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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,