International Journal of Engineering Trends and Technology
ISSN: 2231–5381 / https://doi.org/10.14445/22315381/IJETT-V71I8P210

Volume 71 Issue 8, 119-130, August 2023
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Original Article

Development of Risk-based Work Breakdown Structure (WBS) Standards for Integrated Design and Construction Phase on Design-Build Contract of Mechanical and Electrical Works of High-Rise Building to Improve Construction Safety Performance

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Received: 23 May 2023 Revised: 20 June 2023 Accepted: 22 July 2023 Published: 15 August 2023

Abstract *- Occupational accidents in the construction sector in Indonesia occupy the highest national ranking compared to other industries. Accidents in the construction industry frequently result from mechanical and electrical work. The technological advancements in the mechanical and electrical industries are among the quickest. Because of this, safety in construction should get special consideration. Identifying risks as early as feasible during the design phase is crucial for preventing construction accidents. However, risk analysis is not structured during development, so it only accounts for some risks requiring special attention. To produce a structured inventory of risks, a Work Breakdown Structure (WBS) is used to identify risks. The Work Breakdown Structure (WBS) standard will be the primary input for identifying risks related to employees, equipment, materials, and the environment/public during the design and construction phase. This research provides valuable insight into the main elements that contribute to safety risk through a systematic risk analysis. This study employs a literature review, expert consultation, and qualitative risk analysis to identify the most significant risks and their associated causes, effects, and preventive and corrective actions. This research contributes to the existing body of knowledge by offering a comprehensive understanding of the conception of risk-based WBS standards that integrate design and construction phases. The research findings emphasize the significance of management in improving construction safety performance. Management is responsible for developing explicit and standardized safety policies and procedures.*

Keywords *- Construction safety performance, Design-build, Mechanical and electrical, risk, Work breakdown structure.*

1. Introduction

The construction industry has recorded the highest accident rates of other sectors worldwide. The UK Health and Safety Executive (HSE) estimates that those working on construction sites have a one in three hundred chance of perishing at work as a result of safety negligence [1]. Comparing all industries in Indonesia, the construction industry has the highest national rate of work accidents, which is continuously rising. Based on data from the Indonesian Employment Social Security Administration Agency, the number of work accidents increased from 2017-2021, amounting to 111,230 people. The International Labor Organization (ILO) reports that in 2018, Indonesia and the rest of Southeast Asia accounted for two-thirds of all workplace accidents globally. Mechanical and electrical work are among the construction-related activity that contributes to the most construction accidents [2], resulting in about 17% of fatalities from electric shock [3]. In South Korea, the third highest number of accidents is mechanical and electrical construction work, with the most common accidents being falls, fires, and explosions [25]. In Taiwan, fatal accidents due to electrical work accounted for 14.6% of the total cases, which gave the second position under accidents due to falls from heights, namely 30% [5]. The high rate of construction accidents has many negative consequences. At the micro level, construction accidents result in project delays, excess costs, wasted opportunities, and a negative impact on human safety. It will impact the performance of construction service providers and their legal obligations at the meso level. It impacts national productivity, competitiveness, and business loss costs at the macro level. [6]. To prevent construction accidents, it is necessary to determine their root causes [7]. Several previous studies have demonstrated that the design phase significantly

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impacts the construction site's safety performance [8] [9] [10]. For example, 44% of construction fatalities in Australia are design-related [11]. Another study revealed that 42% of 224 cases of construction-related fatalities were attributable to the design of the construction safety concept [12]. Other researchers discovered that, out of 100 accidents in the United Kingdom, nearly fifty percent involved design-related hazards [13]. This demonstrates that construction safety must be a primary concern during the conceptual design phase because it can potentially significantly impact safety [14] [16] [26]. In fact, 60% of construction fatalities can be reduced, avoided, or even eliminated, according to a European foundation study [17]. Accidents in the construction industry involve contractors and designers, as they play a crucial role in minimizing the risk of accidents [18]. Eliminating risk during the design phase is the key to preventing accidents, increasing productivity, and rectifying design flaws. The application of hazard identification, risk assessment, and risk management is the primary principle of secure design [19]. In risk assessment, generating a categorized inventory of potential threats is essential. This makes it simpler for management to identify job risks requiring special attention and prevents risks from being missed.

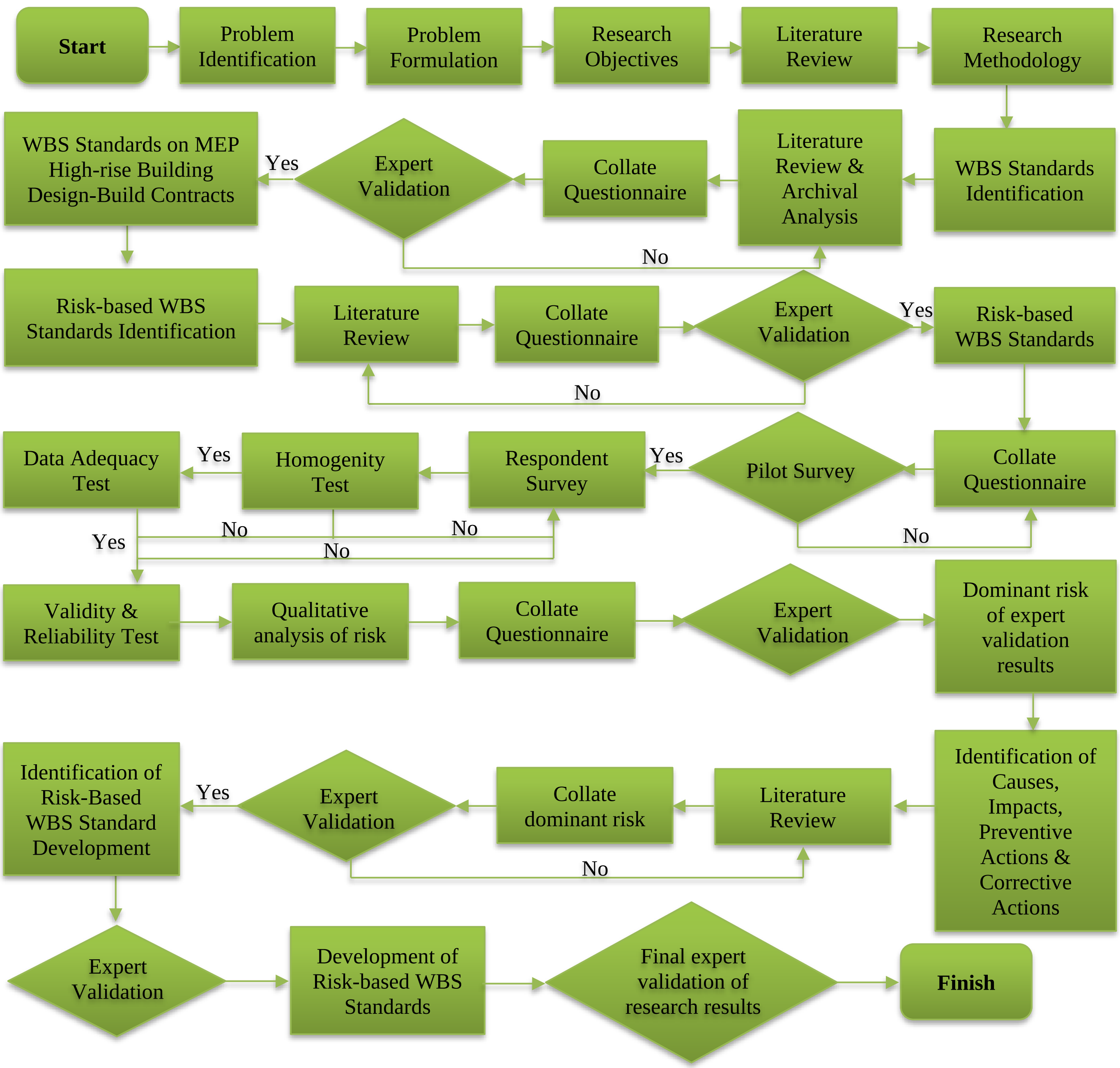

Fig. 1 Research stages flowchart

Using WBS, an exemplary structure for risk management has been proposed [20]. The Work Breakdown Structure specifies and assigns project tasks to the appropriate level. Each level of the determined Work Breakdown Structure (WBS) leads to a more complex level, namely activity, where it is simpler to identify potential hazards and risks [21]. Work Breakdown Structure (WBS) is an effective communication instrument for stakeholders to comprehend the project's scope and identify potential risks and hazards [27]. The Minister of Public Works and Public Housing of Indonesia's Regulation Number 10 of 2021 specifies that implementing the Hazard Identification Risk Assessment Opportunity is based on WBS stages. Previous research has identified several hazards associated with the WBS, but only during the development phase. Even though it has been explained that the design phase is an essential task that affects the high risk of construction accidents, the design phase is still one of the most frequently overlooked phases. This research contributes to developing a Work Breakdown Structure (WBS) that integrates into design and construction work, making it simpler to identify potential risks. In addition, this research will implement risk management by analyzing corrective and preventive actions to reduce the causes and effects of risk exposure. The development of a risk-based WBS (Work Breakdown Structure) standard that can be used to enhance construction safety performance for mechanical and electrical work in high-rise buildings will be based on preventive actions.

2. Methodology

Research Methodology is an essential study component, defining the strategy and procedures used to collect and analyze data. This chapter describes in detail the methods used in this study to answer research questions and accomplish the stated objectives, depicted in Figure 1.

This study identifies WBS standards by reviewing the relevant literature and examining relevant archives. Literature is derived from periodicals with comparable subject matter. Bill of Quantities (BoQ), Budget Plans, Work Plans and Requirements, and Work Unit Price Analysis of examples of mechanical and electrical work of high-rise buildings integrated with an engineering contract provide the basis for archival analysis. Five experts were surveyed to validate the literature review and archive analysis outcomes. Experts were chosen based on their knowledge of the mechanical and electrical industries. They must have a minimum of 10 years of experience. After validating the WBS standard, the next stage is identifying risks based on activity at level 6 of the WBS by conducting a literature review. Workers, equipment, materials, and the environment/public are used to classify risks. Five experts validate the risk before conducting a pilot and survey of respondents. Respondents were chosen based on their mechanical-electrical expertise. They must have experience exceeding five years. Ten individuals responded to the pilot survey questionnaire regarding the ease of understanding hazards. Uncomprehensible risks will be rectified. The respondent survey was administered after the pilot survey. Using a Likert scale, thirty respondents completed the questionnaire. Respondents were asked to rate each risk's frequency and impact. Tables 1 and 2 show the ratings for frequency and impact rating.

Table 1. Frequency rating

Frequency Criteria	Rating
Never	1
Rarely	2
Sometimes	3
Often	4
Always	5

Table 2. Impact rating

Impact Criteria	Rating
Very low	1
Low	2
Moderate	3
High	4
Very High	5

The results of the questionnaire were analyzed statistically using the SPSS program. This study employs the tests of homogeneity, data sufficiency, validity, and reliability. In addition, a qualitative risk analysis is conducted to assess the risk's frequency of occurrence and its potential impact. The homogeneity test determines if the sample data group originates from a population with the same variance [23]. Risk variables that are not homogeneous will not advance to the next stage.

The data adequacy test determines whether sufficient data has been collected—the validity test measures what ought to be measured. If the risk variable is legitimate, the test of its reliability will continue. The Reliability Test determines the reliability, accuracy, thoroughness, and consistency of the questionnaire's indicators [23]. Qualitative risk analysis utilizes the PMBOK Guide 6th Edition to determine the risk factor value by multiplying the average frequency value with the average impact value for each risk factor so that the risk level can be calculated as follows:

- Low risk : 0.01 - 0.05
- Moderate risk : 0.06 - 0.14
- High risk : 0.15 - 0.72

Based on a literature analysis and validation with five experts, high risk will be examined for causes, impacts, and preventative and corrective actions. Several preventive actions will become recommendations for developing a risk-based WBS standard.

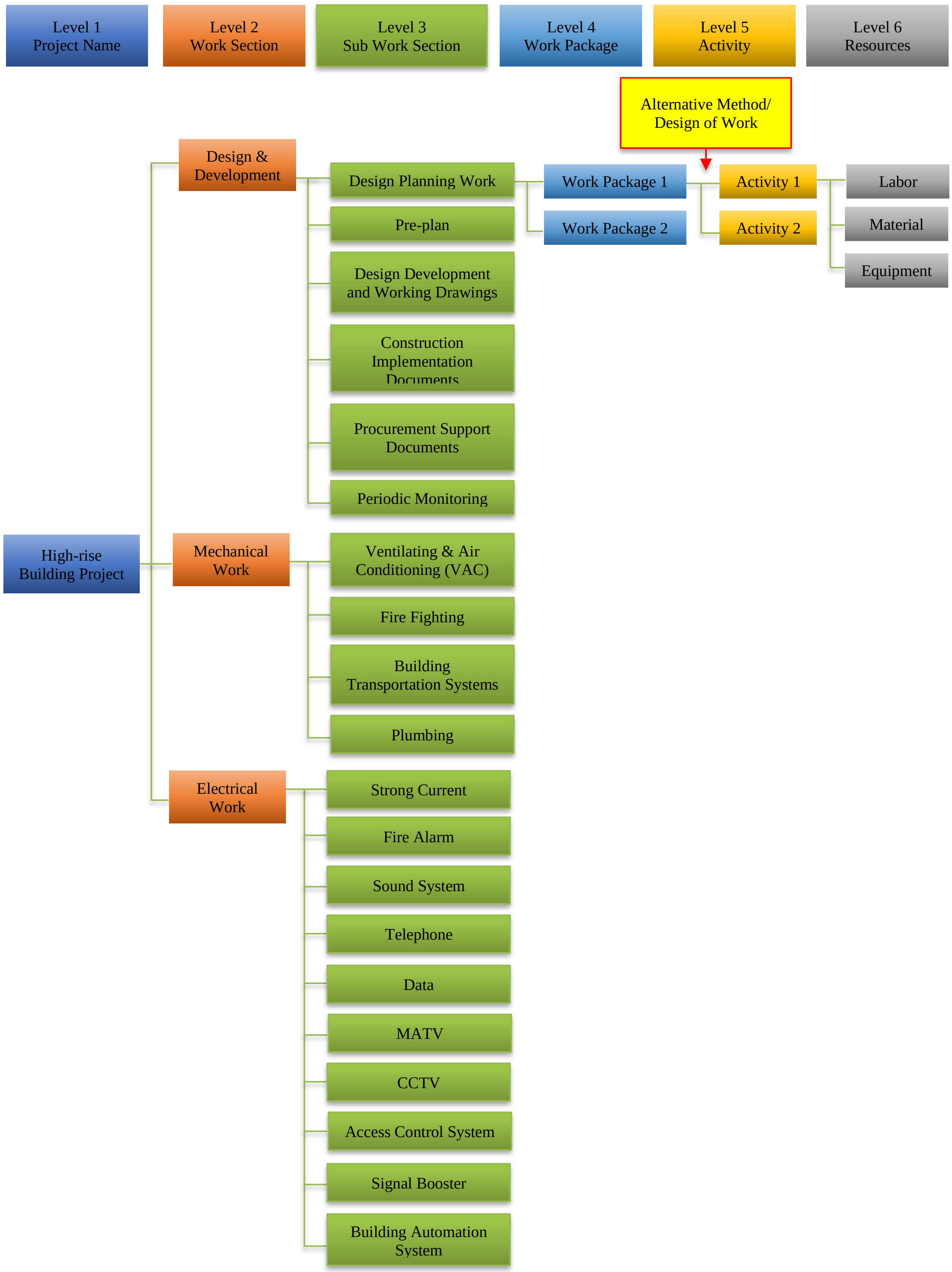

Fig. 2 Diagram tree of WBS standards

3. Results and Discussion

3.1. Standards Work Breakdown Structure (WBS)

The standard WBS derived from the results of expert validation is depicted in Figure 2 as a tree diagram. A tree diagram describes work in greater detail so stakeholders can comprehend project components from the highest to the lowest.

The work breakdown structure (WBS) level groupings that can be mapped into this structure are as follows [24]:

- Level 1 is the identification of the project name.
- Level 2 is the work section. These are more compact project components that, when combined, will create project construction.
- Level 3 identifies work section groupings, which are referred to as sub-work sections.
- Level 4 is a work package. This is the level at which each work package's performance can be assigned to an individual or organization.
- Alternative methods/designs of work are not part of the WBS level, but they are necessary for the compilation of WBS standards because they can detail work activities.
- Level 5 is activity, which outlines the actions necessary to complete a task package.
- Level 6 is resources, the lowest level in the WBS structure consisting of labour, materials, and equipment.

The standard WBS distinction between design-build contracts and conventional contracts is the inclusion of a design and development work group at WBS level 2. The design & development work group has six sub-work sections: design planning, pre-plan, design development and working drawings, construction implementation documents, procurement support documents, and periodic monitoring.

3.2. High Risks to Construction Safety Performance

Based on each level 5 WBS activity, risks are identified. Risk comprises worker, equipment, material, and environmental/public factors. To determine the level of risk, a qualitative risk analysis was performed. There are 388 risks, which are reduced to 16 high risks in Table 3. There were discovered to be ten high risks during the design phase and six during the construction phase. The study demonstrates that elevated risk is more significant upstream or at the beginning of a project. This confirms Szymberski's hypothesis that the risk of construction accidents begins with the design phase and significantly impacts construction safety [14]. Other studies have also shown that if safety is considered during the design phase, risks will be eliminated or minimized during construction [12]. This study's findings highlight interventions that can be implemented to enhance construction safety so that risks can be anticipated entirely.

Table 3. High risk to construction safety performance

Work Section	Code	Hazard Description	Risk Description
Design & Development	X2.4	The allocation of specialists does not correspond with their qualifications.	The design outcomes constitute a potential safety hazard.
	X2.3	Incompatibility of experts' qualifications and experience.	The design outcomes constitute a potential safety hazard.
	X2.28	Experts do not prioritize safety clauses in bidding documents.	Safety standards are not carried out.
	X2.26	Use of outdated/inappropriate standards and regulations.	The job plan and requirements violate technical and safety norms.
	X2.17	The drawing does not comply with applicable standards and regulations.	Unworkable and unsafe design.
Mechanical Work	X2.181	Pipe connection leaks.	Electrical and electronic damage
Design & Development	X2.31	Inaccuracy of experts' advice.	Execution failure
Mechanical Work	X2.180	Pipe connection leaks.	Short circuits
Design & Development	X2.30	Experts cannot use technology-based tools/resources such as BIM, Virtual Reality.	Weaknesses of design modeling
Mechanical & Electrical Work	X2.104	Worker electrocuted.	Pass away
Design & Development	X2.29	Inaccuracy of experts in identifying discrepancies.	Execution failure
	X2.18	Use of outdated/inappropriate standards and regulations.	The specifications are unsafe.
	X2.12	Unreliable data sources.	Error in analyzing data.
	X2.19	The mistake of selecting a reliable material.	System failure
Mechanical & Electrical Work	X2.40	Tools sparking flammable materials.	Fires
	X2.107	Crushed by falling material while moving.	Pass away

Table 4. List causes of high risk

Code	Cause Description
C1	Experts are appointed improperly.
C2	Lack of communication and cooperation between human capital and top management about expert placement.
C3	Expertise gap between job requirements and qualifications.
C4	Limited management budget for qualified professionals.
C5	Not assessing genuine tender documents, leaving essential items out.
C6	Outdated regulations.
C7	Poor management development and learning versus current requirements and regulations.
C8	Inexperience and ignorance.
C9	Poor teamwork and communication.
C10	Expert ignorance of BIM software, Virtual Reality, etc.
C11	Lack of management support for BIM software, VR, etc.
C12	Data collection rules are unclear.
C13	Materials shortages.
C14	The electrical lines are tangled and moist.
C15	Unprotected wires.
C16	Pipe connection problem.
C17	The workplace is combustible.
C18	The Tower crane operator is incompetent.
C19	The Tower crane is unsafe.
C20	Workers are unaware of the situations above.
C21	Unsafe work behavior.
C22	Construction Safety Management System supervision is irregular.
C23	Not holding regular toolbox and safety morning talks.
C24	Work instructions are missing or ignored.
C25	Workers lack PPE.
C26	Safety signs are incomplete.

Table 5. List effects of high risk

Code	Effect Description
E1	Poor job quality.
E2	Due to a shortage of qualified professionals, the workload is severe and imbalanced.
E3	Design faults are unaccounted for technically.
E4	Delayed design.
E5	Lost tender.
E6	Lost revenue.
E7	Work is not appropriately handled / late / stopped.
E8	Weakness in risk assessment, identification, and control.
E9	System failure.
E10	Deterioration.
E11	The project fails to meet cost, time, and quality goals.
E12	Facility destruction.

Table 6. List preventive actions of high risk

Code	Preventive Action
PA1	Make clear and systematic methods for selecting specialists based on qualifications, experience, and suitability for the tasks to be performed.
PA2	Establish regular meetings between human capital and management leaders to discuss the qualifications and positioning of specialists.
PA3 ……	Establish a mentoring program for less experienced specialists to learn from more experienced ones.
PA33	Install comprehensive safety signs and conduct routine inspections.

Table 7. List corrective actions of high risk

Code	Corrective Action
CA1	Provide training and development to specialists based on their placement when the quality of their work is not optimal.
CA2	Conduct tight mentoring/checking by competent experts/division leaders after design faults.
CA3	Conduct regular internal meetings to discuss non-running activities.
CA4	Create performance indicators and conduct regular surveillance to track the design process's development.
CA5	Reviewing/modifying design plans in the presence of competent experts/division leaders.
CA6	Identify, fix, and evaluate the outcomes of the recommendations.
CA7	Changing experts with more capable ones.
CA8	Check for defects using BIM software, Virtual Reality.
CA9	Implement stringent quality control and ensure a rigorous non-conformance review procedure.
CA10	Perform identification, repair, and testing to ensure product specifications meet safety standards.
CA11	Implement stringent quality control and ensure that standards and regulations are rigorously followed.
CA12	Identify and repair data sources to ensure data analysis is accurate and complete.
CA13	Perform identification, maintenance, and testing to guarantee the selection of safe and dependable materials.
CA14	Implement stringent quality control and ensure careful consideration for material selection.
CA15	Evaluate worker qualifications and the safety of materials.
CA16	Fix the entire condition of the cable that serves as the trigger.
CA17	Replace the material with one meeting the necessary specifications.
CA18	Repair leaking pipe junctions using the proper connection technique.
CA19	Repaired facility damage.
CA20	Replace employees with those who are more qualified.
CA21	Conduct periodic audits to evaluate the safety management system for construction.
CA22	Evaluating the safety plan against field conditions during the construction period.

3.3. Development of Risk-Based Work Breakdown Structure (WBS) Standards

Risk-based WBS standards can be developed by analyzing the causes, effects, and preventive and corrective actions associated with high risks shown in Table 4, Table 5, Table 6, and Table 7.

The next stage establishes a pattern between risk causes, effects, and appropriate preventative and corrective actions. Relationship pattern mapping is performed to visualize how each risk cause is related to the potential impact and how preventative and corrective actions are related to each risk cause and potential impact. Fig. 3 shows a mapping of the relationship between each risk's causes, effects, and corrective actions effects, preventive and corrective actions in the form of pattern recognition. The hazard of allocation of specialists does not correspond with their qualifications, where the risk is that the design outcomes constitute a potential safety hazard (X2.4), has multiple causes, including Experts being appointed improperly (C1), lack of communication and cooperation between human capital and top management about expert placement (C2); expertise gap between job requirements and qualifications (C3).

These causes can be avoided with preventive action, including making clear and systematic methods for selecting specialists based on qualifications, experience, and suitability for the tasks to be performed. (PA1); establish regular meetings between human capital and management leaders to discuss the qualifications and positioning of specialists (PA2). The impacts deriving from these risks are that the design cannot be accounted for technically/design defects (E1); the task is not handled properly / late / stopped (E2). This impact can be mitigated by implementing the following corrective actions, including providing training and development to specialists based on their placement when the quality of their work is not optimal (CA1); conducting tight mentoring/checking by competent experts/division leaders after design faults. (CA2); conduct regular internal meetings to discuss non-running activities (CA3).

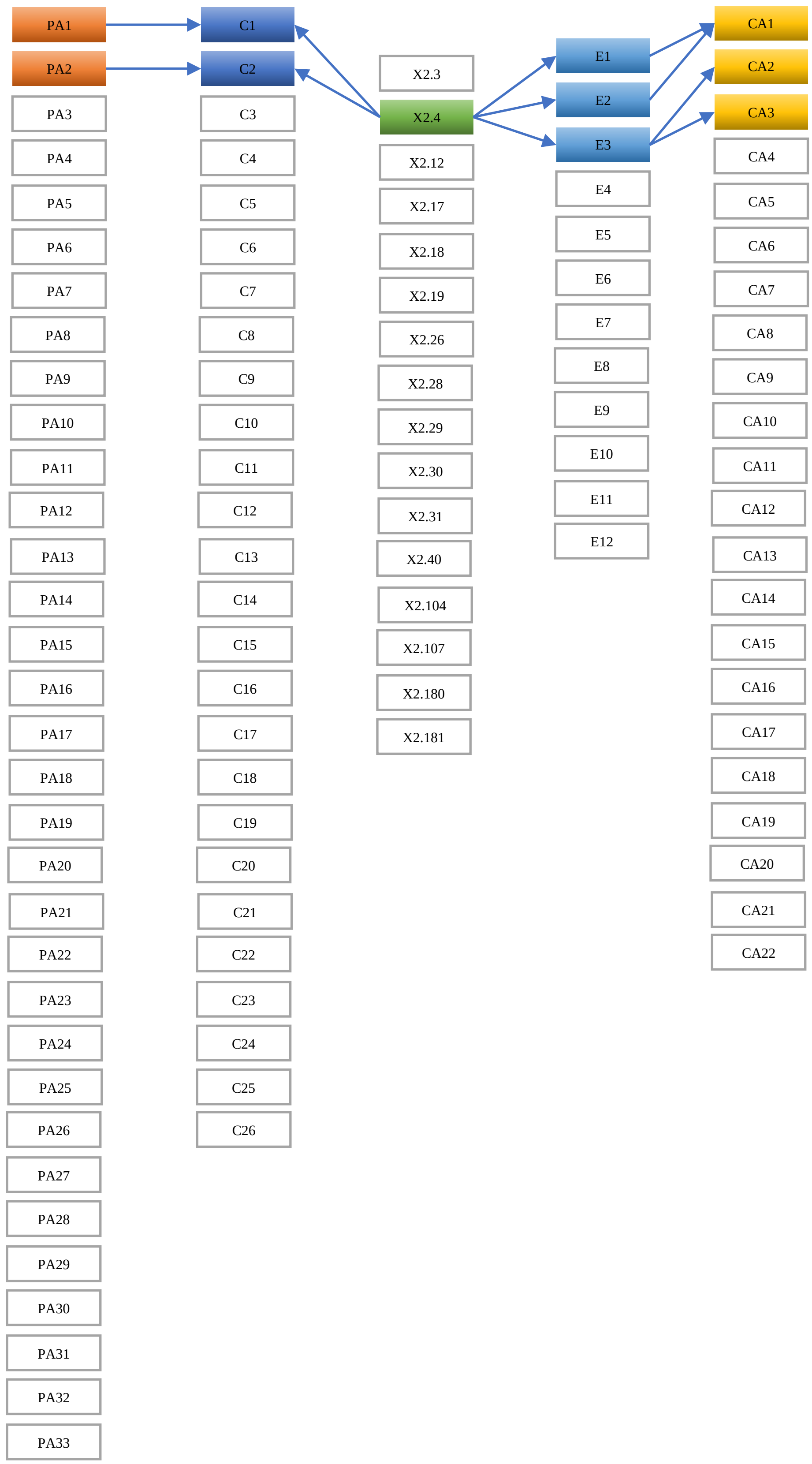

Fig. 3 Pattern recognition X2.4 risk

Table 8. Risk response category mapping for preventive action

No	Preventive Action	Recommendation
PA1	Make clear and systematic methods for selecting specialists based on qualifications, experience, and suitability for the tasks to be performed.	Additional to managerial item
PA2	Establish regular meetings between human capital and management leaders to discuss the qualifications and positioning of specialists.	Additional to managerial item
PA3	Establish a mentoring program for less experienced specialists to learn from more experienced ones.	Additional to managerial item
PA4	Assess expert qualifications, skills, and experience against job criteria.	Additional to managerial item
PA5	Management budget determines execution time.	Additional to managerial item
PA6	Develop training on tender document analysis.	Additional to managerial item
PA7	Actively identify norms and rules using web databases.	Additional to managerial item; Additional to other WBS
PA8	Inviting design and construction safety professionals to review job plans and needs according to the current standards.	Additional to managerial item; Additional to the project requirements
PA9	Learn the newest norms and requirements through training and development.	Additional to managerial item
PA10	Inviting design and construction safety specialists to review the design according to current standards.	Additional to managerial item; Additional to the project requirements
PA11	Train and develop design safety hazard analysis.	Additional to managerial item
PA12	Establish a monitoring system and periodic inspections.	Additional to managerial item; Additional to the project requirements
PA13	Conduct training on using BIM software, Virtual Reality, etc.	Additional to managerial item
PA14	Identify design issues through training and development.	Additional to managerial item
PA15	Inviting design and construction safety professionals to verify requirements according to current standards.	Additional to managerial item; Additional to the project requirements
PA16	Start with clear data requirements.	Additional to managerial item
PA17	Conduct training on the use and understanding of secure materials.	Additional to managerial item
PA18	Analyze alternative materials that satisfy the design specifications.	Additional to managerial item; Additional to relevant WBS elements
PA19	Examine the condition of the cables and nearby areas that could cause an electric discharge.	Additional to the project requirements
PA20	Covers exposed wires for safety.	Additional to the project requirements
PA21	Assuring that applicable standards make conduit connections.	Additional to the project requirements
PA22	Keep materials at a distance and shield combustibles from the work area.	Additional to the project requirements
PA23	Ensure that the operator is knowledgeable and possesses a valid license.	Additional to the project requirements
PA24	Perform inspections by government-appointed firms.	Additional to the project requirements
PA25	Ensuring the site is secure before beginning work and installing barricades in the material lifting area.	Additional to the project requirements
PA26	Conduct consistent monitoring of employee conduct.	Additional to managerial item
PA27	Perform frequent project safety audits.	Additional to managerial item
PA28	Conduct training on project implementation methodologies.	Additional to managerial item
PA29	Supervise routinely and exhaustively the program for the construction safety management system.	Additional to managerial item
PA30	Hold a safety briefing and supply meeting before starting the activity.	Additional to managerial item; Additional to the project requirements
PA31	Make work instructions for each job and tool operation.	Additional to managerial item
PA32	Provide employees with personal protective equipment (PPE).	Additional to managerial item; Additional to the project requirements
PA33	Install comprehensive safety signs and conduct routine inspections.	Additional to managerial item; Additional to the project requirements

Each risk has been assigned risk responses in the form of preventive and corrective actions. The development of a risk-based WBS standard will involve the grouping of preventive actions into recommendations. Because corrective action is a risk response after a construction accident, it is not an additional recommendation in the WBS. The recommendations for the development of a risk-based WBS can be categorized as follows [24]:

1. Additional to managerial item
   The other risk response to project execution is related to the governance of the company's organization throughout the project life cycle.
2. Additional to other work breakdown structures (WBS).
   Risk response is added to work not associated with the job in question.
3. Additional to relevant work breakdown structure (WBS) elements.
   Risk response is integrated into the activity itself.
4. Additional to the project requirements.
   Risk responses are added to work instructions or contracts to control work based on predefined policies.
5. Affects work breakdown structure (WBS) coefficients.

Risk responses are associated with the structure that forms the unit cost of labour, such as material composition, tool capacity, and labourer productivity.

Table 8 shows the grouping of preventive actions recommended for developing a risk-based WBS. The majority of WBS development recommendations in this study are additional management recommendations. In this instance, management is essential in enhancing construction safety performance, including maintaining safe working conditions, instituting safety training, educating employees on good safety habits, implementing adequate controls, and maintaining strict safety supervision. Management must actively support safety efforts to establish behaviour standards for all levels. Previous research has demonstrated that management is one of the most critical success factors for construction safety [6] [9] [28].

Table 9 shows how risk-based WBS development guidelines are integrated into the WBS structure. Requirements columns suggest items to consider when planning and completing project requirements. Technical factors, specifications, and standards must be satisfied to complete work correctly and according to project requirements. The blue column displays updates to the relevant WBS and other WBS. The orange columns display managerial items requiring project planning and management attention. Notes on these items provide more information or managerial attention. Risk-based WBS standard development tables emphasize and annotate project planning and management essentials. This helps the team plan steps, meet requirements, and manage management factors for project success.

Table 9. Development of risk-based WBS standards

WBS Level 3	WBS Level 4	WBS Level 5	WBS Level 6		Requirement
Sub Work Section	**Work Package**	**Activity**	**Type**	**Resources**	
Design Planning Work	Preliminaries	Administrative and technical preparation	Labor	Team Leader	
				Administrator	
		<u>Team building</u>	Labor	Team Leader	
		Field observations and survey preparation	Labor	Team Leader	
				Mechanical Experts	
				Electrical Expert	
				Surveyor	
				Estimator	
				Construction Safety Experts	
		Preliminary report preparation	Labor	Team Leader	
				Mechanical Experts	
				Electrical Expert	
	Implementation	Primary/secondary data collection	Labor	Team Leader	Start with clear data requirements.
				Surveyor	
		Standards and regulations collection	Labor	Team Leader	
				Mechanical Experts	
				Electrical Expert	

4. Conclusion

Identifying Work Breakdown Structure (WBS) standards for integrated design and construction phase of mechanical and electrical works of high-rise buildings generate 3 (three) Work Sections: Design & Development Work, Mechanical Work, and Electrical Work. Within the 3 (three) Work Sections are 20 (twenty) Sub Work Sections and 122 Work Packages. Risks based on the standard Work Breakdown Structure (WBS) framework provide 388 risk variables. The survey of respondents on these risk variables identified 18 high risks that impact construction safety performance. Based on the risk analysis, 26 causes and 12 effects with the highest significance level were identified as potentially impacting construction safety performance. To enhance construction safety performance, 33 preventative actions that can be implemented to reduce risks and the likelihood of accidents have been identified. These preventive actions seek to establish a safe workplace and ensure safety protocols are followed. In addition, 22 corrective actions can be taken to mitigate the risks that have occurred and enhance the safety performance that has been compromised. This corrective action is intended to address deficiencies or failings that may endanger worker safety and to reduce future risks. By instituting appropriate preventive and corrective actions, construction safety performance can be enhanced by decreasing the likelihood of accidents, injuries, and losses. In addition, a thorough comprehension of the causes and effects of risks facilitates the planning and management of resources, thereby enhancing the overall construction safety performance. To achieve high construction safety objectives, it is essential to continuously monitor and assess the efficacy of preventive and corrective actions. Developing Work Breakdown Structure (WBS) standards involves adding or integrating risk responses to several recommendations. The most common recommendation for the development of a risk-based WBS is the addition of additional managerial components. Management should ensure the organization has the necessary organizational capabilities, including policies, systems, resources, and personnel, to fulfil its responsibility for enhancing construction safety performance.

This study will only discuss high-rise building items so that subsequent studies can cover various construction-related topics. The application development of this Work Breakdown Structure (WBS) will be able to be investigated by future research using Building Information Modelling (BIM) because the Work Breakdown Structure (WBS) will continue to be modified to reflect the progress made in both the methodologies and the technology.

Funding Statement

The author expresses his gratitude for the financial support the Ministry of Education, Culture, Research and Technology provided through the PPS-PTM Grant scheme for the Year 2023 with Contract Number: NKB-1167/UN2.RST/HKP.05.00/2023.

Acknowledgments

The author expresses gratitude to the Construction Safety Audit research group members.

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