ICCEPM 2022
The 9th International Conference on Construction Engineering and Project Management
Jun. 20-23, 2022, Las Vegas, NV, USA

A Framework for Computer Vision-aided Construction Safety Monitoring Using Collaborative 4D BIM

Si Van-Tien Tran[1*], Quy Lan Bao[1], Truong Linh Nguyen[1], Chansik Park[1]

[1] *Department of Architectural Engineering, Chung-Ang University, Seoul 06974, Korea,* E-mail address: sitran@cau.ac.kr,
[1] *Department of Architectural Engineering, Chung-Ang University, Seoul 06974, Korea,* E-mail address: baoquylan@cau.ac.kr,
[1] *Department of Architectural Engineering, Chung-Ang University, Seoul 06974, Korea,* E-mail address: linh89@cau.ac.kr,
[1] *Department of Architectural Engineering, Chung-Ang University, Seoul 06974, Korea,* E-mail address: cpark@cau.ac.kr,

Abstract: Techniques based on computer vision are becoming increasingly important in construction safety monitoring. Using AI algorithms can automatically identify conceivable hazards and give feedback to stakeholders. However, the construction site remains various potential hazard situations during the project. Due to the site complexity, many visual devices simultaneously participate in the monitoring process. Therefore, it challenges developing and operating corresponding AI detection algorithms. Safety information resulting from computer vision needs to organize before delivering it to safety managers. This study proposes a framework for computer vision-aided construction safety monitoring using collaborative 4D BIM information to address this issue, called CSM4D. The suggested framework consists of two-module: (1) collaborative BIM information extraction module (CBIE) extracts the spatial-temporal information and potential hazard scenario of a specific activity; through that, Computer Vision-aid Safety Monitoring Module (CVSM) can apply accurate algorithms at the right workplace during the project. The proposed framework is expected to aid safety monitoring using computer vision and 4D BIM.

Key words: 4D BIM, computer vision, safety monitoring.

1. Introduction

Accidents frequently occur in the construction industry, among which human-caused accidents account for the largest proportion [1]. According to the Ministry of Employment and Labor, approximately half of all fatalities in Korea are attributed to the construction industry [2]. Various research on construction safety have concluded that workplace safety might have reduced and even prevented accidents [3,4]. Hence, researchers have put effort into improving safe working spaces, for instance, applying emerging technologies such as BIM, IoT devices, virtual reality, and augmented reality (VR&AR). In particular, technical advancement supported by computer vision has developed into a potent instrument for automatically detecting and predetermining harmful problems on construction sites, which is very useful in the construction industry.

Computer vision technology has been researched and may replace present manual experimental health and safety methods (H&S) monitoring [5]. For example, Kim [6] developed a system that alerts workers to potentially risky situations. Additionally, various types of dangerous situations have been investigated in-depth, including not wearing personal protective equipment (PPE) [7], accessing a hazardous location [8], and failing to follow safety protocols [9]. Furthermore, other studies have continuously improved the applicability of computer vision to construction safety. Accordingly, the number of developed algorithms has increased more and more due to the complex nature of construction sites for detecting hazard events. However, when hazard detection algorithms simultaneously operate during the project, they require a large computational ability of systems. Meanwhile, applying these algorithms can depend on the workplace and schedule. For instance, detecting correlation between worker and excavator is mostly used during the foundation phases and near the excavations more than in other phases, while detecting "not wearing a hard hat" worker is needed in whole project execution.

When building information modeling (BIM) is used in construction planning, it has been shown to improve occupational safety. BIM allows for more realistic site layouts and safety plans, cutting-edge methods for visualizing current designs, providing spatial-temporal information, and facilitating safety communication [10–13]. Through this, the project team can extract useful information for appropriate purposes. For example, with the workspace, schedule information, and properties of construction tasks, the safety managers can prepare a safety plan to prevent hazards. Moreover, this information can be used during the construction phase.

This study proposes a framework for computer vision-aided construction safety monitoring using collaborative 4D BIM information called CSM4D. The CSM4D utilizes extracted 4D BIM data such as workspace, time, and activity to assist the visual intelligence system in improving safety monitoring. CSM4D can control the number of hazard detection algorithms of vision devices at specific locations during a period. Section 2 discusses the present state of safety monitoring for construction using computer vision and 4D BIM. Section 3 will present the recommended framework. The authors produced case scenarios in Section 4 to validate CSM4D. The conclusion and discussion are presented in the concluding section.

2. Literature Review

2.1. Safety monitoring using visual information

When coming to construction, safety monitoring is essential since it allows for the early detection and rapid rectification of safety and health problems by isolating them from the causative process, otherwise impossible. Site observations and inspections have traditionally been used extensively in the construction industry to assess the risks associated with ongoing construction activity and existing site conditions [14]. However, there has been a shift in how site observations and inspections are used in recent years. On the other hand, these systems are expensive and time-consuming since they require supervisors or safety specialists to watch and document the process physically. Additional limitations of manually observed data are caused by the difficulty of promptly gathering comprehensive and correct information.

Numerous research on computer vision-based construction safety has been undertaken. For example, Mneymneh et al. [15] proposed an approach for recognizing individuals not wearing hard helmets and flagging violations of safety norms. Xiao et al. [16] developed vision-based worker monitoring. Khan et al. [4] developed an approach for preventing falling hazards using computer vision and IoT. Various detection algorithms have been developed, concentrating on solving specific scenarios. However, the construction nature is dynamic, and the workers have to conduct their tasks time by time. Some detection scenarios only affect a specific spatial-temporal event.

Meanwhile, other algorithms can be applied to detect hazards anywhere and during project execution. For instance, the need for detecting the "not wearing a hard hat" event is compulsory at the construction site. Hence, there is a need to analyze the specific algorithm with spatial-temporal information.

2.2. 4D BIM for Construction Planning

4D BIM has progressively enhanced the planning process; for instance, it analyzes dynamic sites and spatial-temporal for safety considerations [11]; supports developing logistics management and monitoring construction progress via site layout designs [12]. Four-dimensional building information modeling (BIM) may provide construction teams with useful information for specific purposes by identifying the location and timing of activities or entities. According to Tran et al. [3], a surveillance installation plan was developed using extracted 4D BIM information as a schedule and workspace. Before the construction stage, Tran and colleagues [11] obtained workspace and activity times to detect potential spatial-temporal conflicts that might lead to accidents. Besides, 4D BIM also potentially provides practical and useful information for construction monitoring using vision intelligence. The activity with its location and schedule has been defined from plans that can support the vision system applied the right algorithms to get better output and provide more effective information to the safety manager.

3. A framework for computer vision-aided construction safety monitoring using collaborative 4D BIM information

We proposed a framework for computer vision-aided construction safety monitoring using collaborative 4D BIM information, as illustrated in Figure 1. The framework comprises two modules including collaborative BIM information Extraction Module (CBIE) and Computer Vision-aid Safety Monitoring Module (CVSM). The CBIE extraction information from 4D BIM model. In order to support CVSM, there is a need for planning surveillance camera placement, and algorithm adoption schedule following 4D BIM model. After that, the CVSM will detect potential hazard during construction process and visualize safety status into BIM environment to deliver feedbacks to stakeholders.

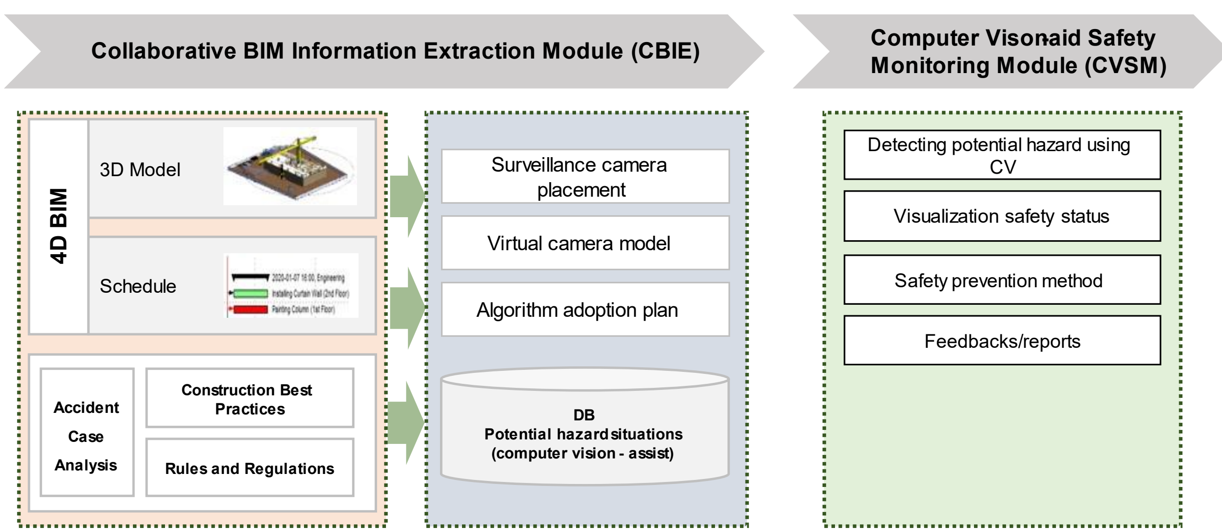

Figure 9. A framework for computer vision-aided construction safety monitoring using collaborative 4D BIM information

The CBIE module is intended to prepare a plan for computer vision-based safety monitoring. To effectively apply a vision monitoring system, there is a need for a surveillance camera placement plan. The previous study convinced the use of 4D BIM in developing the surveillance installation plan [3]. The employee can follow the plan to install the surveillance cameras. Besides, with the virtual camera model, the planners can know the coverage area into the workspace; since then, it may be defined as the location of activity that will be occurred. Figure 2 illustrates the process of preparing computer vision-based safety monitoring. Through the 4D BIM information extraction, the activity includes duration, potential hazard scenario, and workspace defined as a set of camera fields of view.

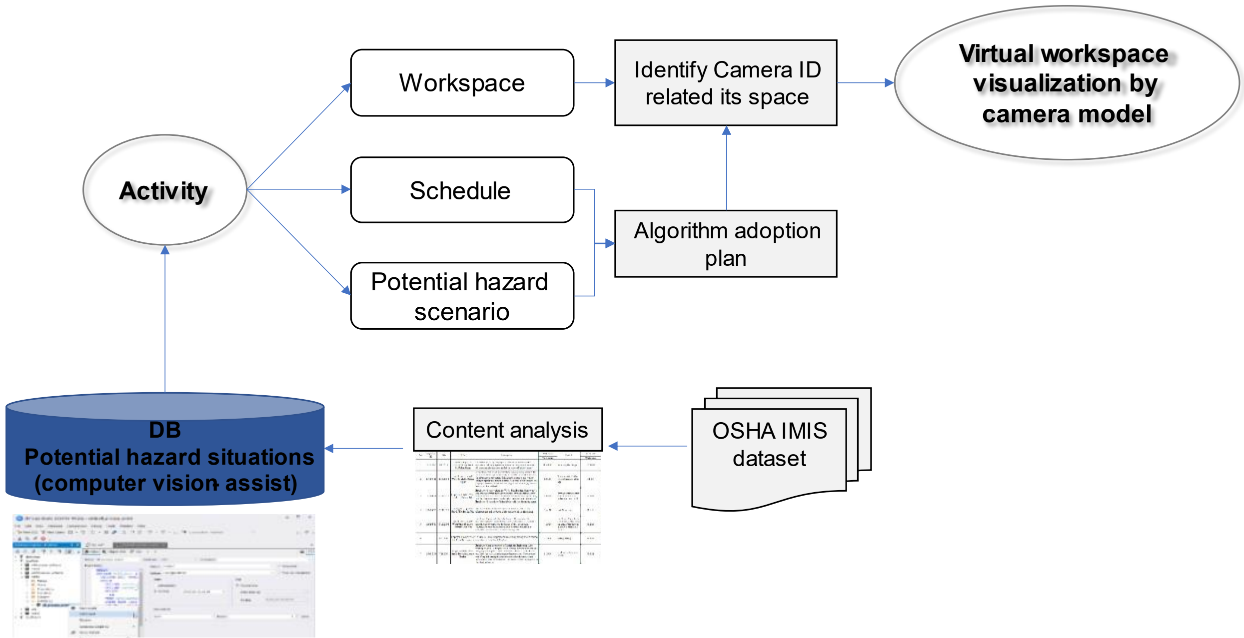

Figure 10. The process of preparing computer vision-based safety monitoring

Furthermore, choosing the algorithm adoption during the monitoring process requires pre-processing. Due to various potential hazard situations that may have occurred during the construction project, many AI algorithms have been developed. In this study, the authors propose the conceptual framework for choosing the AI algorithm following the spatial-temporal aspect of activity during the project. Accident reports, safety regulation, construction best practices offer pivotal information, such as root causes, context-related severity, and recommendations for preventing future accidents of a similar nature. Extracting safety regulations or accident causes allows employees to understand the event's reasons. For instance, Table 1 provides rules extracted from OSHA. Since then, the developers can build a vision algorithm for detecting potential hazard situations, including detecting worker wear/not wearing helmets or when workers work on the mobile ladder at the height of more than 1.2m. Concurrently, the extraction information includes activity information that can integrate into the 4D BIM model. Consequently, the employee can pre-defined the algorithms applied for activity at the right location and time aspect.

Table 1. An example for OSHA rule extraction for assisting computer vison-based safety monitoring

No.	No.	Contents
1	1910.28	Employees working on platforms more than four feet (1.2 m) above the ground must be covered by a fall prevention device.

2	29 CFR 1926.100(a)	Employees operating in locations where there is a potential risk of head injury from collision, or from dropping or flying items, or from electrical shock and burns, should be covered by protective helmets

After retrieving information from CBIE, the CVSM module conducts safety monitoring using the computer vision technique. With a set of AI algorithms adopted into each surveillance camera, the CCVM4D can specify potential hazard detection. Other unusual AI algorithms would temporarily turn off for optimizing analysis resources. In case of detecting hazards, the CCVM4D will update the safety status into the BIM module. Hence, the stakeholders can understand the site situation and deliver feedbacks.

4. Case study

The authors performed a case study for monitoring safety situations of projects that fix and repair facilities on the 2nd floor of building 208 at Chung-Ang University. During winter vacation, the managers decide to fix and repair facilities on the 2nd Floor. The activities were proposed by the project team including checking & repairing HVAC systems, cleaning floor and painting wall. To monitor safety situation of this project, two cameras were installed as illustrated in Figure 3.

Table 2. Schedule of case scenario

I)	Task Name	II) Duration (days) III)	IV)	Start	V)	Finish
VI) HVAC	Checking & Repairing	VII) 8	VIII)	01/07/2022	IX)	01/15/2022
X)	Painting wall	XI) 4	XII)	01/14/2022	XIII)	01/18/2022
XIV)	Cleaning floor	XV) 3	XVI)	01/17/2022	XVII)	01/20/2022

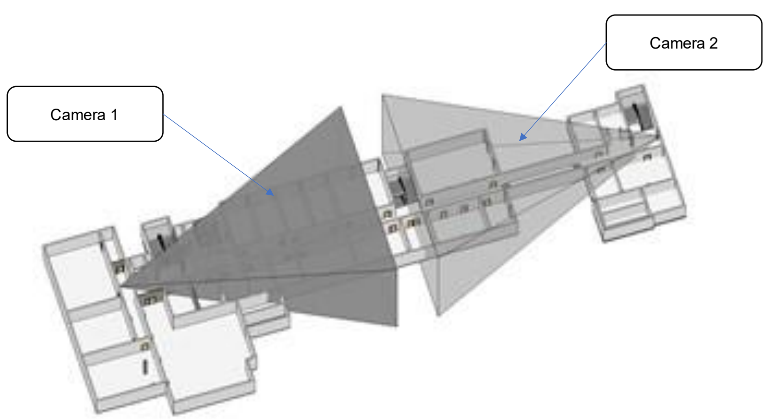

Figure 11. The camera placement

Two algorithms applied for this study, including “Not wearing hard hat” and "working higher than 1.2m'. Therein, the “Not wearing hard hat” algorithm is applied during the project occurred. Besides, the "working higher than 1.2" is adopted for activity "checking & repairing the HVAC system." Hence, these algorithms can be applied for specific activities at the right time and workspace. Figure 4 shows the results of detection working higher than 1.2, and "without helmet" when the worker conducted "fixing & repairing HVAC system". These results would be stored in the MySQL database and then update to the BIM model.

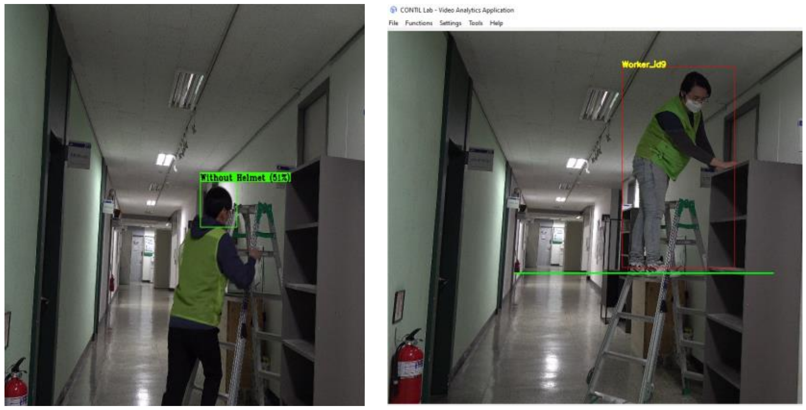

Figure 12. The results of detection algorithms

5. Conclusion

This study's main goal was to improve computer vision-aid construction safety using collaborative 4D BIM information. A thorough literature review depicts those previous efforts found the significance of computer vision support safety monitoring. Moreover, the 4D BIM can provide efficient information to support the vision intelligence system. Based on analyzing accident databases, regulations, and best practices, the safety managers can extract the potential hazard situation related to a specific activity. Besides, the schedule and workplace information extracted from 4D BIM can support vision intelligence systems that apply the right algorithms to specific spatial-temporal situations.

This study proposes a framework for computer vision-aided construction safety monitoring using collaborative 4D BIM information called CSM4D. Information from 4D BIM can support vision intelligence systems for specific purposes. The proposed method was tested with fixing and repairing projects on 208 buildings at Chung-Ang University. During the project, the schedule and workspace information from the 4D model can support CSM4D apply appropriate detection algorithms. Nevertheless, the research has certain limitations: (1) the study focusses on the concept of collaborative information between 4D BIM and computer vision; however, it does not mention the detail of the algorithm (such as architecture, accuracy), (2) the case study is a small project, it leads to fewer algorithms applied into the project. For future study, the author would analyze more accident reports and regulations to develop more potential hazard situations related to a specific activity. The authors would focus on the developing system based on the CSM4D framework. Then, we investigate the system's efficiency with large-scale projects and more project members.

ACKNOWLEGEMENTS

This research was conducted with the support of the "National R&D Project for Smart Construction Technology (No.22SMIP-A158708-03)" funded by the Korea Agency for Infrastructure Technology Advancement under the Ministry of Land, Infrastructure and Transport, and managed by the Korea Expressway Corporation and financially supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government Ministry of Science and ICT (MSIP) [No. NRF-2020R1A4A4078916].

REFERENCES

[1] W. Fang, L. Ding, P.E.D. Love, H. Luo, H. Li, F. Peña-Mora, B. Zhong, C. Zhou, Computer vision applications in construction safety assurance, Autom. Constr. 110 (2020) 103013. https://doi.org/10.1016/j.autcon.2019.103013.

[2] Ministry of Employment and Labor, (n.d.). https://www.moel.go.kr/english/main.jsp (accessed August 27, 2021).

[3] S.V.T. Tran, T.L. Nguyen, H.L. Chi, D. Lee, C. Park, Generative planning for construction safety surveillance camera installation in 4D BIM environment, Autom. Constr. 134 (2022) 104103. https://doi.org/10.1016/J.AUTCON.2021.104103.

[4] M. Khan, R. Khalid, S. Anjum, ; Si, V.-T. Tran, C. Park, A.M. Asce, Fall Prevention from Scaffolding Using Computer Vision and IoT-Based Monitoring, J. Constr. Eng. Manag. 148 (2022) 04022051. https://doi.org/10.1061/(ASCE)CO.1943-7862.0002278.

[5] M. Zhang, R. Shi, Z. Yang, A critical review of vision-based occupational health and safety monitoring of construction site workers, Saf. Sci. 126 (2020) 104658. https://doi.org/10.1016/j.ssci.2020.104658.

[6] K. Kim, H. Kim, H. Kim, Image-based construction hazard avoidance system using augmented reality in wearable device, Autom. Constr. 83 (2017) 390–403. https://doi.org/10.1016/j.autcon.2017.06.014.

[7] M.-W. Park, N. Elsafty, Z. Zhu, Hardhat-Wearing Detection for Enhancing On-Site Safety of Construction Workers, J. Constr. Eng. Manag. 141 (2015) 04015024. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000974.

[8] W. Fang, B. Zhong, N. Zhao, P.E.D. Love, H. Luo, J. Xue, S. Xu, A deep learning-based approach for mitigating falls from height with computer vision: Convolutional neural network, Adv. Eng. Informatics. 39 (2019) 170–177. https://doi.org/10.1016/j.aei.2018.12.005.

[9] H. Luo, C. Xiong, W. Fang, P.E.D. Love, B. Zhang, X. Ouyang, Convolutional neural networks: Computer vision-based workforce activity assessment in construction, Autom. Constr. 94 (2018) 282–289. https://doi.org/10.1016/j.autcon.2018.06.007.

[10] S. Tran, T.L. Nguyen, C. Park, A BIM Integrated Hazardous Zone Registration Using Image Stitching, Proc. 38th Int. Symp. Autom. Robot. Constr. (2021). https://doi.org/10.22260/ISARC2021/0026.

[11] S.V.T. Tran, N. Khan, D. Lee, C. Park, A Hazard Identification Approach of Integrating 4D BIM and Accident Case Analysis of Spatial–Temporal Exposure, Sustain. 2021, Vol. 13, Page 2211. 13 (2021) 2211. https://doi.org/10.3390/SU13042211.

[12] S.V.T. Tran, A.K. Ali, N. Khan, D. Lee, C. Park, A framework for camera planning in construction site using 4d bim and vpl, Proc. 37th Int. Symp. Autom. Robot. Constr. ISARC 2020 From Demonstr. to Pract. Use - To New Stage Constr. Robot. (2020) 1404–1408. https://doi.org/10.22260/ISARC2020/0194.

[13] T.H. Nguyen, L.V. Nguyen, J.J. Jung, I.E. Agbehadji, S.O. Frimpong, R.C. Millham, Bio-Inspired Approaches for Smart Energy Management: State of the Art and Challenges, Sustain. 2020, Vol. 12, Page 8495. 12 (2020) 8495. https://doi.org/10.3390/SU12208495.

[14] J. HINZE, R. GODFREY, AN EVALUATION OF SAFETY PERFORMANCE MEASURES FOR CONSTRUCTION PROJECTS, J. Constr. Res. 04 (2003) 5–15. https://doi.org/10.1142/s160994510300025x.

[15] B.E. Mneymneh, M. Abbas, H. Khoury, Vision-Based Framework for Intelligent Monitoring of Hardhat Wearing on Construction Sites, J. Comput. Civ. Eng. 33 (2019) 04018066. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000813.

[16] B. Xiao, H. Xiao, J. Wang, Y. Chen, Vision-based method for tracking workers by integrating deep learning instance segmentation in off-site construction, Autom. Constr. 136 (2022) 104148. https://doi.org/10.1016/J.AUTCON.2022.104148.