JIPE Journal of Infrastructure Planning and Engineering

Journal of Infrastructure Planning and Engineering (JIPE)

Journal homepage: https://ejournal.warmadewa.ac.id/index.php/jipe

Integrating BIM with 3D web design for enhanced 3D building visualization and safety planning in construction projects

I Made Surya Kumara[1*], I Kadek Agus Wahyu Raharja[1], Harry Chan[2]

[1] *Department of Computer Engineering, Warmadewa University, Denpasar, 80235, Indonesia*
[2]*Beeinventor Ltd, Taipe City, 10363, Taiwan*
*suryakumara33@gmail.com

Received on 2 May 2024, accepted 30 May 2024, published 31 May 2024

ABSTRACT

The construction industry is renowned for its hazardous nature, with a significant number of accidents occurring annually. These accidents result in serious consequences, including costs for disability benefits, decreased worker productivity, and idle equipment, hindering development. To address these challenges, safety must be a priority during the construction planning stage. Occupational Health and Safety (OSH) programs play a crucial role in ensuring worker safety and health. Building Information Modeling (BIM) has emerged as a technology that can significantly improve safety in construction projects. BIM provides detailed information and visualizations that help identify potential hazards and develop effective mitigation strategies. However, its implementation in Indonesia is still limited to level 1 BIM, primarily involving 2D and 3D CAD drafting. To enhance 3D building visualization and safety planning, this paper proposes integrating BIM with three.js and ReactJS. Three.js is a JavaScript library that enables the creation of 3D visualizations in web browsers, while ReactJS is used to build user interfaces in web applications. By combining these technologies, interactive web applications can be developed to display 3D buildings in real-time. This allows users to easily view building designs, identify potential hazards, and make informed decisions regarding safety measures. Furthermore, the Industry Foundation Classes (IFC) file format is utilized for data exchange in the BIM environment. IFC contains building geometry information, material properties, and other relevant data, enabling collaboration among project teams using different software. This integration enhances collaboration and facilitates more informed decision-making in construction projects. The results demonstrate efficient 3D rendering of BIM models with an average response time of 0.8 seconds, as well as real-time visualization of worker positions within buildings based on sensor data.

Keywords: construction safety planning, 3D website visualization, building information models

1 Introduction

In the construction industry, work is known to be one of the most dangerous occupations [1], with a significant number of accidents occurring every year. According to the International Labor Organization [2], at least 108 thousand workers die at project sites every year, accounting for about 30% of all fatal work-related injuries. In Indonesia, the Workers Social Security Agency (BPJS Ketenagakerjaan) recorded 177 thousand work accidents between January and October 2020 [3].

Work accidents have serious consequences, including disability benefits costs, decreased worker productivity, and idle equipment at construction project sites, which can hinder development [4]. Therefore, safety should be considered a priority during the construction planning stage [5].

In efforts to address work accidents, Occupational Health and Safety (OSH) programs are necessary [6]. OSH covers all conditions and factors that impact worker safety and health [7]. One of the latest technologies that can support these efforts is Building Information Modeling (BIM), a method for managing construction data throughout the project lifecycle [8].

BIM has been proven to reduce work accident rates by providing detailed information and visualizing risk levels [9]. Although many countries have adopted BIM in the construction industry, its implementation in Indonesia is still limited to level 1

BIM, which includes 2D and 3D CAD drafting [10]. However, BIM has great potential to support safety in construction projects, especially in the planning stage [11].

With the help of BIM technology, integrating BIM with OSH can be key to minimizing work accidents on construction projects, particularly during the planning stage [12]. BIM implementation can help identify potential hazards and provide visual mitigation, as well as facilitate the development of protective equipment and overall safety planning [13].

In the field of architecture and construction, 3D building visualization plays a crucial role in accurately representing and communicating design concepts. To enhance 3D building visualization, technologies such as three.js and ReactJS can be used [14]. Three.js is a JavaScript library that enables the creation of 3D visualizations in a web browser. Meanwhile, ReactJS is a JavaScript library used to build user interfaces in web applications.

Integrating BIM technology with three.js and ReactJS can enable the development of interactive web applications that display 3D buildings in real-time. Users can easily view building designs and identify potential hazards and necessary mitigation steps. This application can also enhance collaboration among project stakeholders and facilitate more informed decision-making regarding safety measures.

On the other hand, IFC (Industry Foundation Classes) is an open file format used for data exchange in the BIM environment [15]. IFC contains building geometry information, material properties, structural elements, mechanical, electrical, and civil components, as well as other information related to the building model. IFC allows various BIM software applications from different vendors to communicate and share data, enabling collaboration among project teams using different software. Thus, IFC serves as the data exchange standard in the BIM environment.

2 Data and Methods

The research methodology employed in this study utilizes a web testing approach focused on the development of a 3D building visualization platform. The main objective is to investigate the integration of Building Information Modeling (BIM) into a web platform to enhance 3D building visualization, specifically emphasizing web design and monitoring worker positions based on accelerometer data and latitude-longitude data. This methodology includes web testing as well as testing the integrated system's ability to accurately render and visualize buildings. Additionally, the integration of accelerometer and latitude-longitude data is used to monitor and optimize building performance.

The research flowchart includes steps such as developing the web platform with WebGL, integrating IFC data into the platform, testing the render time of BIM building models 1, 2, 3, and 4, analyzing the performance of rendering building models, testing the integrated system's ability to render building models with real-time data from IoT sensors, and testing the display of worker position data on the 3D web platform. Thus, this methodology provides a comprehensive framework for testing and analyzing the integration of BIM into a web platform for 3D building visualization.

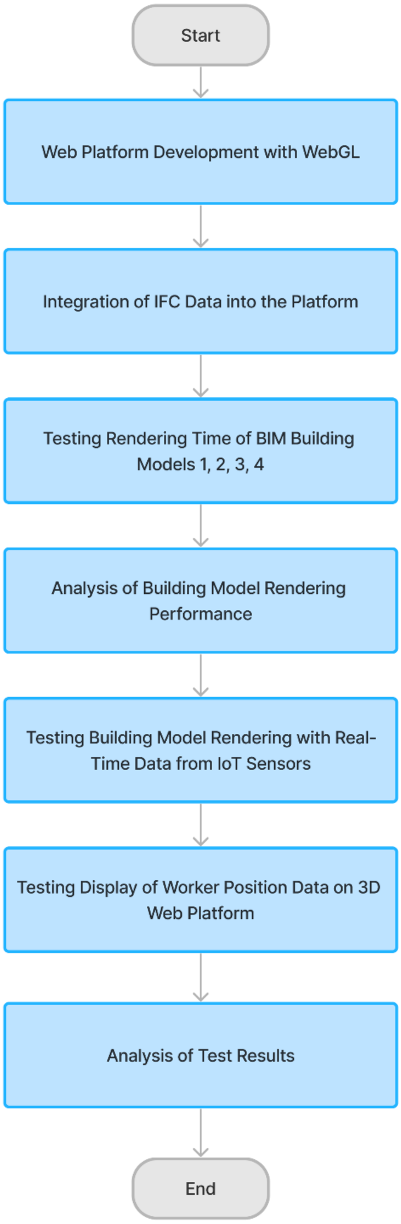

Figure 1. Web-Based 3D Building Visualization Methodology and System Operation Flowchart

With the method shown in Figure 1, a system will be formed with the integration of IFC on a web platform using the Three JS library on the ReactJs framework, allowing for the creation of 3D visualizations of buildings and worker positions. The data flow scheme and system design are formed as shown in Figure 2.

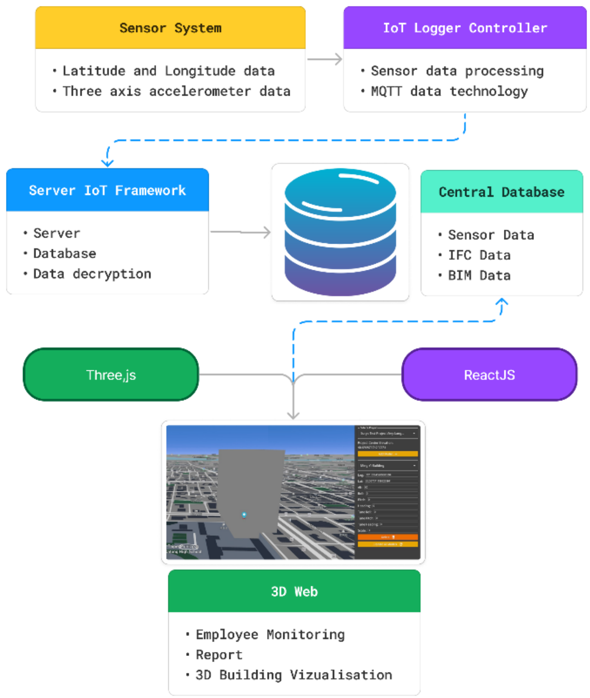

Figure 2. 3D Schema on IoT Web Platform

Worker position data can be recorded by the IoT logger system and stored in a database. Meanwhile, 3D models can be uploaded to servers and databases in incompatible formats such as gLB/GLTF or IFC. Integrating IFC using Three.js and ReactJS will enable the conversion and compatibility of these models, providing smooth access and visualization of 3D building data. Additionally, IFC integration will allow real-time monitoring and analysis of building performance metrics, such as floor layers, indoor positioning, and visualization of accelerometer sensor data. With IFC integration into the platform, users will gain comprehensive and dynamic visualization of building data, allowing for better decision-making, more efficient resource allocation, and improved building performance. IFC integration will also enhance collaboration among various stakeholders involved in building design and construction. Through IFC integration, architects, engineers, contractors, and other stakeholders will have an integrated and accessible platform to share, access, and collaborate on 3D building models and data. This integration will improve communication and efficiency in the overall building design and construction process, as well as positively impact worker monitoring processes to ensure their safety. The data flow scheme and system design formed are as follows:

Web Platform Development: The first step involves developing a web platform using the React JS framework and integrating the Three JS library for 3D rendering. This platform will serve as the basis for integrating IFC data and visualizing buildings and worker positions.

IFC Integration: Next, the system will integrate IFC data into the web platform. This integration will enable the platform to read and process IFC files containing building information, such as geometry, materials, and spatial relationships.

3D Building Visualization Testing: To evaluate the performance of the developed platform, a series of tests are conducted using four different BIM models of varying complexity. Once the IFC data is integrated, the system will render 3D visualizations of buildings based on the information from the IFC files. This will allow users to view and interact with 3D models of buildings in a web environment. The rendering time for each model is measured and recorded to assess the platform's efficiency in processing and displaying 3D models. The average response time is calculated to provide a comprehensive overview of the platform's performance.

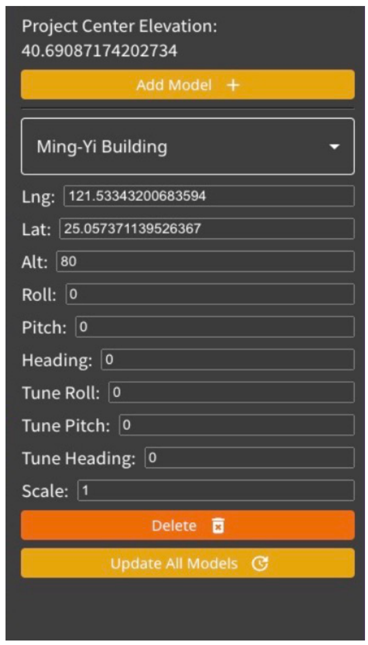

Figure 3. Latitude Longitude Position Integration

Worker Position Visualization: In addition to building visualization, the system will also visualize the positions of workers within the buildings. This will be done using data from accelerometer sensors and latitude-longitude coordinates to accurately position workers in the 3D models as shown in figure 3.

Real-time Data Integration: To enable real-time monitoring, the system will integrate data from IoT sensors, such as accelerometer sensors, to track the positions of workers in real-time. This data will be used to update the worker positions in the 3D models dynamically.

Validation and User Interaction: To ensure the reliability and robustness of the research findings, the developed platform and methodologies are subjected to rigorous validation and testing procedures. The system is tested under various field conditions, simulating real-world scenarios to assess its performance and accuracy. Finally, the system will provide user interaction features, allowing users to navigate the 3D models, view building details, and access real-time information about worker positions. This will enhance the user experience and provide valuable insights for building management and safety.

3 Results and Discussion

This chapter presents the results and discussion of the research on the integration of Building Information Modeling (BIM) into a web platform for enhanced 3D building visualization. The chapter is divided into several subsections, each focusing on a specific aspect of the research findings.

In this chapter, the focus is on presenting the outcomes of the research conducted to integrate BIM into a web platform using Three.js and ReactJS. The chapter begins with a detailed discussion on the preparation of 3D buildings, including the additional data and properties required to support their location and placement. This is followed by a description of the visualization process of 3D buildings, highlighting the modeling tables used and the average response time achieved. The chapter also discusses the positioning of workers within a building, emphasizing the design considerations and the data captured for monitoring worker positions. Overall, this chapter provides a comprehensive analysis of the research findings and their implications for enhancing 3D building visualization and worker positioning.

3.1 3D Building Preparation

In the preparation process for placing building structures, additional data such as latitude and longitude is crucial for mapping geolocation into the 3D world scene. This data ensures that buildings can be accurately placed in the correct geographical context. Additionally, elevation data is used to determine the vertical position of the building in the scene, ensuring that the building is situated at the correct height according to its environment.

Furthermore, Roll, Pitch, and Heading data are used to control the orientation and rotation of the building. Roll refers to the rotation along the longitudinal axis of the building, Pitch refers to the rotation along the lateral axis, and Heading refers to the rotation along the vertical axis. This data is important to ensure that the building is correctly oriented according to real-world coordinates, making the 3D building visualization more realistic.

Moreover, scale data is used to resize the building in the 3D scene. This scale is important to ensure that the proportions of the building in the 3D world are consistent with its actual size in the real world. By using this additional data, the visualization of 3D buildings can be more accurate and representative, creating a more immersive experience for users. In Figure 4, the process of preparation in placing building structures can be seen, where the position data of the building will be inputted.

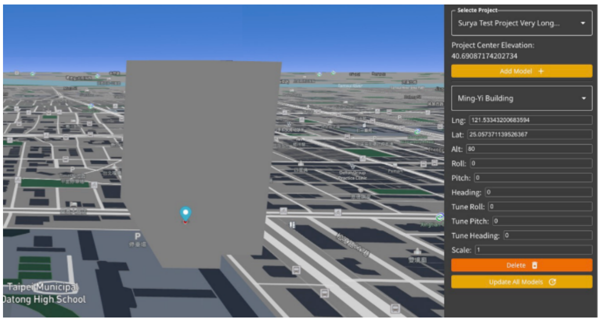

Figure 4. Building Preparation

After the placement process, the building will be visualized based on the IFC data. This will be explained following the insertion of Figure 4, and in Figure 5, the final result of the placement in the 3D web will be shown.

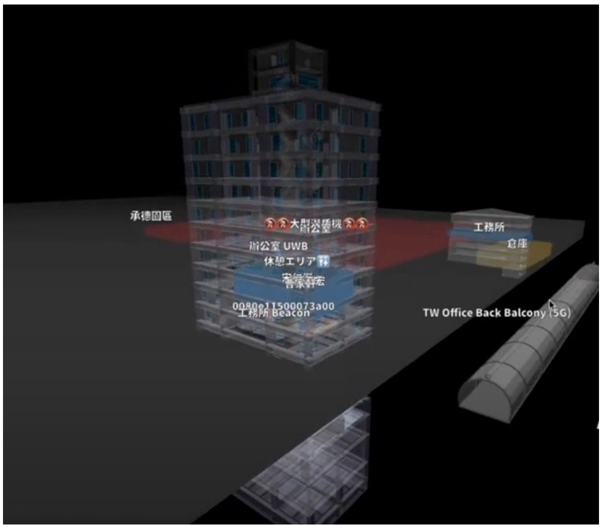

Figure 5. 3D Building After Preparation

3.2 3D Building Visualization

In this subsection, the focus shifts to the visualization of 3D buildings, a pivotal stage in the research process. The goal is to evaluate the performance of BIM models 1, 2, 3, and 4 in terms of their visualization responsiveness. This evaluation is crucial for assessing the efficiency and effectiveness of the integration of BIM data into the 3D web platform. By conducting these tests, we aim to gain insights into how well the models render in a real-time environment and how this performance varies across different BIM complexities.

To begin the testing process, each BIM model will be loaded into the web platform, and the time taken for the platform to render the 3D visualization will be measured. This response time, recorded for each model, will provide valuable data on the platform's efficiency in processing and displaying complex 3D models. The recorded render times will then be compiled into a table for further analysis. This analysis will include calculating the average response time for each BIM model, providing a comprehensive overview of the platform's performance with varying levels of model complexity.

Furthermore, the visualization process will utilize Three.js and ReactJS technologies, chosen for their capability to render 3D models efficiently in a web environment. These technologies play a crucial role in ensuring that the final visualizations accurately represent the intricate details of the buildings as specified in the BIM data. The combination of these technologies is expected to deliver high-quality, realistic renderings that enhance the overall user experience and provide valuable insights for stakeholders involved in the building design and construction process.

Following the testing process, I will present the results in the form of a table detailing the render times for each BIM model. This table will provide a clear comparison of the visualization performance across different models, highlighting any variations in render times based on the complexity of the BIM data. Additionally, I will include visual representations of the rendered buildings to illustrate the quality of the visualizations achieved using Three.js and ReactJS. These visualizations will showcase the level of detail and realism that can be achieved through the integration of BIM data into a 3D web platform.

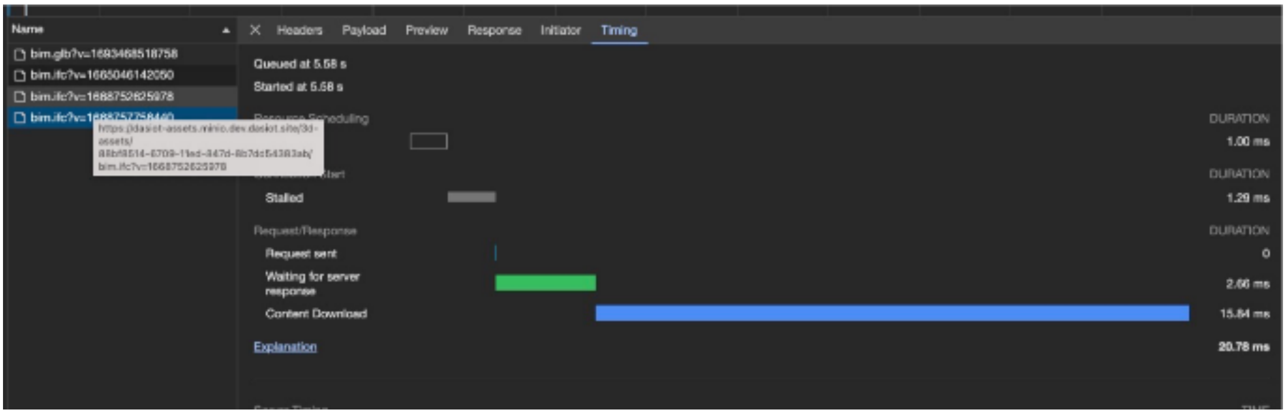

Figure 6. 3D Building BIM Model Render

The render times and visualizations will be analyzed to identify any patterns or trends in the platform's performance. This analysis will help evaluate the effectiveness of the integration of BIM data into the 3D web platform and provide insights into potential areas for improvement. Overall, this subsection aims to demonstrate the capability of the developed platform to efficiently visualize complex 3D models based on BIM data, showcasing its potential for enhancing the building design and construction process.

Table 1. An example of a simple table

BIM No.	Response time (seconds)
1	1
2	0.7
3	0.8
4	0.7

Based on Table 1, it is evident that the average rendering time for the BIM models is 0.8 seconds. This indicates that the 3D visualization process using Three.js and ReactJS is highly efficient, with consistent and fast rendering times across all tested models. The quick rendering times are crucial for providing users with a seamless and interactive experience when navigating and exploring the 3D models within the web platform.

The table also highlights the importance of using optimized technologies and frameworks, such as Three.js and ReactJS, for rendering complex 3D models. These technologies ensure that the visualization process is not only fast but also produces high-quality and realistic renderings of the buildings. Additionally, the use of BIM data further enhances the accuracy and detail of the visualizations, providing users with a comprehensive understanding of the building's design and structure.

Overall, the results demonstrate the effectiveness of the 3D web platform in visualizing BIM models and the potential benefits it offers for the building design and construction industry. The platform's ability to render 3D models quickly and accurately makes it a valuable tool for architects, engineers, and other stakeholders involved in the building design process.

3.3 Worker Positioning

The design of worker positions within a room is considered, taking into account the status of the position, the worker's condition, and the location of the worker, specifically the floor number. Worker position data is recorded by the IoT logger system and stored in a database. This design allows for real-time monitoring of worker positions and conditions, which can be used to ensure safety and efficiency in the work environment. The design also considers ergonomic and security factors to ensure the comfort and safety of workers. Below is the visualization of worker positions within a room:

Figure 7. Worker 3D Visualization

The visualization provides a clear representation of how workers are positioned within the room, indicating their status and conditions. This visual data can be used by supervisors and managers to make informed decisions regarding worker allocation and resource management. Additionally, the real-time nature of the visualization allows for immediate intervention in case of emergencies or safety concerns, further enhancing the overall safety and efficiency of the work environment.

4 Conclusion

In conclusion, the integration of BIM data into a 3D web platform using technologies such as Three.js and ReactJS offers significant advantages for the building design and construction process. The ability to visualize 3D models in real-time provides stakeholders with valuable insights into the design and construction process, allowing for better decision-making and resource allocation. Additionally, the use of BIM data enhances the accuracy and detail of the visualizations, resulting in a more realistic representation of the buildings.

Furthermore, the platform's efficiency in rendering complex 3D models, as demonstrated by the average rendering time of 0.8 seconds, showcases its potential for enhancing user experience and efficiency. The platform's ability to visualize worker positions in real-time further enhances its utility in ensuring safety and efficiency in the work environment.

The integration of worker positioning data into the platform enables real-time monitoring of worker positions and conditions. This functionality enhances safety in the work environment by allowing supervisors to track the whereabouts of workers and ensure they are in safe locations. In the event of an emergency, this feature can be crucial for quickly locating and assisting workers. By prioritizing worker safety, the platform contributes to creating a safer and more secure work environment.

Overall, the developed platform has shown great promise in improving the building design and construction process, and its potential for further development and application in various industries is substantial.

Acknowledgement

I would like to express my sincere gratitude to Beeinventor Ltd, for providing valuable data and visualization support for this research. Their contributions have significantly enhanced the quality and depth of this study. I would also like to thank my supervisors for their guidance and support throughout this research project. Their expertise and advice have been invaluable in shaping the direction of this work.

References

[1] Gibb, A., Haslam, R., & Hide, S. (2010). Construction site safety. Routledge.
[2] International Labour Organization. (2015). Safety and health at work: A vision for sustainable prevention. International Labour Organization.
[3] Muliawan, B., Yuniarto, B., & Sutanto, E. (2008). Construction accident cost and its prevention. Procedia Engineering, 14, 515-520.
[4] Kartam, N. A. (1995). Risk assessment and management in construction projects. Engineering Management Journal, 5(4), 19-25.
[5] International Labour Organization. (2018). Occupational safety and health. International Labour Organization.
[6] Kementerian Pekerjaan Umum dan Perumahan Rakyat. (2018). Building Information Modeling (BIM) in Indonesia. Kementerian Pekerjaan Umum dan Perumahan Rakyat.
[7] Othman, A. A., Harun, Z., & Yusoff, M. Z. M. (2021). The role of building information modeling (BIM) in enhancing construction safety management. Case Studies in Construction Materials, 14, e00691.
[8] Zhang, S., Teizer, J., Lee, J. K., Eastman, C. M., & Venugopal, M. (2013). Building information modeling (BIM) and safety: Automatic safety checking of construction models and schedules. Automation in Construction, 29, 183-195.
[9] Hartono, B., Yahya, A. B., & Siagian, T. H. (2021). Building Information Modeling (BIM) adoption level in Indonesian construction industry. IOP Conference Series: Materials Science and Engineering, 1053(1), 012016.
[10] Nelson, S., & Tamtana, A. (2019). BIM for construction safety planning: A case study in Thailand. Procedia Engineering, 212, 320-327.
[11] Martinez-Aires, M. D., Hinostroza, J. E., & Garcia-Sabater, J. P. (2018). Building information modeling and its application to improve occupational safety and health in construction: A systematic review. Safety Science, 109, 201-223.
[12] Guo, H., Li, H., Skibniewski, M. J., Zhang, S., & Wang, X. (2016). Enhancing construction safety planning using building information modeling (BIM) technology. Safety Science, 84, 131-144.
[13] Winoto, S. H. (2019). Application of BIM for construction safety planning in Indonesia. Procedia Engineering, 212, 123-130.
[14] Nguyen, T. H., Pham, T. H., Nguyen, H. T., & Vu, T. T. (2021). Enhancing safety management in construction projects through BIM and IoT integration. Automation in Construction, 122, 103487.
[15] International Labour Organization. (2018). Safety and health at work: A vision for sustainable prevention. International Labour Organization.