ASEAN Engineering Journal

Full Paper

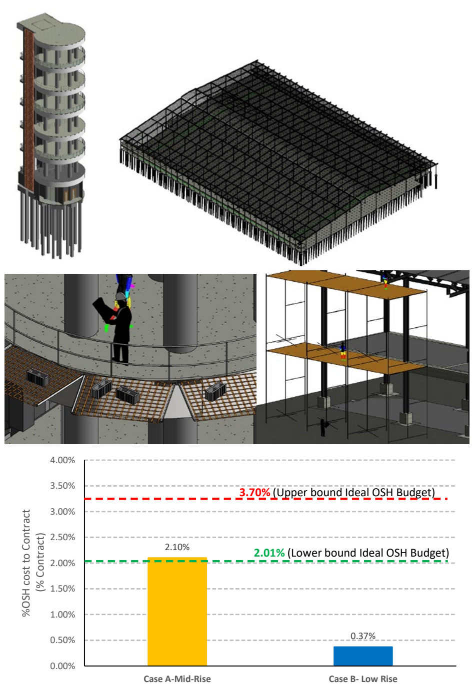
UTILIZATION OF BIM MODEL FOR OSH COST ESTIMATION ON LOW AND MEDIUM RISE BUILDING PROJECTS

Roi Milyardi[a]*, Cindrawaty Lesmana[a], Michael Kristian Satyana[b], Celia Padmanindita[b], Egi Gustian[b], Bunga Olivia Verel[b]

[a]Faculty of Smart Technology and Engineering, Universitas Kristen Maranatha, 40164, Bandung, West Java, Indonesia
[b]Undergraduate Study Program in Civil Engineering, Faculty of Smart Technology and Engineering, Universitas Kristen Maranatha, 40164, Bandung, West Java, Indonesia

Article history
Received
01 March 2024
Received in revised form
09 September 2024
Accepted
11 September 2024
Published online
31 May 2025

*Corresponding author
roi.milyardi@maranatha.edu



Abstract

The Occupational Safety and Health (OSH) accident in Indonesia has reached its highest level in five years. The development of OSH cost includes the project budget to reduce accidents. Building Information Modeling (BIM) can detect potential causes of accidents prior to the construction starts so that the accident can be reduced. Many utilizations of BIM in OSH focus on planning and prevention rather than on OSH cost estimation. This study aims to conduct OSH cost component estimation using BIM for a building project in Indonesia. Two projects in the planning phase, tower building and warehouse building, are studied. The result indicates BIM utilization contributes to a to a more detailed safety equipment budget compared to the actual case. OSH cost reaches 2.01% from total budgeted project cost for tower building and 0.37% from total budgeted project cost for warehouse building. This shows the potential of estimating the OSH budget using the BIM model to achieve the ideal value of the OSH budget (2.01%–3.70%), particularly for mid-rise buildings.

Keywords: Occupational Safety and Health; Building Information Modelling; Cost Structure; Construction Safety; Visualization

1.0 INTRODUCTION

Occupational Safety and Health (OSH) became one of the project constraints in the construction industry. OSH has been identified as a project risk that is managed as a threat as well as an opportunity by the contractors [1]. Although it is a constraint, work accidents frequently occur in construction projects. During 2017-2022 in Indonesia, there were 48 cases of work on infrastructure projects causing injuries, deaths, and temporary suspension of the project. The project. The project consists of 22 cases on toll road projects, 9 cases on building projects, 7 cases on railway projects, 3 cases on LRT projects, 3 cases on bridge projects, 3 cases on dam and embankment projects, and 1 case on other projects [2, 3]. The project risk has become a threat and an opportunity, so OSH has an important role in project cost budgeting.

OSH component cost on project budget varies based on type of projects. Differences in OHS risks in each type of project cost affect the composition of OHS costs in the project budget. OSH components that are accommodated in the project (general) consist of preparation components, personal protective equipment (PPE), OSH personnel, OSH induction and promotion, insurance and licensing, signage, health facilities, work protective equipment, and miscellaneous OSH risk control (consultation with experts, etc.) [4, 5]. Work protective equipment and PPE are confirmed to be the top 5 most significant OSHs, below OSH personnel and insurance. The cost of OSH in Indonesia varies 0.84%-1.708% from project value in different types of projects, consisting of 0.84% on road projects, 0.905% on bridge projects, and the highest 1.290% on building projects [6]. The average OSH cost in building is approximately equal across the Southeast Asia region [7]. But the OSH cost of the building is below the ideal cost (2.01%-3.70%) as mandated by Indonesian authority [4, 8]. The OSH analysis on building projects has been advanced by previous studies with many projects and complex variables. The gap to the ideal cost in a building project could be potentially pursued by utilizing Building Information Modeling (BIM) in OSH integrated planning.

BIM is a technology that is revolutionizing the world of construction. BIM allows the parties involved in the project to collaborate better at each stage of the project life cycle, such as in the procurement, design, construction, prefabrication, and facility management areas [9]. In addition, BIM allows a project enhanced productivity and increased profits. As a new technology, with its many benefits, BIM has barriers to its application, which generally include managerial, technological, personnel, legal, and cost factors [10]. Specifically in developing countries, the use of BIM has significant problems, including construction firms relying on outsourcing of IT services or developing tweaks or workarounds, such as using 'fake' IT licenses, for saving costs and enabling BIM [11].

Despite the barriers to BIM implementation, the benefits are widely recognized as more valuable than ever. Technically, BIM technology helps construction projects in utility sustainability, energy simulation, facilities management, risk management, and cost estimation [12]. The function of BIM as a cost estimation tool shows incremental significance on increasing project complexity, especially significance on the variables of generality, flexibility, efficiency, and accuracy, when compared to traditional cost estimation methods [13–15]. In construction cost estimation, one of the cost components considered is the OHS component. In the development of OHS cost estimation in previous studies, OHS costs were estimated with 2 main cost components, namely direct and indirect, with 4 general categories, including insurance costs, prevention costs, accident costs, and recovery costs [16]. In some previous studies, OHS costs can be estimated at around 2–6.5% of total construction costs with various adjustments to project characteristics [17].

In the risk management utility, BIM has also been utilized in the OHS field. In some previous studies, BIM has been developed for several safety factors, including hazard recognition, hazard prevention, worksite safety, safety planning, and communication/coordination of tasks [18–20]. The development was carried out with several BIM attribute facilities, including those that are often used: visualization, automated rule-based checking, 3D imaging/rendering, and 4D simulation [18, 21]. The benefits of BIM utilization in the OSH field are also quite significant. In hazard identification, with 3D visualization through BIM models, the identification process becomes more detailed compared to the previous technology hazard identification process (2D CAD drawing) [22]. Other specific benefits of BIM utilization in the OHS field, in previous studies in the USA, showed the benefits of reducing construction time, cost savings reaching 1-5%, increasing profits by 1-5%, as well as other indirect impacts such as increased reputation, improved quality, and increased opportunities for new projects [23].

Several studies of BIM utilization on construction's OSH have been conducted. The BIM has been identified as potentially utilized on some OSH issues, such as excavation safety, safety monitoring, safety training, safety planning, and locating potential safety problems [24, 25]. The typical OSH risk that analysis one safety planning using BIM includes fall, slip, collision, electrical hazard, fire and explosion, and noise [25, 26]. The benefit of BIM utilization on OSH analysis involves return on investment, improvement in risk identification, improvement in the quality of training activities, and significantly on OSH performance [23, 27]. One of the potential developments in BIM in safety and health planning is OSH cost component analysis [28, 29].

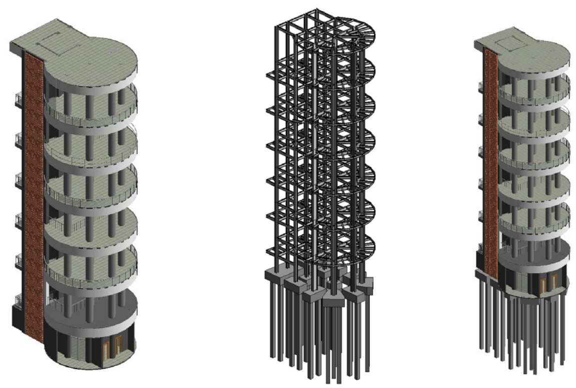
Previous studies on the utilization of BIM models in OSH risk management focused on hazard identification, safety training, and evacuation planning, which all showed a positive trend in many aspects of construction project performance (cost, OSH, schedule). Through the OSH component model that has been developed into various families in the BIM model, this research focuses on developing OSH cost estimation through the component data. The development of the estimation tool does not only depend on component modeling alone but also on OSH-related simulations to estimate other non-good OSH cost components. The development was conducted on OSH hazards limited to case studies of mid-rise and low-rise buildings.

This study aims to conduct OSH cost component estimation using BIM with a study case on a building project in Indonesia. Based on several previous studies, the use of BIM in Indonesia in the field of OSH is wide open to be developed, where the position of contractors in Indonesia is still in the early stages but still using BIM in the construction sector with various challenges at each level of contractors The contribution of development through this article is the utilization of BIM, which has previously been developed as a tool for OSH hazard identification and developed 1 more step for OSH cost estimation through modeling OSH components and analysis that already exists in the BIM model.

2.0 METHODOLOGY

This study takes case studies in two building projects, consisting of tower building (Case A) and warehouse building (Case B), which are both case study planning phase projects. Case A and Case B have different project characteristics; Case A has a multistory building type project, whereas Case B has a horizontal wide building type project. Case A consists of a mid-rise (a 7-story steel moment frame building) (total height +31.4 m) and a driven pile precast foundation system (depth -6.00 m) with a total 570,66 m2 area, occupied as a viewing tower. Case B consists of a 2-story building (total height +22.26 m) and a driven pile precast foundation system (depth -15.00 m) with a total 63,828 m2 area, occupied as a warehouse. Both study case 3D models are shown in Figure 1 and Figure 2. The selection of case studies that have distinctive characteristics to identify OSH cost component analysis in different types of building projects.

In Figure 1, Case A is shown in the form of a high-rise building model consisting of 2 BIM models: the architectural model, shown in Figure 1a, and the structural model, shown in Figure 1b. In the architectural model, floors, architectural column ornaments, walls, railings, doors, and windows are modeled according to the architectural design. In the structural model, the floors, architectural column ornaments, walls, railings, doors, and windows are modeled according to the architectural design, while the structural model is modeled with a steel structure consisting of King-Cross columns, secondary beams, and primary beams with IWF profiles, floor slabs with metal deck and concrete slab profiles, and pile foundations. Figure 1c. shows the integration model between the two models that have been put together.



a b c

Figure 1 Case A Building 3D BIM model; **a** architecture model, **b** structure model; **c** integration model

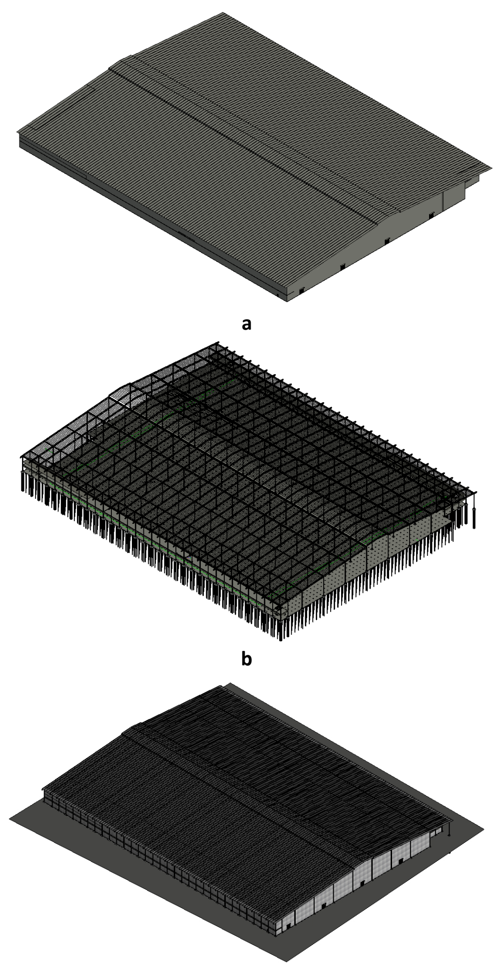
In Figure 2, Case b is shown in the form of a low-level building model consisting of 2 BIM models: the architectural model, shown in Figure 2a, and the structural model, shown in Figure 2b. In the architectural model, floor components, cladding walls, railings, doors, windows, and roofs are modeled according to the architectural design. While the structural model is modeled with a steel structure consisting of concrete columns and beams for the mezzanine floor, rafters with IWF profiles, concrete slab profile floor slabs, and pile foundations. Figure 2c shows the integration model between the two models that have been put together.

Observed OSH risks take the top five risks that were conducted by job hazard analysis. The OSH risks that were identified are elaborated by the risk register provided by authority [30]. The OSH risk scope in this study for each case shown in Table 1.

Table 1 Identified OSH Risk in each case

No.	OSH Risk Register	
	Case A	Case B
1	Falling objects	Falling objects
2	Slips and trips	Slips and trips
3	Work at height	Work at height
4	Fuel fire	Forklift operation
5	Crane operation	Crane operation

The study workflow is shown in Figure 3. The study starts with BIM modeling using Autodesk REVIT for building components (site, architecture, and structure data) from Detailed Engineering Design (DED) data. From the Building BIM model, conduct OSH planning and prevention based on the one-risk register shown in Table 1, using open-source OSH components (safety equipment, machinery model, etc.). The cost estimation of building (preparation, foundation, structure, and architecture) calculated based on REVIT's quantity output multiplied by unit cost from the database [31]. The cost estimation for the OSH cost component consists of OSH personnel, insurance and licensing, OSH induction, and promotion. PPE, safety equipment, health facility, and sign. PPE calculated based on one estimated number of workers from the contractor's data: 100 workers for Case A and 335 workers for Case B. OSH personnel were calculated based on a 1:40 ratio to the number of workers as mandated by the authority for high-risk projects [32]. OSH insurance is calculated based on contract value, and in both cases, the OSH insurance calculated 0.09% from the project contract for accidental insurance and 0.01% from the project contract for death insurance as an authority mandate [33]. OSH induction, health facility estimated by the size of project and the number of workers. The OSH unit cost is calculated by the unit cost database [31].



a

b

c

Figure 2 Case B Building 3D BIM model; **a** architecture model, **b** structure model; **c** integration model

Summarizing the work steps above, the inputs in this study required building DED data, identified OSH hazard limits (5 risks), data on the number of workers, a unit price database, and BIM family components for OSH equipment obtained from open source. The process carried out is modeling the BIM building from structural and architectural components, conducting OSH planning analysis to determine the placement of OSH components, modeling the OSH family on the BIM building model, and processing cost calculations through volume data and a unit price database. The output generated from these processes is the volume output of OSH components through the "Schedule/Quantities" feature and the total OSH cost estimation data.

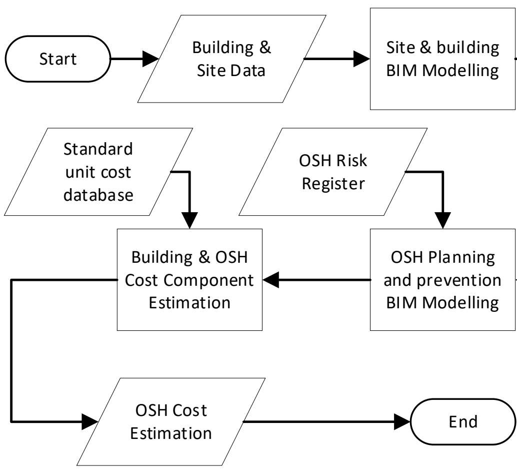


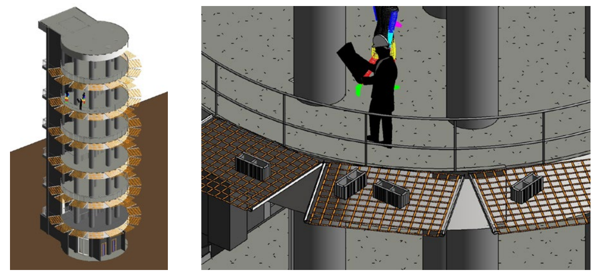
Figure 3 Flowchart of study

3.0 RESULTS AND DISCUSSION

3.1 OSH Risk Planning a Prevention on BIM Model

Case A's OSH risk planning and prevention on the BIM model is shown in Figure 4 until Figure 8 and Table 2. Falling object risk prevention by installing a safety net and safety railing as shown in Figure 4a and Figure 4b. The safety net and safety railing were installed in each floor perimeter during the construction. Slips and trips risk simulated on site is shown in Figure 5. The prevention for the risk conducted by worker flow and accessible area for the worker during the construction. The equipment that was simulated in this risk prevention was clear signage for worker flow. Work at height risk prevention by installing firm scaffolding for the worker access during structure and architectural work and before the permanent stair installed, shown in Figure 6a and Figure 6b.

Another preventive measure for this risk is to model the use of safety harnesses on workers mounted on sturdy safety lines. The number of harnesses is adjusted to the number of workers and the work schedule. Fuel fire risk prevention by installing safety railing and placing the fuel storage in certain areas in the site project shown in Figure 7. The safety railing and location were conducted to minimize victims if the worst scenario happened. The location of fuel storage is also considered in certain areas around the project, with modeling of the estimated need for fire extinguishers at the location. Crane operation risk prevention by determining the boundaries of the working area of the mobile crane, by marking the area with safety cone modeling in the BIM model and considering the crane's working area requirements. area shown in Figure 8. In modeling OSH equipment, not all can be modeled due to the limited availability of models such as PPE equipment (Personal Protective Equipment), so that OSH Equipment information that is not modeled is inputted in the existing OSH model as text information, not a 3D model.



a b

Figure 4 Falling object risk (Case A) safety planning and prevention BIM model; **a** Safety net modelling; **b** Detail of safety net modelling

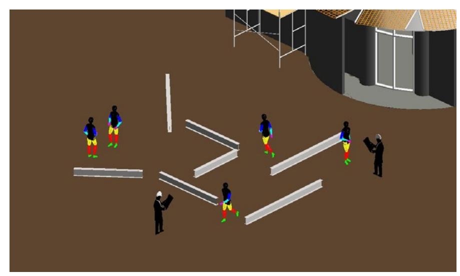
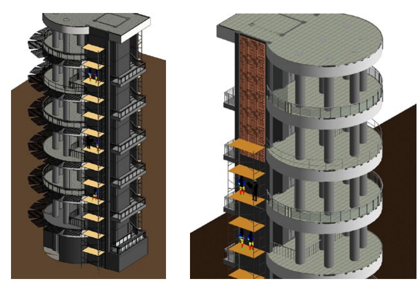


Figure 5 Slips and trips risk (Case A) safety planning and prevention BIM model



a b

Figure 6 Work at heigh risk (Case A) safety planning and prevention BIM model; **a** scaffolding modelling; **b** scaffolding detail modelling

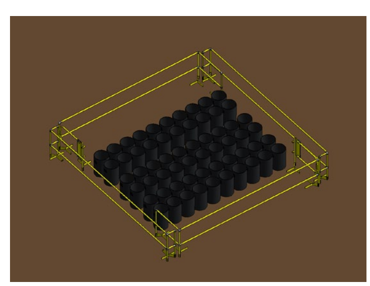
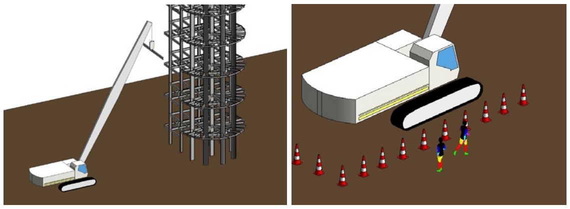


Figure 7 Fuel fire risk (Case A) safety planning and prevention BIM model



a b

Figure 8 Crane operation risk (Case A) safety planning and prevention BIM model; **a** crane operation modelling; **b** cone modelling on crane operation area

Table 2 Planning and prevention on OSH risk Case A

No	OSH Risk Register	
	Case A	**Planning and Prevention on BIM**
1	Falling objects	Installing Safety Net and safety railing, sign, and mandatory equipment of PPE for worker (Safety Shoes, and Safety Helmet)
2	Slips, trips	Simulation worker flow and Installing safety line for worker access, and mandatory equipment of PPE for worker (Safety Shoes, and Safety Helmet)
3	Work at height	Installing sign, Safety Railing and scaffolding for worker access, and mandatory equipment of PPE for worker (Body Harness, Lifeline, Anchor Point, Safety Shoes, and Safety Helmet)
4	Fuel fire	Installing Safety Railing, placing Fire Extinguisher, sign, and special locating area for fuel
5	Crane operation	Install the safety cone and sign on crane operation area

The OSH risk planning and prevention on BIM model in Case B is shown in Figure 9 until Figure 13 and Table 3. Falling object risk prevention by simulating the roof truss erection; ensure below the erection area the worker is prohibited by the mandatory sign and PPE shown in Figure 9. In this simulation strategy, a mobile crane is modeled on the BIM model, and the sequence of the steel roof erection process is simulated to ensure the area that needs to be vacated during erection is adjusted to the general building construction schedule. Slips and trips risk simulated on site are shown in Figure 10. The risk of slipping and tripping can be prevented by modeling a safety line path for workers, thus ensuring workers are safe. In addition, the safety line simulation also ensures that the steel erection work area can run according to the plan schedule.

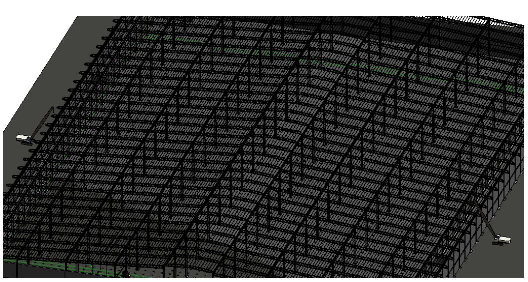


Figure 9 Falling object (Case B) safety planning and prevention BIM model

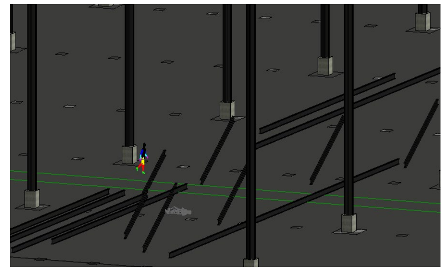
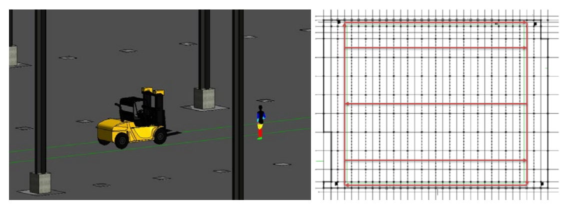


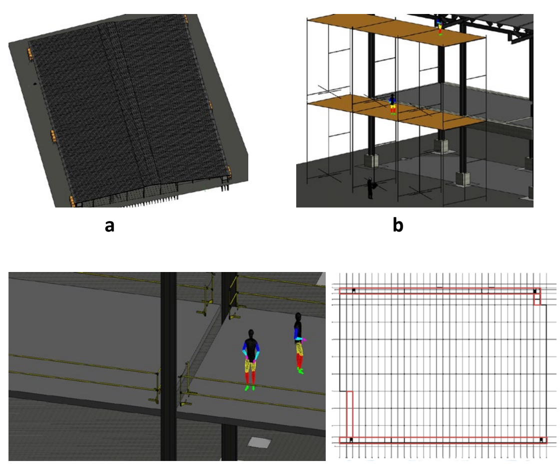
Figure 10 Strip and Slips (Case B) safety planning and prevention BIM model

Forklift operation risk prevention by planning the forklift operation line and signs to minimize accidental hits by forklifts, as shown in Figure 11a and 11b. In the BIM model, the forklift model and the forklift work plan path are modeled. Work at height by installing firm scaffolding for the worker access during structure and installing roof by roll-on-top methods, as shown in Figure 12a until Figure 12b. The other prevention for working at height is installing the safety railing by the plan of safety railing shown in Figure 12c and Figure 12d. In this prevention, it is modeled on the BIM safety railing model in the mezzanine area and the scaffolding and ladder model in the planned area that can be accessed by workers.



a b

Figure 11 Lift Truck Operation (Case B) safety planning and prevention BIM model; **a** forklift Line Operation in site project; **b** forklift Operation Line plan in site project



a b

c d

Figure 12 Work at Height (Case B) safety planning and prevention BIM model; **a** scaffoldings modelling; **b** detail of scaffoldings modelling; **c** Detail of safety railing modelling; **d** safety railing plan

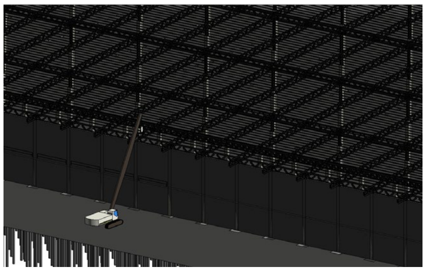


Figure 13 Crane Operation (Case A) safety planning and prevention BIM model

Crane operation risk prevention by locating the safety cone to take attention and avoid the crane operation area shown in Figure 13. In this prevention, the treatment carried out is the same as in case A, which is in the form of determining the boundaries of the mobile crane work area by marking the area with safety cone modeling in the BIM model, also considering the requirements of the crane work area.

Table 3 Planning and prevention on OSH risk on Case B

No	Identified OSH Risk	
	Case B	**Planning and Prevention**
1	Falling objects	Simulating the roof truss erection, ensure below the erection area the worker prohibited by mandatory sign and PPE (Safety Helmet, Safety Shoes)
2	Slips, trips	Arrange the safety line for worker to minimize slip and trip on site project, and mandatory using PPE (Safety Helmet, Safety Shoes)
3	Forklift operation	Plan the forklift operation line and sign
4	Work at height	Installing firm scaffolding, installing the safety railing, sign, and mandatory using PPE (Fall Arrester, Safety Helmet, Safety Lanyard, Anchor Point, Full Body Harness)
5	Crane operation	Install the safety cone and sign on crane operation area

3.2 OSH Cost Estimation

The cost component calculated based on BIM output is shown in Table 4 for Case A and Case B. Each case study calculated the total cost and cost component of OSH. The physical cost of the building is calculated based on the volume of the BIM model that has been modeled. While the OSH costs are based on the quantity of the BIM model that is modeled according to the need to identify the OSH hazards mentioned earlier. The OSH cost for multi-story building (Case A) is 2.1% of the total construction budget shown in Table 5. This number is bigger than the average previous study case in Indonesia, but in accordance with the ideal OSH cost as mandated by the authority (2.01%–3.70%) [8]. The OSH cost for low-rise-horizontal characteristic building (Case B) is 0.37% of the total construction budget shown in Table 5. This number is smaller than the average previous study case in Indonesia and also smaller than the ideal OSH cost as mandated by the authority (2.01%–3.70%), as shown in Figure 14 [8]. Figure 14 shows that the estimation through the BIM model in Case A (mid-rise) reaches the ideal value of the OHS budget in the construction project, while in Case B (low-rise) it has not reached the ideal number. This shows that the area and characteristics of mid-rise buildings also affect the estimation value.

Table 4 Cost component in case A and Case B

No	Cost Component	OSH Cost in Case A (Million IDR)	OSH Cost in Case B (Million IDR)
1	Preparation Work	63.44	462.75
2	Foundation Work	781.45	3,825.54
3	Upper-Structure	5,689.76	169,058.81
4	Architecture Work	398.13	24,452.92
5	OSH Component	148.98	741.10
5a.	OSH Personnel	39.00	216.00
5b.	Insurance	7.08	198.54
5c.	OSH induction and promotion	15.00	30.00
5d.	PPE	30.50	93.26
5e.	Safety Equipment	45.58	176.47
5f.	Health Facility	1.82	1.82
5g.	Sign	10.00	25.00
Estimate Construction Cost		7,081.76	198,541.11

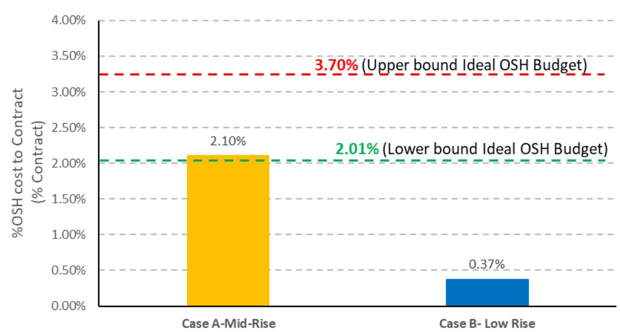


Figure 14 OSH cost estimation comparison

Table 5 also shows the OSH cost comparison in Case A and Case B. The OSH budget per meter area multistory case project is higher than the actual case study, but the horizontal characteristic project (Case B) has a smaller value. On the OSH budget per number of floors, Case A has a smaller value than the actual case study; otherwise, Case B has a bigger value.

On the most significant OSH cost component comparison shown in Table 6. The percentage value of each OHS component is calculated from the cost of each component to the total cost of the OHS component. In Case A, the ranking of OSH cost components is shown in sequence: safety equipment, OSH personnel, PPE, OSH induction and promotion, and sign. In Case B, the ranking of OSH cost components is shown in sequence: OSH Personnel, Insurance and Licensing, Safety Equipment, PPE, and Sign. This shows that in Case B, which has a large building area, which requires a lot of personnel, the number of personnel is a determining factor compared to Case A, which has the characteristics of a multi-story building that requires relatively fewer workers than Case B. The result shows that the top five rank has the same OSH cost component but is different in order. The most significant rank-up cost component is safety equipment. The safety cost component ranks up in both cases; it's indicated that utilizing BIM could potentially give a more detailed cost of safety equipment; besides, it's also dependent on the OSH BIM model.

Table 5 OSH cost comparison

OSH Parameter	CASE A (Estimated)	CASE B (Estimated)	References case study [6, 17]
%OSH cost to Contract	2.10%	0.37%	1.59%-1.78%
OSH Budget to/m^2 (IDR)	261,069	11,611	76,498
OSH Budget/number of floor (IDR)	21,283,108.97	370,547,555.81	118,234,314

Table 6 The most significant OSH cost component comparison

Rank	CASE A	CASE B	References [4, 17]
1	Safety Equipment (28.71%)	OSH Personnel (29.15%)	OSH Personnel (44.10%)
2	OSH Personnel (26.18%)	Insurance and Licensing (26.79%)	Insurance and Licensing (35.42%)
3	PPE (20.47%)	Safety Equipment (21.99%)	OSH induction and promotion (5.82%)
4	OSH induction and promotion (10.07%	PPE (12.58%)	PPE (5.23%)
5	Sign (6.71%)	Sign (3.37%)	Safety Equipment (3.87%)

Through this study, BIM has potential utilization to estimate a more accurate OSH cost in construction projects. It is confirmed by several actual OSH cost studies and the ideal cost of OSH. There is a limitation on the estimation process, which depends on the level of detail of the OSH component modeled/simulated in the BIM model. The other limitation was in modeling OSH equipment; not all can be modeled due to the limited availability of models such as PPE equipment (Personal Protective Equipment), so that OSH Equipment information that is not modeled is inputted in the existing OSH model as text information, not a 3D model. The future development should be focused on diversification of the utilization of BIM one of the project characteristics (area, number of workers, project type, etc.) that show significant dependence in this study.

4.0 CONCLUSION

OSH cost component estimation using BIM model was performed. The estimation was done in 2 case studies: Case A was a mid-rise building, and Case B was a horizontal-type building. The result of Case A shows the OSH cost reaches 2.01% of the total budgeted project cost. Meanwhile, in Case B, OSH cost reaches 0.37% of total budgeted project cost. This shows the potential of estimating the OSH budget using the BIM model to achieve the ideal value of the OSH budget, specifically in mid-rise buildings. The BIM utilization for OSH cost estimation has potential to advance development. Thus, it is highly recommended to further development focus on diversification project parameters such as project area, project type, etc. as the consideration for more accurate OSH cost estimation.

Acknowledgement

The authors sincerely appreciate the support and facilities provided by Universitas Kristen Maranatha, which were instrumental in the successful completion of this research.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

References

[1] Milyardi R 2020 Perbandingan Karakteristik Manajemen Risiko Konstruksi Pada Kontraktor Bumn Dan Swasta. 020. Comparison of the Characteristics of Construction Risk Management in State-owned and Private Contractors. *Jurnal Teknik Sipil.* 16: 12–37. DOI: https://doi.org/10.28932/jts.v16i1.2399

[2] Alexander HB 2019. *High Construction Accidents, K3 Must Be Intensified in Landed House Projects.* Kompas.com

[3] Supriyadi A 2018. 1*4 Construction Accidents 2017-2018 Temporarily Halted the Project.* https://katigaku.top/2018/02/26/14-kecelakaan-konstruksi-2017-2018-menghentikan-sementara-proyek/. Accessed 29 Mar 2023

[4] Wirahadikusumah RD, Adhiwira F, Gayatri R 2019. Tantangan Penerapan Alokasi Anggaran Biaya SMK3 pada Kontrak Konstruksi Proyek Berisiko Tinggi. J*urnal Teoretis Dan Terapan Bidang Rekayasa Sipil.* 26: 67–78. DOI: https://doi.org/10.5614/jts.2019.26.1.9

[5] Fitriani R, Latief Y, Machfudiyanto RA 2023 Cost Structure of Construction Safety on High Residential Buildings in Indonesia BT - Proceedings of the *5th International Conference on Rehabilitation and Maintenance in Civil Engineering.* In: Kristiawan SA, Gan BS, Shahin M, Sharma A (eds). Springer Nature Singapore, Singapore, pp 659–667

[6] Marleno R, Tjendani HT, Bon AT 2019. The cost of occupational safety and health (OSH) in construction project. *Proceedings of the International Conference on Industrial Engineering and Operations Management.* 1342–1347

[7] Hamid ARA, Singh B, Salleh ASM 2014. Cost of compliance with Health and Safety management system among contractor in construction industry. *National Seminar on Civil Engineering Research.10*.DOI: https://doi.org/10.13140/2.1.1158.9445

[8] Ministry of Public Works and Housing of Indonesia 2018. *Peraturan Menteri Pekerjaan Umum dan Perumahan Rakyat Republik Indonesia* RI No. 02/PRT/M/2018. Indonesia

[9] Oraee M, Hosseini MR, Papadonikolaki E, Palliyaguru R, Arashpour M 2017. Collaboration in BIM-based construction networks: A bibliometric-qualitative literature review. *International Journal of Project Management.* 35: 1288–1301. DOI: https://doi.org/10.1016/j.ijproman.2017.07.001

[10] Sun C, Jiang S, Skibniewski MJ, Man Q, Shen L 2017. A literature review of the factors limiting the application of BIM in the construction industry. *Technological and Economic Development of Economy.* 23: 764–779.DOI: https://doi.org/10.3846/20294913.2015.1087071

[11] Bui N, Merschbrock C, Munkvold BE 2016. A Review of Building Information Modelling for Construction in Developing Countries. *Procedia Engineering* 164: 487–494. DOI: https://doi.org/10.1016/j.proeng.2016.11.649

[12] Abanda FH, Kamsu-Foguem B, Tah JHM 2017. BIM – New rules of

measurement ontology for construction cost estimation. *Engineering Science and Technology, an International Journal.*20: 443–459. DOI: https://doi.org/10.1016/j.jestch.2017.01.007

[13] Thu H, Le T, Likhitruangsilp V, Yabuki N 2021 1. A BIM-Database-Integrated System for Construction Cost Estimation. *ASEAN Engineering Journal*. 11: 45–59 DOI: https://doi.org/10.11113/aej.v11.16666

[14] Thu H, Le T, Cong TD 2023. Successful Alternative For BIM-Integrated System: A Successful Alternative For Estimating Cash Flow In Building Projects. *ASEAN Engineering Journal.* 4: 103–112 DOI: https://doi.org/10.11113/aej.v13.19476

[15] 15. Shen Z, A Issa RR, Issa RR, Professor F 2010. Shen & Issa, pg. 234 www.itcon.org-Journal of Information Technology in Construction. *Journal of Information Technology in Construction (ITcon)*. 15: 234–257. https://www.itcon.org/paper/2010/18

[16] Pellicer E, Carvajal GI, Rubio MC, Catalá J. 2014. A method to estimate occupational health and safety costs in construction projects. *KSCE Journal of Civil Engineering.* 18: 1955–1965. DOI: https://doi.org/10.1007/s12205-014-0591-2

[17] Wirahadikusumah RD, Adhiwira F 2019. The cost of implementing OHSMS regulation on high-rise building projects. *MATEC Web of Conferences.* 270: 05007. DOI: https://doi.org/10.1051/matecconf/201927005007

[18] Akram R, Thaheem MJ, Nasir AR, Ali TH, Khan S 2019. Exploring the role of building information modeling in construction safety through science mapping. *Safety Science* 120: 456–470. DOI: https://doi.org/10.1016/j.ssci.2019.07.036

[19] Ammad S, Alaloul WS, Saad S, Altaf M, Alawag AM, Ali M 2021. Building Information Modelling (BIM) and Occupational Safety in Infrastructure Projects. In: *2021 International Conference on Data Analytics for Business and Industry (ICDABI)*. 240–244

[20] Zhang S, Sulankivi K, Kiviniemi M, Romo I, Eastman CM, 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

[21] Fargnoli M, Lombardi M 2020 Building information modelling (BIM) to enhance occupational safety in construction activities: Research trends emerging from one decade of studies. *Buildings* 10(6): 98 DOI: https://doi.org/10.3390/BUILDINGS10060098

[22] Herzanita A, Latief Y, Lestari F 2022 The Application of BIM-Based OHSMS Information Systems to Improve Safety Performance. *International Journal of Safety and Security Engineering.* 12: 31–38. DOI: https://doi.org/10.18280/ijsse.120104

[23] Teizer J, Melzner J 2018 BIM for construction safety and health. *Building Information Modeling: Technology Foundations and Industry Practice* 349–365. DOI: https://doi.org/10.1007/978-3-319-92862-3_21

[24] Kiviniemi M, Sulankivi K, Kähkönen K, Mäkelä T, Merivirta ML. 2011. *BIM-based safety management and communication for building construction.* VTT Technical Research Centre of Finland.

[25] Zielinski Nguyen Ajslev J, Elisabeth Ejstrup Nimb I 2022. Virtual design and construction for occupational safety and health purposes – A review on current gaps and directions for research and practice. Saf *Safety Science.* 155: 1-20 DOI: https://doi.org/10.1016/j.ssci.2022.105876

[26] Lin ETA, Ofori G, Tjandra I, Kim H 2017. Framework for productivity and safety enhancement system using BIM in Singapore. *Engineering, Construction and Architectural Management*.24: 1350–1371. DOI: https://doi.org/10.1108/ECAM-05-2016-0122

[27] Tender M, Fuller P, Vaughan A, Long M, Couto J, Damien P, Chow V, Silva F, Reis F, Reis R. 2022. Real world lessons that can assist construction organisations in implementing BIM to improve the OSH processes. *4o Congresso Português de Building Information Modelling* 1 - ptBIM 155–167.DOI: https://doi.org/10.21814/uminho.ed.32.13

[28] Taiebat M 2011. Tuning Up BIM for Safety Analysis Proposing Modeling Logics for Application of BIM in DfS. ProQuest Diss Theses 178

[29] Gustian E, Milyardi R, Lesmana C. 2022 Analysis of Benefits and Barriers Factors in the Implementation of Building Information Modeling (BIM) in Building Construction for Contractor *Jurnal Teknik Sipil Dan Perencanaan*.24:158–167 DOI: http://dx.doi.org/10.15294/jtsp.v24i2.37026

[30] Minister of Manpower and Transmigration of Indonesia 1980. *Occupational Safety and Health in Building Construction* Minister of Manpower and Transmigration of Indonesia, Jakarta. Pandu Bangun Persada Nusantara2022). *Journal of Unit Prices for Construction and Interior Building Materials*, 41st ed. Pandu Bangun Persada Nusantara

[31] Ministry of Public Works and Housing of Indonesia 2022. Special Specification SKh-1.1.22--Occupational Health and Safety Management System (SMKK). 1–122

[32] BPJAMSOSTEK 2023. *Construction Service worker Insurance in Indonesia.* https://www.bpjsketenagakerjaan.go.id/jasa-konstruksi.html. Accessed 24 Apr 2023