Automation in Construction 95 (2018) 284–295

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

Review

Digital engineering potential in addressing causes of construction accidents

Hamed Golizadeh[a,*], Carol K.H. Hon[a], Robin Drogemuller[a], M. Reza Hosseini[b]

[a] School of Civil Engineering and Built Environment, Queensland University of Technology (QUT), QLD 4000, Australia
[b] School of Architecture and Built Environment, Deakin University, Geelong, VIC, Australia

ARTICLE INFO

Keywords:
Digital engineering
Building information modelling
Accident causes
Safety
Construction industry
Literature review

ABSTRACT

With the emergence of digital engineering in the construction context, significant opportunities have arisen for safer project execution. Several studies in recent years have described various applications of digital engineering to improve safety performance. However, what is missing is a systematic review that shows the direct links between the potential of these approaches and how they address the causes of construction accidents. This study is an attempt to fill this gap by conducting a realist systematic review of the literature published since 2012. The study draws from the Loughborough Construction Accident Causation (ConAC) model to create a comprehensive list of accident causes and relates these causes to the identified digital engineering potential, as reflected in the literature. This approach identifies the research gaps and neglected research domains, particularly six endemic problems, within the current digital engineering literature pertaining to safety, while introducing future areas associated with the identified gaps. This study provides useful insights to investigators who gain direction towards the top priorities for future research. In practical terms, the study collates and presents various areas of potential within digital engineering to address the causes of accidents on construction sites, providing a concise source of knowledge for practitioners.

1. Introduction

Regarded as the most dangerous industry, the construction industry's safety performance continues to be a persistent problem across the globe [1]. Annually, occupational accidents on construction sites cause the death of over 60,000 workers around the world [2]. In the United States (US), the construction industry accounted for 19.09% of all occupational fatalities in 2016, even though the industry only employed 4.3% of the US workforce [3]. In Europe, close to 21% of fatal accidents at work occur in the construction sector [4].

Digital engineering, namely, integrating multiple digital technologies—integrating digitisation—based on Building Information Modelling (BIM) to harness the full potentials of these applications, provides valuable input into construction practices [5]. The potential uses of digital engineering can also drastically alter safety practices in the construction industry [6]. Digital engineering facilitates project information exchange and management and supports better collaboration and project planning [7,8]. Since 2012, these opportunities have resulted in an exponential growth in interest in the digitalised management of construction safety [9], and an ensuing burst of research in this field [6]. This sudden increase in research output can result in uncertainty in the status of the body of knowledge; burst in research activity can result in pivotal areas remaining unnoticed within the large volume of available publications [10]. A rigorous critical review is thus needed.

Despite their contributions, existing review studies on the topic have two main shortcomings. Firstly, their focus is on describing various applications of specific digital techniques to enhance safety performance. Examples include the following: Guo et al. [9] reviewed the literature on visualisation technologies; Li et al. [6] had a narrow focus on virtual/augmented reality (VR/AR) applications; and Zou et al. [8] investigated BIM applications. Secondly, these studies have not explored the potentials of digital engineering in addressing the causes of accidents, whereas understanding systemic causes must be central to any effort related to safety enhancement in the construction context [11]. That said, the present study's thorough search of the literature failed to find any study that has linked digital engineering to accident causation models.

To address the above deficiencies, this study aims to provide a systematic review of the role of digital engineering in preventing the causes of accidents, through the lens of a construction accident model. To this end, the following three objectives are formulated:

I. Identify the causes of construction accidents based on a rigorous

* Corresponding author.
E-mail addresses: h.golizadeh@qut.edu.au (H. Golizadeh), carol.hon@qut.edu.au (C.K.H. Hon), robin.drogemuller@qut.edu.au (R. Drogemuller), reza.hosseini@deakin.edu.au (M. Reza Hosseini).

https://doi.org/10.1016/j.autcon.2018.08.013
Received 25 October 2017; Received in revised form 29 July 2018; Accepted 26 August 2018
Available online 07 September 2018
0926-5805/

theoretical lens,
II. Review the potential of digital engineering to address the identified causes, and
III. Outline the research gaps and areas in need of further research.

The remaining part of this paper is structured as follows. The selected research design and methods are first described. The sections that follow are accordingly allocated to address the three objectives defined above. As a result, a list of construction accident causes is collated and presented to address the first objective. Next, the various types of potential of digital engineering to address the causes of accidents are discussed. The paper concludes by outlining the gaps in the body of knowledge, identified as the outcome of the literature review, thus fulfilling the third objective.

2. Research methods and design

2.1. Realist systematic review

The objectives of the present study are to identify key concepts, review related literature and outline gaps in the literature. All these objectives are in accordance with the capabilities of systematic review methods [12]. Among the various forms of systematic review, the realist approach is the most suitable one for showing how digital engineering solutions work for various causes of accidents. The reason is that the realist approach is designed to provide an explanatory analysis of what works for what, in what respect and under what conditions [13]. The realist approach is also preferred in the present study, in view of its capabilities in analysing complex phenomena, such as construction accidents and their causes, a point argued by Pawson et al. [13].

2.2. Review process

To carry out a realistic review, this study adopted a five-step process, as illustrated in Fig. 1, following the approach taken by Pawson et al. [13] and Chong et al. [14].

Subsequent to Step 1, that is, clarifying the objectives and boundaries, Step 2 entailed the search for evidence in which search keywords were collated. The keywords for the present study were the outcome of combining all the keywords used by Zou et al. [8] and Guo et al. [9], thus producing the following two categories of keywords:

- Digital engineering, Building Information Modelling, BIM, 4D BIM, 4D CAD, knowledge management (KM), model checkers, Virtual Reality (VR), Virtual Prototyping (VP), Virtual Construction (VC), Augmented Reality (AR), Real Time Location System (RTLS)
- Construction safety, construction accidents, construction hazards.

Using the keywords, the search was conducted in two main academic publication databases, namely, Web of Science and Scopus. These two sources were selected due to their credibility and their inclusion of most engineering journals [8,9,15]. The present study searched for journal articles published from January 2012 to April 2017 (the search time), given that the major proportion of articles on the use of digital technologies for construction safety management has been published after 2012 [6,9].

In total, 257 papers were found in the initial search. Content analysis was conducted on the title and abstract of each collected paper to ensure that it covered at least one accident cause. As a result, 61 papers were found to be relevant for this study. To make sure that all relevant articles are included in the data set, Webster and Watson [16] recommend considering the reference lists of the collected papers, as illustrated in Fig. 1. By taking this approach, eight additional relevant articles were identified, bringing the total number of papers to 69. After finalising the search for evidence, the selected papers were read by all members of the research team. The text of the papers were then coded, using as codes the terms for referring to the ConAC model's factors (see Table 1). External factors were excluded from this study as they are often specific to the regional context and hard to investigate [17].

3. Construction accident causes

A review of accident models by Katsakiori et al. [18] shows a gradual paradigm shift from looking for a singular cause of accidents to seeking the causes of a number of systemic failures. Systemic accident causation models provide a theoretical lens through which to capture the dynamic interaction of environmental, cultural, organisational and other factors in creating a hazardous situation [19].

The Loughborough ConAC model is one of the systemic accident causation models that have been developed to investigate construction accidents. Gibb et al. [20] analysed 100 mostly minor construction accidents (e.g. accidents resulting in a few days' lost work time and no significant injury) within a 3-year research program at Loughborough University. A hierarchical ConAC model was developed to facilitate the identification of a set of events leading to unfortunate incidents. As defined by Behm and Schneller [19], the ConAC model is not a checklist but rather a comprehensive model developed based on Reason's 'Swiss cheese' model [21] to identify and break down accidents to flaws at organisational and individual levels. The Loughborough ConAC framework became a prominent method due to the comprehensive nature of the primary research, which included collecting possible details from interviews and focus groups with victim(s) and witnesses, site observations, photographs, etc. The ConAC model is presented in three levels of contributing factors, namely, immediate accident circumstances, shaping factors and originating influences, as illustrated in Fig. 2. Fig. 2 also shows causal relationships between the factors of each level starting from originating influences and ending with the four immediate accident circumstances of the work team, workplace, materials and equipment. The ConAC framework was utilised by Behm and Schneller [19] to investigate 27 non-fatal construction accidents that took place within the US State Department of Transportation. In addition, Cooke and Lingard [22] used the same model to analyse causalities in 258 fatal accidents in Australia. Both research teams reported on the ConAC framework's credibility for the construction safety research domain and organisational learning.

In a technical report to the US Department of Transportation, Behm [17] elaborated on the terminologies of the ConAC model in more detail (Table 1). To facilitate the structure of the report, the model is divided into five major groups: work team, workplace, equipment, material, and originating factors.

4. Digital engineering potential for safety

4.1. Publication distribution by journal

Identifying the journals that act as key outlets for publishing studies on a topic is of value to practitioners, directing them towards the best knowledge resources on the topic, and to investigators, identifying the best outlets for publishing [10]. In the present study, nearly half of the selected publications (a number far outweighing that of other journals) were published in the journal *Automation in Construction* (Table 2). Some relevant papers were published in the *Journal of Computing in Civil Engineering* (ASCE), the *Journal of Construction Engineering and Management* (ASCE) and the journal, *Safety Science*.

4.2. Publication distribution by year

Over the past five years, the number of publications has gradually increased. Fig. 3 shows the distribution of papers on digital engineering applications in construction safety according to publication year.

Another interesting observation emerged when comparing the growth in the total number of published papers against that of papers