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Review

Building information modeling and safety management: A systematic review

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ABSTRACT

Occupational Health and Safety (OHS) in building construction remains a worldwide problem in terms of workplace injury, illness and fatality statistics. Construction Safety requires care and planning throughout the project life-cycle, from the design phase to maintenance. Initial attempts to improve OHS consider the safety aspects in the design phase and the development of manual safety processes in the execution phase. The application of Building Information Modeling (BIM) is currently experiencing rapid growth in construction operations, planning and management, as well as in Safety Management. Thanks to the use of this new tool, we can expect to see a change in the way that safety is addressed, as seen in the literature review, based on the large number of contributions in recent years.

This study reviews the existing literature surrounding BIM and Construction Safety in order to explore both useful findings and the gaps in knowledge for future research. The main result shows that the growing implementation of BIM in the Architecture, Engineering and Construction (AEC) industry is changing the way safety can be approached. Potential safety hazards can be automatically identified and corresponding prevention methods can be applied using an automated approach.

1. Introduction

When comparing workplace accidents in the EU over a period from 2008 to 2016, the construction sector presents the highest number of fatal accidents (Eurostat, 2016). Several factors contribute to these statistics (Haslam et al., 2003; Gibb et al., 2006) and result in many safety hazards which may arise at any given stage of the construction process (Gibb et al., 2006; Qi et al., 2014).

In recent years, different technologies and construction methods have been developed with the aim of providing new ways of enhancing safety management throughout the whole project lifecycle. The objective is to improve rather than replace, management-driven safety (Teizer et al., 2010). For example, all this helps to identify human errors and deal with them quickly in order to prevent construction accidents, as well as predicting, planning, and controlling the schedule. Since 1991, different studies have highlighted the possibility of linking the CAD and planning process (Cherneff et al., 1991) as an alternative to mock-ups, and have looked at the opportunities that are available in the near term data (Tatum et al., 1994).

Nowadays, the most flourishing technology in the construction sector is Building Information Modeling (BIM). This technology is a new approach to design, construction, and facilities management, wherein a digital representation of the building process is used to facilitate the exchange and interoperability of information (Eastman et al., 2011). Due to its increasing power, BIM has also been adopted by most of the commercial CAD software, like, for example: Autodesk Revit (2017), ArchiCAD (2017) and Allplan (2017).

Currently, as reflected in the literature, there are many proposals that use BIM technology to assist with different construction management tasks. Despite this, the construction industry is a sector which is typically slow to accept changes; the adoption of BIM has only just begun to take off around the world in recent years (Silva et al., 2016). Through the use of BIM, conventional 3D or four-dimensional (4D) models become an nD model that incorporates multiple aspects of design information required at each stage of the lifecycle of a project (Ding et al., 2014; Shou et al., 2015).

In the early 1990s, Mattila et al. (1994) predicted that there was a need to study the connections between good management, in general, and safety. Since then, many studies related to safety management have been developed. The overall interest surrounding BIM and its applications mean a wide variety of attempts have been made, some of which have also addressed occupational safety issues.

The main objective of this paper is to review existing proposals in this field of research in order to identify the applications and evolution

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of BIM for safety management in the construction domain. As the authors will show, there are many outstanding proposals. Additionally, the authors will analyse the current situation and make further suggestions with the aim of fostering and directing future research on BIM for safety management.

The remainder of the paper is structured as follows. Section 2 poses the background of the research domain. Section 3 explains the methodology of reviewing existing literature while Section 4 details the results and discussion. Finally, the paper will finish with some conclusions and guidelines for future research.

2. Background

Several studies show BIM could greatly benefit the Architecture, Engineering and Construction (AEC) industry as a tool that contributes to safety management, e.g. through scheduling, clash detection, construction progress tracking, design consistency and visualization, data integration, cost estimations, implementation of lean construction or improved team member collaboration, etc.

In a recent review regarding safety studies from 1978 to 2013, in which 1628 documents are analysed, it is shown that BIM is not a unique tool for this purpose. The study identifies 21 types of applied innovative technologies and only 6 documents related to BIM uses (Zhou et al., 2015b).

In a recent survey (Issa and Suermann, 2009), questions collected data regarding perceptions about the effects of BIM on commonly accepted construction Key Performance Indicators (KPIs) that were defined by Cox et al. (2003): quality control, on time completion, cost, safety, $/unit, units/manhour.

The results indicated that some respondents did not realise the advantages for safety or for lost manhours in construction projects. Ding et al. (2014) conducted a study that shows the percentages of published works on BIM from the perspective of project management, with 7% related to safety management and 17% related to schedule management.

The following subsections detail the main highlights taken into account by different research studies: planning and, innovative technologies for safety and collaboration and communication

2.1. 4D = 3D + schedule

Unsatisfactory architectural and/or organizational options or poor project planning at the project preparation stage have played a role in more than half of the occupational accidents occurring on construction sites in the EU (Council Directive 92/57/EEC, 1995). Effective safety planning contributes to the prevention of accidents and ill health of site personnel. Proper planning for safety plays an important role in reducing unnecessary costs and delays (Sulankivi et al., 2009; Saurin et al., 2004; Bansal, 2011). The identification of overlapping activities is also a concern since the workspace for those activities may be conflicting and accidents can occur (Moon et al., 2014a).

In 1994, Euler (1994) also stated the need to consider a schedule for the overseeing of accidents and their integration in graphic programs. Kartam (1997) developed a framework for a computerized health and safety knowledge-intensive system that has since been implemented and integrated with the current Critical Path Method (CPM) scheduling software.

The term 4D is used by McKinney et al. (1996), defined as 3D plus time. In 1998 (McKinney and Fischer, 1998) strongly suggested that the construction perspective was often neglected due to the fact that an important dimension for construction-time was missing and stated the necessary efforts to develop 4D tools that generate 4D + x models which more realistically represent the construction process. Guo (2001) and Koo and Fischer (2000) concluded that 4D models are a useful alternative to project scheduling tools like CPM.

Since 2005, publications have used the term BIM as we know it today (Tse et al., 2005). Software is commonly known as BIM, virtual building, parametric modeling, or model-based design. As previously mentioned, many authors have defined 4D as 3D plus schedule from the beginning of the BIM studies. This can be seen in studies from 2008 (Hu et al., 2008) up to more recent works (Hu and Zhang, 2011; Zhang et al., 2015b; Zhou et al., 2015a). Moreover, the concept 4D is not only related to other concepts but also to BIM, such as its utility on projects that involve a large number of co-builders, as is reflected in a recent study (Trebbe et al., 2015). Therefore, the potential of 4D CAD models to avoid costly on-site improvisation by providing tools to better anticipate conflicts in the planning phase has been widely acknowledged.

The advances in digital technologies have led to the development of new construction process planning techniques in order to enable users to establish more effective construction plans by predicting the results of projects (Faghihi et al., 2015; Martínez-Rojas et al., 2016) such as, genetic algorithm, GIS, and CBR.

2.2. Safety and use of other innovative technology applications

The use of simulation and virtual construction methods was developed earlier than the generalization of BIM. The more widespread technologies applied to construction safety are – Virtual Reality, 4D CAD, BIM, etc. These technologies are widely used in tools designed for site hazard prevention and safe project delivery (Zhou et al., 2012)

The use of new technologies for these purposes occurred prior to the development of BIM. In 1992, Yamazaki (1992), and later, Jung and Gibson (1999), associated the use of *Computer Integrated Construction* to maximize the integrated utilization of information systems throughout the project's entire lifecycle to different functions, among which is safety. Among others, Seo et al. (2015) reviews other research studies regarding Health and Safety, monitoring and identifying 22 studies from 2007 to 2013.

On the other hand, BIM was used for the modification of schedules to minimize spatial conflicts (Akinci et al., 2002; Clayton et al., 2002; Dawood et al., 2003; Waly and Thabet, 2003). In other cases, it was used to permit management for construction projects (Chau et al., 2005a, 2005b; Kang et al., 2007; Ma et al., 2005; Wang et al., 2004).

Subsequently, many authors have combined BIM with different technologies, e.g. location tracking, Augmented Reality (AR) and game technologies (Park and Kim, 2013), Virtual Prototyping (VP) (Wang et al., 2006; Guo et al., 2013); RFID (or WSN in a broader scope) (Motamedi and Hammad, 2009). Moreover, different research studies have combined schedule, BIM, and simulation as a tool able to predict risks so as to minimize conflicts at the workplace, as well as something to be used as an active schedule management tool (Kim and Teizer, 2014; Moon et al., 2014a, 2014b).

2.3. Collaboration, communication and life-cycle

Shen et al. (2010) consider that these technologies can provide a consistent set of solutions to support the collaborative creation, management, dissemination, and use of information through the entire product and project lifecycle. These technologies play an important role in improving productivity and efficiency in the construction industry.

One of the main barriers in this sector is the lack of communication across the project. Unfortunately, the data referring to safety on a construction site are rarely shared with all other interested practitioners. New directions of research on construction safety and digital design could, for example, focus on technologies that enable constructors to share their knowledge with designers (Zhou et al., 2012).

Over the last decade, a new concept has appeared on the scene with a great deal of impetus. It is known as Prevention through Design (PtD). The wide acceptance of PtD is due to the fact that it has proved itself to be an extremely effective instrument in the elimination of risks during the execution phase of a project (Hinze and Wiegand, 1992; Gambatese and Hinze, 1999; Gibb, 2004; Gibb et al., 2006; Frijters and Swuste, 2008; Martínez Aires et al., 2010). Moreover, several authors have shown how useful BIM is in improving the implementation of the PtD (Melzner et al., 2013; Zhang et al., 2013, 2015b; Chavada et al., 2012; Qi et al., 2014). The use of BIM in the design and in the final stages of the project is related to safety management and the prevention of accidents and its use from the beginning stages of the lifecycle of the project is linked to a decrease in accident rate (Gibb, 2004; Gibb et al., 2006; Martínez Aires et al., 2010).

The implications of BIM adoption across the project lifecycle and the team member collaboration aspects related to its adoption produce the highest positive financial impact (Gu and London, 2010; Eadie et al., 2013). BIM is a tool used to share knowledge, provide information and to offer a solid foundation for decision-making the throughout the projects lifecycle. Thus, Ding defined the use of BIM from design to demolition (Ding et al., 2014), although Shou et al. (2105) highlight the fact that the use of BIM is mainly related to the construction stage. Moreover, it can be shown that BIM is becoming more useful, due to its use in the pre-construction phase as a tool that supports collaboration (Succar, 2009; Succar and Kassem, 2015; Wang and Chong, 2015).

3. Materials and methods

This section outlines the systematic review as a methodological approach to explore useful findings into the existing construction safety literature and BIM, and to identify the lack of knowledge for future research. A systematic review is used for identifying, selecting and appraising all the literature of a certain agreed level of quality that is relevant to a research question (Booth et al., 2012). This systematic review is conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Liberati et al., 2009).

The databases sources used were the ISI Web of Science (WoS) and Scopus. The period studied ranges from 1981 to 2016 and the search was carried out using the "Title/Abstract/Keyword" field of the databases. The full search is "Title/Abstract/Keyword *Construction* and *BIM* and *Safety*" or "Title/Abstract/Keyword *Construction* and *Building Information Modeling* and *Safety*".

In the mentioned period, the first published document regarding this criterion is in 2008. There were 209 documents identified through a database search, and after removing duplicates, this number was reduced to a total of 189 documents. Furthermore, 16 documents under search criteria "*Title/Abstract/Keyword Construction, BIM and Management*" were included, 5 of which were reviews. The topic of *Safety* was discussed in all of them.

Of the total number of documents (n = 205), 106 were conference papers and 99 were articles. The systematic review focused on the published articles because they are not fully available.

After reviewing all the information, the structural safety based texts were removed as this is not the focus of our study (n = 15) so as some other review articles (n = 8). FigFig.1 illustrates PRISMA flow diagram where the number of documents after applying the selection criterion is shown in each stage. Finally, as can be seen in the figure, 76 documents are reviewed.

From the period of 2005 to 2016, 790 publications were found on the considered databases which deal with *BIM* or *Building Information Modeling* on the area of Engineering linked to Construction-AEC. However, those related to safety represent only the 9.62% of that total.

Taking the results presented in Section 2 into account, five key areas have been identified, which define BIM use as a safety management tool: construction or safety management, 4D schedule and planning, visualization/simulation, collaboration and communication, and identifying hazards.

The 76 articles have been analysed using the following protocol: (1) work title; (2) year of publication; (3) magazine title; (4) country; (5) project phase identification where BIM is used: design, construction, maintenance, namely, during the project's whole lifecycle; (6) highlights identification; (7) innovative technology use identification and other differentiating aspects. The information gathered at each step has been presented in a database, which has allowed us to obtain the results.

4. Results and discussion

Based on the literature review and after applying the previously explained analysis protocol, the obtained results have been classified into two sections. In Section 4.1 results from steps 1 to 4 are presented, which allow us to establish the publishing framework of the texts being analysed. In Section 4.2, the results from steps (5) to (7) of the analysis method have been gathered in Table 3, with the objective of organising construction safety and BIM content proposed by the authors, identifying the key areas addressed as well as certain distinguishing features, such as Lean, Geographic Information System (GIS), and Radio Frequency IDentification (RFID).

4.1. Publishing framework

Fig.2 shows the annual distribution of articles linking BIM and construction safety, which were selected for the study. At first glance, it is clear that the number of articles related to this subject has increased during the last years, concretely in the last three year.

Table 1 shows the number of publications according to the different country/territory for each of the authors. This information is in line with the research carried out by Porwal and Hewage (2013) – which proves that, even if BIM implementation is still a challenge for the North American construction industry, the Canadian construction industry, for instance, is still lagging far behind. Moreover, Succar (2009) shows a non-exhaustive list of publicly-available guides, reports and models relating to BIM, which demonstrate that the USA is where the greatest number of Construction Safety and BIM research articles have been published since 2009.

Table 2 shows the journals where a minimum of two articles on construction safety and BIM have been published, including JCR® Impact Factor and SJR Impact Factor.

4.2. Highlights of comparative review

As previously mentioned, in this section, the results from steps (5) to (7) of the analysis method are detailed. To achieve this, articles are arranged in a table composed of seven columns, as can be seen in Table 3. The first one presents each article by author and year of publication. The next five present the five key areas established for this study: Construction or Safety Management (SM), 4D Schedule and Planning (SP), Visualization/Simulation (VS), Collaboration and Communication (CC), and Identifying Hazards (IH). The seventh column gathers other distinguishing features from the research published in the articles.

Fig. 3 gives a summary of the results in Table 3. The percentages of articles that addressed the five defined key areas are shown. As can be seen from the figure, 78.95% of studies have safety management as their main focus, followed by 48.68% which refer to BIM use for visualization or simulation. The identification of hazards is a key objective, which is present in 47.37% of the documents. Falls are one of the main risks analysed (Melzner et al., 2013; Zhang et al., 2013) and scaffolds are among the most studied systems (Clevenger et al., 2015; Hu et al., 2010b; Kim and Teizer, 2014; Kim et al., 2016b).

BIM is used as a tool to enable collaboration and communication; these topics are today's active research topics and will still be active in the next 5–10 years (Shen et al., 2010).

Often, many proposals explore the combined application of techniques because of the different functions of the same innovative technologies such as GIS (Bansal, 2011; Bansal and Pal, 2011; Min and Zhao, 2014; Kumar and Bansal, 2016), RFID (Xu et al., 2011; Arslan

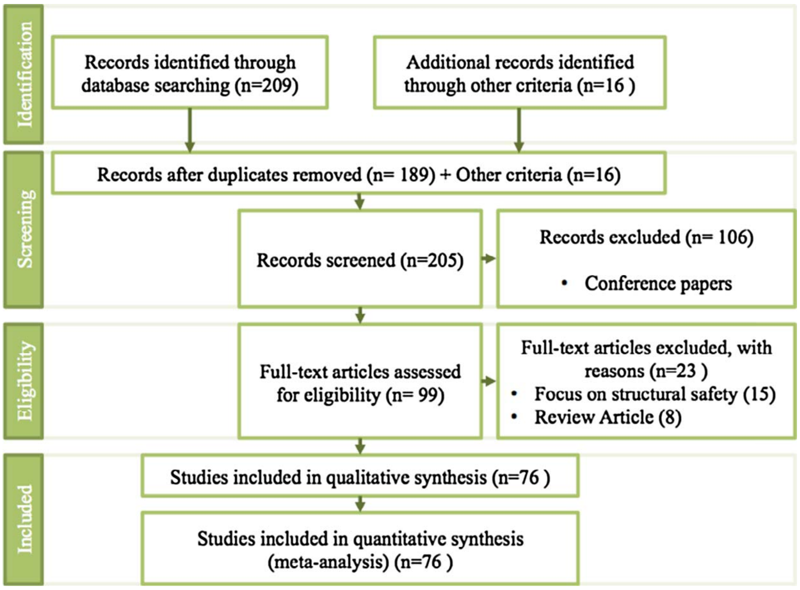

Fig. 1. Flowchart of systematic review process. (PRISMA flow diagram).

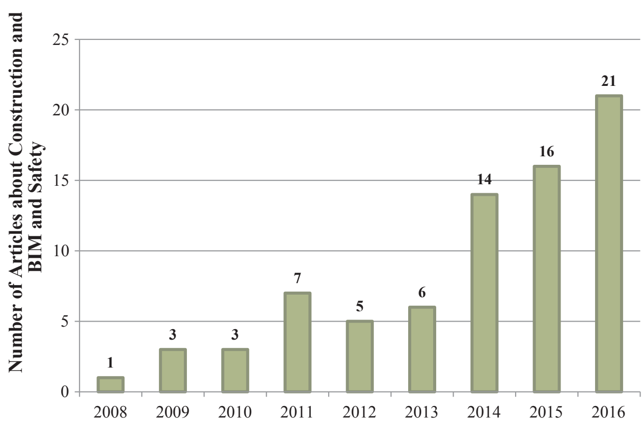

Fig. 2. Annual distribution of articles.

Table 1
The number of publications regarding construction safety and BIM published by authors' country/region.

Country/Territory	Authors	Country/Territory	Authors
United States	33	Hungary	1
China	19	Iran	1
South Korea	9	Israel	1
Germany	8	Italy	1
Australia	6	Malaysia	1
United Kingdom	6	Netherlands	1
Hong Kong	3	Norway	1
India	3	Palestine	1
Finland	2	Poland	1
Pakistan	2	Puerto Rico	1
Singapore	2	Saudi Arabia	1
Taiwan	2	Spain	1
Egypt	1	Viet Nam	1

et al., 2014; Li et al., 2015a; Zhou et al., 2015a; Costin et al., 2015; Fang et al., 2016a), GPS (Akula et al., 2013; Zhang et al., 2015c; Golovina et al., 2016) or sensors (Arslan et al., 2014; Riaz et al., 2014; Teizer, 2015).

However, the increasing concern for safety training has resulted in this becoming the objective of a great number of research studies regarding the use of BIM to improve workers' education or training (Becerik-Gerber et al., 2012; Clevenger et al., 2012, 2015; Eadie et al., 2013; Park and Kim, 2013; Korman and Huey-King, 2014; Bozoglu, 2016).

Table 2
Number of documents regarding construction safety and BIM by source and Impact Factor (only includes journals where two articles or more are published).

Source	Documents	JCR® Impact Factor 2015	SJR Impact Factor 2015
Automation in Construction	22	2.442	1.571
Journal of Construction Engineering and Management - ASCE	7	1.152	1.219
Journal of Information Technology In Construction	7		0.410
Safety Science	4	2.157	0.928
Journal of Computing In Civil Engineering	3	1.855	1.219
Advanced Engineering Informatics	3	2.000	1.265
International Journal of Construction Management	2		0.203

On the other hand, Fig. 4 shows the percentage of publications regarding BIM a project lifecycle viewpoint. 60.27% of the projects use BIM in the construction phase. Nevertheless, 38.36% of the studies include the first stages of the projects, as well as lifecycle (10.96%) and design phase (13.70%) or design and construction phase (13.70%). This demonstrates the usefulness of BIM in terms of prevention of accidents through design (Melzner et al., 2013; Qi et al., 2014; Zhang et al., 2013, 2015b).

Finally, different research studies have highlighted the current existing gaps in knowledge. The main reason for not adopting BIM on current projects can be put down to the lack of expertise within the project team and external organizations (Eadie et al., 2013; Li et al., 2012). Some of the main challenges for implementing BIM include the generation of 3D models, retrieving the job site environmental information, and updating current data from the job site to the 3D models, as the construction process moves forward. Another remaining gap to be treated is a hybrid approach toward addressing multiple objectives associated with scheduling (Faghihi et al., 2015). An example is the need for a new hybrid tool that can automate schedules by ensuring the structural stability of the project while optimizing its schedule and cost.

The study carried out by Wang and Chong (2015) concludes that BIM must evolve in order to be fully integrated with other technologies,

Table 3
Key areas Comparative Review.

Source	SM	VS	IH	SP	CC	Other
Akula et al. (2013)	Yes	Yes	Yes			Real-time. GPS
Arslan et al. (2014)	Yes	Yes				BIM & RFID & Sensors. Real-time
Bannier et al. (2016)	Yes	Yes		Yes		4 D. Decision tree
Bansal (2011)	Yes	Yes	Yes	Yes		BIM & GIS
Bansal and Pal (2011)	Yes	Yes		Yes		BIM & GIS
Becerik-Gerber et al. (2012)	Yes					Facilities management. Trainning
Bozoglu (2016)	Yes	Yes		Yes	Yes	Education
Chavada et al. (2012)	Yes	Yes		Yes		CPM & BIM. 4D/5D. Real-time management
Chen and Liu (2015)	Yes					Bayesian Network, BIM
Chen and Luo (2014)	Yes			Yes		BIM & Quality control process
Choi et al. (2014)	Yes			Yes		Work-space plan. Preconstruction phase
Ciribini et al. (2016)	Yes	Yes		Yes	Yes	Model Checking. 4D. IFC
Clevenger et al. (2012)		Yes				Construction education
Clevenger et al. (2015)		Yes				Education and training. Scaffolds
Costin et al. (2015)	Yes	Yes				RFID
Ding et al. (2016)	Yes		Yes			
Dossick and Neff (2010)					Yes	R & D
Eadie et al. (2013)	Yes				Yes	Facilities Management. Education and Training
Enshassi et al. (2016)	Yes				Yes	Survey
Fang et al. (2016a)	Yes					RFID. Localization system
Fang et al. (2016b)	Yes			Yes		
Forsythe (2014)			Yes			Real-time audio warnings
Ganah and John (2015)	Yes				Yes	
Getz and Saenz (2015)	Yes		Yes			
Golovina et al. (2016)	Yes		Yes			GPS
Golparvar-Fard et al. (2011)			Yes	Yes	Yes	BIM & Photographs & Point-cloud models. RM
Hartmann et al. (2012)	Yes			Yes		
Hu et al. (2008)		Yes	Yes			
Hu et al. (2010a)		Yes	Yes			Developed algorithm
Hu et al. (2010b)		Yes	Yes			Scaffold
Hu and Zhang (2011)	Yes	Yes	Yes	Yes		4D space–time model. Conflict analysis
Hu et al. (2016)	Yes					Large-scale mechanical. Electrical and plumbing
Kim and Teizer (2014)	Yes	Yes		Yes		Temporary facilities. Scaffolding systems
Kim et al. (2015)	Yes		Yes			Accident cases. Retrieval system
Kim et al. (2016a)	Yes		Yes			
Kim et al. (2016b)	Yes		Yes	Yes		Automated-scaffolding
Korman and Huey-King (2014)					Yes	Engineering education
Kumar and Bansal (2016)	Yes					GIS
Le and Hsiung (2014)	Yes		Yes	Yes	Yes	Mobile web service. GIS. Decision making
Li et al. (2015a)	Yes	Yes				Training. Real-time location system. VC & RFID
Li et al. (2015b))	Yes	Yes	Yes			VC System. Safety training
Luo and Gong (2014)			Yes			Compliance checking
Malekitabar et al. (2016)			Yes			
Marzouk and Abubakr (2016)	Yes			Yes		Crane
Melzner et al. (2013)			Yes	Yes		PtD. Fall protection. Decision-making
Merschbrock et al. (2016)	Yes	Yes				Gaming technology. Facilities management
Min and Zhao (2014)	Yes					GIS. 3D model library
Moon et al. (2014a)	Yes	Yes		Yes		BIM & Genetic algorithm. 4D CAD
Moon et al. (2014b)		Yes		Yes		Workspace conflict. Bounding box model
Nawari (2012)	Yes				Yes	BIM standard in Off-Site Construction
Niu et al. (2016)	Yes	Yes	yes		Yes	Smart construction object, Internet of Things, ubiquitous computing
Park and Kim (2013)	Yes	Yes	Yes		Yes	BIM & AR. Mobile screen. Education and Training
Park and Kim (2015)	Yes	Yes	Yes		Yes	Quality control. Checking process.
Qi et al. (2014))	Yes		Yes			PtD
Riaz et al. (2014)			Yes			BIM & Wireless sensor. Confined spaces
Sacks et al. (2009)	Yes	Yes				Lean
Shen and Marks (2016)	Yes					Near-miss
Suermann and Issa (2009)	Yes					Researh about the impact of BIM
Sulankivi et al. (2009)	Yes	Yes	Yes	Yes	Yes	Recording & verification of inspections
Teizer (2015)	Yes	Yes	Yes			Machine learning. Sensor & photo & video cameras
Tixier et al. (2016)	Yes					Machine learning
Wang et al. (2013)	Yes	Yes	Yes			Facilities Management
Wang et al. (2014)	Yes	Yes		Yes		BIM & MS Access & MS Excel & MS Project.
Wang et al. (2015)	Yes		Yes	Yes		Cloud Data. Laser scanning
Xie et al. (2011)	Yes	Yes				RFID & Real-Time Visual Reality
Xu et al. (2011)					Yes	Integrated Project Delivery
Yi et al. (2015)	Yes	Yes	Yes			Early warning. 4D
Zhang and Hu (2011)	Yes	Yes	Yes	Yes		4D space–time model
Zhang et al. (2013)	Yes	Yes	Yes	Yes	Yes	PtD. Fall protection. Automated rule-based safety
Zhang et al. (2015a)	Yes	Yes	Yes			Automated safety planning
(Zhang et al. (2015b)	Yes	Yes	Yes	Yes		PtD
Zhang et al. (2015c)	Yes	Yes	Yes			GPS. Lean construction. Resource location tracking
Zhang et al. (2016)	Yes		Yes		Yes	System in tunnel construction. Tunel
Zhou et al. (2015a)		Yes	Yes	Yes		RFID

(continued on next page)

Table 3 *(continued)*

Source	SM	VS	IH	SP	CC	Other
Zou et al. (2016)	Yes					Data mining. Bridges
Zulkifli et al. (2016)	Yes			Yes		ASRC-Automated Safety Rule Checking

ACRONYM		ACRONYM	
AR	Augmented reality	RFID	RFID
BIM	Building Information Modeling	R & D	Research and Development
CPM	Critical Path Method	RM	Reality Model
GIS	Geographic Information System	VC	Virtual Construction
GPS	Global Positioning System	VR	Virtual reality
PtD	Prevention through Design		

thereby contributing to project performance in various stages of the project lifecycle.

5. Conclusions

The use of Information & Communication tools has been a key factor in the AEC industry in the last few decades. BIM is the most promising technology due in part to its capability and versatility, which allows its use in different areas of the AEC industry, particularly in safety management. In addition, this technology facilitates effective project collaboration and integration of data from the design phase to the completion of the project. However, the huge potential of BIM has not been fully explored, mainly because of the use of different BIM models among different project participants, leading duplication of information and interoperability problems. To establish a reference framework, BIM solutions will come from collaboration between the different participants at an early stage. Additionally, and as previously mentioned, the integration of other technologies is imperative in order to increase the representation capability of the construction processes.

According to a review of the literature, BIM can help to improve safety in construction, identifying potential hazards through 4D scheduling: using 4D model, 4D scheduling, and sequencing with site logistics planning. BIM can easily help in the task of identifying potential hazards and eliminating hazards in the early stages of the project lifecycle. The control program identifies the conflicts brought about in the workplace activities, so as to be implemented simultaneously.

In addition, BIM provides a solid visual understanding of a site and the working conditions before the initiation of the construction phase, as well as facilitating a visual representation of site conditions. Moreover, the combined application of various innovative technologies - such as GIS, AR - allows visualization of the workplace in real time owing to the different functions of these technologies.

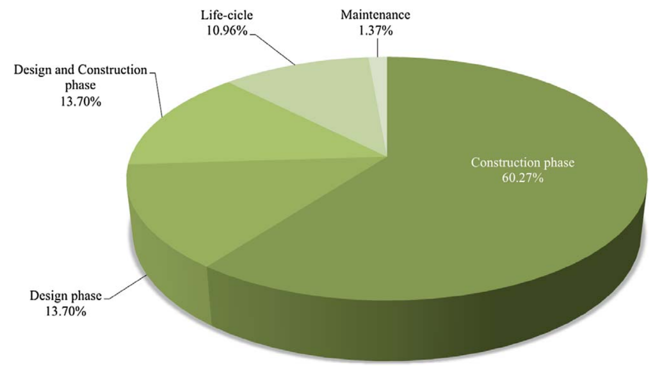

Fig. 4. Percentage of BIM publications from the viewpoint of project life cycle.

BIM helps to identify the risks, prepare for the work at hand and, therefore, complete the task more efficiently and safely, identifying each task and work area with their corresponding hazards, enabling communication and collaboration between different team members, both in the design stage and construction.

Although BIM is expected to greatly benefit the construction sector, it is still in the first stages. The main reason for this is the necessity to integrate BIM with other technologies, which results in a lack of interoperability with several standards competing for data management. It also results in a lack of expertise within the project team and external organizations. Therefore, it is necessary to keep working on a process of standardization so as to improve the use of BIM technologies and its anticipated benefits.

The implementation of BIM, from a safety management perspective, allows staff to save time and effort. In addition, BIM increases safety through an automated safety code checking and simulation tools. For

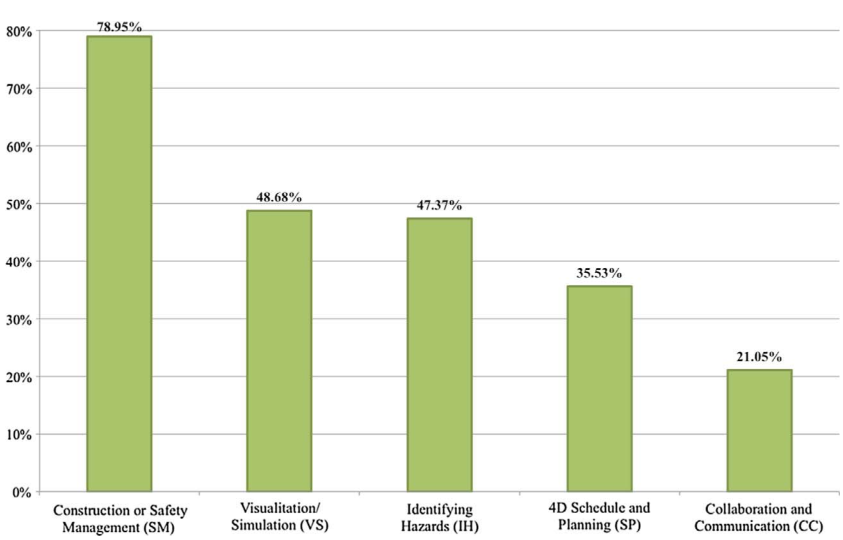

Fig. 3. Key areas and percentage of BIM publications.

example, hazardous workspaces can be identified and potential hazards can be prevented at the design stage itself, prior to the initialization of any fieldwork.

To sum up, the growing implementation of BIM in the AEC industry is changing the way safety can be approached. Potential safety hazards can be automatically identified and corresponding prevention methods can be applied using an automated approach. Moreover, its ease of utilization in worker safety training and education, design for safety, safety planning (job hazard analysis and pre-task planning), accident investigation, and facility and maintenance phase safety should be taken into account.

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