretation, in which the researcher analyzes the data that has been reduced and organized so that clear conclusions can be drawn. The validation carried out by experts on these processes and activities also led to a standardized audit procedure and became a knowledge base. As shown in the Table 1, the following variables were validated, a) 6 audit processes, 26 audit activities, and 25 objective clauses of the construction safety audit on high-rise buildings, b) 26 preventive actions, 25 causes, 32 risks, 20 impacts, and 22 corrective actions for the risk strategy of the safety performance, and c) the Construction Safety Plan (RKK) for the construction safety audit process in Regulation of the Minister of Public Works and Housing Number 10 of 2021 [21]. The safety performance audit process for high-rise buildings with design-build method consists of (1) establishing the audit program objectives, (2) determining and evaluating audit program risks and opportunities, (3) establishing the audit program, (4) implementing the audit program, and (5) monitoring the audit program.

The process of implementing a construction safety audit and preparing RKK documents is shown in Figure 1. The audit process of construction safety began from the assignment level, by appointing auditees and auditors for the job. In this process, the stakeholders involved were the internal auditors of each company, the Construction Safety Committee (K2K) as external inspectors, as well as the Project Managers and HSE Managers that became auditees. Based on this context, auditees are employed because of their understanding of the audit process information and risk strategy. This was accompanied by the efforts of auditees in filling in and out, as well as uploading the general data information, checklist, and supporting audit documents, respectively. Furthermore, the assigned auditors downloaded the input audit output document, to assess and monitor the inspection process and progress, as well as provide an evaluation. Based on this evaluation, auditors prepared an audit report to be submitted to the assignor.

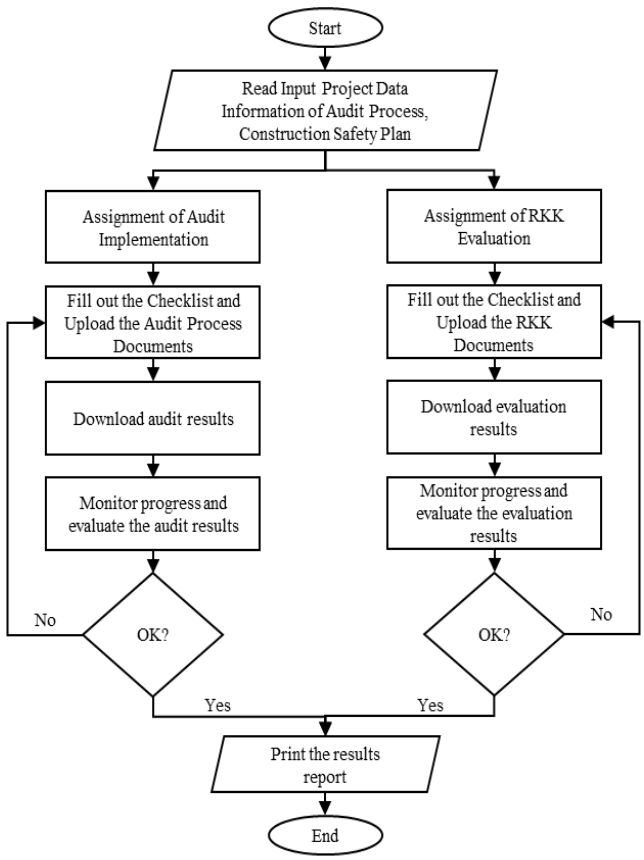


Figure 1. The algorithm designs

According to Figure 1, the process for preparing the RKK documents was described. The auditee will be able to understand sample documents required and study the results of previous safety performance evaluations. After understanding these documents, the general project data and required RKK files were filled out and uploaded, respectively. This was accompanied by auditors' effort to download the RKK document, monitor the process, and evaluate the uploaded files. This evaluation will be conducted by checking compliance with the standards. In addition, auditors compiled the evaluation outputs when the incomplete documents awaiting auditees' correction were observed.

Table 1. The validated activity of the construction safety audit process on high-rise buildings [17-20]

No	Audit Activity	Objective
1	Audit Process: **Establishing Audit Program Objective**	
1.1	The organization establishes consistent audit program objectives and supports the organizational policies and goals	To obtain a common goal with all parties in the organization, according to the organizational policies and objectives
1.2	The organization reassures that the audit program objective is decided for planning and execution, as well as effective implementation	To determine that audit program objectives are in line with planning and execution, as well as effective audit program implementation
2	Audit Process: **Determining and Evaluating Audit Program Risks and Opportunities**	
2.1	The organization identifies audit program risks and opportunities	To minimize the possibility of risk occurrence
2.2	The organization identifies audit program opportunities	To maximize the opportunities in the audit program
2.3	The organization evaluates the risks of the audit program	To measure and control possible risk occurrence
2.4	The organization evaluates opportunities in the audit program	To identify and plan improvements to opportunities in the audit program
3	Audit Process: **Establishing Audit Program**	
3.1	The organization defines the roles and responsibilities of the person managing the audit program and the team/auditors	To streamline work because everyone who works in the audit/auditor team already knows their respective roles and responsibilities
3.2	The organization determines the competence of the person managing the audit program and auditor team	To improve the standard and performance of the audit program due to the observation of a minimum competency threshold
3.3	The organization selects the person capable of managing the audit program	To maintain the quality of the audit program, with the selected people accountable for their work
3.4	The organization determines the level of the audit program	To classify the audit program according to the existing situation
3.5	The organization establishes procedures for audit programs	To assist in running the audit program
3.6	The organization identifies audit program resources	To determine the resources needed in the audit program
4	Audit Process: **Implementing Audit Program**	
4.1	The organization defines the audit objectives, scope, schedule, and criteria, including the competence of auditors	To determine and carry out audit programs according to the objectives, scope, schedule, and criteria, including auditors' competence and evaluation process
4.2	The organization selects an audit method	To determine the appropriate audit method and use
4.3	The organization selects audit team members	To determine people based on their competence to work in an audit team
4.4	The organization assigns responsibility for the audit to the lead	To submit and ensure that the implementation of the audit is responsible and in line with procedures
4.5	The organization manages the results of the audit program	To obtain the final results and conclusions from the implemented audit program
4.6	The organization manages and maintains records of the audit program	To maintain audit program records for storage and subsequent usage
5	Audit Process: **Monitoring Audit Program**	
5.1	The organization monitors compliance with the audit program, schedule, and objectives	To ensure that the audit program operates according to the plan
5.2	The organization monitors the performance of audit team members	To ensure that the audit team works optimally
5.3	The organization monitors the ability of the audit team to carry out the plan	To ensure that the audit team is capable of handling and performing the plan properly
5.4	The organization monitors feedback from top management, auditees, auditors, and other interested parties	To ensure that every interested party in the audit program is satisfied with the implementation of the audit program
5.5	The organization assigns responsibility for the audit to the monitoring lead	To submit and ensure that the implementation of the audit is responsible and in line with procedures
6	Audit Process: **Reviewing and Improving Audit Program**	
6.1	The organization reviews the audit program to assess the achievement level of the objectives	To ensure that the implemented audit program has achieved its objectives
6.2	The organization reviews the overall implementation of the audit program, identifies areas of improvement, and changes the system when necessary. It also reviews auditors' continuous professional development and reports the outputs of the audit program to top management	To determine the overall results of the audit program based on improvement requirements, program changes, and auditors' level of professionalism; and to also ensure that top management obtains the information related to audit program reviews
6.3	The organization uses the review of the audit program as input for the continuous improvement process	To improve audit programs in the future, by learning from the previous programs

2.2 Web-based information system for knowledge management

To provide the needs of the proposed information system, a use case diagram was employed. This helps to visually explain the interaction of the adopted system actors or users [22]. Figure 2 shows a use case diagram, emphasizing the knowledge management website for the audit process of the construction safety performance plans.

This diagrammatic design is a mapping description of the processes provided in the built system, including the people involved. Therefore, the proposed use case diagram prioritized the development of a knowledge management information system for construction safety audit.

Based on Figure 2, the administrator was able to log into the website, as well as enable user and system settings. This indicated that the unauthorized general users (other users) accessed the audit process information, as well as downloaded supporting forms and data. Meanwhile, users who wish to log in as auditors or auditees are required to register to access specific menus. This was accompanied by auditees' efforts in processing checklist activities, RKK, developing new project data, filling out and uploading the audit supporting documents, as well as downloading the required forms and sample documents. To provide the assessment of the documents implemented by auditees, auditors then accessed the audit process checklist menu, RKK, and provided notes, as well as downloaded the required files.

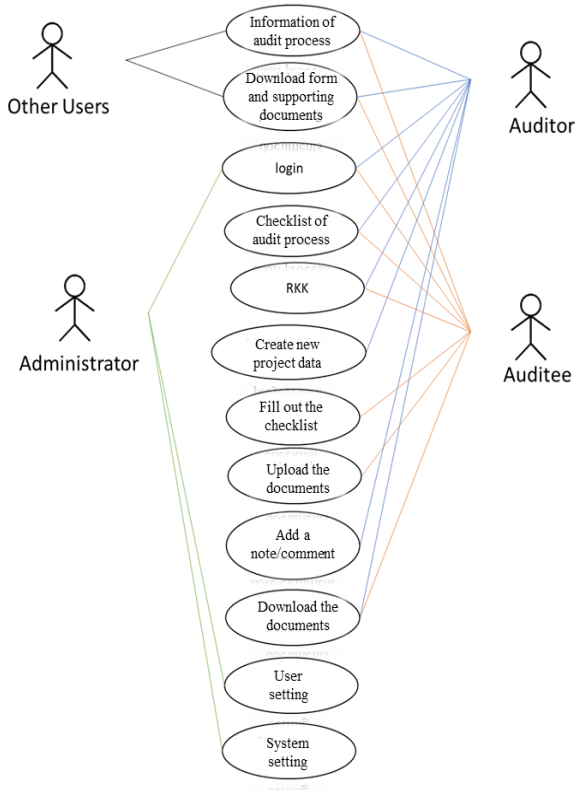


Figure 2. The use case diagram designs

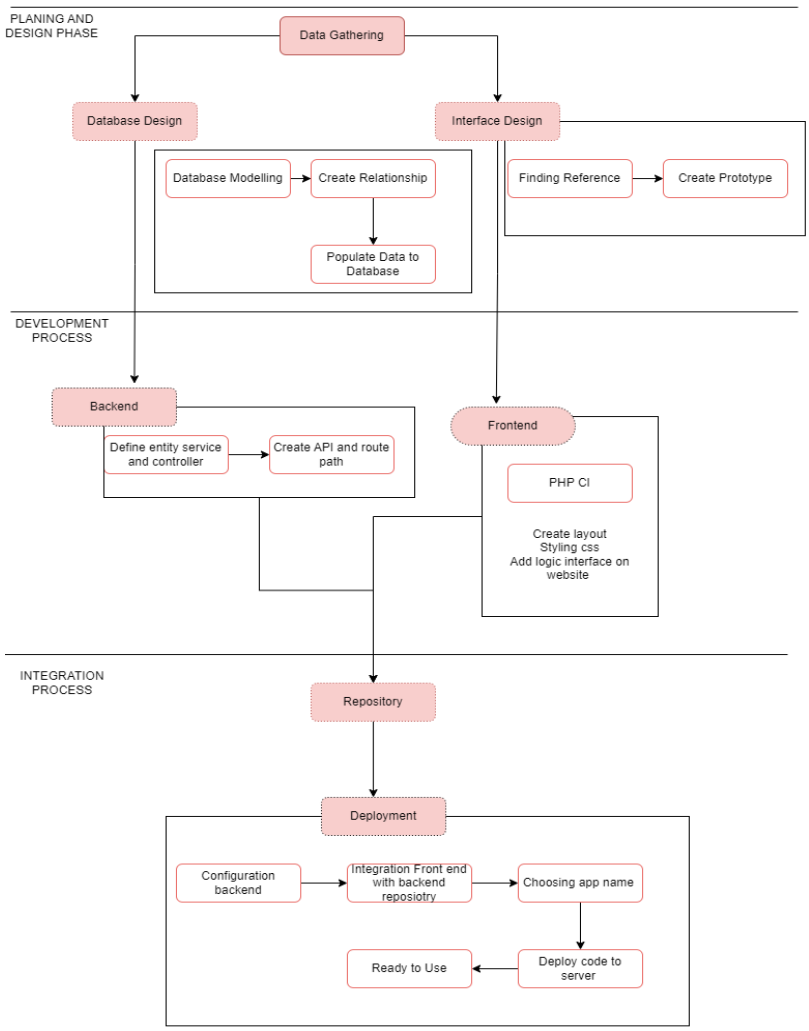
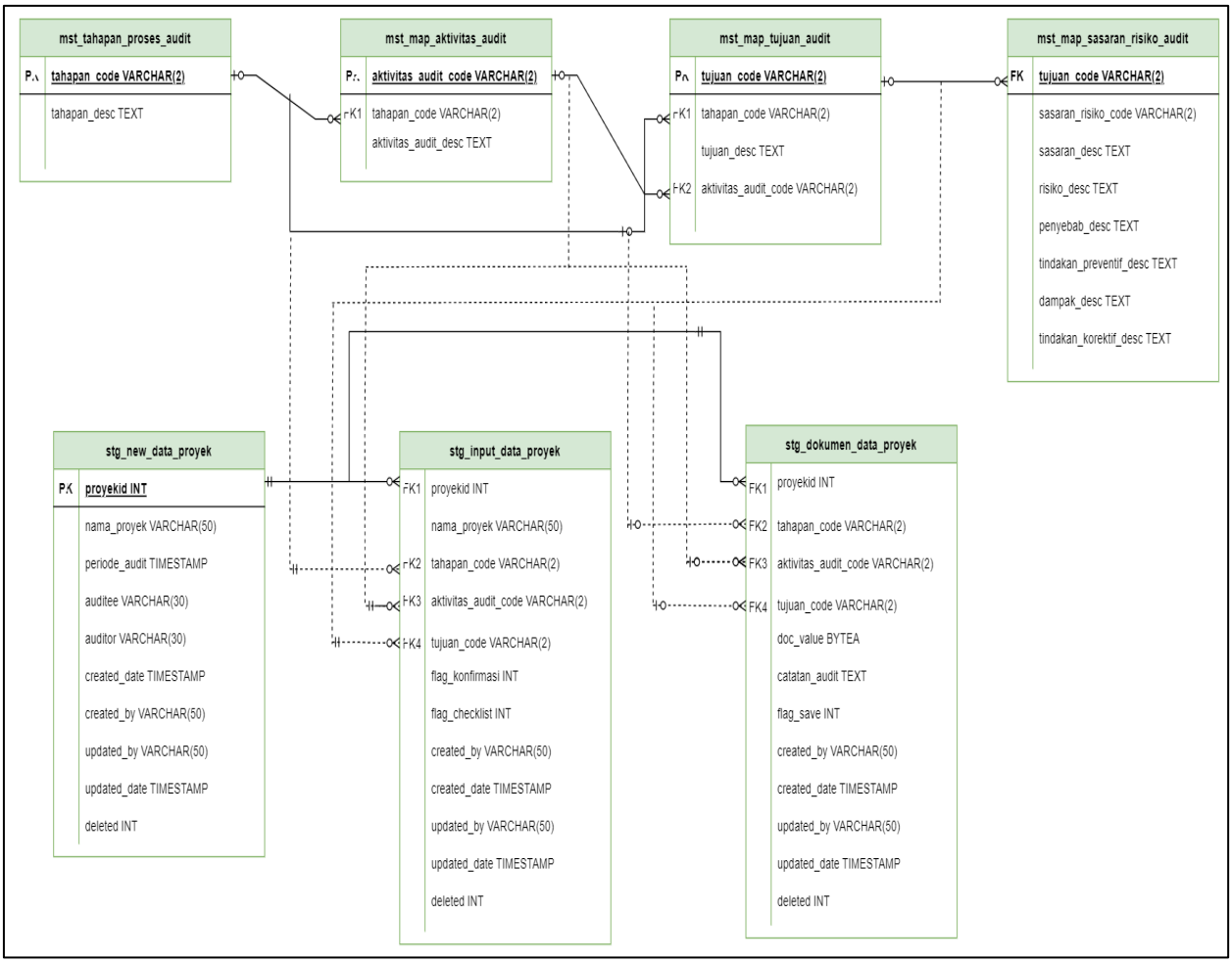
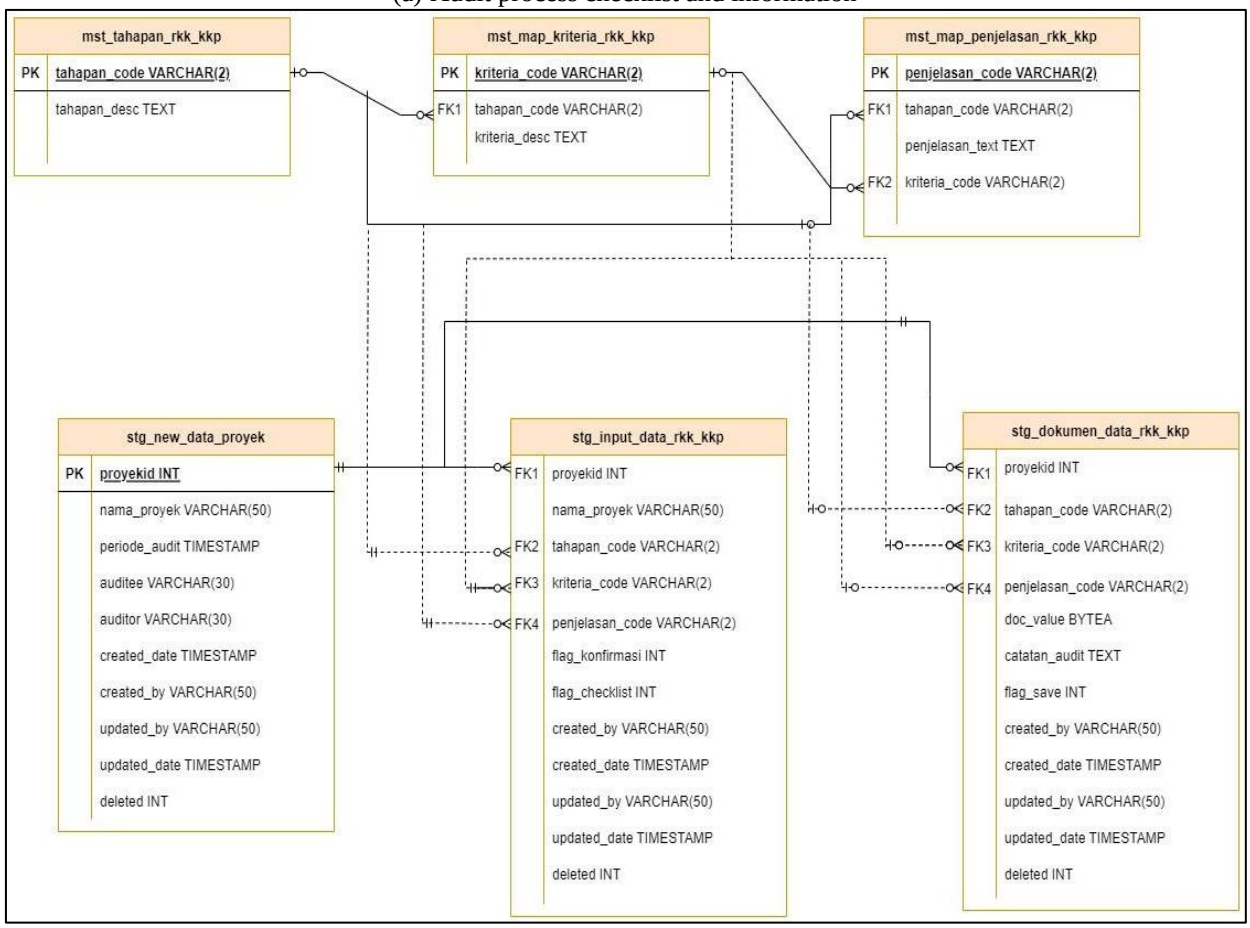


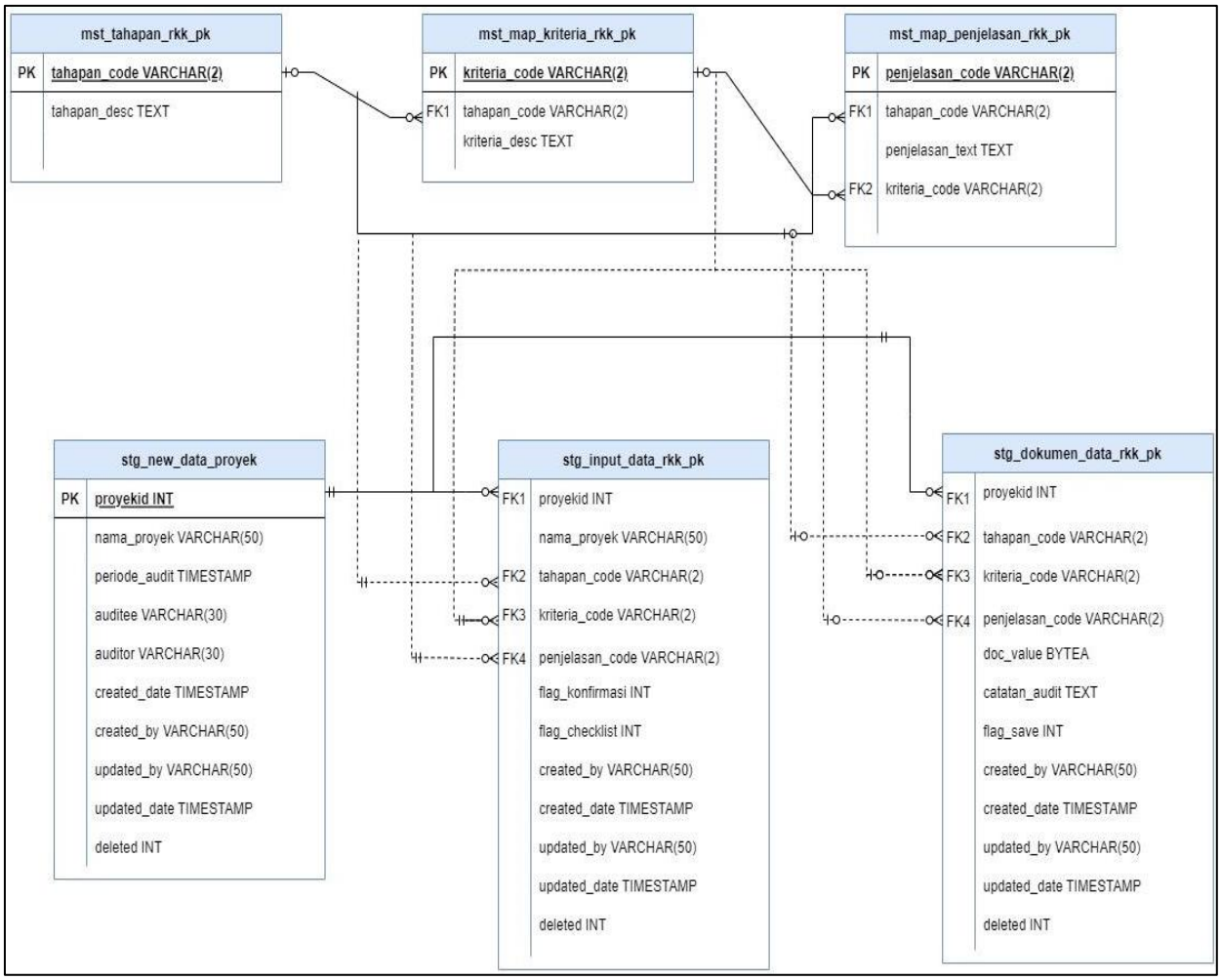
Figure 3. Systematics of website development



(a) Audit process checklist and information



(b) Assessment of RKK supervision construction consulting



(c) Assessment of RKK construction work execution

Figure 4. Website database design for knowledge management of the construction safety audit process

Based on the development of a knowledge management information system, data collection was carried out through the knowledge base of the construction safety audit process. In this case, website development was used for knowledge sharing and application through the steps shown in Figure 3.

The applications used in developing this website included PHP CodeIgniter Framework, PostgreSql, Java Spring Boot Framework, and Heroku. The first process focused on the collection of the required data as system input, accompanied by filling the obtained information into the PostgreSql Database model. PostgreSql is a Database Management System (DBMS) used to store or modify data through SQL (Structured Query Language) commands. In the audit process knowledge management, the stored data were in a grouped form, based on the correlation between audit activities, objectives, targets, risks, causes, impacts, as well as preventive and corrective actions. The data were also organized in table format and stored within a database, with the observed relationships shown in Figure 4.

Based on Figure 4 (a), the database design contained on the knowledge management website of the construction safety audit process was described. This design was grouped into 3 diagrams, indicating the data processing on the website. For audit process information and checklists, data were also stored in 4 main tables, namely the mst_phase_audit_process, mst_map_activity_audit, mst_map_audit_purpose, and mst_map_target_risk_audit. These tables showed various information, such as the audit activities and objectives. To carry out the audit process checklist, the four main tables need to be integrated with other illustrations capable of accommodating general information when data are added, changed, and deleted. This analysis led to the formulation of 3 temporary tables, namely stg_new_data_project, stg_input_data_project, and stg_dok_data_project.

From Figure 4 (b), 3 main tables were formed at the assessment stage of the RKK supervision, namely mst_tapahan_rkk_kkp, mst_map_kriteria_rkk_kkp, and mst_map_penjuangan_rkk_kkp. The functions of these tables were to store criteria data, RKK explanation, as well as the process, reserve, and change information of RKK. Based on these results, the main table was integrated with the temporary types, including stg_new_data_project, stg_input_data_rkk_kkp, and stg_dok_data_rkk_kkp.

According to Figure 4 (c), the relationship between the tables in the RKK process was observed at the work assessment stage. This analysis led to the development of 3 main tables, namely mst_stage _rkk_pk, mst_map_kriteria_rkk_pk, and mst_map_explanation_rkk_pk. These tables functioned to store information in the form of criteria and explanations at the RKK assessment stage. Meanwhile, the temporary tables stored the documents, audit records, and processes carried out in the RKK execution of construction work assessment.

In each process, the data from the main and temporary tables were then processed by using the Java Spring Boot Framework application, to produce an Application Programming Interface

(API). This interface was implemented to allow users to develop changes, as well as save and delete data in the website database. From this context, the program obtained from the API was then processed through the PHP Codeigniter application, by implementing the "Model View Controller" before being displayed to the users. Table 2 presents a list of API on the knowledge management website of the construction safety audit process.

Table 2. API list on the knowledge management website of the construction safety audit process

No	Method	Description	API URL
1	POST	General information data generation	api/insertNew Data
2	POST	Retrieval of audit process information data	api/getAll
3	POST	Retrieval of information data on the audit process that has been carried out	api/getProgres sBar
4	POST	Retrieval of data document information on the audit process	api/getDocum ent
5	POST	Storage of checklist data and information on the audit process	api/updateFla gKonfirmasi
6	POST	Storage of data document information on the audit process	api/editDocu ment
7	POST	Assessment data collection of RKK Supervision Construction Consulting	api/getAllRkk Kkp
8	POST	Assessment document data retrieval of RKK Supervision Construction Consulting	api/getDocum entRkkKkp
9	POST	Data storage of RKK Supervision Construction Consulting	api/updateFla gKonfirmasiR kkKkp
10	POST	Document data storage of RKK Supervision Construction Consulting	api/editDocu mentRkkKkp
11	POST	Document data retrieval of RKK Construction Work Execution	api/getAllRkk Pk
12	POST	Assessment document data retrieval of RKK Construction Work Execution	api/getDocum entRkkPk
13	POST	Data storage of RKK Construction Work Execution	api/updateFla gKonfirmasiR kkPk
14	POST	Document data storage of RKK Construction Work Execution	api/editDocu mentRkkPk

Based on Table 2, the final expert validation was carried out to validate the development of a knowledge management information system. This was conducted for the audit process on high-rise buildings that was previously analyzed. At this stage, 5 experts were required to meet the following criteria: (1) being members of the construction safety committee or occupational safety and health auditors, (2) having a minimum of 5 years of experience in the field of high-rise building construction, and (3) holding at least a bachelor's degree (S1/D4) in a related field. The introduction of these experts into the analysis was to determine and validate the ease of understanding the web-based information system. Determination of the number of experts using the Slovin method. The population of K2K members of the Building Subcommittee, based on the Decree of the Minister of Public Works and Public Housing No.33/KPTS/M/2021, is 9 people. So that with a tolerance limit of 10%, the number of respondents can be calculated as Eq. (1).

$$n = \frac{N}{1+N\,e^2}$$
$$n = \frac{9}{1+(9)\,(0{,}1)^2} = 4{,}7 \approx 5 \quad (1)$$

This was accompanied by the analysis of questionnaire data, using descriptive methods. In this case, 4 value categories were observed on the aspects of usability, design, and operation, namely SB (very good), B (good), CB (quite good), and TB (not good). Each category was provided with a weight before calculating the average values of the analyzed aspects. Based on the results, the development of a knowledge management information system in the form of a website was used and approved.

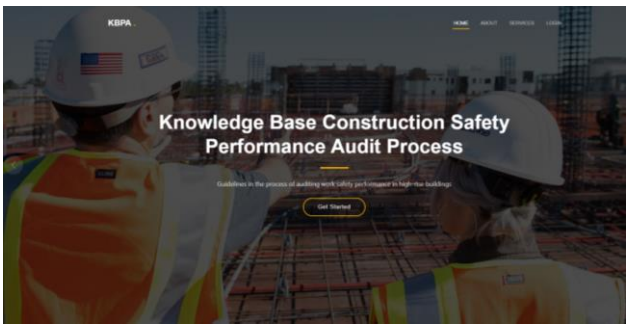
3. DISCUSSION

This web-based information system used to develop knowledge management of the construction safety audit process was accessed at https://km-base-audit.herokuapp.com. This system was used to perform the following, (a) Obtaining information related to the construction safety process for high-rise buildings, by using the design-build method with risk control strategies, (b) Conducting construction safety audit, as guides, on the design and construction contracts of high-rise buildings, emphasized the Regulation of the Minister of Public Works and Housing Number 10 of 2021, by assessing a checklist process and document storage, (c) Completing the RKK documents as a tool or guide, through a checklist process and document storage, and (d) Supporting the audit process as a repository for documents, such as forms, previous project reports, rules/standards, and examples of RKK files.

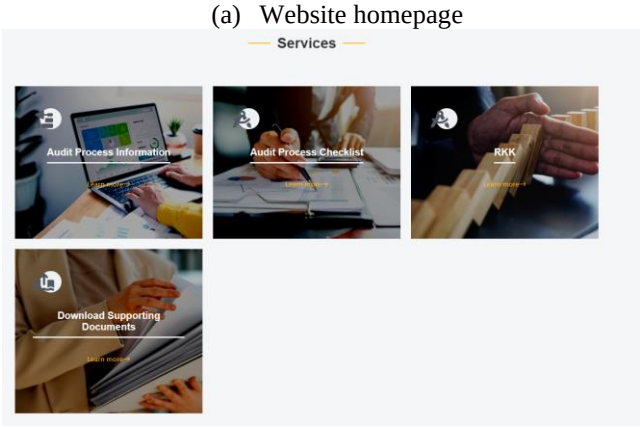
According to Figure 5, the homepage of the knowledge management website was displayed for the construction safety audit process for high-rise buildings, through design-build method. On this page, users were able to log in as needed, to access the audit process checklist and RKK sections. The audit process information menu was also accessed by the public without the need to log in to the website. Moreover, the users were required to input their previously provided usernames and passwords on the log-in page. When the activity in the audit process was carried out, a button was clicked to generate a checklist, with supporting documents uploaded for each audit activity. In this case, the "Save Data" button needs to be clicked before proceeding with the next audit process. This activity enabled the proper storage of all documents and records related to the completed audit process in the database. After the completion of the audit process, the users were able to acquire the corresponding data by selecting the "Download Information" option located on the "Checklist" homepage.

Table 3 shows an assessment analysis of the developed website system. This shows that the Benefit Aspect is rated "Very Good", with an information system that makes it easy to obtain data related to the audit process, activities, and construction safety risk management in high-rise buildings. As a guideline, the usefulness of this website in construction safety is also rated "Very Good". This is emphasized by

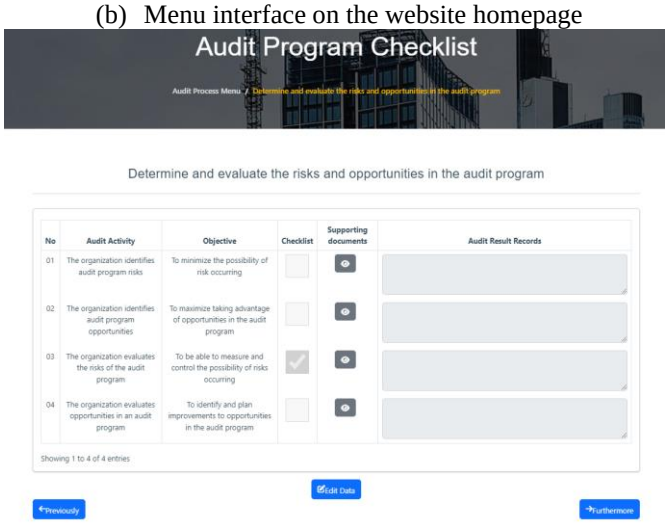
assisting the checklist process, storing audit results, and providing supporting information and case studies. For the Operational Aspect, the indicators: The system was used easily (user-friendly), Ease of understanding the format of the output information displayed, and Compatibility of the output with the requested input, were also rated "Very Good". While the Speed of system response to user requests gets a "Good" value. The system design aspect was also rated "Good" by experts, regarding the Placement of content and features for easy understanding, Selection of the design used, and the composition of the colours used.



(a) Website homepage



(b) Menu interface on the website homepage



(c) Audit process checklist interface

Figure 5. Website interface design for knowledge management of the construction safety audit process

The benefits aspect of the website was in line with [9, 23, 24], where a requirement for establishing a knowledge management system supported the life cycle of proficiency sustainability from formation to distribution and administrative levels. The website's benefits also supported one of the main objectives of using the information system [25]. This prioritized the economical processing of data into information or knowledge [26]. In addition, the system enabled more structured human activities, adjusting them from individual to system-based actions.

Table 3. Result of website validation data analysis

No	Assessment aspects	Indicator	Result
1	Benefits aspect	The information system provided convenience in obtaining the data related to the construction safety audit process for high-rise buildings	Very Good
		The system provided data related to construction safety audit activities	Very Good
		The system produced the data emphasizing risk management in the construction safety audit process, such as the relationship between Uncertainty, Cause, Impact, as well as Preventive and Corrective Actions	Very Good
		The system was also a guideline in the construction safety audit process for high-rise buildings	Very Good
		The system provided supporting information and case studies in the audit process	Very Good
2	Operational aspect	The system was used easily (user-friendly)	Very Good
		Ease of understanding the format of the output information displayed	Very Good
		Compatibility of the output with the requested input	Very Good
		Speed of system response to user requests	Good
3	Design aspect	Placement of content and features for easy understanding	Good
		Selection of the design used	Good
		The composition of the colours used	Good

4. CONCLUSIONS

Based on the results, the development of this web-based information system assisted the audit process in knowledge sharing and application aspects. This was to provide convenience in obtaining the information related to the audit process, activities, and risk management in construction safety audit on high-rise buildings. This risk management included the relationships of uncertainties, causes, impacts, as well as preventive and corrective actions. The website information system also supported various data, such as applicable regulations and case studies in safety audit. From the results, the development of a web-based information system should be redeveloped in subsequent analysis for another building objects or contract methods, to obtain greater benefits for auditors and auditees.

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NOMENCLATURE

n	Number of samples
N	Total population
e	Error tolerance limit