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Developing 8D Building Information Modeling and Virtual Reality to Minimize Safety Hazards In Construction Building Projects

Jati Utomo Dwi Hatmoko[a*], Fajar Mega Rakhma[b], Naufal Sultan Azzam Khan[c], and Frida Kristiani[d]

[a,b,c,d]Departement of Civil Engineering, Diponegoro University, Semarang, 50275, Indonesia

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Abstract

Construction accidents remain a significant challenge in the construction industry. One of the biggest challenges is to design and communicate the safety plan of the project to all parties and people working on the construction site. The emergence of 8D Building Information Modeling (BIM) represents a technological advancement focusing on project safety, yet its implementation remains limited globally, including in Indonesia. This research was aimed to develop an 8D BIM model of a building project which allow project stakeholders to plan and examine the safety aspect of the project via virtual reality (VR). The digital model allows stakeholders to virtually identify construction hazards, plan the placement of safety equipment, and simulate safety protocols before implementation. It also facilitates clearer communication of safety plans to stakeholders and provides a realistic project experience via VR. This study marks an initial effort to leverage 8D BIM in construction projects, aiming to improve safety management by preemptively addressing potential accidents on-site.

Keywords: 8D BIM; Virtual Reality; Construction Safety; Hazard Identification; Safety Management

1. Introduction

Work accidents in the construction industry are the largest contributor to fatal accidents in the world (Wahyuni et al., 2022). The construction industry sector has the largest number of fatalities, which account for approximately 20% of the total fatalities. United States Bureau of Labor Statistics data shows that as many as 1,056 construction workers died while working in 2022. Of these deaths 349 people (39.9%) were caused by falling from a height, 74 people (8.5%) due to electricity, 73 people (8.4%) falling objects, and 12 people (1.4%) due to other accidents (United States Department of Labor, 2014). These data suggest the poor implementation the Construction Safety Management System (CSMS) in the construction industry.

The CSMS serves as a guideline in realizing work safety on construction projects, and this is actually the first step to prevent work accidents on construction work, as well as to minimize safety risks of a project. However, inefficiencies are still evident in the current methods used for processing and planning related to safety and health on construction projects (Abraham et al., 2024). One of the major obstacles to effective safety planning is that traditional safety planning still largely relies on paper-based 2D drawings and schedules to understand the need for safety equipment at construction sites (Chantawit et al., 2005). The construction industry needs to address the inefficiencies of the paper-based and manual safety processes currently in use (Zhang et al., 2013).

Building Information Modeling (BIM) as one of the latest technologies is able to provide convenience for construction professionals to manage a construction project. BIM is not only able to present 3D models to integrate the wishes of designers and contractors, but also has other dimensions that can overcome time-spatial, safety, sustainability and other problems. The growing implementation of BIM in the Architecture/Engineering/Construction (AEC) and Facilities Management (FM) industries is changing the way safety is approached (Zhang et al., 2013). The application of BIM is currently increasing rapidly in the planning and management of construction operations and also in safety management (Zhang et al., 2015).

This technological development in the construction world can be utilized as a first step to improve construction work safety. One of the starting points is to emphasize safety aspects early on in the design and engineering phase of the building (Zhou et al., 2012). The use of BIM can provide a risk assessment of safety hazards in construction projects, identify imminent hazards from the planning stage and recommend controls to ensure worker safety. This research was aimed to develop an 8D BIM model of a building project which allow project stakeholders to plan and examine the safety aspect of the project via virtual reality (VR). The objectives of this study were to visualize construction work safety planning,

*) Corresponding author: jati.hatmoko@ft.undip.ac.id

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identify the placement of construction safety equipment visually, and simulate the project conditions into virtual form as a means of inspection with virtual reality. The novelty of this research is to visualize construction work safety planning with BIM 8D integrated with virtual reality in identifying hazards and work safety to prevent and minimize construction work accidents in building construction projects.

2. Previous Research Studies

In previous research developed BIM in construction safety modeling and planning more specifically discussed the prevention of height fall hazards in building projects (Kiviniemi et al., 2011). The purpose of the research is to investigate how potential fall hazards are integrated into construction project scheduling and identified and planned early in the construction project planning stage. In their research, two forms of case studies were used. The first case study highlighted the comparison of manual vs automated safety modeling of fall protection systems. The research also describes details for several as built designs and scenarios where protective safety equipment is modeled. The second case study presents the results of applying the framework to a project schedule. It specifically simulates the detection and prevention of fall hazards. The results of the modeling showed effectiveness in detecting and visualizing potential hazards, especially falls from height during the design and construction safety planning stages.

The second previous research discussed BIM-based procedures and construction professional needs for BIM tools (Zhou et al., 2012). This research is known as the BIM Safety research project by considering several things as the main idea of using BIM in order to improve construction work safety including BIM-based safety planning, risk analysis and evaluation of safety-related plans with the help of BIM, 3D and 4D visualization in construction safety-related communication. The research was conducted with seven different field trials during the research to test and realize the ideas with the following research results.

The third previous research examines the BIM methodology for building safety planning and shows the potential of this technology for the integrated application of safety measures during the design and construction site management phases (Rozenfeld et al., 2010). The research resulted in safety-based construction modeling, namely modeling the installation of safety guardrail, safety scaffolding, construction site preparation, scaffolding and exterior walls execution and complete modeling related to construction safety. It also highlights that using BIM can optimize the construction process, making it possible to plan effective safety measures across space and time through 4D BIM simulation, with real-time control and work planning knowledge.

All three of previous studies discussed the use of BIM 8D as a planning tool in minimizing construction work accidents. Where all three use different applications and different focuses in making construction work safety planning modeling research. The new research to be carried out also has several differences from what has been done by the three previous researchers listed in table 1.

Tabel 1. Differences between Previous Research and Research Conducted

Distinguishing Indicator	Previous Research Studies			Previous Research Studies
	(Zhang et al., 2015)	Kiviniemi et al., 2011)	(Rodrigues et al., 2022)	
	Investigate how potential fall hazards are integrated into construction project scheduling and identified from the beginning of the project planning stage construction.	Safety planning can be part of 4D BIM planning.	Know the benefits and technology of BIM for construction work safety	Visualize work safety planning with BIM, identifying the placement of construction safety tools and virtually simulate project conditions for inspection.
The software used	Tekla	Tekla	Naviswork	CerTus HSBIM
Boundary Model	Limited to modeling the planning of the placement of safety devices to minimize falls from height and fall from height scenarios.	Limited to BIM 8D modeling which is used as a tool to identify potential work accidents and the placement of safety equipment.	Time-integrated modeling as a means of detecting equipment and work accidents at every stage of construction.	Limited to modeling the design of safety equipment safety equipment, work accident identifiers integrated with scheduling and modeling results for virtual inspection tools. modeling results for virtual inspection tools.
Modeling Result Modeling Result	Produced building modeling with a safety rule checking platform developed to detect and prevent falls from height	Produce a tool layout model, BIM-based 3D safety fence	Produce safety-based construction modeling, namely modeling the installation of safety	Produce building modeling that is integrated with scheduling from the

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Distinguishing Indicator	Previous Research Studies			Previous Research Studies
	(Zhang et al., 2015)	Kiviniemi et al., 2011)	(Rodrigues et al., 2022)	
	with Building Information Modeling that was successfully implemented in two case studies.	component model, visualization of wall demolition work and its risks, visualization of fall prevention from virtual spaces, and building safety inspectors.	guardrail, safety scaffolding, construction site preparation, scaffolding and exterior walls execution and complete modeling related to construction safety.	beginning of the construction process to the end, planning the use of safety equipment. safety equipment at each stage of construction and certain locations, datasheets as a safety data storage for each stage of construction. construction stage.

3. Traditional Method of Construction Risk Analysis and Safety Planning

Safety risk analysis is an important process to prevent construction work accidents (Kiviniemi et al., 2011). Other research have been carried out to develop a construction work safety analysis to identify potential loss-of-control events and to assess the likelihood of construction work accidents (Rozenfeld et al., 2010), a construction safety level index for tower crane operations (Shapira et al., 2012), and a safety risk level quantification method for concrete formwork construction (Hallowell & Gambatese, 2009).

Although research has concentrated on developing safety risk levels using technology proactively (Cheng et al., 2011; Cheng & Teizer, 2013; Teizer et al., 2013), there has been no approach on how data can be integrated for practitioners to use easily (Zhang et al., 2015). This shows that there has been no integrated construction safety planning in previous studies. Therefore, it is important to investigate more advanced methods to integrate information in construction safety planning.

4. Modeling in Construction Safety Planning

Emerging technologies in construction including simulation, visualization and computer-aided databases provide new opportunities to improve construction safety planning (Zhang et al., 2015). Implementation of the Prevention through Design (PtD) concept in BIM 8D is divided into 3 components: hazard profiling of BIM model elements, providing safe design suggestions for revising hazard profile elements, and performing on-site risk control for hazards that cannot be controlled through design revisions (Kamardeen, 2010).

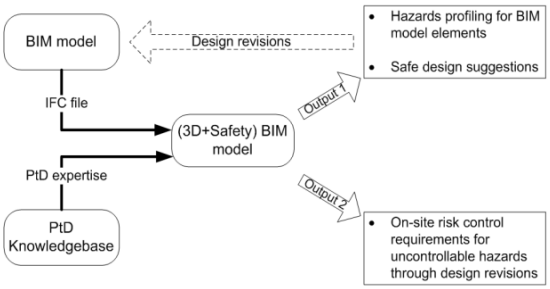

Fig. 1. PtD-based 8D BIM.

BIM has been rapidly recognized to transform the construction project process into a more efficient one. BIM can be utilized to promote safety management, and combine safety with other construction planning processes (Zhang et al., 2015). Research conducted in Finland has developed a detailed framework for fall protection modeling and 4D visualization (Kiviniemi et al., 2011). The work includes modeling temporary safety structures and equipment required to carry out safe construction work. It also models the permanent installation of safety equipment in buildings for the construction, operation, and maintenance stages.

Efforts have also been made to uncover best practices to improve collaborative planning procedures between general contractors, designers and subcontractors. These existing studies certainly pave the way to improve safety planning and hazard identification using BIM, while compared to manual processes, a smarter approach is needed to provide automatic and time-saving safety rule checks.

In addition, a research has been conducted to produce safety-based construction modeling, namely modeling the installation of safety guardrail, safety scaffolding, construction site preparation, scaffolding and exterior walls execution and complete modeling related to construction safety (Rodrigues et al., 2022). This modeling aims to determine the benefits and technology of BIM for construction safety integrated with time. Additional knowledge on safety, time, and technical resources are required in BIM-based planning activities to facilitate practical implementation. Thus, it would be beneficial for practitioners to understand the modeling and benefits

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of such BIM-based hazard detection and prevention tools before they are implemented in the field on a larger scale.

5. Research Methods

The research was started by extracting data from the building of Faculty of Public Health Diponegoro University as a reference model. This data includes construction work safety risk information from journals and previous research. Using this data, researchers create a BIM model integrated with Virtual Reality (VR) for construction safety planning. The analyzed modeling includes 3D and 4D BIM-based visualization for construction safety planning, placement identification of safety equipment, and virtual simulation of project conditions using Virtual Reality (VR) for inspection purposes.

Fig. 2. Building Object.

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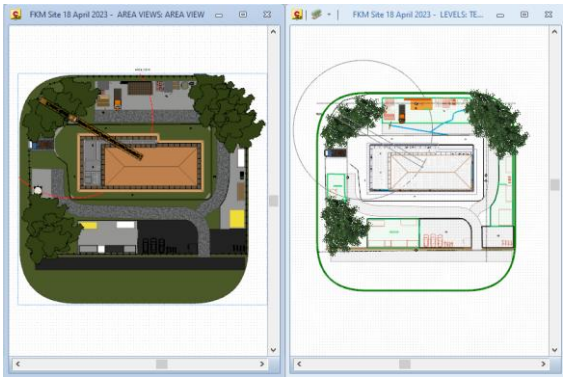
6. Developing The 8D BIM Model

This 8D BIM model visualizes the entire construction process, focusing on safety, from foundation to architectural completion. It depicts the tools used, project site layout, worker visualization, project signs, and simulates work accidents due to tool misplacement. Construction safety modeling visualization is enhanced through real-time rendering, allowing users to explore the project site in detail, viewing objects precisely as needed (Figures 3 and 4).



(a)

(b)

Fig.3. (a) 2D Modeling Visualization Results; (b) 3D Modeling Visualization Results

Fig.4. Realtime Rendering Feature

In this BIM model, safety experts can proactively identify potential construction site accidents through visual hazard assessments at each construction stage. Hazard identification results are documented in datasheets within the model, serving as guidelines and reminders throughout the construction process. These datasheets detail job-specific hazards that integrate into scheduling, allowing safety experts to foresee

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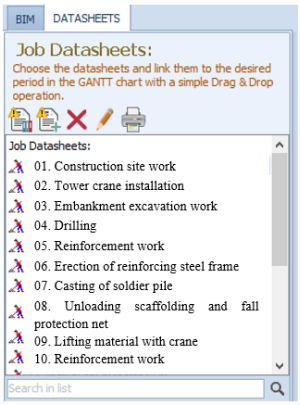
potential accidents during specific timeframes. This foresight facilitates timely preventive measures (Figure 5).

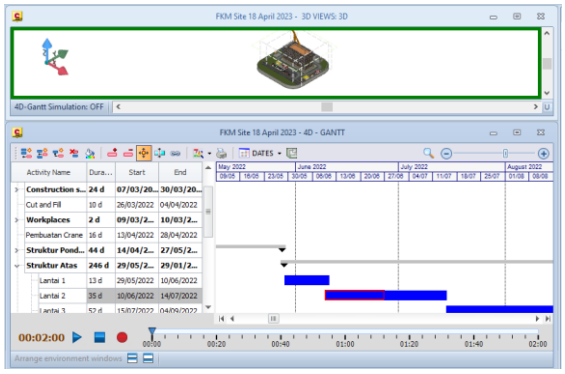


(a)

(b)

Fig.5. (a) The shape of the datasheets, (b) The shape of each job datasheet

The CerTus HSBIM application focuses on identifying construction accident hazards during planning rather than detecting them in real-time. It serves to guide safety experts by storing hazard data for reference throughout construction. Additionally, the modeling generates 4D scheduling that outline project stages, durations, tools used, job-specific hazards, and required personal protective equipment (Figure 6). This scheduling aids in minimizing equipment downtime and costs, allowing safety experts to prepare effectively for future needs.

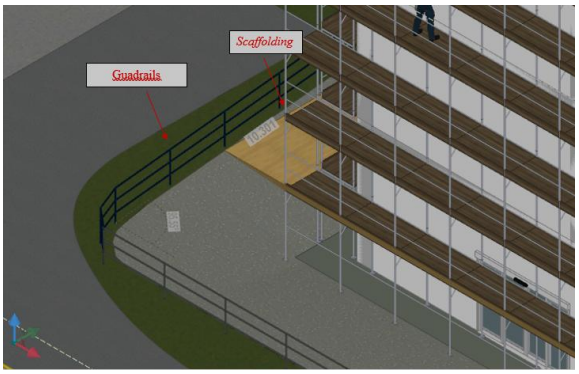


(a)

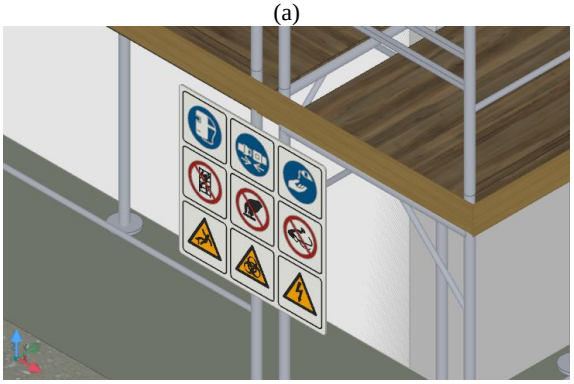
(b)

Fig.6. (a) Construction safety modeling schedule; (b) 4D Realtime Rendering Visualization Results

From this modeling in CerTus HSBIM, safety experts can strategically plan the placement of safety equipment tailored to specific construction needs, locations, and stages. This includes work protective equipment such as scaffolding, safety fences, and safety nets, as well as heavy equipment and safety signs required on the project site. Planning ensures efficient deployment and minimizes errors during installation, expediting the construction process (Figure 7).



(a)



(b)

Fig.7. (a) The results of the placement of work protective equipment; (b) The results of the placement of work safety signs

Data sheets in CerTus HSBIM facilitate safety experts in preparing personal pro-tective equipment (PPE) and tools required for each construction stage,

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streamlining planning and ensuring readiness throughout the construction process.

Fig.8. Datasheets

In CerTus HSBIM modeling, identifying tools helps safety experts efficiently adjust their quantities based on safety or efficiency concerns. However, the application has limitations in automatically quantifying tool usage; quantities must be estimated manually during planning stages. Building modeling in CerTus HSBIM is restricted to Revit imports for basic structures and predefined safety and worker components. It requires user-created scenarios for visualizing work accidents, as automatic dis-play of such incidents is not supported. 2D prints are available but only show site layouts, lacking floor or room cross-sections. Safety equipment in the software adheres to Italian standards, necessitating manual addition of components meeting Indonesian standards in terms of size and quantity tracking. Automated quantity tracking may be achieved through custom programming with applications like Solibri.

7. Simulation of 8D BIM With Virtual Reality

The 8D BIM model can be used as a means of simulation and safety training for safety officers before carrying out their duties in the project. This virtual model enable them to understand and know the conditions of the project. The use of the 8D BIM model integrated with virtual reality produces an immersive simulation that makes the safety officers feel that they are really in the real project. Figure 9 shows the researcher run the simulation experiment of work safety planning using the 8D BIM model integrated with virtual reality (VR)

(a)

(b)

Fig. 1. (a) Simulation experiment using Virtual Reality; (b) Virtual reality feature on CerTus HSBIM

From this simulation, a new experience is obtained where with the use of VR the user will feel that he/she is in the building project and can conduct virtual inspections of the project to find some improvement related to safety aspect of the project. This model can be used as a learning tool for a new safety officer to feel being in the project without having to visit the project.

There are several features that can be used by safety officers using CerTus HSBIM and VR, for example: changing the situation around the project, including the weather, adding or removing components of project safety equipment, and opening the files needed. These features are useful as a means of making corrections to the model or as a means for novice safety officers to practice. A safety officer can also witness activities carried out in real time at certain stages of work, such as at the upper structure and lower structure stages. But in this model a safety expert can only see activities or events that have been designed beforehand, such as workers falling from a height. He or she cannot see and trial and error the possibility of events that can occur through virtual reality.

8. Conclusion

This research has successfully developed an 8D BIM model of a building project using CerTus HSBIM, which allow safety officers to plan and examine the safety aspect of the project via virtual

reality (VR). The ultimate digital model facilitates the virtual recognition of potential hazards throughout every phase of construction, the strategic arrangement of safety equipment on-site, and the modification of safety protocols before actual implementation. Furthermore, this digital model aids safety officers in effectively conveying safety plans to project stakeholders and experiencing project conditions more authentically through VR simulations. This study marks the initial endeavor to improve the utilization of 8D BIM within construction projects. The proposed model is anticipated to enhance safety management, allowing for more effective anticipation of potential accidents on construction sites. This 8D BIM model is merely an initial attempt with some limitations, future research can be done by developing more comprehensive model for different types of projects utilizing various 8D BIM software, which might allow more useful features to be explored in terms of safety aspect.

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