Application of BIM in construction site safety: Systematic review

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Abstract. Construction safety has become and establishment ever since decades. Construction industry especially workers involve in many activities that may expose them to serious hazards. However, with the transformation of current development in technology, safety has become vital especially the needs in improvement of its application on site via digitalization. The exploration on the needs of safety especially in Building Information Modelling has become crucial and there is a need for the application especially the digital twin. The construction industry needs to improve the safety performance by new technology. Building Information Modeling is one of the technologies that are being explored recently. Hence, this paper aims to obtain a comprehensive review especially on the current trend of analysis based on current practice of emerging technology that applied in current practice. Methodology of this paper by info analysis and VOS Viewer. There were 11 different terms were used to obtain the relevant literature including Scopus, Google and books guideline. After data cleaning, there's almost 371 journal articles reviewed in between Jan 2011 and Aug 2021. There are 4 steps of framework being proposed which are analysis on the source of title, researcher, co-occurrence keyword and discussion. Hence from the results of co-occurrence based on the results shows that 21 keywords, as for the researcher were top 10 highlighted. It can be concluded that Building Information Modeling (BIM) and safety construction has the most citation for the current trend of research. Besides it is expected that this study has the potential outcome of research as references for next study on BIM and safety.
Keywords: Building Information Model, Construction Safety, Co-occurrence Analysis, Vos Viewer

1. Introduction

Occupational accident statistics were recorded every year by Department of Occupational Safety and Health (DOSH), Malaysia. Occupational accident in statistic was divided by sector and there were 3 parts of accident that were been classified which is non-permanent disability, permanent disability and death [1]. The occupational fatal accident (death) based on DOSH statistic in Malaysia constructions sector there were around 45% in 2018, 32% in 2019 and 31% in 2020. The statistics shows that construction sector every year have the highest rate of fatal accident. Therefore, safety construction needs to improve by using recent new technology.

In the past few decades, the development of the relevant technology and techniques were risen. BIM, computer vision, radio-frequency identification (RFID), augmented reality (AR), virtual reality (VR), and other technologies are the examples of technology utilised in the creation of safety management systems[2]. By implementing new technologies, proper modification or considerations in design phase should reduce the construction accident or hazard. The designers should have safety

knowledge which is more understanding on hazard identification to enhance safety management in the designs.

Building Information Modeling (BIM) one of the most often utilised technology in construction (BIM). BIM used to visualize by virtual models of a building are created digitally in the architectural, engineering, and construction (AEC) sectors [3]. Hence, BIM contributes as an advancement tool in safety management for clash detection, scheduling progress, cost estimation, improved team collaboration, or design consistency and visualizations, etc. In addition, BIM also provides a comprehensive framework for handling and exchange the information with high capability to store large amount of information in BIM models [4].

Primary component in AEC projects is design phase which impact on other construction and management process. The application of BIM provides better building design with significant of information includes safety management. For time being constructions employees might be not used new technology as it high cost which is the cons of the new technology but there a lot of pros to be compared which are more safety significant during the design, save time during the work progress and engineer also can aware of the safety design when monitoring the construction work. Hence BIM is the crucial and it brings the whole application of transformation.

2. Research Methodology

The study refers to finding issues and conducted based on available literature. The BIM and safety construction literature are analyses by following steps: (i) Set of keywords based on the different context of safety concepts (Table 1) used to identify the scientific publications of the journals; (ii) analysis the content of article and abstract; (iii) exclusions the duplicates and articles that not related on the subject; (iv) categorised the literature based on construction safety context; (v) analysis of the literature.

Table 1 Scientific publications of journals based on BIM and safety based on keywords at Scopus.

Keywords 1 'BIM'	Keywords 2 'Safety'	No. of scientific publications (journals)
'BIM OR Building Information Model'	'Safety'	1311
'BIM OR Building Information Model'	'Safety Management'	468
'BIM OR Building Information Model'	'Safety Construction'	1255
'BIM OR Building Information Model'	'Safety Prevention Tools'	97
	Total	3131

The analysis to explore the most relevant studies between Building Information Modeling (BIM) and construction safety. The systematic review is based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [5]. In adapting the process for the purpose of the study, minimal modification applied in PRISMA. Scientific publications need to be identified as to ensure the study was thoroughly covered by using two search attempts and using Scopus database by Elsevier was selected for literature exploration.

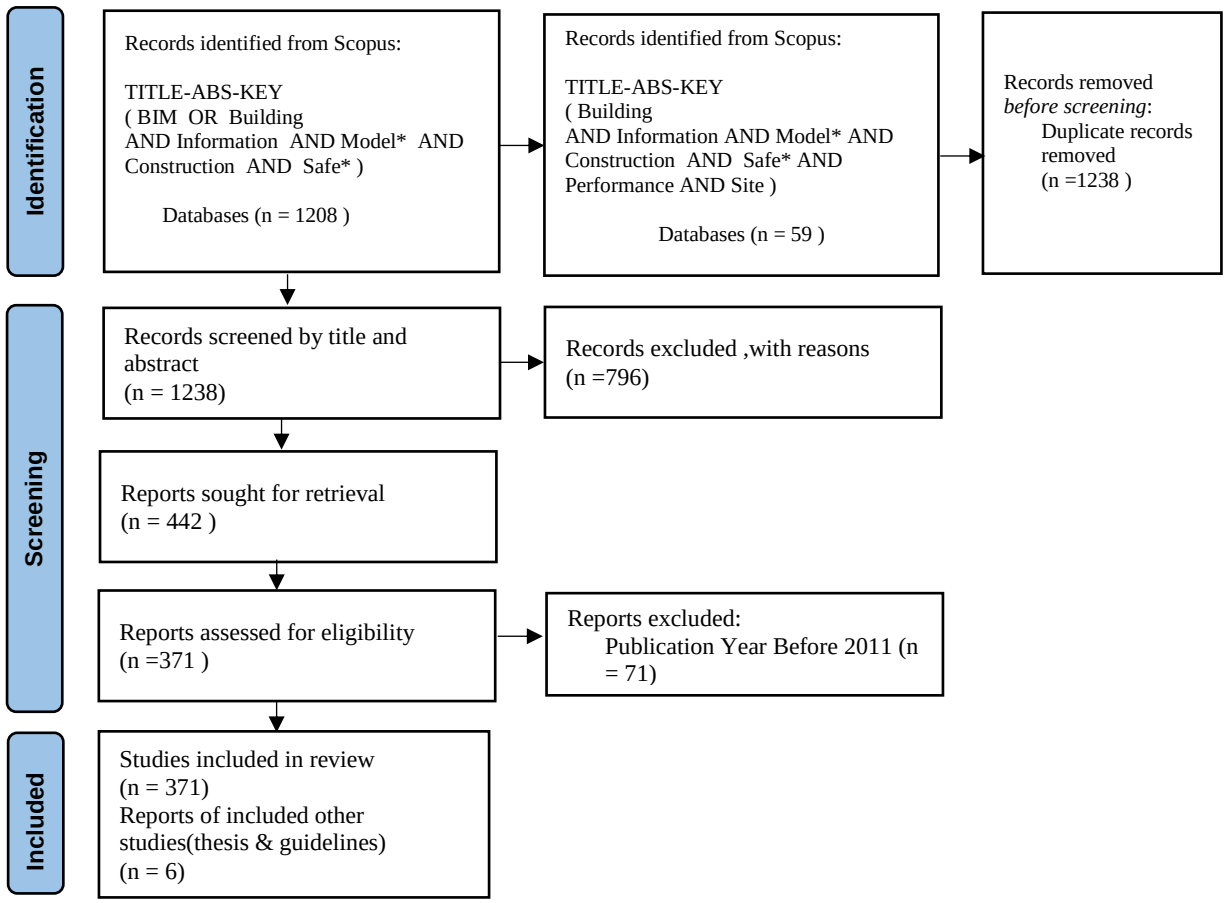

Fig. 1 The process of the systematic review (based on the PRISMA method)

The results of two search were combine as illustrates as in Fig. 1 and duplicates were removed, as total 1238 publications were founded. The publications were screened based on the title and the consistency of relevant studies in BIM and safety construction. Hence, the study more focusing on safety management or safety issue during the construction phase. A total 371 publications were selected based on the title and abstract.

Therefore, 371 articles were used for quantitative and qualitative analysis. The result of the quantitative analysis will be explained further in *Analysis of Publications* sections and qualitative will be explained in *Discussions* sections.

3. Analysis of Publications

As previous mentioned, 371 articles published between Jan 2012 until Aug 2021 were analysed. Based on Table 2, there were top 10 journal published according to source title. Therefore, 'Automation in Construction' was the scientific journal that published most articles on this subject (30%), followed by 'Journal of Construction Engineering and Management' (12%) and 'Safety Science' (11%). In context of year publication, the higher articles in the research is in 2019.

Fig. 2, using Vos Viewer analysis on linked of citation and source title shows that Automation in construction is a large number followed by Safety Science and Journal of Construction Engineering and Management. Hence, concluded that this research has higher number in Automation in Construction publications titles.

Table 2 Top 10 journals published in 2011 until 2021 on the Source title of BIM and safety construction in Scopus

Journal (Source title)	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	TOTAL NUMBER OF ARTICLES
Automation in Construction	1	3	4	6	5	2	3	10	4	2	40
Journal Of Construction Engineering and Management	0	0	1	1	3	2	3	2	1	3	16
Safety Science	0	0	0	3	2	1	3	5	1	0	15
International Journal of Environmental Research and Public Health	0	0	0	0	0	0	3	3	5	2	13
Applied Sciences Switzerland	0	0	0	0	0	0	0	2	5	5	12
Engineering Construction and Architectural Management	0	0	0	0	1	2	0	4	1	1	9
Engineering Structures	1	0	0	0	0	0	2	0	2	4	9
Sustainability Switzerland	0	0	0	0	0	0	1	0	3	5	9
Advanced Engineering Informatics	0	0	2	1	0	0	0	1	1	1	6
Advances In Civil Engineering	0	0	0	0	0	0	0	2	1	2	5
Total top 10	*2*	*3*	*7*	*11*	*11*	*7*	*15*	*29*	*24*	*25*	*134*

Frequency of the journals

>9 articles >4 articles >0 articles 0 articles

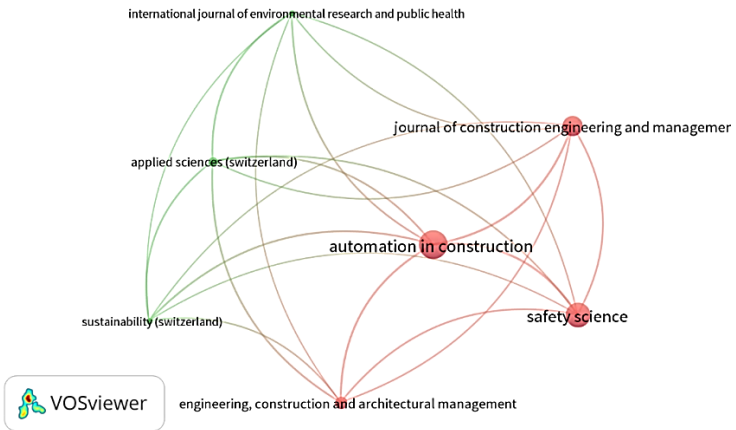

Fig. 2 Source title linked with citation using VOS viewer

Table 2 list of researchers which have most citations and most documents on BIM and safety construction. The most contributed researcher in this field were Teizer, J.; Zhang, S.; Li, H.; Lu, M. and Hollowell M.R.; which have more than 200 citations. Additionally, in Fig. 3 link between the top author by using Vos viewer. As shown, Zhang, S. and Teizer, J collaborate with Wang, J. Meanwhile, Wang, J. had collaborated with Wang, X. Most of the argument in the articles highlighted that included the safety guidelines into new technology.

Summary of the analysis in Table 2 and Fig. 2 can be used as to collaborate with other researchers to work on projects which related to BIM and safety construction. Furthermore, the researchers had more experienced that can guide according to this related field.

Table 3 Top 10 researchers published document in 2011 until 2021 on the on the role of BIM in safety construction

Authors	No. of documents	Citations
Teizer, J.	7	732
Zhang, S.	5	643
Hallowell, M.R.	4	207
Kim, H.	4	71
Li, H.	4	255
Wang, J.	4	120
Wang, X.	4	74
Lu, M.	3	255
Manzoor, B.	3	5
Rajagopalan, B.	3	195

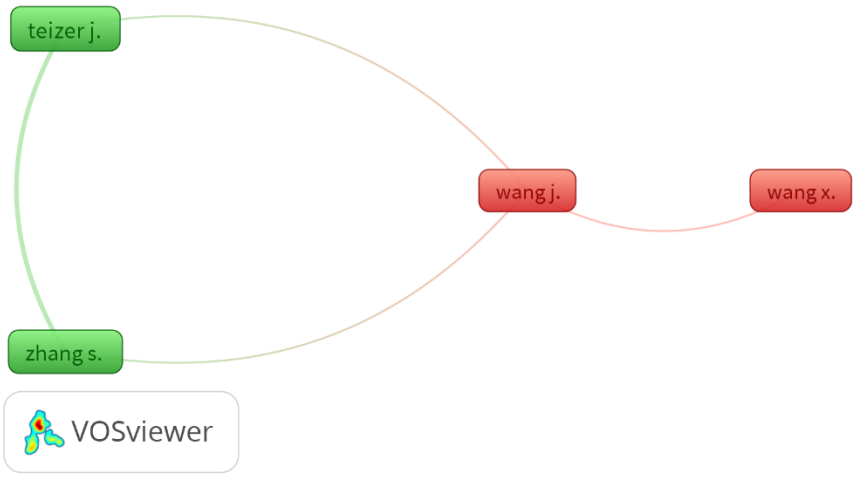

Fig. 3 Top Author linked using VOS viewer

In Table 4, shows more than 21 keywords co-occurrence in 371 publications. The highest occurrence is architectural design which had almost 102 link strengths followed by Building Information Model – BIM that 101 total link strength and the third is construction industry which 80 total link strengths. There were 3 types of keywords have the same meaning but different spelling which were (i) Building Information Model - BIM; (ii) Building Information Modelling (iii) Building Information Modeling.

Architectural design is very high link strength with Building Information Model -BIM based on Fig. 4 shows that design is important in BIM.

Table 4 Top keywords of co-occurrences in 371 publications

Keywords	Occurrences	Total Link Strength
Architectural Design	19	102
Building Information Model - BIM	18	101
Construction Industry	14	80
Construction Sites	10	46
Information Theory	10	57
Project Management	10	58
Accidents	9	56
Construction Safety	9	59
Safety Engineering	9	44
Accident Prevention	8	56
Building Information Modelling	8	27
Construction	8	30
Construction Projects	8	29
Information Management	8	27
Building Information Modeling	7	52
Decision Making	7	27
Safety	7	34
Building Industry	6	29
Human Resource Management	6	40
Robotics	6	26
Safety Performance	6	31

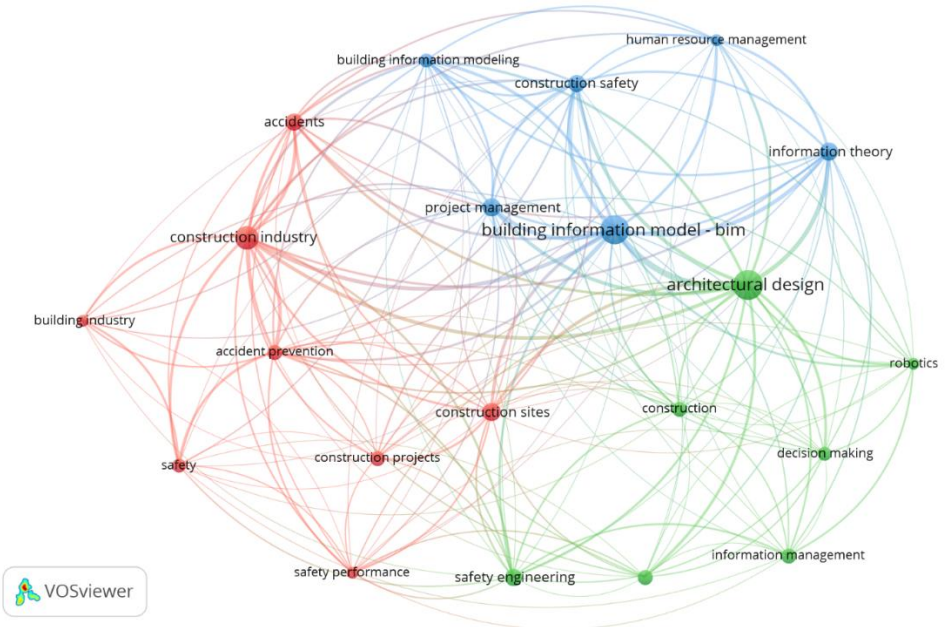

Fig. 4 Linked of top keywords of co-occurrences in 371 publications using VOS viewer

4. Discussions

4.1 BIM-Integrated in Construction Design Process

The design stage plays an important role of whole information that were created. Usually, development project consists of pre-development phase, construction phase, and post-construction phase. The project was classified into eight stages as outlined by the Royal Institute of British Architects [6], which are, strategic definition (Stage 0), preparation and briefing (Stage 1), concept design (Stage 2), spatial coordination (Stage 3), technical design (Stage 4), manufacturing and construction (Stage 5), handover (Stage 6) and use (Stage 7). In Stage 3, spatial coordination deals between architectural design and engineering design. This stage accommodates the technological evolution of design and construction processes through the application of BIM.

BIM software applications are able to create parametric elements that automatically define the relationships and constraints of parameters in building objects, or also known as parametric modelling [7]. The implementation of BIM in construction projects enhance better collaborative working environment among project participants through seamless data integration and exchange [8].

BIM concluded by Holzer[9] is a more accurate way of working. By improved design and construction processes BIM will reduce waste (materials, resources & cost) [10]. Therefore, safety data on construction site are rarely shared with other employees. Research on construction safety and BIM should have new path in designing that supposedly can share their knowledge with designer by using the up-to-date technologies [11][12].

Generally, building design process starts with feasibility studies, followed by concept design, scheme design and detail design, and ends with the production of construction design information.Thus, it is the responsibility of the design team to gather additional information related to the site and spaces for the building, construction technology and materials to be used, the environmental and safety issues, building regulations, any precedent or historical perspectives that need to be considered, and the costs.

4.2 Integration of Safety Planning in BIM

The manual of safety planning should be proposed by using BIM. BIM as an approach tool of automated checking on site. Manual safety planning usually considers more time and more people, hence BIM presented safety management in the design. For example, temporary staging may be included in the design process, as most of safety hazard at site was falls from height. Furthermore, temporary staging needs a good space as for no clash between other work in progress. Safety hazard need to prevent and identify, hence the constructions plans and safety plan will combine in BIM.
Improving site construction management by using BIM is promising solutions. This is because to construct temporary structures in the building required reality visualization.

Integrated BIM in safety risk can aid designers in identifying potential safety hazards as well as design ideas to minimise and reduce risk levels, giving a guideline on essential actions to be performed throughout construction work[16]. BIM was utilised to determine safe working zones and edges in a building using automated rule-based inspection. These data may be analysed further to prevent worker accidents[14].

4.3 Advantages of BIM Application

The advantages associated use of BIM in construction industry are categorised into nine types: technical; knowledge management; standardization, integration; economic, planning/scheduling; building life cycle assessment; decision support; diversity management benefits such as quality control, maintenance and facility and energy management, that reviewed by Ghaffarianhoseini et al[15]. BIM platform should provide benefits as follows: openness, interoperability and compatibility;

simplicity and functionality; the accuracy of data; expandability, the capability of advanced modelling; time management and clash detection; cost estimation; and facility management[13].

4.4 The Challenge in BIM

The issues that cause difficulties in BIM adoption such as software, cost, expertise or skill, and the representative of BIM. One of the important concerns that must be addressed if BIM is to be implemented is government support.

Only the specified software is used to save data, drawings, and documentation. Only a few providers' websites, according to Abanda[17], offer a statement about the types of file formats supported by the presented application. Most organizations for beginners stated that BIM is difficult to utilise due to the transition from 2D conventional to 3D. The merchant's website does not expressly specify whether a certain software system is applicable as BIM or not.

The challenge was heightened by the fact that many design and construction organizations were modest and lacked the resources needed to fully use innovative information transfer technology. Thus, simulation at the design stage is required to achieve sustainability throughout the life cycle.

5. Conclusion

The role of BIM and safety construction of latest publications studies had shown many significant studies based on 371 publications in 2012-2021. Analysis was carried out by journals publication; year publication and occurrence of keywords use by the authors. This BIM technology could assist the designer in checking safety parameter as providing tool. Significant number of studied that related to construction safety had shown many benefits for the construction industry. The gaps in future research are quantitative of the relationships. Studies should be done the role in construction safety. There were two research perspectives in construction safety which are management and technology. As to enhance safety management performance are important to ensure safety and avoid injuries or fatalities on site. BIM will only assist the safety management which conclude that technology still deal with human error (human behaviour). The main issues and gaps (i) problem of integrations between BIM tools and safety construction and (ii) adoption of BIM were lacking in standards of safety construction industry. Hence further studies need to include these gaps.

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