IIETA International Information and Engineering Technology Association
Advancing the World of Information and Engineering

International Journal of Safety and Security Engineering
Vol. 12, No. 1, February, 2022, pp. 31-38
Journal homepage: http://iieta.org/journals/ijsse

The Application of BIM-Based OHSMS Information Systems to Improve Safety Performance

Ayu Herzanita[1*], Yusuf Latief[1], Fatma Lestari[2]

[1] Civil Engineering Department, Faculty of Engineering, Universitas Indonesia, Depok 16424, West Java, Indonesia
[2] Occupational Health & Safety Department, Faculty of Public Health Engineering, Universitas Indonesia, Depok 16424, West Java, Indonesia

Corresponding Author Email: ayu.herzanita91@ui.ac.id

https://doi.org/10.18280/ijsse.120104

Received: 29 December 2021
Accepted: 20 January 2022

Keywords:
safety plan, WBS, BIM, safety performance

ABSTRACT

The accidents recorded during university construction projects usually affect the safety performance of the institution. This indicates it is important to recognize the hazards and construction risks at the design stage in order to have an optimal safety plan. Moreover, the university area has several organizations involved in the implementation of Occupational Health and Safety Management Systems (OHSMS). Therefore, there is a need to develop the OHSMS information system to accommodate the role of the parties involved and to disseminate information and communication more effectively. This study was conducted to develop a WBS and BIM-based safety plan for the OHSMS information systems to improve the safety performance using the case study method. The result showed that the WBS is the basic constituent of the safety plan integrated with the BIM to visualize the project in real terms in order to ensure easier identification of hazards and risks. The process involved building data security information in BIM to develop web-based information systems and the BIM-based OHSMS information system developed is expected to improve safety performance in the university area.

1. INTRODUCTION

Universities are spacious areas with several facilities and unique workplaces which have different potential hazards and risks [1]. Most of the activities conducted are susceptible to hazards with subsequent effects on occupational safety and health of people on the property [2-4]. The existence of several occupational accidents and diseases in these universities led to the implementation of Occupational Health and Safety Management Systems (OHSMS) [5]. This is considered important due to several accidents usually experienced which make a university environment an unsafe place to study [6] even though these institutions are obliged to ensure the health, safety, and well-being of all students, lecturers, executives, and anyone working on campus [7].

The potential hazards and risks are often recorded in laboratory activities to have caused chemical explosions, radiation, as well as physical and biological exposure [1, 3, 8]. This led to the focus of most previous studies concerning work accidents in universities on laboratory activities [3-5, 9-11]. Some other examples of hazards include fire [3, 12, 13], construction works [1], and natural disaster [14, 15].

The poor application of OHSMS in higher education is caused by the perception that universities are safe and comfortable environments to conduct academic activities [16]. This assumption prevents the climate and culture of safety in the formation of these institutions [6]. Meanwhile, the lack of safety knowledge causes OHS managers to be unaware of potential hazards, emergency response, risk control for occupational accidents and diseases, and the use of PPE [5, 16-19].

One of the causes of accidents in universities is construction works which subsequently affect safety performance. This implies there is a need for good communication and information sharing strategy between those involved in the university and project management [19, 20]. Some of the factors observed to be causing construction work accidents in universities include weak safety policies, poor risk management, weak supervision, inadequate project management skills, design errors and construction methods, errors in selecting contractors/subcontractors, lack of understanding of construction safety at the university management level which causes lack of supervision, unsafe behavior, and a lack of technological innovation during the implementation of construction safety strategies [19-21].

Universitas Indonesia (UI) is one of the largest campuses in Indonesia and the main problems associated with the implementation of OHSMS in its environment include inadequate communication between OHSMS managers from both the university and faculty levels, lack of an optimal system for documenting incidents and accidents, and the existence of third parties or contractors that fail to report incidents/accidents in their workplace. Moreover, construction work has been discovered to be one of the major contributors to the fatality figure recorded in the university environment. Examples of these include the killing of construction workers at the Pusgiwa building by lightning in 2018 and the collapse of the Menwa building roof during renovation which injured 3 workers in 2016. It was also discovered from the data compiled by PUPR (2016) that the construction industry has the largest number of accidents. ILO data also estimated that at least 60,000 fatal accidents were recorded at construction sites worldwide and they occurred every 10 minutes [22].

The recent technological developments have made it possible to improve the safety performance at UI in line with Government Regulation no. 50 of 2012 Article 15. It is important to note that OHSMS is implemented in three organizational levels of the university environment which include the university, faculty, and project levels. There is, therefore, the need for an information system to integrated these levels using computer hardware and software utilities, procedure manuals, databases, models for analysis, planning, control, and decision-making [23]. This is necessary to ensure a more effective and efficient OHSMS, easier decision-making process, and to reduce management operational costs [24].

The use of BIM (Building Information Modeling) is increasing in the construction industry of Indonesia in line with the provisions of the Minister of Public Works Regulation No. 22 of 2018. BIM contains data and information needed from the planning to control stage of a project and has the ability to collaborate with an integrated information system to ensure safety management. This is supported by previous findings that its application in construction projects was able to improve safety performance due to its ability to visualize site conditions and identify hazards [25, 26].

There is a need to develop an appropriate safety management process which accommodates communication and information sharing between the OHS managers in UI [27, 28]. Therefore, this study was conducted to develop a BIM-based information system for OHSMS in the school.

2. METHODOLOGY

The case study method was applied in order to observe the phenomena in depth [29]. The stages involved include the development of a WBS-based safety plan, a BIM-based safety plan, and a BIM-based OHSMS information system.

2.1 WBS-based safety plan

The safety plan is an activity to identify, analyze, and control hazards before the construction project begins [30]. It was also defined by Hallowell and Gambatese [31] as the document that contains specific project safety goals and objectives, as well as methods to achieve project success. Wardahni, Latief [32] explained a safety plan as a document prepared at the project planning stage which contains risk identification, assessment, and mitigation results.

The Minister of PUPR Regulation No. 10 of 2021 showed that hazards and risks can be identified based on the stages of activity derived from the WBS (Work Breakdown Structure). It is important to note that this study compiled the WBS using literature studies and scope of work references from the building projects at UI.

The safety plan was also prepared based on the Minister of PUPR Regulation No. 10 of 2021 with the hazard and risk identification divided based on the worker, material, environment, and public. Meanwhile, the risks identified in architectural works and common wall works are presented in the following Table 1.

Table 1. Risk identification

<table>
<tr><th rowspan="2">No</th><th colspan="2">Risk Identification</th><th rowspan="2">Impact of Risk</th><th rowspan="2">Risk Prevention</th></tr>
<tr><th>Type of Risk</th><th>Description</th></tr>
<tr><td colspan="5">Work Package: Common Wall Works</td></tr>
<tr><td rowspan="25">1</td><td rowspan="25">Workers</td><td rowspan="10">Fall from height</td><td rowspan="10">Injury, Death</td><td>There is a strong and wide workbench/platform</td></tr>
<tr><td>Safety fence installation</td></tr>
<tr><td>Horizontal safety net installation</td></tr>
<tr><td>Lighting in an open area</td></tr>
<tr><td>There is a body line to connect the body harness</td></tr>
<tr><td>Fall hazard sign is on</td></tr>
<tr><td>Implement Tool Box Meeting</td></tr>
<tr><td>HSE officer patrols every 2 hours</td></tr>
<tr><td>Periodic checking of work equipment at height</td></tr>
<tr><td>Using PPE and safety belt or safety body harness</td></tr>
<tr><td rowspan="4">Dust/Splash exposure</td><td rowspan="4">Eye irritation, Cause of blindless</td><td>Keep a safe distance from getting splashed</td></tr>
<tr><td>Install "communication" signs</td></tr>
<tr><td>Wear safety goggles</td></tr>
<tr><td>Use a face shield</td></tr>
<tr><td rowspan="5">Overload of vertical conveyance</td><td rowspan="5">Can cause serious injury if it falls on people</td><td>Initial load test</td></tr>
<tr><td>Periodic checking of tools</td></tr>
<tr><td>Operator License Check</td></tr>
<tr><td>Make sure the safety device (alarm) is functioning properly</td></tr>
<tr><td>Maximum load sign installation</td></tr>
<tr><td rowspan="6">Getting hit, due to falling/moving objects, etc.</td><td rowspan="6">Injury, death</td><td>Material handling and binding is conducted with care</td></tr>
<tr><td>Safety deck installation</td></tr>
<tr><td>Use HT communication devices</td></tr>
<tr><td>Put up a sign which shows "Beware of Falling Materials"</td></tr>
<tr><td>People available as flagman/rigger</td></tr>
<tr><td>People available as flagman/rigger</td></tr>
<tr><td rowspan="2">Electric Shock</td><td rowspan="2">Damaged muscle tissue, nerve</td><td>Avoid many flow sharing connections</td></tr>
<tr><td>Provide safety insulation on chipped cables</td></tr>
</table>

No	Risk Identification		Impact of Risk	Risk Prevention
	Type of Risk	Description		
Work Package: Common Wall Works				
			disruption, decrease/increase in blood pressure, death	Electrical connection is coordinated by an electrician
				Prevent/avoid puddles
				Make sure the cable is hung and not attached to the floor, especially wet ones
				Make sure the cable used is adjusted to the power capacity
				Make sure the electrical connection uses a socket and is connected to the specified panel
				Create a grounding path
				Install the "Electricity Hazard" sign
				Periodic checks for electrical installations
				Wear rubber gloves and safety shoes
		Slip	Injury	Placement of materials arranged neatly
				Set up access road for people
				Create 5S workplace conditions
				Installation of a "safety sign"
2	Material	Material is messy and lost due to lack of supervision	Material Loss	Material placement is neat and there is access for people to walk
				Create 5S workplace conditions
3	Environment	The rest of the material is bad for the environment	Air pollution, material waste, environmental pollution	The remains of the material are deposited and placed in a sealed place
4	Public	There is traffic at the time of material arrival	There is a traffic density outside the work area leading to community inconvenience	Provide flagman to control the time of material transfer and traffic

2.2 Safety plan BIM-based

The safety plan data compiled based on WBS activities which include the identification, impact, and prevention of risks are known as safety building information [33] and were further integrated into the 3D BIM modeling.

This is necessary because BIM modeling is normally used to identify hazards and risks during the design stage [34]. Moreover, the 3D BIM modeling integrated with work schedules has the ability to simulate potential hazards and risks more effectively [33, 34].

BIM-based safety plans can be applied to universities, especially the typical college buildings, to identify hazards [25]. The case study is a 6-storey lecture building at the Faculty of Engineering, Universitas Indonesia with a focus on architectural work using the 3D BIM modeling on Revit software.

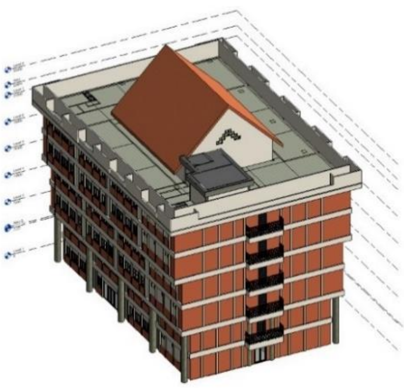

Figure 1. 3D model BIM

It is important to note that the 3D models in Revit are usually developed based on the 2D floor plans designed using AutoCAD. The building components usually modeled include the floor work, walls, ceilings, doors and windows, hardware, sanitary, facade, and roof as indicated in the following Figure 1.

The essence of BIM in the safety plan is to include safety building information data into the modeling. This involves inputting the information on the identification, impact, and prevention of risk previously prepared using the WBS for each architectural element of the building. This process requires adding new parameters through the project parameters menu in the Revit as indicated in Figure 2.

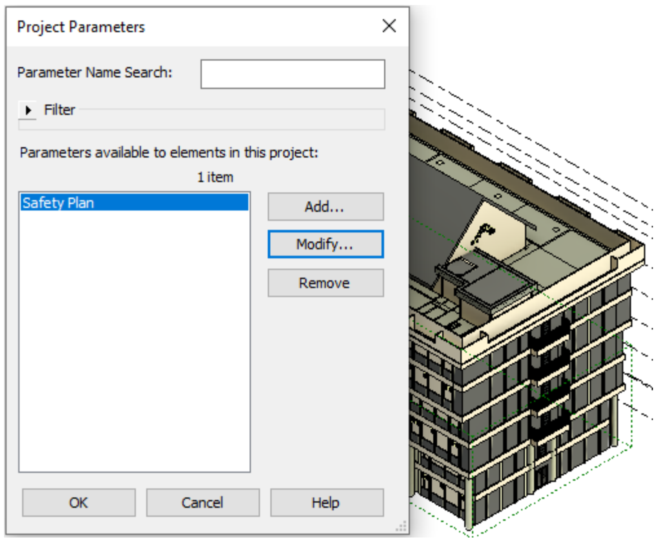

Figure 2. Project parameters

The field details to be filled in Parameter Properties include *Parameter Name*: Safety Plan, *Type of Parameters*: URL, and *Group parameter under*: Text. This was followed by the selection of the building elements to be inputted with the information building data and the wall was used as the case study in this present research, as shown in Figure 3.

The safety plan data inputted into the BIM modeling can be viewed by clicking on the element being reviewed as shown in the following Figure 4.

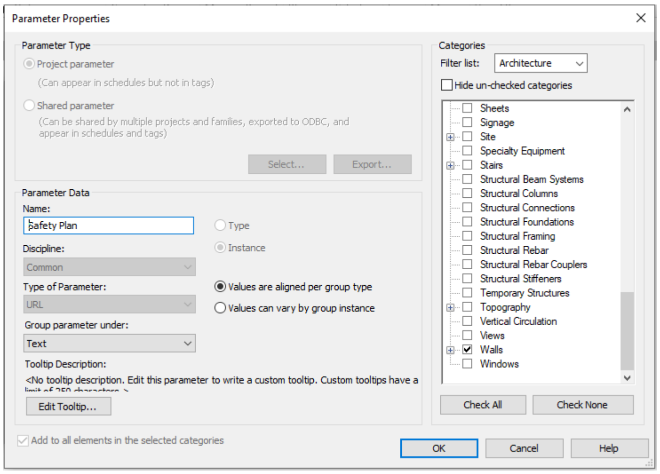

Figure 3. Parameter properties

The BIM-based safety plan data were further integrated into an information system to make it easier for all OHSMS managers in the UI Area including those from the university, faculty, and project level to view. The goal is to ensure all parties understand the potential hazards, risks and controls, and are able to coordinate effectively. It is important to note the information system was developed based on the web to allow everyone to access the application without having to install the BIM software.

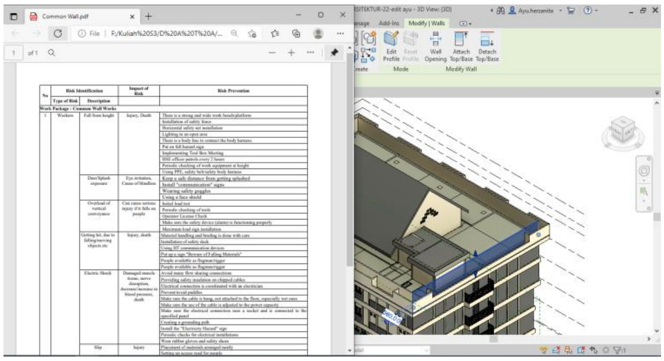

Figure 4. Safety plan data in BIM

2.3 Information system for the OHSMS

Information technology which is in the form of a web-based information system was used as the innovation to improve the safety performance of the OHSMS in the UI Area. It was developed using the Waterfall method approach [35, 36] based on the following stages:

(a) Analyze the requirements of the system to be developed. The needs analysis was later used as the basis to compile the information on the identification of website/application visitors, design of the form and color for the display, menu arrangement, application system platform, display language, and completeness of features.

(b) Develop system design through the PHP programming language (Hypertext Preprocessor) as well as the interface using HTML (Hypertext Markup Language), AJAX, and Bootstrap while the database was managed using MySQL.

(c) The integration of the design code into the PHP programming language and MySQL database using Laravel and bootstrap frameworks.

(d) The flowchart of the development process of the OHSMS information system is presented as follows Figure 5-7.

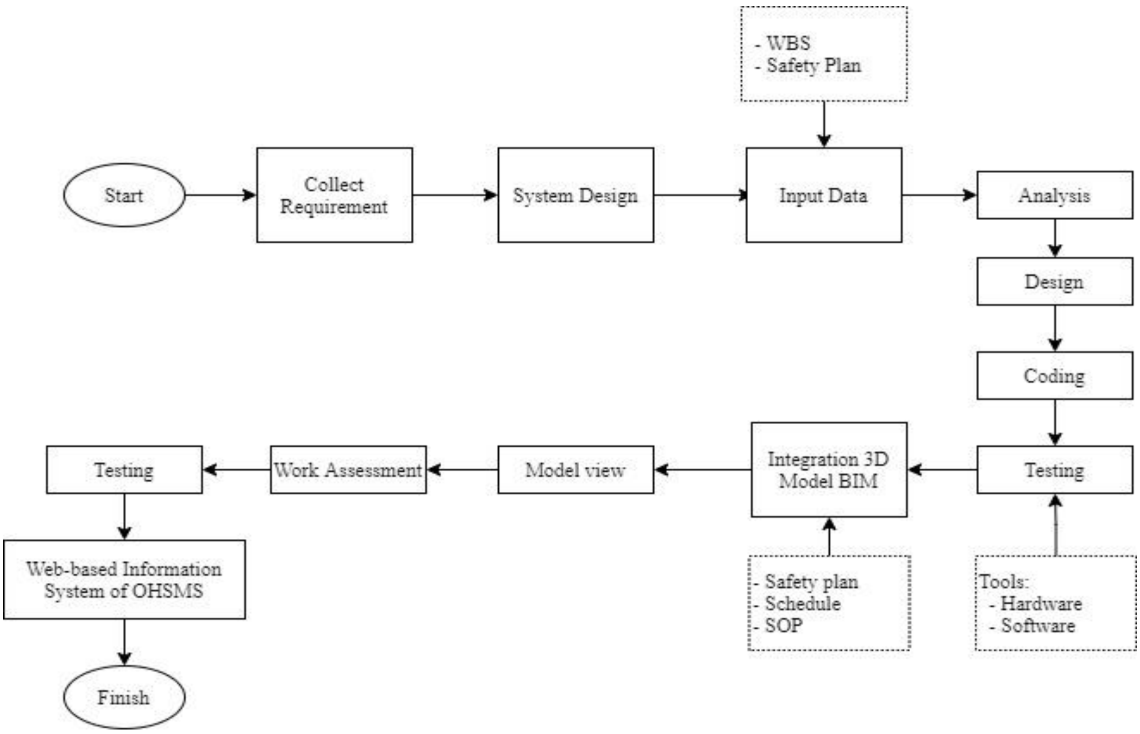

Figure 5. Information system development flowchart

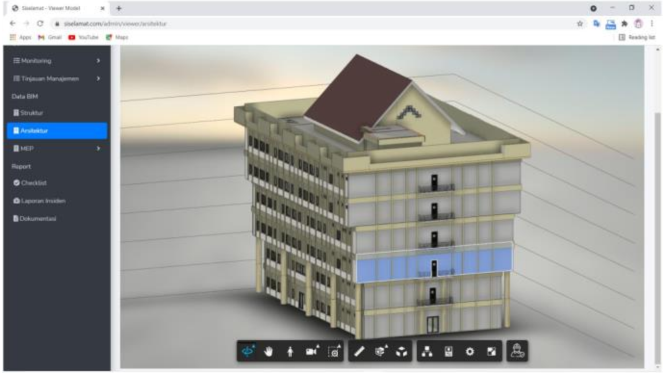

Figure 6. BIM-based information systems (architectural works)

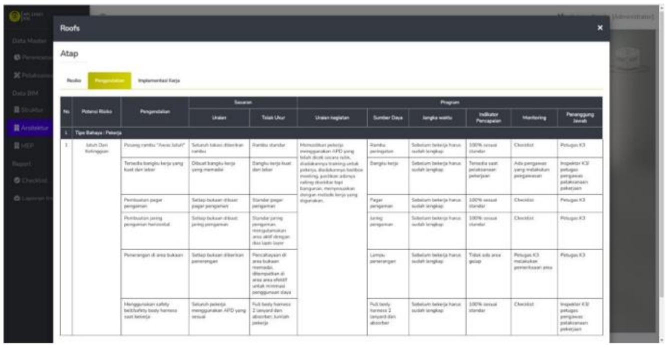

Figure 7. Interactive page display of architectural OHS risk information

3. DISCUSSION

The project life cycle starting from design to construction planning and maintenance requires special attention and appropriate strategy to ensure safety [37]. There is a need to identify and eliminate potential hazards and risks during the project planning stage [38]. This is due to the fact that a construction project consists of risky activities which lead to the development of a safety plan in recognizing the hazards as well as devising for their control towards overcoming work accidents [32, 39].

It is important to note that the safety plan is usually derived from the work package formed in the project WBS [32, 40]. This is in line with the provisions of the Minister of PUPR Regulation No. 10 of 2021.

Safety performance in construction work can be enhanced through the application of BIM technology to the management of construction safety issues. This is due to its possible application in the design of safety plans, inspection and monitoring of designs, emergency response, and communication of safety issues to all parties involved [25]. It can also be used to model 2D CAD drawings of the construction plans translated into WBS to 3D, 4D, and *n*D towards ensuring the components of the projects are visualized better [41]. It is important to note that the BIM 3D modeling is the basis of BIM [42] while BIM 4D modeling is a combination of 3D modeling and project schedule which is normally used to control the implementation of the project schedule effectively and to reduce the total cost [37, 41]. The 4D modeling can also be used to develop a project site safety plan which involves field logistics, project traffic layout development, and identification of potential hazards in the field [26]. Meanwhile, 5D modeling is usually used to control project implementation costs and budgets [43] while 6D focuses on the energy use in a building [44] and 7D modeling deals with the development of the facility management life cycle during the operational and maintenance phases [45]. It can be observed from this present study that the BIM-based safety plan integrates the WBS template and 3D object modeling to produce 4D BIM modeling [34, 46].

BIM technology is currently mostly used in design and pre-construction stages [41, 47] by planners to visualize the project site and identify potential hazards [25]. Meanwhile, there is a need to continuously monitor the safety plan during the period of project implementation because the hazards and risks identified can still occur. This indicates the BIM technology should not be limited to the planning stage only but also extended to the implementation and maintenance stages. It is important to acknowledge that the combination of 3D BIM and project schedule makes it possible to monitor the implementation process in real-time. This is due to its ability to serve as an effective communication tool during project implementation such as toolbox meetings to explain potential work hazards to workers [41].

Safety performance can be measured by monitoring the implementation of a safety management plan. It should be pointed out that the requirements, methods, and instructions related to safety need to be documented in safety regulations, specifications, and work implementation standards after the hazards and risks are identified in the planning stage for employees to access while doing the work [34]. The 4D BIM, however, contains the information related to potential hazards and their mitigation [41] and this indicates it can be used to prepare safety requirement documents during the implementation stage [41]. Moreover, a web-based information system can be used to ensure easy access to the document and real-time project visualization while cloud-based safety information using a web portal has been discovered to have the ability to improve safety performance. The data normally used as input in the BIM include the WBS, project team member data, identified hazards, and real project images [48].

There is a need for an information system in the OHSMS at UI to improve communication between OHS managers at both the university and faculty levels. It is also required to maximize the documentation of incidents and accidents in the university, especially for third parties (contractors) in order to have an adequate report in their workplace and use the lessons learned in the next construction project. The web-based information system also allows the management to disseminate information among project team members [49]. This, therefore, shows that safety information and web-based communication can improve safety performance [48].

The BIM-based OHSMS information system developed has a positive impact on the smooth running of construction projects in the UI Area. This is associated with the ability of the workers to recognize potential hazards from the visualization of the BIM model, thereby, increasing their awareness. Another advantage of this system is that safety information on the building can be accessed easily, anywhere, and anytime without having to go through a long process. Moreover, it is also possible for the OHSMS manager to assess the performance of contractors by checking reports submitted to the information system. This, therefore, indicates the system can improve safety performance.

4. CONCLUSIONS

Safety plan is normally prepared to describe the risk activities, types of risks, types of hazards, levels of risk, and preventive actions highlighted in a project WBS. Hence, there is a need for comprehensive identification of hazards and risks to minimize the occurrence of work accidents.

Previous methods of identification were based on 2D AutoCAD drawings after which the activities are usually translated into WBS but this study used BIM technology to identify hazards and risks. The method was observed to be more effective due to its ability to visualize the objects more realistically. Moreover, the BIM also contains other information related to the project including the safety plan.

This makes the safety plan data accessible to all parties involved in OHSMS UI, thereby, leading to the development of a BIM-based OHSMS information system to reduce the potential for workplace accidents. This is possible because the workers have a better awareness of their responsibilities and easily understand the potential hazards and risks associated with the job with the help of visualization. Moreover, the process of monitoring the OHSMS also becomes more effective because of this information system and this implies the BIM-based OHSMS information system has the ability to improve safety performance.

ACKNOWLEDGMENT

The authors express their gratitude to UI for the financial support provided through PUTI Doctor of the Fiscal Year 2020 with the contract number: NKB-689/ UN2.RST / HKP.05.00 / 2020 managed by the Directorate of Research and Community Engagement (DRPM) Universitas Indonesia.

REFERENCES

[1] Venables, K.M., Allender, S. (2006). Occupational health needs of universities: A review with an emphasis on the United Kingdom. Occupational and Environmental Medicine, 63(3): 159-167. http://dx.doi.org/10.1136/oem.2005.022145

[2] Hossain, M.A., Hossain, M.M., Tarannum, S., Chowdhury, T.H. (2015). Factors affecting OHS practices in private universities: An empirical study from Bangladesh. Safety Science, 72: 371-378. https://doi.org/10.1016/j.ssci.2014.10.007

[3] Lestari, F., Bowolaksono, A., Yuniautami, S., Wulandari, T.R., Andani, S. (2019). Evaluation of the implementation of occupational health, safety, and environment management systems in higher education laboratories. Journal of Chemical Health & Safety, 26(4-5): 14-19. https://doi.org/10.1016/j.jchas.2018.12.006

[4] Olewski, T., Snakard, M. (2017). Challenges in applying process safety management at university laboratories. Journal of Loss Prevention in the Process Industries, 49: 209-214. https://doi.org/10.1016/j.jlp.2017.06.013

[5] Tomita, K., Nishikimi, T., Hayashi, R., Mishina, T., Murata, S. (2017). New approach for safety education in Nagoya University. Journal of Environment and Safety, 8(2): 49-52. https://doi.org/10.11162/daikankyo.E16PROCP02

[6] Gong, Y. (2019). Safety culture among Chinese undergraduates: A survey at a university. Safety Science, 111: 17-21. https://doi.org/10.1016/j.ssci.2018.09.010

[7] Lingaswaran, A., Arjunan, L., bin Habidin, N.F., Bin, M.S. (2019). Safety practices evaluation conceptual model for malaysian public universities. International Journal of Academic Research in Business and Social Sciences, 9(5).

[8] Olewski, T., Ahammad, M., Quraishy, S., Gan, N., Vechot, L. (2016). Building process safety culture at Texas A&M University at Qatar: A case study on experimental research. Journal of Loss Prevention in the Process Industries, 44: 642-652. https://doi.org/10.1016/j.jlp.2016.08.022

[9] Hill Jr, R.H. (2019). Recognizing and understanding hazards—The key first step to safety. Journal of Chemical Health and Safety, 26(3): 5-10. https://doi.org/10.1016/j.jchas.2018.11.005

[10] Lestari, F., Budiawan, Kurniawidjaja, M.L., Hartono, B. (2016). Baseline survey on the implementation of laboratory chemical safety, health and security within health faculties laboratories at Universitas Indonesia. Journal of Chemical Health & Safety, 23(4): 38-43. https://doi.org/10.1016/j.jchas.2015.11.002

[11] Naroeni, A., Bachtiar, E.W., Ibrahim, F., Bela, B., Kusminanti, Y., Pujiriani, I., Lestari, F. (2016). Challenges in implementing a biorisk management program at Universitas Indonesia: A checklist tool for biorisk management. Health Security, 14(6): 375-381. https://doi.org/10.1089/hs.2016.0013

[12] Tabirca, S., Yang, L.T., Tabirca, T. (2015). Fire hazard safety optimization. Procedia Computer Science, 51: 2759-2763. https://doi.org/10.1016/j.procs.2015.05.425

[13] Wei, Y.Y., Zhang, J.Y., Wang, J. (2018). Research on building fire risk fast assessment method based on fuzzy comprehensive evaluation and SVM. Procedia Engineering, 211: 1141-1150. https://doi.org/10.1016/j.proeng.2017.12.121

[14] David, C.C., Monterola, S.L.C., Paguirigan Jr, A., Legara, E.F.T., Tarun, A.B., Batac, R.C., Osorio, J. P. (2018). School hazard vulnerability and student learning. International Journal of Educational Research, 92: 20-29. https://doi.org/10.1016/j.ijer.2018.07.005

[15] Mulyani, R., Ahmadi, R., Pilakoutas, K., Hajirasouliha, I. (2015). A multi-hazard risk assessment of buildings in Padang city. Procedia Engineering, 125: 1094-1100. https://doi.org/10.1016/j.proeng.2015.11.093

[16] Karim, M.A., Hariyono, W. (2018). Implementation of occupational safety and health (OSH) at Universitas Gadjah Mada Indonesia. IJAEDU-International E-Journal of Advances in Education, 4(10): 93-99.

[17] Sheffield, J., Gregg, J., Lee, J. (2016). A commentary regarding campus safety and security for institutions of higher education. In Allied Academies International Conference. Academy of Educational Leadership. Proceedings, 21(1): 18-22.

[18] Sisli, Z. (2019). The role of universities in the promotion of worker protection: UCLA labor occupational health and safety program as a model for countries with developing economies. Labor History, 60(4): 309-324. https://doi.org/10.1080/0023656X.2019.1537024

[19] Woolley, M.J., Goode, N., Read, G.J., Salmon, P.M. (2019). Have we reached the organisational ceiling? A review of applied accident causation models, methods

and contributing factors in construction. Theoretical Issues in Ergonomics Science, 20(5): 533-555. https://doi.org/10.1080/1463922X.2018.1558305
[20] Saeed, Y.S. (2017). Safety management in construction projects. Journal of Duhok University, pp. 546-560. https://doi.org/10.26682/sjuod.2017.20.1.48
[21] Zhou, Z., Goh, Y.M., Li, Q. (2015). Overview and analysis of safety management studies in the construction industry. Safety Science, 72: 337-350. https://doi.org/10.1016/j.ssci.2014.10.006
[22] Noviastuti, T.K., Ekawati, E., Kurniawan, B. (2018). Analisis upaya penerapan manajemen k3 dalam mencegah kecelakaan kerja di proyek pembangunan fasilitas penunjang bandara oleh Pt. X (Studi Kasus di Proyek Pembangunan Bandara di Jawa Tengah). Jurnal Kesehatan Masyarakat (e-Journal), 6(5): 648-653. https://doi.org/10.14710/jkm.v6i5.22106
[23] Boell, S.K., Cecez-Kecmanovic, D. (2015). What is an information system? In 2015 48th Hawaii International Conference on System Sciences. https://doi.org/10.1109/HICSS.2015.587
[24] Sui, Y., Ding, R., Wang, H. (2018). An integrated management system for occupational health and safety and environment in an operating nuclear power plant in East China and its management information system. Journal of Cleaner Production, 183: 261-271. https://doi.org/10.1016/j.jclepro.2018.02.101
[25] Azhar, S., Behringer, A. (2013). A BIM-based approach for communicating and implementing a construction site safety plan. in Proc., 49th ASC Annual International Conference Proceedings. http://ascpro0.ascweb.org/archives/cd/2013/paper/CPRT43002013.pdf.
[26] Azhar, S., Behringer, A., Sattineni, A., Mqsood, T. (2012). BIM for facilitating construction safety planning and management at jobsites. In Proceedings of the CIB-W099 International Conference: Modelling and Building Safety, Singapore, pp. 10-11.
[27] Hatmoko, J.U.D., Fundra, Y., Wibowo, M.A. (2019). Investigating building information modelling (BIM) adoption in Indonesia construction industry. In MATEC Web of Conferences. https://doi.org/10.1051/matecconf/201925802006
[28] Telaga, A.S. (2018). A review of BIM (Building Information Modeling) implementation in Indonesia construction industry. In IOP Conference Series: Materials Science and Engineering, Volume 352, The 7th AIC-ICMR on Sciences and Engineering 2017 18-20 October 2017, Banda Aceh, Indonesia. https://doi.org/10.1088/1757-899X/352/1/012030
[29] Yin Robert, K. (1994). Case study research: design and methods. sage publications. https://doi.org/10.1088/1757-899X/352/1/012030
[30] Choe, S., Leite, F. (2017). Construction safety planning: Site-specific temporal and spatial information integration. Automation in Construction, 84: 335-344. https://doi.org/10.1016/j.autcon.2017.09.007
[31] Hallowell, M.R., Gambatese, J.A. (2009). Construction safety risk mitigation. Journal of Construction Engineering and Management, 135(12): 1316-1323. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000107
[32] Wardahni, N.I., Latief, Y., Machfudiyanto, R.A. (2020). Development of safety plan to improve OHS (occupational health and safety) performance for construction of dam (supporting infrastructure) based on WBS (work breakdown structure). In IOP Conference Series: Earth and Environmental Science, 426(1): 012017. https://doi.org/10.1088/1755-1315/426/1/012017
[33] Putra Lim, A. W., Latief, Y. (2020). The Development of Safety Plan Using Work Breakdown Structure (WBS) for Building Information Modeling (BIM)-Based Building Structure Work. Journal of Computational and Theoretical Nanoscience, 17(2-3): 1402-1413. https://doi.org/10.1166/jctn.2020.8818
[34] Benjaoran, V., Bhokha, S. (2010). An integrated safety management with construction management using 4D CAD model. Safety Science, 48(3): 395-403. https://doi.org/10.1016/j.ssci.2009.09.009
[35] Sasmito, G.W. (2017). Penerapan metode waterfall pada desain sistem informasi geografis industri kabupaten tegal. Jurnal Informatika: Jurnal Pengembangan IT, 2(1): 6-12. http://openjournal.unpam.ac.id/index.php/ESIT/article/view/18174.
[36] Tristianto, C. (2018). Penggunaan metode waterfall untuk pengembangan sistem monitoring dan evaluasi pembangunan pedesaan. in ESIT.
[37] Martínez-Aires, M.D., Lopez-Alonso, M., Martinez-Rojas, M. (2018). Building information modeling and safety management: A systematic review. Safety Science, 101: 11-18. https://doi.org/10.1016/j.ssci.2017.08.015
[38] Zhang, S., Sulankivi, K., Kiviniemi, M., Romo, I., Eastman, C.M., Teizer, J. (2015). BIM-based fall hazard identification and prevention in construction safety planning. Safety Science, 72: 31-45. https://doi.org/10.1016/j.ssci.2014.08.001
[39] Satrio, G., Latief, Y. (2018). Development of risk-based standardized WBS (Work Breakdown Structure) for safety planning of cable-stayed bridge project. In Proceedings of the International Conference on Industrial Engineering and Operations Management, pp. 110-117.
[40] Susiawan, T., Latief, Y., Riantini, L. (2019). Development of WBS (Work Breakdown Structure) risk based standard for safety planning at seaport project. in Journal of Physics: Conference Series, 1360(1): 012007. https://doi.org/10.1088/1742-6596/1360/1/012007
[41] Ganah, A., John, G.A. (2015). Integrating building information modeling and health and safety for onsite construction. Safety and Health at Work, 6(1): 39-45. https://doi.org/10.1016/j.shaw.2014.10.002
[42] Mohanta, A., Mohanty, R.N., Das, S. (2019). Technical issues of using BIM: East Indian architects' perspective. In Research into Design for a Connected World, pp. 565-574. https://doi.org/10.1007/978-981-13-5974-3_49
[43] la Fuente, D., Lozano-Miralles, J. (). Establishment of a didactic methodology for the construction of a model BIM 4d and 5d developed from a modeled industrial building in 3d. Cost Analysis and Simulated Execution Planning, pp. 1-10.
[44] Azhar, S., Brown, J. (2009). BIM for sustainability analyses. International Journal of Construction Education and Research, 5(4): 276-292. https://doi.org/10.1080/15578770903355657
[45] Politi, R.R. (2018). Project plannig and management using Building Information Modeling (BIM). Izmir Institute of Technology.
[46] John, G., Ganah, A. (2011). Integrating BIM and

planning software for health and safety site induction. In: COBRA 2011, The Royal Institution of Chartered Surveyors International Research Conference, 12-13 September 2011, University of Salford, UK. http://clok.uclan.ac.uk/2787/.

[47] Martínez-Rojas, M., Marín, N., Vila, M.A. (2016). The role of information technologies to address data handling in construction project management. Journal of Computing in Civil Engineering, 30(4): 04015064. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000538

[48] Zou, P.X., Lun, P., Cipolla, D., Mohamed, S. (2017). Cloud-based safety information and communication system in infrastructure construction. Safety Science, 98: 50-69. https://doi.org/10.1016/j.ssci.2017.05.006

[49] Chen, C.S., Tsui, Y.K., Dzeng, R.J., Wang, W.C. (2015). Application of project-based change management in construction: A case study. Journal of Civil Engineering and Management, 21(1): 107-118. http://doi.org/10.3846/13923730.2013.802712