A Conceptual Framework for Knowledge Management of Integrated Design and Construction Phase Audit Process on Infrastructure Project Based on Risk, Using WBS, BIM and Web to Enhance Construction Safety Performance

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Abstract

Infrastructure development is massively done, but the current implementation of construction safety audit is not yet effective to prevent accident. Generally, the audit is limited to construction phase. Audit is rarely done in design phase, and if done, the audit result has never been used as reference for future audits. This research aims to formulate A Conceptual Framework for Knowledge Management of Integrated Design and Construction Phase Audit Process on Infrastructure Project Based on Risk, Using WBS, BIM and Web to Enhance Construction Safety Performance. The method that uses in the research is qualitative and quantitative analysis to formulate the development. And the result targeted A Conceptual Framework for Knowledge Management of Integrated Design and Construction Phase Audit Process on Infrastructure Project Based on Risk, Using WBS, BIM and Web to Enhance Construction Safety Performance so construction safety audit can be optimized to improve construction safety as an effort to prevent construction accident and mitigate infrastructure calamity during accelerated development era in Indonesia.

Keywords

Keywords: Knowledge Management, Safety Audit, Infrastructure, Risk, Construction Safety Performance

1. Introduction

The current era of government is indeed the most aggressive in the development of infrastructure projects. The boost in massive and evenly distributed infrastructure development throughout Indonesia has received positive responses, especially from national and foreign business and investment circles. Infrastructure is one of the main wheels driving the economic growth of a nation. From the budget allocation for APBN, public, private, foreign loans, and assignments, infrastructure is seen as the locomotive of national development. Without consistent and growing infrastructure development, it is difficult for the government to increase economic growth. From the 2021 APBN budget, the Minister of Finance has set IDR 417 trillion, an increase of 48% from 2020. (Ministry of Finance 2021). The benefits of infrastructure development are, indeed, long-term, and expensive. After the Reformation, infrastructure development in Indonesia almost stopped instantly not only due to emergence of the multi-dimensional crisis in 1998, but also the government's policy at that time did not prioritize infrastructure development but post-crisis economic recovery. Massive infrastructure development only started again in the era of President Joko Widodo in 2014.

Unfortunately, after the aggressive infrastructure policy, the construction safety audits that have been carried out so far have not been effective in preventing accidents. In general, the audits carried out are limited to the construction phase. Audits are rarely implemented in the design phase, and if done, the audit results have never been used as reference for future audits. Whereas construction accidents in the workplace are originated from many factors, not only from workers and organization in the workplace, but also the planning stage by the planner and the concept stage by the client (Suraji et al. 2001).

Consequently, increase in infrastructure development is followed by increase in the number of construction accidents. Construction Accident is an event due to negligence at the Construction Work stage because the failure to fulfill Security, Safety, Health, and Sustainability Standards, which results in loss of property, working time, death, permanent disability, or environmental damage (KemenPUPR 2021). The Ministry of Public Works and Public Housing (PUPR) stated that data on the proportion of work accidents in Indonesia for the construction sector was the largest contributor along with the manufacturing industry at 32 percent. This contrasts with the transportation sector (9%), forestry (4%) and mining (2%). In addition, the International Labor Organization (ILO) states that there are 6000 cases of work accidents that occur daily fatal. Work accidents in Indonesia proportion state that for every 100,000 workers there are 20 victims of work accidents that result in fatalities. In developing countries, losses due to work accidents are four times higher than in industrialized countries at US$1.25 trillion or equivalent to 4% of Gross National Product (GNP). Referring to data from the Social Security Administering Agency for Employment (BPJS Employment), nationally the number of work accidents in the construction sector is recorded as the sector that contributed the most to the number of work accidents. Work accident cases that occurred in 2016 (until November) recorded 101,367 incidents with 2,382 deaths, while in 2015 there were 110,285 people with 2,375 deaths. The total number of work accidents in 2017 was 123,000 cases with claim value of more than IDR 971 billion. This figure increased from 2016 with a claim value of only Rp792 billion. (BPJS Employment 2018). Not to mention the impact of the extra costs that must be incurred as repairs to accidents that are rarely published to the mass media.

To prevent construction accidents, the government issues the Minister of Public Works and Public Housing Regulation Number 10 Year 2021 concerning Guidelines for Construction Safety Management Systems, as well as establishes a Construction Safety Committee in charge of monitoring and evaluating the implementation of construction that is predicted to have large Construction Safety Risk, carrying out investigations of construction accidents, providing suggestions, considerations, and recommendations to the Minister based on the results of monitoring and evaluation of Construction Works with major Construction Safety Risks and/or construction accident investigations in the context of realizing Construction Safety, and carrying out other tasks assigned by the Minister (KemenPUPR 2021). However, the large number of infrastructure works supervised is inversely proportional to the limited number of Construction Safety Committee auditors. This is the reason why construction safety audit process has not run optimally.
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1.1 Objectives

The general objective of this research is to optimize the construction safety audit process on infrastructure work, to improve construction safety, specifically to formulate a conceptual framework model Knowledge Management Development Integrated Audit Process Stage of Risk-Based Infrastructure Project Design and Development using Work Breakdown Structure (WBS), BIM, and Web to Enhance Construction Safety Performance. This research will directly benefit the improvement of the construction safety audit process that enhance construction safety as an effort to prevent construction accidents and mitigate infrastructure catastrophes in the era of accelerated development in Indonesia.

2. Literature Review

2.1 Construction Safety Management System

Construction Safety Systems is an integrated governing protocol of safety planning, safety engineering, safety financing, safety assurance, safety control, and safety organization as well investigation of near miss incident and/or accident causation within overall organizational business process and construction project management for preventing any deficiencies, defects, failures and potential hazards within construction projects leading to risk of incidents causing damage to people, public, property and environment as well as undermining business value (Arifuddin et al. 2019).

Pre-Project Stage	Pre-Construction Stage			Construction Stage	
Phase 3: Substantive Feasibility & Outline Financial Authority	Phase 4: Outline Conceptual Design	Phase 5: Full Conceptual Design	Phase 6: Coordinated Design, Procurement & Full Financial Authority	Phase 7: Production Information	Phase 8: Construction
Initial Safety Assessment	Revised Safety Assessment	Updated Safety Assessment	Updated Safety Assessment	Finalised Safety Assessment	Manage Safety
Based on the solution identified at this phase: a. Planning Criteria, b. Design Criteria, c. Integrate Safety into Quality of Planning Suraji (2012)	Based on site and environmental revisions: a. Incorporating constructability, maintainability factors into outline design analysis, b. Initial CHAIR c. Integrate safety into Q of Concept Design,	Pre-tender safety plan: a. Design to build, b. Design to maintain, c. Design to demolish d. Design for special safety e. Updated CHAIR, f. Integrate Safety into DED	a. Safety plan based on detailed design solution and b. safety cost analysis based on constructability, c. Integrated Safety into Q of Contract Document,	a. All safety issues before construction works should be documented and finalised, b. Safe system of construction works including method statement, c. Integrated Safety into Construction Planning,	All actual safety should be presented and compared with the plan to enable the feedback loop for future projects.

Figure 1. Construction Safety Business Process (Suraji 2012)

The Construction Safety Management Systems (SMKK) Business Process can be seen in Figure 1 which explains that the implementation of SMKK must be implemented early, even from the feasibility study of a project (Suraji 2012). The implementation of SMKK must meet the Security, Safety, Health, and Sustainability Standards, by ensuring construction engineering safety, occupational safety and health, public safety, and environmental safety (KemenPUPR 2021).

Considering the hazardous nature of the construction industry several countries have regulated the safety management systems (SMS). The Health and Safety at Work etc. Act 1974 was enacted by the United Kingdom's Health and Safety Commission (HSC) to provide occupational health and safety rules. The Health and Safety at Work Act of 1974 imposes obligations on all stakeholders to safeguard the safety of their employees, as well as members of the public, during the project. Following that, in 2007, the Construction (Design and Management) Regulations 2007 became the primary set of construction regulations (CDM). CDM regulations imply roles and responsibilities on all parties to contribute to the health and safety of construction projects. Detailed requirements for those involved in pre-construction and planning phases are explicitly mentioned in CDM Regulations. Moreover, the CDM regulations are meant to bring together all the stakeholders involved in the design and construction process by creating the safety culture in the industry to overcome the health and safety issues that ascend at different stages of development (Zhou et al. 2012).

2.2 Knowledge Management

Knowledge management can be defined as performing the activities involved in creating, transferring, and applying knowledge to enhance, in a cost-effective model, the impact of knowledge on the unit's goal achievement. Knowledge management is important for organizations that continually face downsizing or a high turnover percentage due to the nature of the industry. Today's decision maker faces the pressure to make better and faster decisions in an environment characterized by high domain complexity and market volatility, even considering lack of experience typically from the decision-maker, and outcome of those decisions could have such a considerable impact on the organization (Becerra-Fernandez and Sabherwal 2014).

Knowledge management is defined as the ability to improve the skills of individuals to allow them to take effective action. Knowledge management is a process of capturing, distributing, and using knowledge effectively (Rodgers et al. 2017). Knowledge management is grounded inability, shaping the performance of the organization, and the associated management processes. There is still a lack of adequate knowledge (tacit and explicit) on how to combine social, environment and business aspects into the core processes of the organization and how to overcome existing barriers to encourage companies to achieve their goals. Consequently, interdisciplinary knowledge processes need to be investigated in the context of various fields in an integrative manner. Integration is a very important feature of

research and is debatable (Figure 2). The integration of knowledge is an important process in organizations (Masuin et al. 2019).

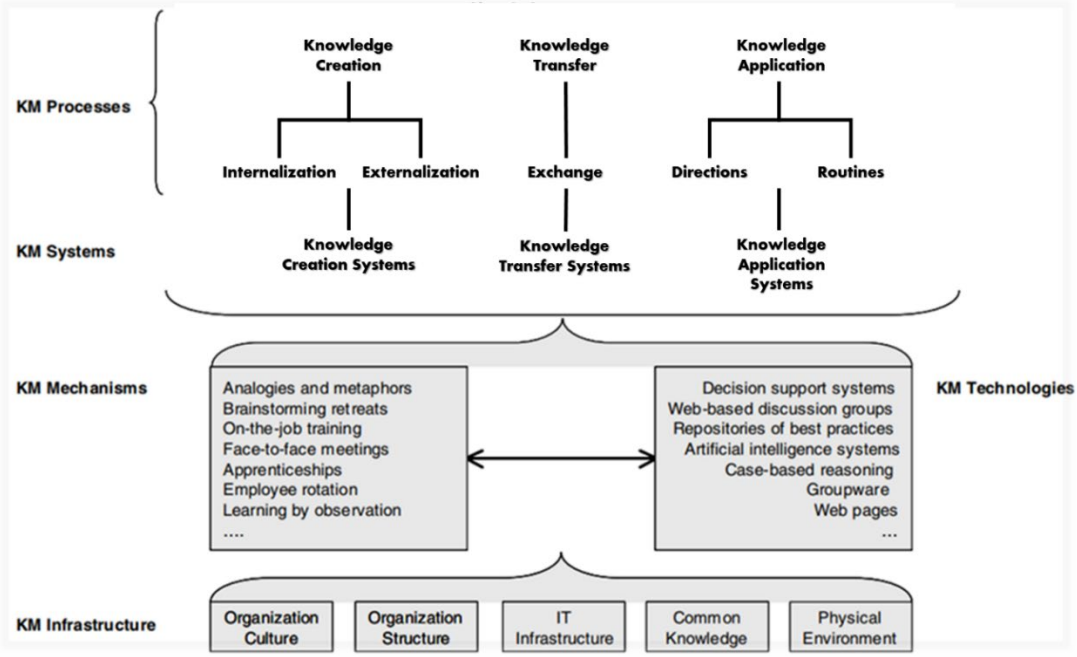

Figure 2. Knowledge Management (edited from Becerra-Fernandez and Sabherwal 2014)

According to Hadikusumo (2004), both explicit and tacit knowledge of construction site safety employees must be collected to obtain advantages in knowledge management, which is usually reflected in the form of a business system that is enabled by a variety of technologies, including:

1. Establishment of an effective safety program that considers the actual safety risks. Diverse people may have different perspectives on a situation; one person may see it as a safety hazard, while another does not. This issue can be resolved by capturing knowledge and examining and debating whether a particular construction condition or method would be regarded a true safety threat. An organization can ensure that the safety engineers and operational units have the same perspective of the actual threats once the knowledge has been captured. This can be used to create a safety program that includes a procedure for dealing with the actual hazards.
2. Establishment of an effective training program that improves workers' ability to deal with the recognized safety hazards. Once the safety management team has gathered the information, they can develop an effective training program to increase workers' ability to deal with the identified hazard**.**

2.3 Construction Safety Audit

An audit is basically an effort to ascertain or compare whether a work results in accordance with the criteria or plan that was previously determined and to achieve continuous improvement. Some of the benefits from audit integration are optimizing business and resources; make organization to work as a unit with integrated goals to achieve its goals and mission; also create lighter workload; reduce the time of certification, costs, and documentation requirements of the system (Mourougan 2015).

The audit examines the implementation of SMKK elements, namely leadership and workforce participation in Construction Safety (sub-elements: leadership concern for external and internal issues; SMKK management organization; Construction Safety commitment and workforce participation; and supervision, training, accountability, resources, and support), Construction Safety planning (sub-element: IBPRP; engineering, management, and manpower action plans contained in the targets and programs; and compliance with Construction Safety standards and regulations), Construction Safety support (sub-elements: resources in the form of technology, equipment, materials, and costs; workforce competence; organizational awareness; communication management; and documented

information), Construction Safety operations (sub-elements: RKK implementation planning; Construction Safety operation control; preparedness and response to emergency conditions; and Construction accident investigations), and performance evaluation of SMKK implementations (sub-elements: monitoring or inspection; audits; evaluation; management review; and improvement of Construction Safety performance) (KemenPUPR 2021).

2.4 Infrastructure Delivery System: Design, And Construction Phase

Every project goes through a project life cycle. The implementation system of all stages related to the parties who will be involved in each stage is called the project implementation system or project delivery system (PDS). Planning can be interpreted to transform perceptions of environmental conditions into a meaningful plan and can be carried out regularly (Figure 3). Planning is a process to determine the right course of action in the future through systematic choices. (Shrode and Voich 1974).

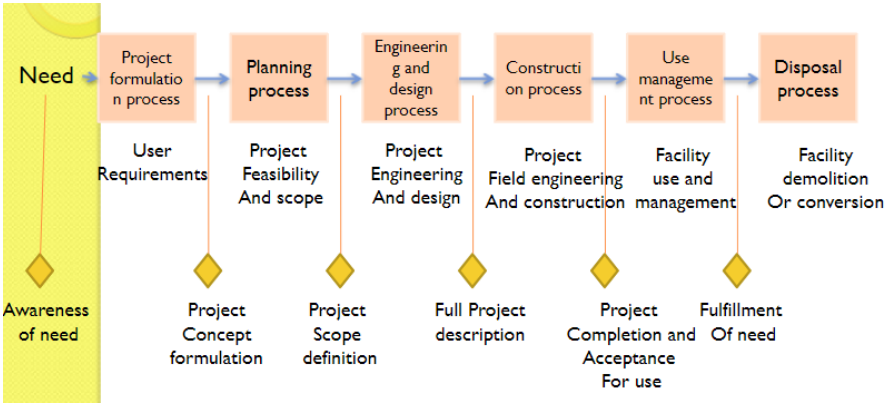

Figure 3. Infrastructure Delivery System

According to Alexander (1983), design is an attempt to find the right physical components of a physical structure. Design is the main proposal that changes something that already exists into something better, through three processes: identifying problems, identify methods for problem solving, and implementation of problem solving. In other words, it is programming, drafting, and implementing the design. Planning will produce plans, while design will produce designs. Hierarchy, planning is done first then the design is executed. Planning is aimed at large (macro) scales, while design is related to small (micro) parts of the planning.

2.4 Risk Management

Risk management for program is a methodological process of identifying, analyzing, responding to, and controlling risks that may occur during a program implementation. Risk management is related with the goal to increase the possibility and/or positive risk impacts as well as reducing the possibility and/or negative risk impacts to optimize the success of a program (Helbo and Hasle 2017, Park et al. 2022). Risk management is a crucial part of the decision-making process in construction project management that will affect scope, time, integration, quality, human resources, cost, communications, and project procurement. Therefore, to do risk identification, WBS must be categorized based on work packages, methods/designs, activities, material resources, equipment, and labor and the environment so that risk events can be identified that can affect safety performance objectives (Dionisio 2017). Creating stratified risk management with RBS can improve uncertainty and probabilities identification in the future projects (Sharma and Swain 2011).

2.5 Work Breakdown Structure

Work Breakdown Structure (WBS) is a hierarchical division of work that is deliverable-oriented to be done by the project executor to achieve project goals and required achievement. Achievement in question is a unique output, result, or capability to display the services that must be achieved to complete the process, phase, or project (PMBOK 2017). WBS often narrowly used as reference to external achievement, which are subjected to sponsor or customer of the project's approval. Making WBS itself is a system of describing project deliverables and work into individual components which translated into a list that is top down and ordered explains the components that must be constructed and its associations. Each WBS level derivative represents an increasingly detailed definition of the project. It is

important to note that the safety audit process is usually derived from the work package formed in the project WBS. This is in conformance with The Minister of Public Works and Public Housing (PUPR) Regulation No. 10 of 2021 (Herzanita 2022).

2.6 Building Information Modelling

Building Information Modelling (BIM) is a holistic process of creating and managing information for a built asset. Based on an intelligent model and enabled by a cloud platform, BIM integrates structured, multi-disciplinary data to produce a digital representation of an asset across its lifecycle, from planning and design to construction and operations (Beliveau 2011, Riantini et al. 2020). This research will develop a framework for embedding safety design knowledge into a BIM modeling system. However, that work was limited to the theoretical stage and has not been implemented (Figure 4).

Figure 4. Countries with BIM mandates (Autodesk 2022)

According to the United Nations, by 2050 the world's population will be 9.7 billion. The global AEC industry must look for smarter, more efficient ways to design and build, not just to keep up with global demand but to help creating spaces that are smarter and more resilient too. BIM does not only allow design and construction teams to work more efficiently, but it allows them to capture the data they create during the process to benefit operations and maintenance activities. Therefore, BIM mandates are increasing across the globe (Autodesk 2022).

3. Methods

A literature review is what research method used in this research, a few papers, books, thesis, and regulations were collected and analyzed. The conceptual framework was conducted based on literatures of knowledge management model and the implementation of safety audits in construction industry. Then the papers were grouped, filtered, and explored to develop a conceptual framework connecting knowledge management, construction safety audit, BIM, WBS, risk, and infrastructure delivery system that affecting the construction safety performance. Correlation among the concepts examined by previous studies was applied to different concept to develop a conceptual framework with hypothesis that will be tested in this research. The next evaluation step is setting up research indicators on each variable and dimension conducting the knowledge management model of construction safety audit process. The indicators will be used to determining quantitative and qualitative relationship among variables and dimensions.

4. Data Collection

The study uses a systematic literature review as a research methodology to look at how variables affect construction safety performance in peer-reviewed studies and establish a conceptual framework for improving construction safety performance. Based on a specified search criterion, publications from important journals and conference proceedings that have been widely used by scholars and practitioners in the field were chosen for review. The selection of articles

was the initial phase in the evaluation process; we selected 137 articles from peer-reviewed sources such as Science Direct, ASCE, and a few IOP conference proceedings publications. The selection criteria were based on specific search keywords linked to research goals and publication dates. (1) Construction safety audit, (2) Knowledge management for construction safety audit, (3) Information system for construction safety audit, (4) BIM for construction safety audit, and (5) Factors influencing/affecting construction safety performance were the search keywords applied. Next, no paper older than 2000 was chosen as part of the research, which attempted to examine articles over the past 25 years to gain insight into comprehensive safety issues. As a result, the papers were chosen during the review process based on the title, year of publication, and keywords.

5. Results and Discussion

This conceptual framework will examine the relationships among the knowledge management, construction safety audit process, Web-Based Information System, risk management, design, and construction phase, WBS, and BIM with the elements of construction safety performance.

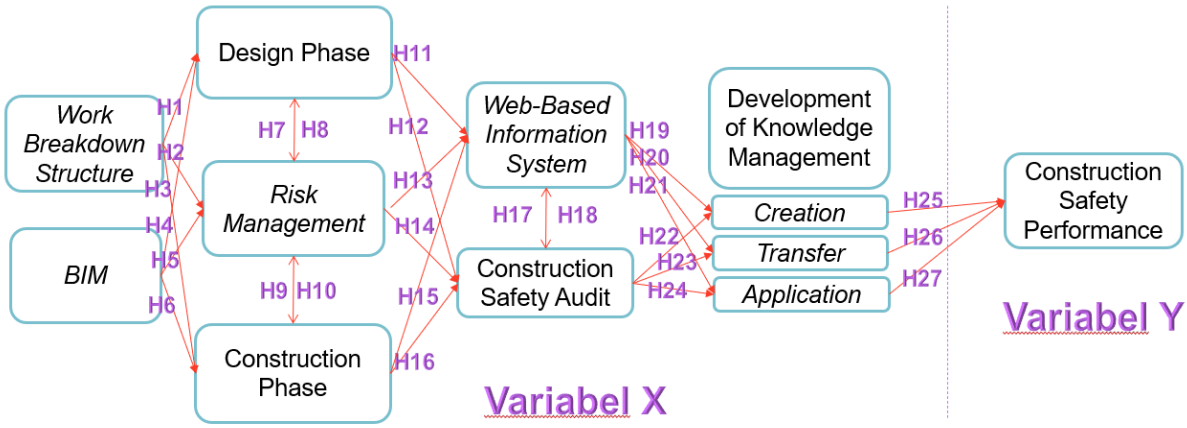

Figure 5. The Conceptual Framework Model

To prove that concept as seen in Figure 5, several hypotheses are developed, which can be summarized as follows, H1: WBS affect Design Phase on Infrastructure Works; H2: WBS affect Risk Management; H3: WBS affect Construction Phase on Infrastructure Works; H4: BIM affect Design Phase on Infrastructure Works; H5: BIM affect Risk Management; H6: BIM affect Construction Phase on Infrastructure Works; H7: Design Phase affect Risk Management; H8: Risk Management affect Design Phase on Infrastructure Works; H9: Construction Phase affect Risk Management; H10: Risk Management affect Construction Phase on Infrastructure Works; H11: Design Phase affect Web-Based Information System; H12: Design Phase affect Construction Safety Audit; H13: Risk Management affect Web-Based Information System; H14: Risk Management affect Construction Safety Audit; H15: Construction Phase affect Web-Based Information System; H16: Construction Phase affect Construction Safety Audit; H17: Construction Safety Audit Process affect Web-Based Information System; H18: Web-Based Information System affect Construction Safety Audit; H19: Web-Based Information System affect Knowledge Creation as a dimension of Knowledge Management; H20: Web-Based Information System affect Knowledge Transfer as a dimension of Knowledge Management; H21: Web-Based Information System affect Knowledge Application as a dimension of Knowledge Management; H22: Construction Safety Audit Process affect Knowledge Creation as a dimension of Knowledge Management; H23: Construction Safety Audit Process affect Knowledge Transfer as a dimension of Knowledge Management; H24: Construction Safety Audit Process affect Knowledge Application as a dimension of Knowledge Management; H25: Knowledge Creation as a dimension of Knowledge Management has positive impact on Construction Safety Performance; H26: Knowledge Transfer as a dimension of Knowledge Management has positive impact on Construction Safety Performance; and H27: Knowledge Application as a dimension of Knowledge Management has positive impact on Construction Safety Performance.

5.1 Impact of Work Breakdown Structure on Design Phase

WBS approach is accomplished in the design phase by breaking down the works into sub-works up to a specific level. This will result in the creation of system components for an escape route that will be necessary in a dangerous or emergency.

5.2 Impact of Work Breakdown Structure on Risk Management

The Minister of Public Works and Public Housing (PUPR) Regulation No. 10 of 2021 showed that hazards and risks can be identified based on the stages of activity derived from the WBS (Work Breakdown Structure). It is important to note that this study compiled the WBS using literature studies and scope of work references from the infrastructure projects in Indonesia. Hazards and risks can be detected utilizing the stages of activity generated from the Work Breakdown Structure (WBS), according to Minister of Public Works and Public Housing (PUPR) Regulation No. 10 of 2021. It's important to remember that this study compiled the WBS using literature studies and scope of work references from the infrastructure projects in Indonesia.

5.3 Impact of Work Breakdown Structure on Construction Phase

In all projects, the act of specifying, visualising, and developing the planning schedule for construction has been done using dedicated work breakdown structures (WBS), which is now a common approach in projects. After such plans have been developed, they are put into action in executing the project (Ganah and John 2017).

5.4 Impact of Building Information Modelling on Design Phase

During the design stage, the BIM is typically utilized to identify hazards and risks. Furthermore, 3D BIM modeling combined with work schedules allows for a more accurate simulation of potential dangers and risks. It's worth noting that Revit's 3D models are typically based on AutoCAD's 2D floor layouts (Putra 2020; Benjaoran 2010). The floor, walls, ceilings, doors and windows, hardware, sanitary, facade, and roof are the most modeled building components, as shown in Figure 6.

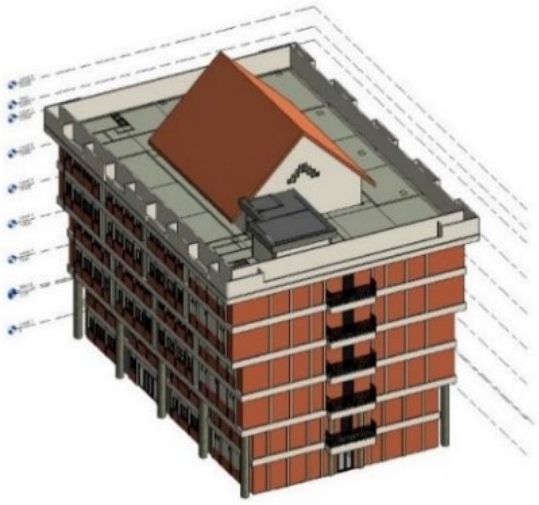

Figure 6. 3D Model BIM (Herzanita 2022)

The application of BIM technology to the management of construction safety issues can improve safety performance in construction work. This is because technology might be used to design safety plans, auditing and monitoring of designs, respond to emergencies, and communicate safety issues to all parties involved (Herzanita 2022).

5.5 Impact of Building Information Modelling on Risk Management

The BIM is an information system to make easier for identify the risk that impact construction safety performance. The purpose is to ensure that all project participants are aware of potential dangers, risks, and controls and can work

together efficiently. It's worth noting that the information system was built on the web to allow anyone to use the program without needing to install BIM software. Designers currently use BIM technology to visualize the project site and identify potential dangers during the design and pre-construction stages. Meanwhile, because the dangers and risks mentioned can still occur throughout project implementation, the connstruction safety plan must be regularly monitored and audited. (Herzanita 2022)

5.6 Impact of Building Information Modelling on Construction Phase

The BIM can visualize safety in construction schedules, plan installation and removal activities, present options, and methods for both permanent and temporary building pieces and simulate these processes. Since the construction schedule is linked to the model objects in BIM only a few weeks before the construction starts, it is essential to check the model for changes and update the checking results after a project's structural model, the schedule, or the original installation order change. The developed system assists human decision makers in this review process by eliminating the hazards, making sure that safety equipment is procured and ready for installation at the right place and time when needed. (Zhang 2015)

5.7 Impact of Risk Management on Design Phase

To ensure construction safety, the project life cycle, particularly design, necessitates careful attention and a suitable plan. The risks are managed in two stages; at the pre-construction stage risks are identified and controlled during the design and planning phases, it is necessary to identify and eliminate any hazards and risks (Khalid 2021). Hazard identification and control must be conducted before the construction phase begins to ensure that safety challenges are avoided as the means, methods, and site layout is designed. Once construction starts, workers and foremen must conduct pretask planning meetings every day to ensure that hazards are recognized and communicated prior to worker exposure (Hallowell et al. 2013).

5.8 Impact of Risk Management on Construction Phase

Risk management is recognized as identifying and controlling the safety risks in the construction phase to help the organisation meet the time, quality, and financial goals. The literature shows that this is one of the most important parts of the construction safety management system is risk identification and analysis. The decision made on the identified risks has an immense impact on the project overall performance. The risks are managed in two stages, during the construction stage, site inspections are carried out to mitigate potential risks (Khalid 2021).

5.9 Impact of Design Phase on Web-Based Information Systems

Effective safety planning is recognized as a two-stage process: planning and implementation (Zhang et al. 2013). The risk assessment and hazard identification are the essential parts of the safety planning that needs to be done at the pre-construction stage. The ability to identify the potential hazards on construction sites before initiating the actual work is a decisive part of the safety plan to mitigate the risks. It doesn't only contribute to the prevention of accidents but also deters the ill health of the workers on construction sites.

5.10 Impact of Risk Management on Web-Based Information Systems

Web-Based Information Systems are essential in the construction industry to maximize the documenting of incidents and accidents, particularly for third parties (contractors) to have an adequate report in their workplace and apply the lessons learned to the next construction project. The management can also disseminate information among project team members using the web-based information system. As a result, safety information and web-based communication can contribute to enhance safety performance.

5.11 Impact of Construction Phase on Web-Based Information Systems

Due to the fact that most of the safety data and information in infrastructure construction phase are location-based, systems with spatial data management and analysis capabilities would be more effective. The systems should be able to process information in real-time in order to achieve efficient safety data/information capture and transfer. Cloud computing is a relatively new technology that allows for real-time processing of massive amounts of very complex data (Zou et al. 2017).

5.12 Impact of Design Phase on Construction Safety Audit Process

The design phase has an important role in enhancing construction safety performance. One of the innovative hazard prevention solutions for decreasing and eliminating both fatal and non-fatal occupational injuries is the design for safety concept. The idea for this concept came from two theories: Lorent's 1987 report's theory that construction accidents are caused by facility design attributes, and the Time-Safety Influence Curve theory (Ibrahim 2022). The growth of this concept will of course have a positive impact in order to enhance construction safety performance, so when a construction safety audit at the design phase, an examination must be carried out on the implementation of the design for safety.

5.13 Impact of Risk Management on Construction Safety Audit Process

The current safety auditing also fails to reflect the contractor's operation's fairness. The contractor's performance can only be explicitly reflected if there is a systematic method and tight survey on the contractor's practice. It is the contractors' guarantee made in the contract, including the penalties or additional work taken by the contractors if they fail to follow the contract, that motivates the contractors to perform their tasks and conduct them safely on site. Contractors can only be warned and instructed to work more safely on site by safety officers. When potential safety risk is accurately perceived, workers can take proper measures to prevent potential accident. Meanwhile, inattention or selective attention is linked to the performance of hazard awareness and safety perception. Both of these elements are totally acquired through visual inspection/audit (SungJoon 2022). In other words, the risk management is one of the most important safety management tools for optimizing construction safety audit.

5.14 Impact of Construction Phase on Construction Safety Audit Process

In the construction phase information system can be used to conduct site safety auditing, safety data exchange and big data management. The Dashboard page offers a view to exchange and access all safety audit reports, photographs, videos and data collected with authorization. Those safety officers, safety auditors, safety consultants, and project managers can use mobile devices, tablets, or computers to verify the most up-to-date construction safety conditions. If any improper actions occur, reminders or notices will be sent instantly to the project team and the administrators. Users can, therefore, better understand safety and culture on-site, and detect any infringed action taken by on-site construction workers. They believe that such safety auditing apps may be combined with Building Information Modeling (BIM) technology. BIM is very prevailent in the construction industry and there is large promotion in academia and social advertisement. With the development of BIM, there shall be a new dimension of BIM about construction health and safety in the new future as well (Or 2020).

5.15 Impact of Web-Based Information Systems on Knowledge Management

The Web-Based Information Systems is used for knowledge capture, safety planning, and a training tool. Web-Based Information Systems, as a planning tool, can assist a user in identifying safety hazards and determining accident pre-caution to prevent accidents in the hazards identified. A safety database is available as part of the Web-Based Information Systems. The correlations construction components–possible safety hazards–accident precautions have been used to create this database. A single construction component can have multiple potential safety hazards, and a single potential safety hazard can have multiple accident prevention measures. The ability to associate safety hazard information connected to a construction component and its installation process to a construction component is one advantage of adopting this connection (Hadikusumo and Rowlinson 2004).

The semantic web is an enhancement of the present web that allow clients and people to better exchange knowledge by accessing material based on meaning. One of the most important aspects of the semantic web is ontology. Ontology is a formal explicit specification of a shared conceptualization in the context of IM, and it provides a mechanism for categorizing/classifying domain knowledge items/information into interrelated ideas. Many systems have been developed for organizing information and knowledge to improve productivity and performance in various processes within specific portions of the construction supply chain, with a focus on construction. The majority are focused at sharing and disseminating documents and experiences on construction projects at the firm level (Forcada et al. 2010).

5.16 Impact of Construction Safety Audit Process on Knowledge Management

In the auditing context, Rodgers et al. (2017) found that forensic auditors develop knowledge transfer skills in deductive reasoning. Deductive reasoning provides the tools needed to form inferences about the motives that people may have in problem-solving. The ability to form inferences is an important part of the decision-making process in the initial knowledge transfer phases. An expert must be able to develop an appropriate solution tableau based on the

initial evidence and in situations where there is significant uncertainty, be able to deduce outcomes based on imperfect information. Experts, through their background and experience, are much better equipped to connect the dots and to correctly assess the situation.

5.17 Impact of Knowledge Management on Construction Safety Performance

Knowledge is defined as a justified belief that increases an entity's capability for effective action, while safety is defined as the control of recognized hazards to attain an acceptable level of risk. Thus, safety knowledge can be defined as a justified belief that increases an entity's capability to effectively control the recognized hazards to attain an acceptable level of risk. Several researchers have addressed the importance of safety knowledge to improve construction safety. The creation, transfer and application of safety knowledge provide continuous feedback of what was learned and implements the lessons learned, which enhances the ability to perceive, recognize and control hazards. However, construction industry is a knowledge-rich industry in terms of the knowledge it creates the exchange among participants, and the information absorbed from external sources. Without an overview of the required safety knowledge and the associated relationships in the risk management activity, their use can be confusing (Dong et al. 2018).

6. Conclusion

The results of this study indicate that enhancing the construction safety performance in Indonesian construction industry, it is necessary to optimize the construction safety audit process by the development of knowledge management. This conceptual framework will be developed for the further research to find out the relationship between the variables and know the way to develop knowledge management of integrated design and construction phase audit process. This optimizing audit process aims to enhanced construction safety performance by integrating the design and construction phase audit using the development of knowledge management.

References

Arifuddin, R., Suraji, A. and Latief, Y. Study of the causal factors of construction projects vulnerability to accidents, *International Journal of Innovative Technology and Exploring Engineering*, vol. 8, no.6, pp. 711–716, 2019.

Autodesk.com, Available: https://www.autodesk.com/industry/aec/bim/benefits-of-bim, Accessed on March 11, 2022.

Becerra-Fernandez, I. and Sabherwal, R. , *Knowledge management: Systems and processes*. Routledge.

Benjaoran, V. and Bhokha, S, An integrated safety management with construction management using 4D CAD model. Safety Science, vol. 48, no. 3, pp. 395-403, 2010.

Beliveau, Y. ,Tuning Up BIM for Safety Analysis Tuning Up BIM for Safety Analysis Proposing modeling logics for application of BIM in DfS, 2011.

Dionisio, C.S. *A Project Manager's Book of Forms: A Companion to the PMBOK Guide*. John Wiley & Sons, 2017.

Dong, C., Wang, F., Li, H., Ding, L., and Luo, H., Knowledge dynamics-integrated map as a blueprint for system development: Applications to safety risk management in Wuhan metro project. Automation in Construction, vol. 93, pp. 112–122, 2018.

Nuria, F., Miquel, C., Alba, F., Marta, G., and Xavier, R. A web-based system for sharing and disseminating research results: The underground construction case study. Automation in Construction, vol. 19, no. 4, pp. 458-474, 2010. doi:https://doi.org/10.1016/j.autcon.2009.12.018

Ganah, A.A. and John, G.A. BIM and project planning integration for on-site safety induction. J. Eng., Des. Technol, 2017.

Hadikusumo, B.H.W. and Rowlinson, S., Capturing Safety Knowledge Using Design-for-Safety-Process Tool. Journal of Construction Engineering and Management 130, 281–289. doi:10.1061/(asce)0733-9364(2004)130:2(281, 2004.

Helbo, A. and Hasle, P. , Developing a concept for external audits of psychosocial risks in certified occupational health and safety management systems, *Safety Science*, 99, pp. 227–234, 2017.

Herzanita, A., Latief, Y., and Lestari, F, The application of BIM-based OHSMS information systems to improve safety performance. International Journal of Safety and Security Engineering, Vol. 12, No. 1, pp. 31-38, 2022.

Hallowell, M. R., Hinze, J. W., Baud, K. C., and Wehle, A, Proactive Construction Safety Control: Measuring, Monitoring, and Responding to Safety Leading Indicators. Journal of Construction Engineering and Management, 139(10), 04013010, 2013.

Ibrahim, C. K. I. C., Manu, P., Belayutham, S., Mahamadu, A. M., and Antwi-Afari, M. F. , Design for safety (DfS) practice in construction engineering and management research: A review of current trends and future directions. Journal of Building Engineering, 104352, 2022.

Khalid, U., Sagoo, A., and Benachir, M, Safety Management System (SMS) framework development – Mitigating the critical safety factors affecting Health and Safety performance in construction projects. Safety Science 143: 105402, 2021.

KemenPUPR , The Ministry of Public Works and Public Housing Regulation No. 10 of 2021, pp. 1–38, 2021.

Masuin, R., Latief, Y. and Zagloel, T.Y, Development of knowledge management in integration management systems in order to increase the organisational performance of construction companies, 2015.

Ministry of Finance , The Ministry of Finance of The Republic of Indonesia, 2021.

Mourougan, S, Planning Integrated Management System audit to ensure Conformance, Consistency and Continual Improvement, *OSR Journal of Business and Management (IOSR-JBM)*, vol. 17,no. 10, pp. 41–53, 2015.

Or, S. H. , Innovative construction safety auditing system under smart contract platform: Construction Safety Audit with Blockchain (CSAB 2020).

(Outstanding Academic Papers by Students (OAPS), City University of Hong Kong) , 2020.

Park, S., Park, C. Y., Lee, C., Han, S. H., Yun, S., and Lee, D. E. (2022). Exploring inattentional blindness in failure of safety risk perception: focusing on safety knowledge in construction industry. Safety science, 145, 105518, 2022.

PMBOK 6th Edition, PMBOK 6th Edition, A Guide to The Project Management Book of Knowledge), in *Project Management Institute*, pp. 7–8, 2017.

Putra Lim, A. W., and Latief, Y, The Development of Safety Plan Using Work Breakdown Structure (WBS) for Building Information Modeling (BIM)-Based Building Structure Work. Journal of Computational and Theoretical Nanoscience, vol. 17, no. (2-3), pp. 1402-1413, 2020.

Riantini, L.S. *et al.* , Structural Equation Model Relationship Between Policy , Work Breakdown Structure (WBS), Guidelines , Information System (IS), and Building Information Modeling (BIM) on Maintenance Perfomance of High Rise Building, 13(10), pp. 2660–2667, 2020.

Rodgers, W., Mubako, G.N. and Hall, L, Computers in Human Behavior Knowledge management : The effect of knowledge transfer on professional skepticism in audit engagement planning, *Computers in Human Behavior*, vol. 70, pp. 564–574, 2017.

Sharma, S.K. and Swain, N. , Risk Management in Construction Projects, *Asia Pacific Business Review*, vol. 7,no.3, pp. 107–120, 2011.

Shrode, W.A. and Voich, D. , *Organization and management: Basic systems concepts*. McGraw-Hill/Irwin., 1974.

SungJoon, P., Chan Young, P., Changjun, L., Seung Heon, H., Sungmin, Y., and Dong-Eun, L. , Exploring inattentional blindness in failure of safety risk perception: Focusing on safety knowledge in construction industry. Safety Science, 145, 105518, 2022.

Suraji, A., Duff, A.R. and Peckitt, S.J, Development of causal model of construction accident causation, *Journal of construction engineering and management*, vol. 127, n o.4, pp. 337–344, 2001.

Zhang, S., Sulankivi, K., Kiviniemi, M., Romo, I., Eastman, and C.M., Teizer, J, BIM-based fall hazard identification and prevention in construction safety planning. *Safety Science*, 72: 31-45, 2015.

Zou, P. X. W., Lun, P., Cipolla, D., and Mohamed, S. , Cloud-based safety information and communication system in infrastructure construction. Safety Science, 98, 50–69, 2017.

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