

Integrating BIM and computer vision for preventing Hazards at construction sites

Si Tran^{1*}

¹Chung-Ang University, Seoul, Korea

*Corresponding author: sitran.cauvn@gmail.com

ARTICLE INFO

DOI:10.46223/HCMCOUJS.tech.en.14.1.2966.2024

Received: September 17th, 2023

Revised: December 20th, 2023

Accepted: January 04th, 2024

Keywords:

construction safety
monitoring; computer vision;
BIM

ABSTRACT

Construction safety monitoring is vital in enhancing site safety, such as tracking entering hazardous areas and the correlation between workers and other hazard entities. Therein, computer vision-based image/video processing, one of the emerging technologies, has been actively used to automatically identify and recognize unsafe conditions. However, the construction site has various potential hazard situations during the project. Due to the site's complexity, many visual devices simultaneously participate in monitoring. It challenges developing and operating corresponding detection algorithms at specific workplaces and times. Besides, safety information detected by computer vision must be organized before being delivered to stakeholders. Hence, this study proposes an approach for construction safety monitoring using vision intelligence technology and BIM-cloud, called BMT. The BMT comprises two modules: (1) the virtual model based on the 4D BIM-cloud model, which provides the spatial-temporal information to decide computer vision algorithm adoptions; (2) the construction physical model built the vision intelligence technologies, which is supported by (1) and deliver safety status and update into the BIM-cloud model to visualize and deliver the risk level to related employees. The efficiency of the BMT approach is validated by testing with the preliminary implementation of a prototype.

1. Introduction

In the construction industry, safety and sustainable development have been straightforward relationships while being affected by three pillars: environment, people, and economy (Nguyen et al., 2020; Tran, Khan, Lee, & Park, 2021). The construction project is usually required by its reliance on money, lengthy construction periods, and large numbers of site workers. Once a safety catastrophe happens on a building site, there will be a significant loss of life and property and severe repercussions. In 2020, according to the most current OSHA data (Occupational Safety and Health Administration, n.d.), the construction sector accounted for 1,008 deaths annually, with falls from heights accounting for nearly thirty-three percent of fatalities. South Korea's construction industry was responsible for over half of all industry-wide fatality incidents (Statistics Korea, n.d.). The consequence reduces the quality of victims' lives, affects their families, and causes environmental and ecological damage. Studies have indicated that creating a safer workplace can lead to a decrease in construction accidents (Cortés-Pérez, Cortés-Pérez, & Prieto-Muriel, 2020). Therein, there is a need to identify the potentially hazardous zones from the planning phase and monitor intrusion during construction. The information can support safety

managers and stakeholders in finding potential hazards and delivering prevention. In particular, technical advancement has become a potent instrument that automatically detects and predicts hazardous events during construction.

Academics and industry professionals have started acknowledging the shifts in construction safety monitoring procedures using automated applications driven by computer vision. The computer vision technique uses the visual data collected from the surveillance systems and analyzes them to detect job site entities automatically through deep learning algorithms. Visual information-based construction safety monitoring has many advantages over traditional methods, such as manual inspection or paper-based documentation, such as higher accuracy, efficiency, reliability, and scalability. For instance, various types of dangerous situations have been investigated in-depth, including not wearing Personal Protective Equipment (PPE) (Khan, Khalid, Anjum, Tran, & Park, 2022), accessing a hazardous location (Tran et al., 2023), and failing to follow safety protocols (Zhang, Shi, & Yang, 2020). However, in a study of research publications published over the previous decade, Love, Matthews, Fang, and Luo (2023) pointed out that previous research concentrated on testing the accuracy of object detectors. Meanwhile, while these technological advancements offer immense promise, they also confront notable challenges and limitations that necessitate thorough examination before widespread adoption. An essential aspect is effectively disseminating hazard detection results to the responsible personnel, such as site supervisors and safety managers.

Furthermore, the integration of BIM has emerged as a transformative strategy for enhancing occupational safety, particularly in construction planning. BIM empowers project teams to devise precise site layouts, formulate safety plans, visualize existing designs innovatively, offer valuable spatial-temporal information, and facilitate seamless safety communication (Tran, Ali, Khan, Lee, & Park, 2020; Tran, Nguyen, Chi, Lee, & Park, 2022). This enables the creation of comprehensive safety strategies and allows for the integration of additional information into the BIM model, serving many purposes throughout the construction lifecycle (Jin, Zhang, Liu, & Yan, 2020; Valinejadshoubi, Moselhi, Bagchi, & Salem, 2021; Zhou et al., 2022). The advent of cloud computing technologies has expedited this integration process, effectively dissolving boundaries across diverse technological domains, for instance, visualizing detection results into BIM models.

This study proposes the development of BMT, a computer vision-based automatic safety status update system with BIM data help. The BMT is divided into two modules: (1) the construction virtual model, which is based on the 4D BIM-cloud model and provides spatial-temporal information to decide computer vision algorithm adoptions; and (2) the construction physical model, which is supported by (1) and delivers safety status and updates into the BIM-cloud model to visualize and deliver the risk level to related employees. Section 2 addresses the current state of construction safety monitoring with computer vision and BIM. Section 3 will outline the proposed approach. In Section 4, the authors developed example scenarios to validate the technique. The final portion contains the conclusion.

2. Literature review

In construction, safety monitoring is crucial as it can quickly identify and address safety and health issues by effectively isolating them from underlying causal factors. Observations and inspections conducted on construction sites have long been utilized in the construction industry to evaluate the potential hazards connected with active construction operations and the prevailing circumstances of the site (Huang, Ninić, & Zhang, 2021; Soltani, Zhu, & Hammad, 2018). Nevertheless, manual monitoring, which heavily relies on periodic visual inspections and paper-

based documentation, possesses intrinsic disadvantages like vulnerability to human mistakes, limited coverage, and a shortage of real-time insights. On the other hand, the construction industry's current state of safety monitoring is characterized by incorporating sophisticated technology. For instance, using Internet of Things (IoT) devices and computer vision systems has become increasingly prominent due to their ability to collect real-time data, ongoing analysis, and immediate alarm generation (Kanan, Elhassan, & Bensalem, 2018; Kim, Liu, Lee, & Kamat, 2019; Tang, Shelden, Eastman, Pishdad-Bozorgi, & Gao, 2019). The start-up company Newmetrix.com has implemented its capacity to distinguish 50 unique safety-related objects (such as rebar caps, hardhats, and ladders) from photographs and videos recorded at over 1,000 construction sites (Newmetrix, n.d.). To prevent hazardous area entry, Tran et al. (2023) developed an IDC4D approach to extract hazardous area objects from the BIM model and then determine the correlation between workers and hazardous area objects. These technological breakthroughs allow the rapid detection of possible threats and the implementation of proactive risk management strategies. This shift represents an enhancement in the construction industry's precision, comprehensiveness, and promptness of safety monitoring protocols.

The use of computer vision technology in safety monitoring protocols has attracted significant interest. Computer vision provides a dynamic and automated methodology for collecting and analyzing real-time data, hence playing a crucial role in improving the effectiveness of safety systems. Computer vision systems can rapidly detect possible risks, risky behaviors, and equipment failures through the utilization of cameras and complex image processing algorithms (Fang et al., 2020; Huang et al., 2021; Liu, Han, & Lee, 2016). This technological advancement facilitates proactive action by promptly notifying supervisors or employees of impending hazards, thus preventing accidents. In addition, computer vision can enhance adherence to safety rules by constantly monitoring compliance with safety measures, including using Personal Protective Equipment (PPE) and maintaining safe distances. The potential benefits of implementing computer vision technology for construction safety monitoring are significant, as it can enhance workplace safety, reduce hazards, and protect the welfare of construction workers.

Over the past decade, much research has been conducted to improve conventional building safety planning by utilizing BIM. Numerous studies have examined the utilization of BIM for safety planning, focusing on temporary facilities inside building sites (Khan et al., 2022). A suggested BIM technology method was introduced to mitigate fall accidents through an automated, rule-based safety planning approach (Wu et al., 2019).

Nevertheless, upon careful examination of the data obtained from the curriculum vitae-based analysis, it is evident that the supplementary safety monitoring measures have not been considered sufficiently. For example, the laborers are promptly alerted, and this notification also necessitates dissemination to safety supervisors or other relevant stakeholders. In addition, it is imperative to preserve the possible hazard occurrence in a database using case-based reasoning techniques to facilitate future projects and enhance safety education. Hence, BIM, as a digital representation of the construction project, offers a comprehensive database of information regarding the project's elements and spatial relationships. Computer vision algorithms can leverage this information to enhance safety monitoring protocols (Xu, Lu, Wu, Lou, & Li, 2022). By employing BIM data, computer vision systems gain insights into the dynamic and complex environment of a construction site (Akram, Thaheem, Nasir, Ali, & Khan, 2019). These algorithms can effectively identify and assess potential safety hazards, risky behaviors, and equipment failures by utilizing real-time camera data. By establishing a strong link between

virtual models and physical reality, the construction industry can harness the full potential of computer vision technology for proactive safety monitoring, leading to a safer working environment and improved risk management strategies.

3. Proposed approach

As illustrated in Figure 1, the BMT framework has a BIM-based Hazardous Visualization module, which highlights the capacity of BIM to visualize possible hazards effectively. This module is supported by a comprehensive range of factors, including rules, regulations, historical accident data, best practices, and the current safety condition of a site. In addition to this, there is the Hazardous Detection module based on Computer Vision, which utilizes sophisticated algorithms to identify any risks. The system provides a high degree of flexibility in adopting algorithms, allowing customization to suit unique building circumstances.

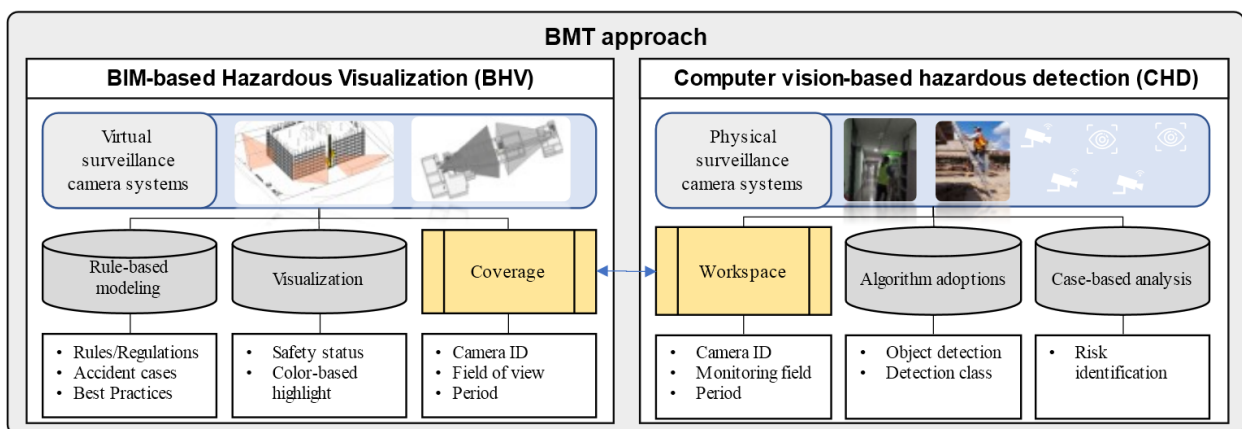


Figure 1. A framework for construction safety monitoring using vision intelligence technology and BIM-cloud, called BMT

3.1. BIM-based Hazardous Visualization (BHV)

The primary objective of the BHV module is to extract critical details from BIM data, specifically focusing on the workspace. This information is the foundation for devising plans for installing surveillance cameras and adopting algorithms. These plans are formulated proactively, preceding the actual monitoring phase during construction. Many cameras may be necessary at the construction site to ensure safety monitoring throughout the project. Every camera must be positioned inside designated operational areas and adhere to predetermined monitoring schedules as outlined in the plan. Therefore, security cameras need specific data, including identification, monitoring area, and duration.

Moreover, many AI algorithms have been devised in response to diverse potential hazardous scenarios that may have arisen throughout the implementation of the building endeavor. The selection of an algorithm for adoption throughout the monitoring process is contingent upon site characteristics, which may be ascertained from the design phase using the BIM model. As seen in Figure 2, it is necessary to supervise the excavators or bulldozers during the excavation stages. Besides, supervising personnel engaged in scaffolding activities throughout the foundation and structural phases is essential.

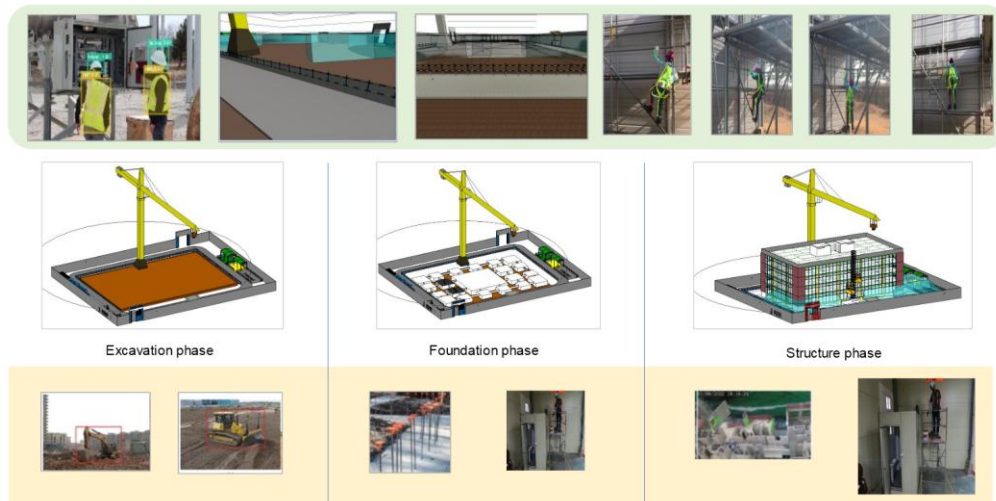


Figure 2. An example of algorithm adoption plans following construction phases

3.2. Computer vision-based Hazard Detection (CHD)

The safety manager can use the BHV information to determine the input parameters for the second module, the site observations module (CHD). Before safety monitoring, the surveillance cameras are installed following the plan. Through this, the camera can cover the workspace to detect potential hazards of proper activity occurring. Given the diverse range of possible hazard scenarios in construction projects, numerous AI algorithms have been devised. This research employs a case-based analysis approach to select the most suitable AI algorithm for the specific context. Accident reports, safety laws, and building best practices provide crucial information, including the underlying reasons, severity of the context, and recommendations for mitigating future incidents of a similar sort. The extraction of safety standards or identification of accident causes enables employees to comprehend the underlying factors contributing to the occurrence. For instance, Table 1 provides rules for helmet requirements at job sites removed from regulations. The CHD module is designed to identify whether employees wear helmets. Subsequently, the detection outcomes may be included in the BIM model using the BHV module.

Table 1

An example of wearing safety helmet requirements at construction job sites.

No.	Safety Standard	Standard Number	Contents
1	OSHA (USA)	1910.135	The employer is responsible for ensuring that employees at risk of head injury from falling items wear a protective helmet when working in designated locations.
2	Health and Safety Executive (UK)	EN 397	The HSE states that helmets must be provided for workers and visitors to a job site.
3	Local Rule on Occupational Safety and Health STANDARD (Korea)	KOSHA 4.32	Safety helmets must be worn at construction sites for protection when doing work that entails the risk of flying or falling items or the worker falling.

Source: The researcher's data analysis

4. Case study

The considerable congestion at the building site creates a complex working environment, which provides notable obstacles for the management team responsible for overseeing operations. Implementing manual supervision for every on-site construction worker is essential, as it allows for the prompt identification and communication of possible safety risks. Moreover, the existing methodology for documenting intrusions predominantly depends on self-disclosure, a process hindered by a prevailing culture of attributing fault for mistakes, burdensome administrative procedures, and a shortage of communication on the use of provided data. Therefore, the primary goal in safety management throughout the various stages of a construction project is the identification of potential risks using automated means and prompt communication of such dangers to the relevant safety management professionals.

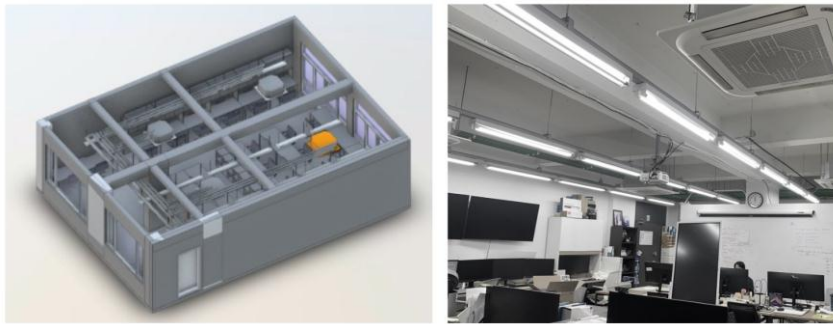


Figure 3. Case application

The authors utilized the Autodesk platform for BIM creation to solve the safety issues. They implemented Yolo-V8 for autonomous visual monitoring in the development of a prototype. Implementing a dual-camera system at the construction site facilitated the surveillance of project personnel's compliance with the mandatory practice of wearing protective headgear. The author's utilization of a pre-existing TensorFlow model was seen in the context of helmet identification. The training was performed on a server equipped with an Intel i9-10940X Central Processing Unit (CPU), four NVIDIA RTX 3090 Graphics Processing Units (GPUs), and 24 gigabytes of Random-Access Memory (RAM). It was noted that the training images underwent a resizing process, wherein embodiments of varying dimensions were adjusted to a standardized size of 800 pixels. The model underwent training with a learning rate of 0.001 for 500 epochs.

Additionally, weight decay and learning momentum were configured to 0.0001 and 0.9, respectively. Following that, a model based on cloud computing was developed with Autodesk Forge. To achieve a smooth integration between the cloud and computer vision models, the code conversion was carried out using TensorFlow.js, enabling their cohesive functioning.

4.1. Result

In the practical context of a construction project site, it is imperative to consider workers wearing/not wearing helmets. The results (Figure 4 (a), (b)) illustrated the safety status, namely the degree of adherence among personnel to wearing helmets when traversing various zones. Notably, the cloud-based technology promptly notifies project personnel in hazardous circumstances, such as when employees are not using protective helmets. The alarms were communicated by the visual representation of the camera view and the virtual camera being emphasized in red, as illustrated in Figure 3.

Table 2 presents the results of the helmet detection process achieved through the BMT approach. The authors conducted experiments using three different videos, each spanning distinct time intervals, to evaluate the accuracy and performance of their helmet detection model. The

process involved breaking down the videos into individual frames per second, allowing for a granular assessment of the model's performance. The primary metric for evaluating the model's effectiveness was its accuracy in correctly identifying helmet presence versus incorrectly identifying instances. The table provides a comprehensive summary of the outcomes for each video, including the number of helmets correctly detected and incorrectly detected and the resulting accuracy percentage. The term "Correctly detected" signifies the count of helmets that the model accurately identified within the video frames. Conversely, "Incorrectly detected" indicates the number of instances where the model made erroneous identifications of helmets.

Notably, the accuracy percentages are computed by comparing the sum of correctly and incorrectly detected helmets to the total number of helmets present in the video frames. For instance, in Video 1, the model correctly identified 105 helmets and incorrectly identified eight helmets, resulting in an accuracy rate of 92.9%. Similarly, for Video 2, the model achieved a higher accuracy rate of 94.0%, with 63 helmets and four helmets incorrectly detected. Lastly, in Video 3, the model correctly identified 123 helmets but made ten incorrect identifications, resulting in an accuracy rate of 92.5%. The observed average precision of 93% across the three videos indicates a consistent and commendable performance of the BMT helmet detection approach. These results underscore the model's ability to effectively identify helmets within various video scenarios, signifying its potential for enhancing safety measures in contexts where helmet usage compliance is critical, such as construction sites or industrial environments.

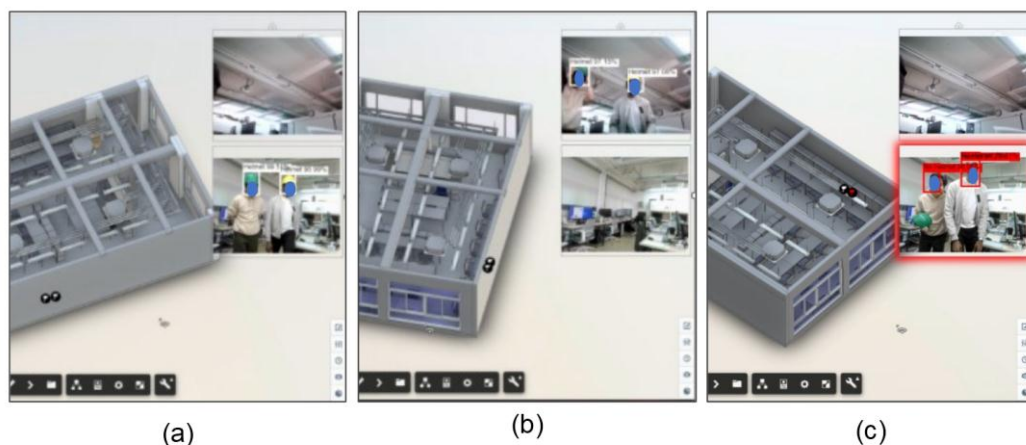


Figure 4. The detection results

Table 2

The results of helmets detection of BMT approach

Video	Helmets Detection results		Accuracy (%)	Average (%)
	Correctly detected	Incorrectly detected		
1	105	8	92.9	93
2	63	4	94.0	
3	123	10	92.5	

4.2. Discussions

Workers' safety and well-being are paramount in the practical context of a construction project site. Ensuring that personnel adhere to safety protocols, such as wearing protective helmets, is crucial for mitigating potential hazards and minimizing accidents. The results presented in

Figure 4 (a) and (b) shed light on the safety status within the construction site, explicitly addressing the extent to which workers comply with helmet-wearing regulations when moving through different zones. One noteworthy aspect of this safety monitoring approach is cloud-based technology, which enables real-time monitoring and immediate responses to hazardous situations. When workers are observed without protective helmets in designated areas, the system triggers alarms that promptly notify project personnel. This notification mechanism is visually represented through the camera view, with the virtual camera being highlighted in red, as depicted in Figure 3. This immediate and visual alert system is a powerful tool for enhancing on-site safety by enabling rapid responses to non-compliance with safety regulations.

Furthermore, the outcomes generated by the hazard identification algorithms are not merely relegated to real-time alerts; they are also meticulously recorded in a database. This data repository is pivotal in facilitating further analysis and application of safety management protocols. The recorded information can be leveraged to identify trends, patterns, and potential areas of improvement in safety practices. It also serves as valuable documentation for compliance monitoring and regulatory reporting, ensuring that safety standards are consistently upheld. By harnessing AI's capabilities for pattern recognition and anomaly detection and combining them with the rich project data available through BIM, it becomes possible to create advanced safety monitoring systems that identify safety breaches and predict and prevent them.

However, it is essential to acknowledge that the research has significant limitations: (1) This study's primary objective is to examine the integration between BIM and cloud computing and computer vision techniques to update safety status. The study did not focus on developing and evaluating the performance of algorithm metrics such as precision accuracy, F1 score, and recall. (2) The case study in this research pertains to a small-scale project, limiting the number of algorithms that can be implemented within the project's context. (3) Misdetectors and errors were made during detection. Because the information used to identify the on-site individual was acquired from a single source. The data set must be gathered from several building sites to deal with the changing dynamics of the environment. Furthermore, it should be obtained from many locations, including various viewpoints, occlusion circumstances, and specularities.

5. Conclusion & recommendations

This paper introduces a novel BMT approach, seamlessly integrating computer vision-based detection with the BIM model to enhance safety monitoring in construction projects. While earlier studies have acknowledged the significance of computer vision in this context, the proposed BMT method advances the field by providing a systematic process for BIM rule-based modeling aligned with safety regulations. This empowers laborers to install monitoring devices effectively and enables autonomous threat identification through a computer vision algorithm within the surveillance system. An innovative aspect of this research lies in uploading detection findings to cloud services, further displayed within the BIM-cloud model. This integration fosters efficient communication among project stakeholders, streamlining safety measures. The implementation and validation of the proposed technique, utilizing Autodesk Forge for BIM-cloud model construction and TensorFlow for the helmet's detection computer vision model, substantiate the approach's feasibility. Moving forward, the development direction for this research should delve into refining and expanding the BMT approach, considering scalability, real-time data integration, and the potential incorporation of emerging technologies, thus contributing to the continual evolution of construction safety monitoring methodologies.

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