JTUS, Vol. 03, No.10 October 2025
E-ISSN: 2984-7435, P-ISSN: 2984-7427
DOI: https://doi.org/

Journal Transnational Universal Studies

Knowledge Base in the Development of Knowledge Management Processes for Mechanical and Electrical Work Audits in High-Rise Building Projects with Design-Build Contracts to Improve Construction Safety Performance

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Abstract
Safety performance is a critical benchmark for assessing the success of construction projects, particularly in high-rise buildings where mechanical and electrical (M&E) works carry significant risks. Previous cases of construction failure in projects with Design and Build contracts highlight the urgent need for improved safety management strategies. This study aims to develop a knowledge-based framework of knowledge management for M&E work processes in high-rise building projects with Design and Build contracts, with the ultimate goal of enhancing construction safety performance. The research employs a quantitative approach by distributing structured questionnaires to professionals involved in M&E works. The collected data are analyzed through statistical methods, including homogeneity, adequacy, validity, and reliability tests, followed by risk assessment using a risk matrix. Findings are expected to identify key knowledge management parameters—such as audit processes, information systems, and knowledge sharing—that directly influence safety outcomes. Each activity within the M&E work cycle will be critically evaluated to map potential risks and determine appropriate management strategies. The implications of this research lie in providing construction stakeholders with a systematic method for integrating knowledge management into safety practices, thereby reducing the probability of failures, improving organizational learning, and supporting sustainable project performance. By linking knowledge management with risk evaluation, this study contributes to both theoretical insights and practical solutions for improving safety in complex construction environments.
Keywords: Construction Safety Performance, Knowledge Base Audit Process, Information System, Knowledge Management.

INTRODUCTION

Data from the Central Statistics Agency (2024) indicates that infrastructure development in Indonesia is one of the key factors contributing to the increasing role of the construction sector in the national economy. This is evident from the construction sector's significant contribution of 10.06% to Gross Domestic Product (GDP) in the third quarter of 2024 (Algabry et al., 2020; Gaosong & Leping, 2021; Kocot et al., 2024; Nugroho et al., 2023; Sirait, 2022).

The Ministry of Public Works and Public Housing (PUPR) has prepared a new strategy to accelerate infrastructure development in Indonesia. It is not sufficient to simply hold an auction; the project also plans to change the auction scheme. The auction method applied is the Project Design and Build (DB) method, or integrated design projects, which must be followed by auction participants (Ministry of Public Works and Housing, 2016).

Based on the Minister of Public Works and Public Housing Regulation No. 25 of 2020, which amends Regulation No. 1 of 2020, the Design and Build method encompasses all construction-related work. Under this method, the provider has full responsibility for both the design and execution of construction activities, as stipulated in Article 1, paragraph 16. This method offers advantages in terms of time and cost efficiency compared to the conventional design-bid-build approach. However, its implementation often faces challenges, such as delays in schedules, discrepancies in costs, contractual disputes, and quality issues that fail to meet specifications (Abdullah, 2018; Afan et al., 2022; Bustamin et al., 2023; Manurung, 2020; Setyaningrum & Kuntadi, 2019; Stefanus & Sulistio, 2022; Yalina & Sugiri, 2021).

In practice, Design and Build contracts in Indonesia have revealed several problems that hinder development progress. Data on problematic projects show frequent delays and issues of poor construction quality (Barri et al., 2022; Christina et al., 2012; Hayati et al., 2023; Setiawan, 2005). For

instance, in the Emerald Bintaro Apartment project, reports indicate that the actual project duration exceeded the planned timeline by 12.68%. Similarly, in the Cempaka Putih Health Center Building project, poor-quality construction required post-completion repairs. Furthermore, work accidents in the construction sector—especially in mechanical and electrical (M&E) works—remain a serious concern. Reports highlight frequent accidents resulting in injuries and fatalities, underscoring the critical importance of occupational safety in this sector.

Work accidents in the Indonesian construction sector have increased significantly. A Ministry of Manpower report shows that in 2024 alone, there were 462,241 recorded cases of workplace accidents, the majority of which involved wage recipients. The impacts extend beyond the workforce to society and the state, leading to delayed projects and cost overruns. These accidents cause substantial financial losses estimated at up to 4% of GDP (Kapuasiana & Hardjomuljadi, 2020). To address this problem, stakeholders in construction projects must improve safety standards and work quality to minimize risks and negative consequences. According to the Ministry of Public Works and Housing (2020), the main causes of construction accidents include poor coordination and communication among personnel, weak design-to-construct execution that fails to meet specifications, neglect of standard operating procedures (SOPs), incomplete work breakdown structures (WBS), and work methods reduced to mere administrative requirements. Additionally, unidentified work scopes often lead to unmitigated risks, while poor attention to the K4 aspect (workers, construction, public, and environment) results in inadequate identification and control of hazards (Abduh, 2010; Alsadila & Latief, 2019; Brix, 2014, 2017; Putro & Latief, 2020).

To anticipate construction failures, knowledge management is required to audit M&E processes in high-rise building projects with Design and Build contracts (Gressgård, 2014; Hallowell, 2011; Hoch, 2014; Lyles, 2014; Mariana et al., 2023). Effective knowledge exchange within and across organizations enhances employees' ability to learn from others' experiences, thereby improving their own knowledge and skills (Reagans, 2005).

Explicitly articulating individual knowledge is critical, as knowledge must be transformed into forms that others can understand, absorb, and apply (Ipe, 2003). Knowledge and skills are fundamental determinants of safe behavior, and knowledge exchange—including both sharing and seeking—plays an essential role (Wang, 2010). Such exchange improves safety compliance by reducing accidental violations and enhancing competencies. By learning from colleagues' experiences with operational challenges and complications, workers are encouraged to adopt more consistent safe work behaviors (Gressgård, 2014).

Cater H. (2010) explains that the formal implementation of Knowledge Management (KM) can strengthen risk management strategies through several measures: mapping organizational knowledge, conducting KM audits, identifying knowledge gaps, forming project teams to acquire and document knowledge, and reviewing results to drive continuous improvement. These practices significantly contribute to more effective safety management and risk reduction in construction projects.

Several studies also explore links between Knowledge Management and safety performance, as well as the application of knowledge bases in human resource management audits (Deepak M.D. & Gangadhar Mahesh, 2020; Karin Kuimet, 2016). This study seeks to integrate the knowledge base into the auditing process of M&E works in high-rise building projects using Design and Build contracts, while also analyzing its influence on construction safety performance. Covering development from the design stage to construction execution, this research is expected to provide valuable insights for researchers, academics, and practitioners seeking to enhance safety management and project quality in complex construction environments.

RESEARCH METHOD

The research strategy adopted in this study was based on three main factors, as suggested by Yin (2003): the research questions, control over the phenomenon being studied, and the focus on current or historical events. Appropriate strategies were selected to address the research questions, including surveys and case studies, which were used to support the development of knowledge management in the context of construction projects.

The research process was divided into three phases: problem identification, research plan design, and implementation of research instruments. In the first phase, the research object and methodological design were determined. In the second phase, the methods for answering the research questions were

conceptualized. The third phase involved data collection and analysis. Primary data were obtained through interviews and questionnaires, while secondary data were gathered from the literature. For each research question, data collection techniques were customized, including expert validation to confirm the findings. Data analysis was conducted descriptively and with the Delphi method to assess the influence of knowledge management on construction safety performance, with the objective of improving effectiveness in high-rise construction projects.

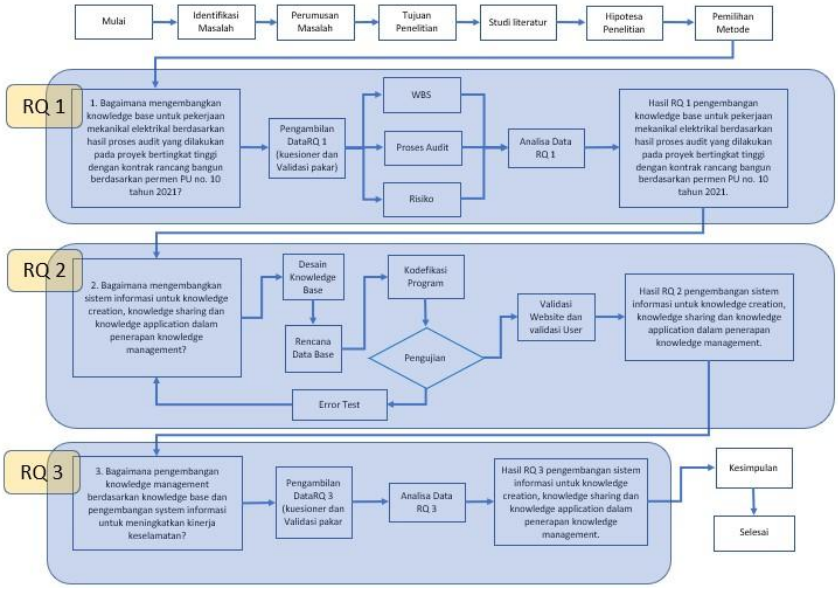


Figure 1. Research Process Flow Diagram
Source: Author's Processing (2022)

RESULTS AND DISCUSSION

Discussion of Research Question 1

Data Collection research Question 1 (RQ1)

Data collection to answer research questions (RQ1) by making WBS standards for mechanical electrical work in the design and build stage is carried out by collecting secondary data in the form of archive analysis from previous research and journals related to the bill of quantity (BoQ). The basis for selecting objects for BoQ includes:

1) The BoQ data was selected according to the object of the research, namely high-rise buildings, especially mechanical and electrical work components.
2) BoQ data is selected that is relevant to the latest developments on mechanical and electrical work
3) BoQ data is selected from a source of contractors experienced on mechanical and electrical work.

From the results of the collection of several archives of the ringgi multi-storey building project, it can be concluded that the mechanical and electrical work WBS consists of:

1) WBS level 1 : Project Name of High-Rise Building
2) WBS level 2 : Job Cluster
3) WBS Level 3: Job Type
4) WBS Level 4: Work Package
5) WBS Level 5: Activities

Discussion of Research Question 2

Data Collection Research Question 2

Data collection was carried out to answer Research Question 2, namely "How to develop an information system for knowledge sharing and knowledge application in the application of knowledge management? The research method used to answer this is using case studies. The data that has been collected includes:

1) There were 389 electrical mechanical work activities with design contracts, 26 risk causes, 12 impacts, 33 preventive actions and 22 corrective actions.
2) The construction safety plan in the construction safety performance audit process refers to the Minister of Public Works Regulation Number 10 of 2021.

From this data, the information system for knowledge sharing and knowledge application in the application of knowledge management is as follows:

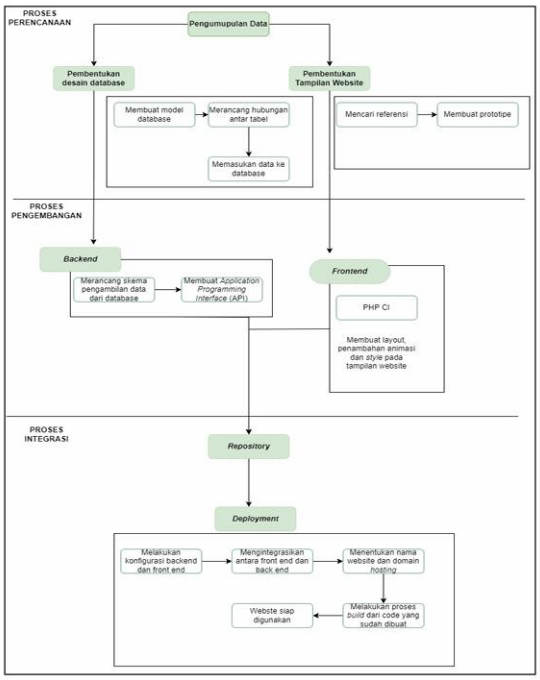


Figure 2. Systematics of the Development of RKK Knowledge Base Information System
Source: Author's Processing (2025)

To clarify the user case, it is explained in the information system illustration that will be used the use case diagram to visually describe the interaction between system users. (Lamar 2005). The image below is a user case diagram for the use of websites for knowledge sharing and knowledge application in the application of knowledge management.

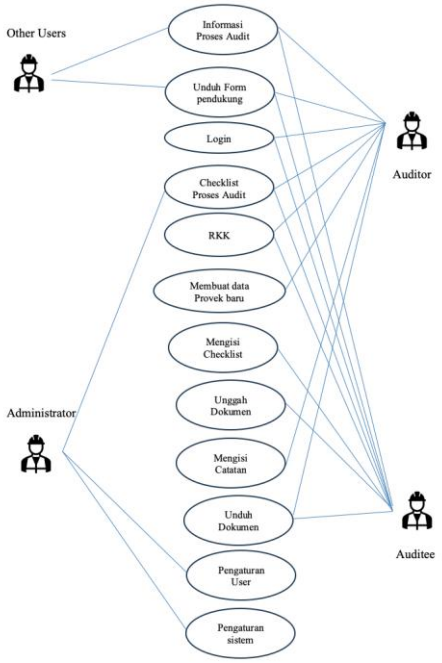


Figure 3. Use Case Diagram Website

Based on the diagram above, the administrator logs in and sets up the user and system settings on this website. Other users do not need to log in to access this site and access the audit process information and download the required form. Auditors and uditees go through the login process to be able to access certain menus. Auditees can carry out checklist activities for the audut process, rkk, create new project data, fill out the required forms. The access given to the auditor includes the audit process checklist, RKK, providing notes and downloading documents so as to provide an assessment of the documents input by the auditee.

In the development of this information system, the latest technology is used, namely PHP Codeigniter Framework, WordPress, MySql Database, Javascript Node, and Heroku. The first step starts with collecting the data needed by the Audit Process Knowledge Base information system and filling the data into the MySql database model. MySql is a Database Management System (DBMS) that is in the process of storing or changing data using SQL (Structured Query Language) commands. The data stored in the Audit Process Knowledge Base is a collection of information on work activities that are grouped based on the correlation between risk causes, impacts, preventive actions and corrective actions. The data is stored in the form of a table in the database with the following table relationships:

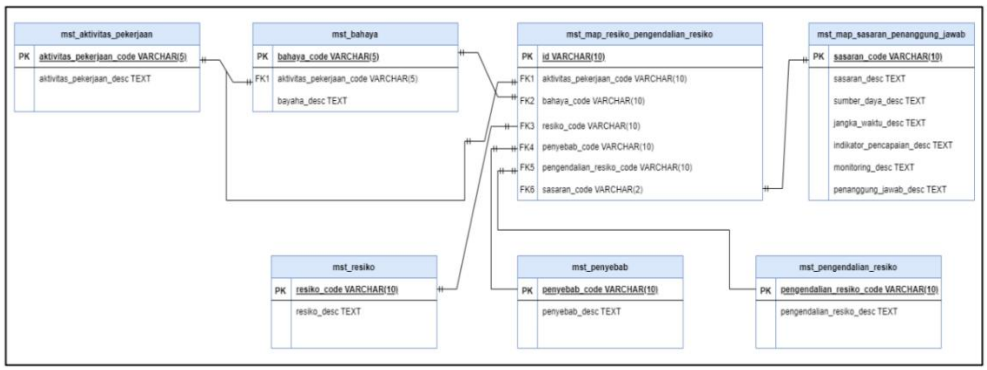


Figure 4. Database Design Knowledge Base Audit Process Information System
Source: Author's Processed Results (2025)

The database design is in the Audit Process Knowledge Base information system. The database design is divided into 6 main tables, namely mst_aktivitas_pekerjaan, mst_bahaya, mst_risiko, mst_penyebab, mst_pengendalian _risiko, mst_map_sasaran_penanggung_jawab tables. Of the six main tables, they will be mapped or normalized to mst_map_risiko_pengendalian_risiko table with the aim of making it easier to retrieve data using SQL commands.

Knowledge Base Information System for Mechanical and Electrical Work

Intranet website-based information system for the development of knowledge base knowledge management Audit Process of mechanical and electrical work of high-rise building projects with design contracts. This website is used for,

1) Obtain information on the audit process of mechanical and electrical work of high-rise building projects with design contracts linked to construction safety performance.
2) Guidance in the construction safety performance audit process on high-rise building projects with design contracts based on the Minister of Public Works Regulation Number 10 of 2021.
3) Facilities and guidelines to complete the completeness of the Construction Safety Plan documents in the checklist process and become the subject of document storage.
4) The repository of documents supporting the audit process is the report on the results of the evaluation of the safety performance of previous projects, ongoing processes and sample construction Safety Plan documents.

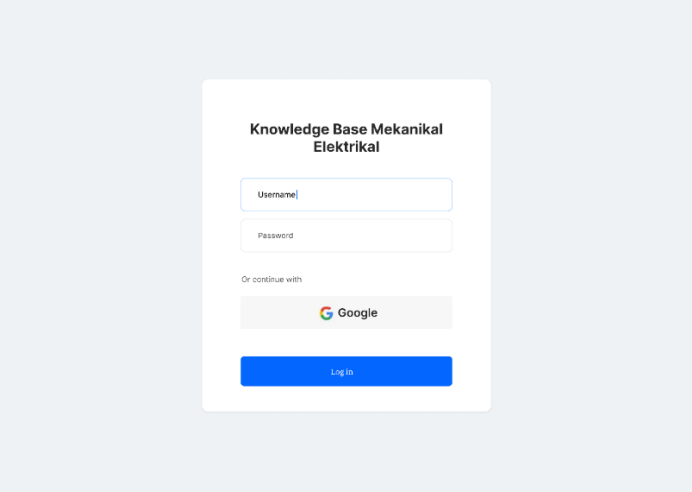


Figure 5. Login user
Source: Author's Processed Results (2025)

Users can access through the organization's intranet to help identify construction safety risks, objectives and programs from knowledge management process to mechanical and electrical work audit of high-rise building projects with design contracts. On the login page, users need to enter their username and login.

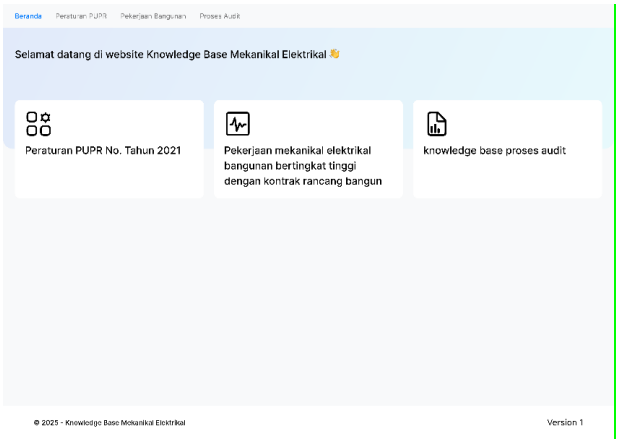


Figure 6. Home Page
Source: Author's Processed Results (2025)

On the home page, the Ministerial Regulation icon from PUPR Number 10 of 2021, Mechanical and electrical work of high-rise buildings with design contracts and knowledge bases for the audit process. Users can choose which page they want to access by clicking on the tab in question.

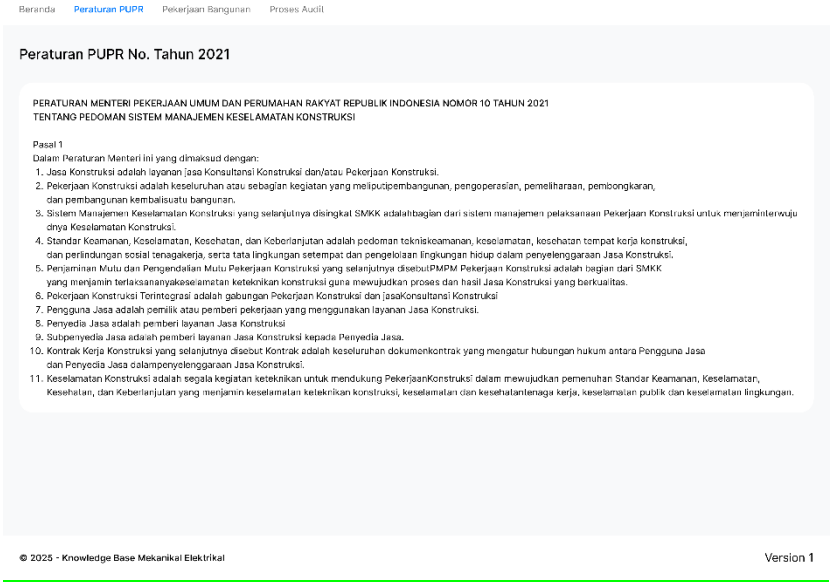


Figure 7. PUPR Regulation No. 10 of 2021
Source: Author's Processed Results (2025)

The PUPR Regulation No. 10 of 2021 icon displays the Ministerial Regulation on Guidelines for Construction Safety Management Systems which aims to provide guidelines for all related parties in the implementation of construction services, ensure the fulfillment of safety, safety, health and sustainability standards and improve the quality and effectiveness of construction management.

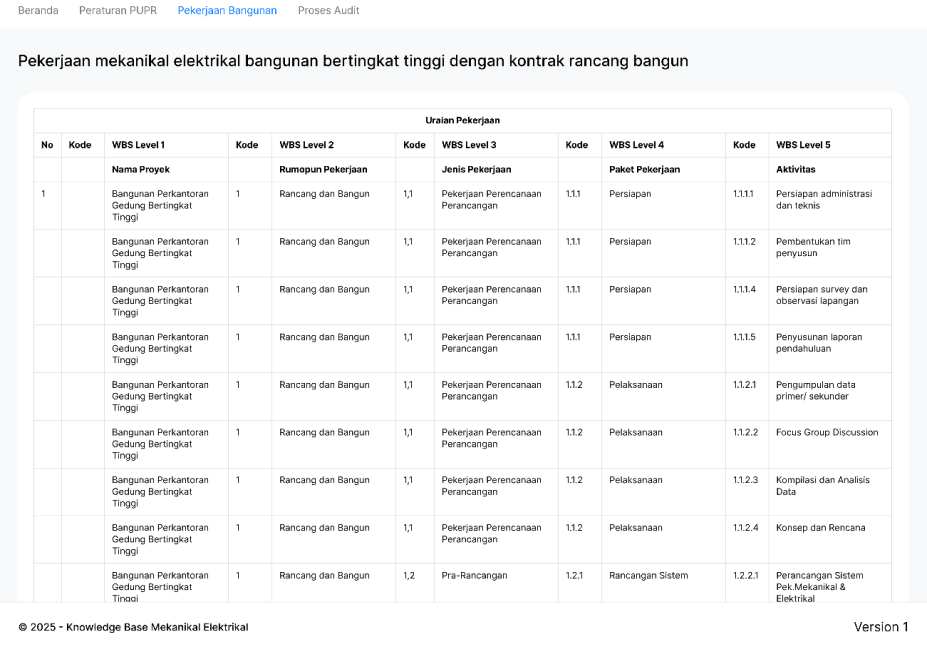


Figure 8. content of mechanical and electrical work of high-rise buildings with design contract
Source: Author's Processed Results (2025)

Mechanical and electrical work icons of high-rise buildings with design contracts featuring a work breakdown structure (WBS). Activities are identified based on level 1 to level 5.

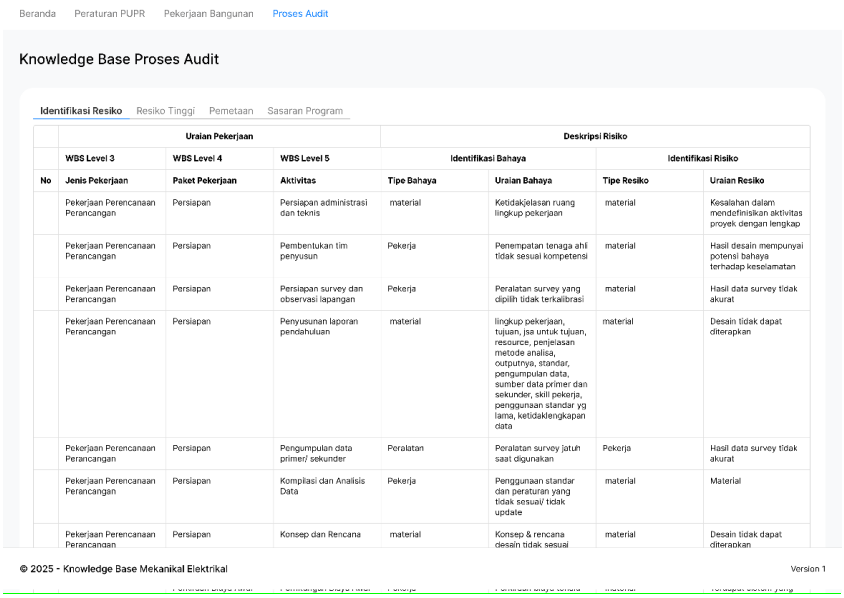


Figure 9. Identification of Hazards and Risks of Work Activities
Source: Author's Processed Results (2025)

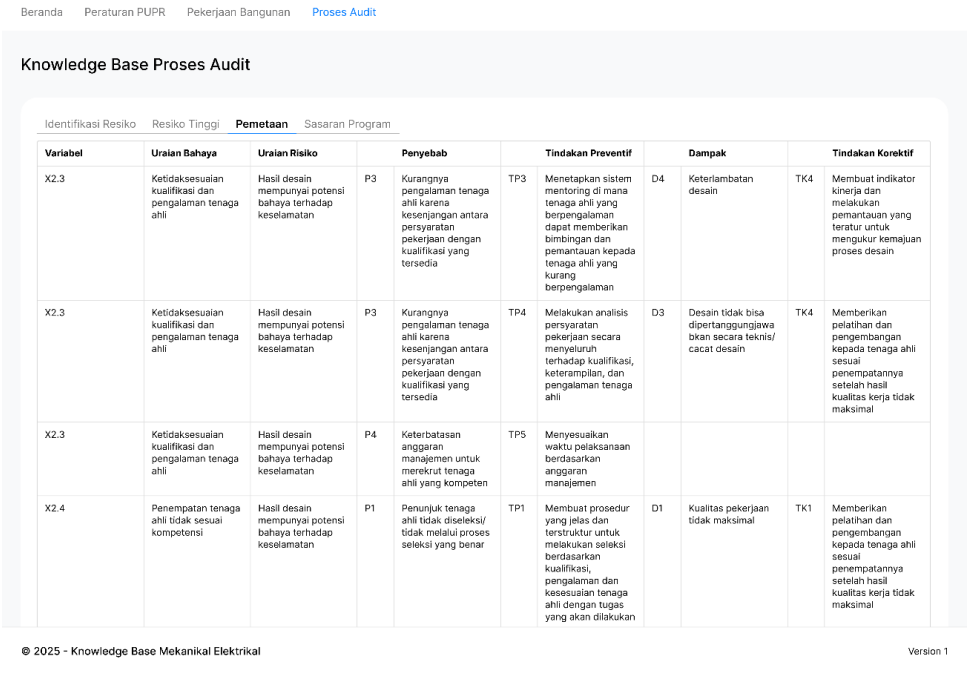
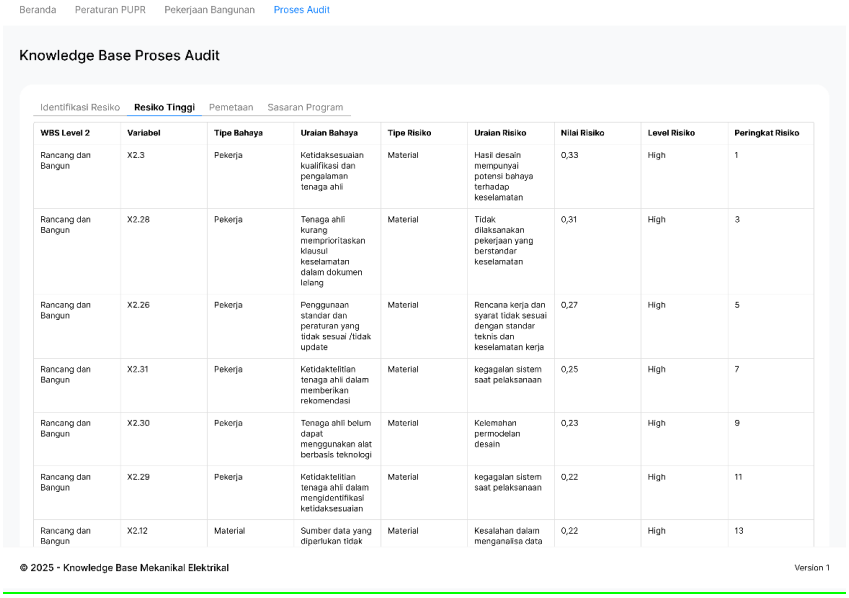


Figure 10. Mapping of Hazards, Risks, Causes, Preventive and Corrective Actions
Source: Author's Processed Results (2025)



Beranda Peraturan PUPR Pekerjaan Bangunan Proses Audit

Knowledge Base Proses Audit

Identifikasi Resiko **Resiko Tinggi** Pemetaan Sasaran Program

WBS Level 2	Variabel	Tipe Bahaya	Uraian Bahaya	Tipe Risiko	Uraian Risiko	Nilai Risiko	Level Risiko	Peringkat Risiko
Rancang dan Bangun	X2.3	Pekerja	Ketidaksesuaian kualifikasi dan pengalaman tenaga ahli	Material	Hasil desain mempunyai potensi bahaya terhadap keselamatan	0,33	High	1
Rancang dan Bangun	X2.28	Pekerja	Tenaga ahli kurang memprioritaskan klausul keselamatan dalam dokumen lelang	Material	Tidak dilaksanakan pekerjaan yang berstandar keselamatan	0,31	High	3
Rancang dan Bangun	X2.26	Pekerja	Penggunaan standar dan peraturan yang tidak sesuai /tidak update	Material	Rencana kerja dan syarat tidak sesuai dengan standar teknis dan keselamatan kerja	0,27	High	5
Rancang dan Bangun	X2.31	Pekerja	Ketidaktelitian tenaga ahli dalam memberikan rekomendasi	Material	kegagalan sistem saat pelaksanaan	0,25	High	7
Rancang dan Bangun	X2.30	Pekerja	Tenaga ahli belum dapat menggunakan alat berbasis teknologi	Material	Kelemahan permodelan desain	0,23	High	9
Rancang dan Bangun	X2.29	Pekerja	Ketidaktelitian tenaga ahli dalam mengidentifikasi ketidaksesuaian	Material	kegagalan sistem saat pelaksanaan	0,22	High	11
Rancang dan Bangun	X2.12	Material	Sumber data yang diperlukan tidak	Material	Kesalahan dalam menganalisa data	0,22	High	13

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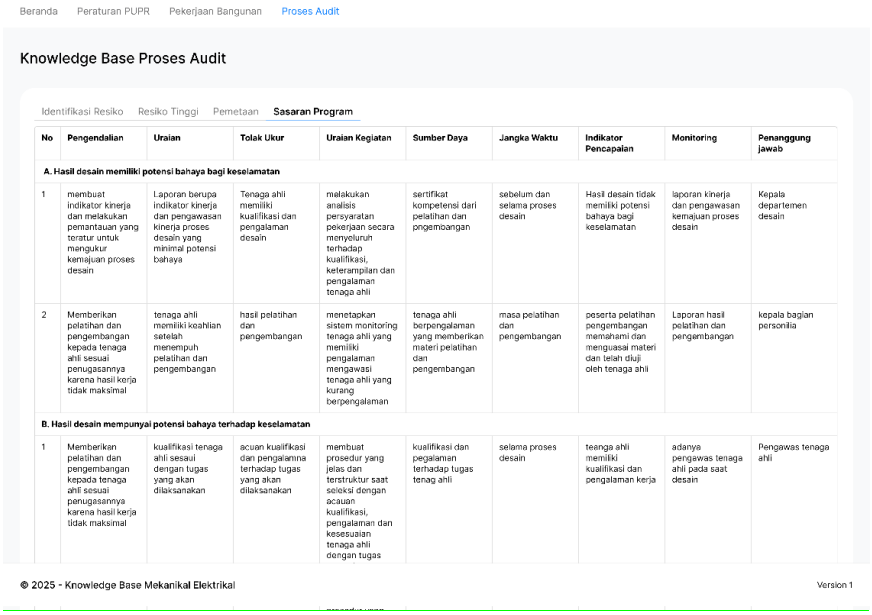
Figure 11. Mapping of Hazards, Risks, Causes, Preventive and Corrective Actions
Source: Author's Processed Results (2025)



Beranda Peraturan PUPR Pekerjaan Bangunan Proses Audit

Knowledge Base Proses Audit

Identifikasi Resiko Resiko Tinggi Pemetaan **Sasaran Program**

No	Pengendalian	Uraian	Tolak Ukur	Uraian Kegiatan	Sumber Daya	Jangka Waktu	Indikator Pencapaian	Monitoring	Penanggung jawab
A. Hasil desain memiliki potensi bahaya bagi keselamatan									
1	membuat indikator kinerja dan melakukan pemantauan yang teratur untuk mengukur kemajuan proses desain	Laporan berupa indikator kinerja dan pengawasan kinerja proses desain yang minimal potensi bahaya	Tenaga ahli memiliki kualifikasi dan pengalaman desain	melakukan analisis persyaratan pekerjaan secara menyeluruh terhadap kualifikasi, keterampilan dan pengalaman tenaga ahli	sertifikat kompetensi dari pelatihan dan pngemoangan	sebelum dan selama proses desain	Hasil desain tidak memiliki potensi bahaya bagi keselamatan	laporan kinerja dan pengawasan kemajuan proses desain	Kepala departemen desain
2	Memberikan pelatihan dan pengembangan kepada tenaga ahli sesuai penugasannya karena hasil kerja tidak maksimal	tenaga ahli memiliki keahlian setelah menempuh pelatihan dan pengembangan	hasil pelatihan dan pengembangan	menetapkan sistem monitoring tenaga ahli yang memiliki pengalaman mengawasi tenaga ahli yang kurang berpengalaman	tenaga ahli berpengalaman yang memberikan materi pelatihan dan pengembangan	masa pelatihan dan pengembangan	peserta pelatihan pengembangan memahami dan menguasai materi dan telah diuji oleh tenaga ahli	Laporan hasil pelatihan dan pengambangan	kepala bagian personilia
B. Hasil desain mempunyai potensi bahaya terhadap keselamatan									
1	Memberikan pelatihan dan pengembangan kepada tenaga ahli sesuai penugasannya karena hasil kerja tidak maksimal	kualifikasi tenaga ahli sesuai dengan tugas yang akan dilaksanakan	acuan kualifikasi dan pengalamna terhadap tugas yang akan dilaksanakan	membuat prosedur yang jelas dan terstruktur saat seleksi dengan acauan kualifikasi, pengalaman dan kesesuaian tenaga ahli dengan tugas	kualifikasi dan pegalaman terhadap tugas tenag ahli	selama proses desain	teanga ahli memiliki kualifikasi dan pengalaman kerja	adanya pengawas tenaga ahli pada saat desain	Pengawas tenaga ahli

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Figure 12. Audit Process Objectives and Knowledge Base Programs
Source: Author's Processed Results (2025)

Data collection of Research Question 2

Data collection at this stage is by validating the development of information systems for knowledge sharing and knowledge application in the implementation of knowledge management process Audit of mechanical and electrical work of high-rise buildings with design contracts based on the Minister of Public Works Regulation No. 10 of 2021. Five experts with expert criteria who are experienced in the field of construction, mechanical and electrical work of high-rise buildings with design contracts.

Table 1 Expert Profile for WBS Questionnaire Validation of the Integrated Design and Construction Contract Design Contract Validation on Mechanical and Electrical Work of High-Rise Buildings

Table 1. Results of the Expert Validation Recapitulation Research Question 2

No	Expert Code	Final Education	Company	Work Experience	Position
1	P1	S2	PT Adhi Karya	27 years old	HES Manager
2	P2	S2	PT PP	30 years	Project Manager
3	P3	S1	PT PP	18 years old	MEP Members
4	P4	S2	PT Nindya Karya	22 years old	Engineering Manager
5	P5	S2	PT Total Bangun Persada	28 years old	Project Manager

Source: Author's Processing (2025)

From the results of the above expert validation, it is concluded that the development of information systems for knowledge sharing and knowledge application provides a positive impact on the knowledge management of the mechanical and electrical work audit process of high-rise buildings with design contracts.

RQ 3 Data Collection and Analysis

RQ Questionnaire Data Collection 3

Through literature studies and previous research, knowledge management indicators related to construction safety performance were obtained. This indicator is validated by experts through a survey method (questionnaire). The following are the profiles of the five profiles of experts who provide their expertise in this research stage.

Table 2. RQ Questionnaire Expert Profile 3

No.	Expert Code	Final Education	Company	Work Experience	Position
1	P1	S2	PT Adhi Karya	27 years old	HES Manager
2	P2	S2	PT PP	30 years	Project Manager
3	P3	S1	PT PP	18 years old	MEP Members
4	P4	S2	PT Nindya Karya	22 years old	Engineering Manager
5	P5	S2	PT Total Bangun Persada	28 years old	Project Manager

Source: Author's Processing (2025)

To validate the knowledge management indicators, whether the activity is included in the knowledge management audit process and affects the performance of construction safety. The results of the questionnaire from the experts were collected and then analyzed from the experts' answers in the recapitulation of indicators for the application of knowledge management to improve construction safety performance.

Data Analysis

Data analysis was carried out related to validation by experts of knowledge management indicators of the Audit Process of mechanical and electrical work based on website information systems. The analysis method used is the Delphi method, which is the process of gathering the opinions of experts related to certain topics. The goal is to obtain the most reliable mutual consensus from experts. Five experts provide answers with conclusions from each topic. Conclusions are drawn in other ways, among others,

1) The answer to the indicator if more than half of the total experts agree.
2) Summarize the responses and improvements provided from experts.
3) The indicator is reduced if more than half of the total experts disagree or the expert considers it irrelevant.

Based on the results of the recapitulation of table 3 above, the conclusions of the experts agree with the indicators presented. However, experts disagree with the indicator "X3.1.3.1 Information related to construction safety (nearmiss, accident, incident, etc) that is old and unused is discarded or deleted". Experts consider that information related to construction safety that is old and unused should not be discarded or deleted. In fact, the information becomes a knowledge base for construction safety information that must be documented and prevented from happening again in the future.

Findings and Discussion of Research Question RQ 1 (RQ1)

To answer the formulation of the first problem, namely how to develop a knowledge base for electrical mechanical work based on the results of the audit process carried out on high-rise projects with a design contract based on the Ministry of Public Works no. 10 of 2021 is carried out by analyzing archives in the form of previous research on work break structure (WBS) mechanical and electrical work of high-rise buildings. Then the WBS is validated to experts in the form of interviews and questionnaires who have expertise in the design and construction phases of mechanical and electrical work. From these results, 5 levels of WBS were obtained and activities with risk categories were analyzed based on four aspects in the Regulation of the Minister of Public Works and Public Housing Number 10 of 2021 concerning Guidelines for Construction Safety Management Systems. The four aspects of risk are the risk of workers, equipment, materials, and the environment.

Through literature studies and discussions with 5 (five) experts, there is one variable that is not used, namely X2.1 because the validation results of 4 out of 5 experts' risk of the design process being hampered do not affect the performance of construction safety, so there are 388 variables that will be continued to the respondent survey stage.

The following is a discussion of the highest risks, goals and programs of mechanical and electrical work that affect construction safety performance.

1) The danger of placing experts is not in accordance with competence so that the risk of design results has a potential danger to safety. These dangers and risks management is not able to place well-performing experts in the design process. Management must be aware of the increase in organizational productivity and awareness of the importance of safety performance at the time of selection of competent personnel (Moon, 2018).
2) The hazard of incompatibility, qualifications, and expert experience risks potential safety hazards. Accidents tend to occur due to a lack of competence, knowledge and skills of human resources in the work area (Asibey, 2021).
3) The danger of experts who are not aware of safety standards in analyzing auction documents. From the Tymvios survey, 41.4% of planners revealed that the contract system does not require planners to pay attention to the safety of workers in the work area. The ability of planners to understand the rules and standards on the leleng can change the mindset of planners and create a sense of responsibility for construction safety (Morrow, 2015)
4) The danger of using standards and rules is not up-to-date, where the risk arises when the work plan and requirements are not in accordance with technical standards and occupational safety. Saunders (2016) in his research found that safety decisions are determined at the beginning of the planning stage with the aim of being responsible for construction safety. To increase the sense of responsibility, this is a commitment from experienced stakeholders where the culture of implementation of safety design regulations is better so as to provide a further understanding of the latest standards and rules (Jin, 2022).
5) The danger of drawings is not in accordance with applicable standards and regulations, where the risk arises is that the design is not workable and unsafe. According to Manu (2019), safety practices at the time of design are slightly applied to prepare the drawings for the identification of significant hazards that the contractor may not understand. For example, work drawings that do not take into account the area for worker access, sufficient ventilation, protection against electrical hazards, distance to pipe laying to avoid risks to workers.
6) The danger of leakage in pipe connections, where the risk is damage to electronic and electrical equipment. The results of discussions with experts that leaks in pipe connections resulted in water or other fluids affecting electronic and electrical equipment, namely electrical panels and control panels. Uncontrolled and unexpected electrical current interference results in damage to electronic and electrical equipment and the risk of accidents. Water exposure can reduce the service life of the equipment, the performance decreases, that it is permanently damaged.
7) The danger of inaccuracy of experts in providing recommendations is the risk of system failure during implementation. Experts give input if experts do not provide accurate recommendations, resulting in system failures during project implementation. For example, experts do not calculate

the electrical load on the additional system, as a result of which the installed electrical system is overloaded with electricity, resulting in system failure, power outages and permanent damage.

8) The danger of leakage of pipe connections that risks a short circuit of the electrical circuit. Expert experience, leaking pipes at the electrical circuit connection cause an electrical short circuit hazard. Short circuits due to water cause sparks and fires. Pipe installation is carried out accurately and precisely so that leaking pipes can be prevented.
9) Experts who cannot use technology-based work tools (BIM, Virtual Reality, etc.) are at risk of design modeling weaknesses. Jin (2025), stated that the results of the analysis of 39 references stated that construction technology was able to overcome and control risks at the beginning of the project. BIM helps in identifying, assessing and controlling construction safety hazards during design. However, there is a gap in the use of BIM so it is necessary to carry out wider education and socialization of construction suit actors to optimize construction safety performance from the beginning of the project.
10) The danger of workers being electrocuted, at risk of death. Health Act (2002) research states that some electrical accidents are caused by failure to turn off the electrical system, maintain a safe distance, improper use of personal protective equipment (PPE), damaged materials, improper grounding and unsafe work areas such as wet areas, confined spaces and strong winds.
11) The danger of inaccuracy of experts in identifying non-conformities, be system failures during implementation. According to experts, inaccuracies in identifying discrepancies result in inaccurate specifications, inaccurate plans or incorrect components. In addition, it results in misconfiguration, poor connections and lack of protection for lcitric hazards.
12) The danger of using standards and regulations that are not in accordance / not updated, there is a risk that the resulting specifications do not meet safety standards. Experts give input, mechanical and electrical work needs coordination and integration between different systems and there is a potential for serious danger, for example an electrical short circuit. If the standards used are not compliant, it results in inadequate and unsafe specifications during system installation, even construction accidents.
13) The danger of the required data source is incomplete or inaccurate, risking errors in analyzing the data. Expert validation, insufficient or inaccurate data results in errors in analyzing mechanical and electrical installation systems so that it negatively impacts the reliability and safety of the system to equipment failure, the risk of electrical short circuits, pipe leaks and fires. Mechanical and electrical work requires coordination and integration of various other skills such as architects, architects.
14) The danger of mistake choosing a safe and reliable material is the risk of system failure. In Manu's (2019) study, the least planning practice is to determine the materials with the least potential hazards. Amiri (2017) examines poor material quality, the use of toxic and flammable materials and poor safety conditions. Experts assess that the selection of safe and reliable materials reduces the risk of work accidents, for example, the selection of cables that suit the needs to prevent possible electrical short circuits and fires.
15) Sparks from work tools that hit flammable materials are at risk of fire. The welding activity generates light and steam as well as sparks. These sparks when they hit flammable materials cause fires and explosions (Smaranda, 2021). Experts assess that sparks hitting flammable materials are difficult to control, tend to spread quickly and fire extinguishing efforts become difficult. Uncontrolled and fast-spreading fires damage buildings, equipment and other valuable assets, serious injuries and even death when caught in a fire.
16) Being hit by material that falls when it is moved is at risk of death. Experts assess that falling materials occur quickly and without warning, making the opportunity to avoid and protect themselves limited. If workers do not use PPE such as protective helmets and safety shoes, they are at risk of serious injury or death. Wrong use of lifting equipment such as tower cranes or crane cars, is the cause of sudden material falls.

Findings and Discussion of Research Question 2 (RQ2)

The discussion of research Question 2 is the development of information systems for knowledge sharing and knowledge application in the application of knowledge management of the audit process of mechanical and electrical work of high-level buildings with design contracts. Data from RQ

1 becomes inputs such as high-risk tables to goals and programs that have been validated by experts are included in the information system. The benefits of using website-based information on the development of the audit process can be shared among stakeholders and applied to the audit process. Intranet website-based information system Where it can be accessed by members of the organization who have the appropriate permissions and credentials (Nonaka et al., 2014; Park & Lee, 2014; PUPR, 2020; Wang & Noe, 2010; Zou et al., 2017).

The results of expert validation allow information systems to be useful for the implementation of construction safety management systems. The innovation system helps solve construction safety problems in the sharing of knowledge related to safety plans and preventive and corrective follow-up. The information system has a positive impact on the smooth running of the project and prevents work accidents because stakeholders become aware and vigilant. Another benefit is that the information stored becomes a reference for work and stakeholders can access it quickly.

Yiu (2019) stated that organizations that implement construction safety management systems have better hazard control so as to prevent work accidents. The results of the expert evaluation, in the aspect of operating the information system provide ease of use, understanding of the output of the information produced, the suitability of inputs, processes and outputs. The system's response to the user's needs is considered good. The aspect of the layout of the content and features is easy to understand, the selection of design and composition used is considered good.

The validation results prove the hypothesis that the implementation of the audit process using the mechanical and electrical work information system of high-rise buildings with design contracts improves construction safety performance. Previous research stated that information systems that use WBS-based can improve construction safety performance (Pangastuti, 2021).

Findings and Discussion of Research Question 3 (RQ3)

The results of expert validation stated that one indicator that was considered to have no effect on improving construction performance, namely indicator X3.1.3.1 Information related to construction safety (nearmiss, accident, incident, etc) that has been around for a long time and is not used is discarded or deleted. Experts consider that information related to construction safety that is old and unused should not be discarded or deleted. In fact, the information becomes a knowledge base for construction safety information that must be documented and prevented from happening again in the future.

Carol (2014), that construction safety management has the potential to improve construction safety performance by sharing knowledge. Knowledge management is developed into an invasive method in order to switch from traditional to digital ways of managing archives and information so that organizational management implements better workflows (Abusweilem, 2019).

Hypothesis Proof

The results of the findings and discussions of RQ 1, RQ 2 and RQ 3 can be proven that the development of the mechanical and electrical work audit process at the WBS stage, high risk, hazard and risk mapping, goals and programs, information systems and knowledge management have a positive impact on construction safety performance.

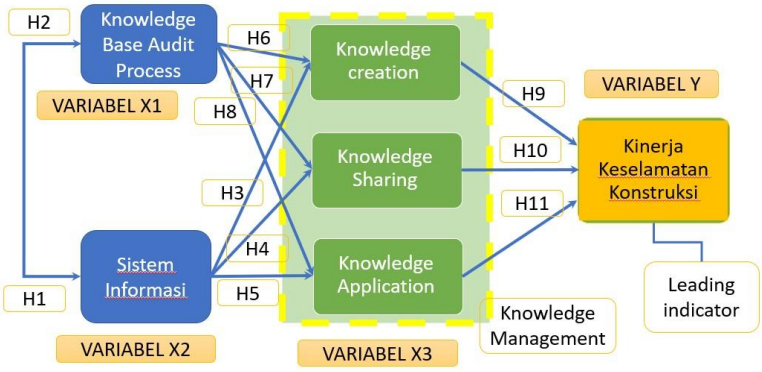

Figure 13. Proof of Hypothesis
Source: Author's Processing (2025)

CONCLUSION

The research concluded that 389 activities related to mechanical and electrical (M&E) works in high-rise building projects with Design and Build contracts influenced construction safety, with 16 identified as high-risk variables requiring priority attention. Through expert validation, risks were analyzed in terms of causes, impacts, preventive measures, and corrective actions, supporting the development of a risk-based work breakdown structure (WBS). Findings emphasized that preventive and corrective strategies, when combined with knowledge management practices—particularly information systems for knowledge sharing and application—can significantly improve safety performance. The study also highlighted the need to transition from traditional methods to digital systems for managing knowledge and archives, thereby enhancing workflow efficiency. Future research should focus on testing and implementing digital knowledge management systems in real construction projects to evaluate their effectiveness in reducing high-risk variables and improving safety outcomes.

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