Use of BIM in the Analysis of Concrete Damage Structures: A Review of the Literature

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Abstract

The application of Building Information Modeling (BIM) technology allows a digital representation of physical and functional characteristics of places, which is particularly beneficial to civil engineering. The present article proposes to evaluate the utilization of BIM technology to quantify the damage caused to concrete structures, based on a systematic review of the literature. The findings support the view of BIM as a promising path for the analysis of concrete structures, both in terms of representation and prevention of non-occurring events. It also highlights the existence of few studies exploring the topic and consequently the need for research into this area.

Keywords –

BIM; Civil engineering; Damage; Concrete structure

1 Introduction

During a building life cycle, around 20% of the expenses are associated with design and execution phases, while the remaining 80% refers to the operation and building management costs. The importance of effective communication from the initial project phase to the complete stage of construction challenges project managers to find ways to improve project efficiency since traditional methods don't meet up with operational requirements and are no longer effective [1].

The discussion about the maintenance of buildings is critical as it predicts and corrects possible problems, also optimizing service lives of systems and components. It should be noted that this must be done through actions that prevent the occurrence of disasters and/or unnecessary expenditures related to recuperation or reconstruction as result of damage. In other words, building maintenance consists on a set of activities to be carried out in order to preserve, conserve or remedy the integrity and functional state of the building and its systems [2].

In this context, it's possible to say that designing projects through BIM software will have a direct impact on the operation and management phases. The models represented by 3D (project), 4D (planning), and 5D (budget) spheres are rich in data that can be extracted at any time, providing detailed information about the elements of construction [1].

Nonetheless, when building maintenance or adverse events that affect the building such as, fires and earthquakes are neglected, the task of identifying the source of damage in order to plan the correct action is very difficult. Therefore, as discussed by Ma et al. [3], during the subsequent phase of reconstruction and recovery, the inspectors need information about deformation and displacement that has occurred in the components of the building structure in order to properly assess damages. Thus, BIM technology provides a useful and appropriate method to collect and communicate all these data.

The role of structural engineering in the management of existing buildings consists of safety assessments and the planning of retrofit interventions, if required. The process begins with the acquisition of a set of data that forms the input when defining a structural model that represents the mechanical behavior of a construction [4].

Independent of the country, it is necessary to register defects and damages for later assessment and maintenance planning. Modeling damages within a BIM context is a pre-requisite to support the full life cycle of built infrastructure. Aiming at modeling damage information it is important to know existing damage types and related parameters [5].

Therefore, if the concept of building maintenance is already in place, then we can say that the recovery process would be facilitated since the building in question has been regularly monitored. On the other hand, the absence of important information, consequently, will make the task harder, and require procedures to detect

deterioration, monitor possible deformation and estimate post-disaster damage.

Considering the discussion above, the present work seeks to evaluate, through a systematic literature review (SLR), the different methods of quantification of damage using BIM technology. This study highlights not only different techniques used as assessment tools but, also, promotes an important discussion among scientific community embracing the insertion of multi-professionals into this field.

2 Research Method

Systematic literature review consists on secondary studies that aim to map, find, critically assess, consolidate, and aggregate findings from relevant primary studies about a specific research topic. With this in mind, it is possible to state that the SLR allows the identification of gaps in the researched topic that still need to be filled in. The term "systematic" implies that the review must be based on a method that mainly guarantees the impartiality, precision and replicability of the study [6].

This paper deals with the use of different BIM approaches to analyze structural concrete damage. To do so, we used the P.I.C.O. model, as illustrated in Table 1, to address some of the research questions i.e. Population, Intervention, Context/Comparison and Outcome.

Table 1 PICO model for research questions

P.I.C.O.	**Research Questions**
Population	Buildings with presence of damage
Intervention	Use of BIM methodologies in damage analysis
Comparison	Different ways to determine and quantify damage
Outcome	Check the use of BIM methodology in the calculation, quantification and simulation of damage to buildings

Databases such as Springer, Scopus, ASCE and Compendex were selected to conduct this SLR. The search string used included the use of keywords related to the theme such as: BIM, damage, concrete, structure and simulation. The boolean operator “and” was used throughout the search period, which occurred from December 2020 to February 2021. The stages of the review as followed and carried out are illustrated in Figure 1, according to Vilela et al. [7].

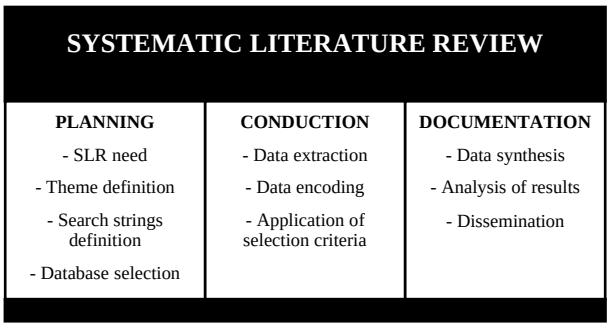

Figure 1. Stages of the Systematic Literature Review

The search strategy consisted in running the searches in the previously mentioned databases and related papers filtered out according to the following inclusion criteria: (1) publications from the last 6 years, (2) published papers in conferences and journals and, (3) open access articles. The exclusion criteria were the following: (1) papers not addressing the theme and, (2) repeated publications between databases. The selection process is illustrated on Table 2 which shows a total of 10 relevant papers to the topic in question.

Table 2 Assessment and selection of studies for the SLR

Databases	Total	Inclusion criteria			Exclusion criteria		Total per database
		(1)	(2)	(3)	(1)	(2)	
Springer	178	120	51	40	4	4	4
Scopus	7	1	1	1	1	1	1
ASCE	134	81	79	78	4	4	4
Compendex	12	6	4	4	2	1	1
						TOTAL	10

The results allow us to identify geographic areas conducting research on the topic. Thus, we highlighted countries where papers have been published with more frequency (Figure 2) along with the growth of publications over the last 6 years (Figure 3).

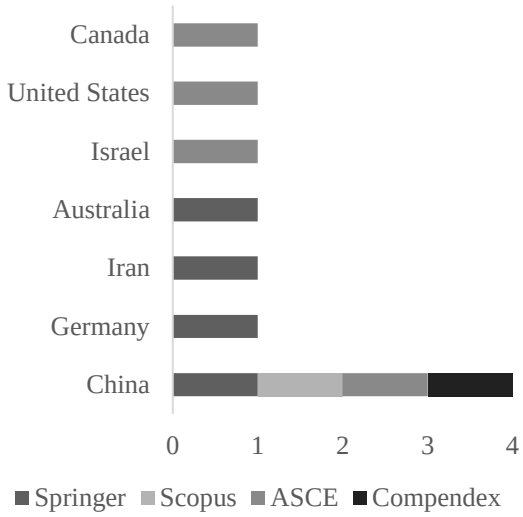

Figure 2. Number of publications on the topic by countries

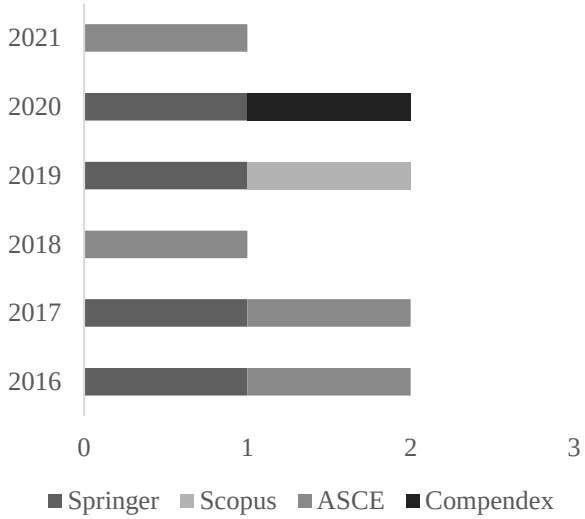

Figure 3. Number of publications on the topic over the course of 6 years

3 Results and Discussion

3.1 Damage Type

The structures in service can suffer serious durability problems, whether due to the natural aging mechanism, the lack of building maintenance or even unforeseen events, as discussed by Ghahremani et al. [8]. Therefore, it is essential to analyze the type of damage that could impose risk to the safety of the structure.

In the studies covered by the SLR, the following types of damage were investigated: seismic events, terrorist attack, degradation and cracking as seen in Figure 4.

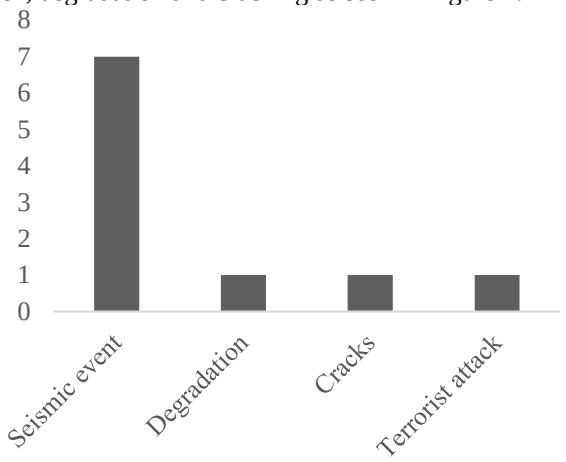

Figure 4. Number of publications about the type of damage studied

Vogelbacher et al. [9] used a plan-level approach to assess risk and analysis of urban neighborhoods with vulnerability to terrorist attacks in accordance with empirical risk analysis, based on the history of terrorism events. At the plan level, the urban topology becomes known, including the location and infrastructure of the buildings. However, without having information about the exact geometry and materials used, it is only possible to identify city blocks and not individual buildings.

Zakeri et al. [10] presented a review of several image processing approaches to check cracks in asphalt surfaces. In addition, they also addressed emerging and evolving technologies to automate processes, such as non-contact assessment techniques classified as Charged-Coupled Device (CCD), Ground Penetration Radar (GPR), Laser Systems (LS) and Hybrid Systems (HS).

Ghahremani et al. [8] analyzed the degradation in structures through a methodology consisting in automatic and systematic detection along with the quantification of damage in structural components. They used a high-fidelity 3D point cloud data in conjunction with a finite element analysis.

The article written by Xiong et al. [11] proposed the simulation of multiple levels of detail (LOD) considering various structural types, available data and simulation scenarios in a real application of seismic damage to urban buildings.

The research carried out by Zhen et al. [12] discussed a simulation method (5D) for post-earthquake building repair process using BIM technology; the repair activities were linked to a 3D model along with estimation of time and related costs.

Ren et al. [13] analyzed seismic events through the junction between BIM and finite element analysis. The study suggested that it is possible to identify patterns of damage from different structures using skyscraper and

community building simulations. Ma et al. [3] also supported the use of BIM technology for damaged buildings and synthetic scan generation. The authors discussed a post-earthquake reconstruction analysis with precision based on a representative database.

The research conducted by Xu et al. [14] proposed a post-earthquake fire simulation method. The seismic damage of the sprinkler systems was considered in order to assess the effects of fire damage in buildings. Lu et al. [15] addressed the simulation of an indoor post-earthquake fire rescue scenario using building information modeling (BIM) and virtual reality (VR).

Finally, Gavrilovic and Haukaas [16] completed a post-earthquake visual damage analysis along with methodology for estimating seismic losses based on the type of damage prediction, estimation of repair costs, length and working hours.

3.2 The usage of BIM

There are several types of BIM usage models. BIM Excellence (BIMe) - a tool for evaluating BIM performance - brings a classification of BIM usage models based on surveys by Succar and other international collaborators. According to the Model Uses List [17] the studies were classified in six domains as shown in Figure 5.

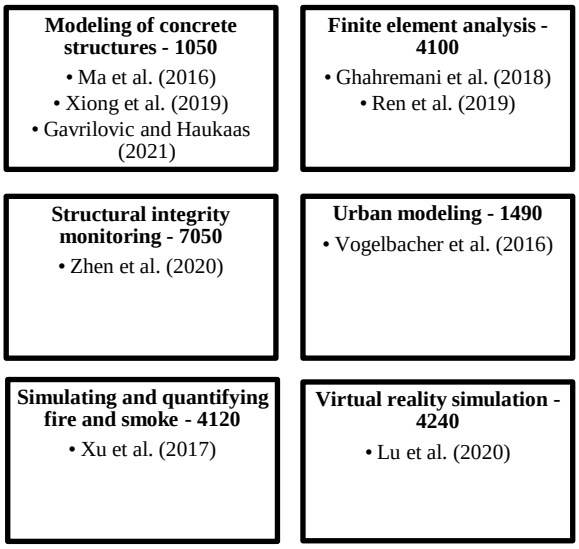

Figure 5. Classification according to the BIM usage model

The model used that had the greatest prominence was the modeling of concrete structures on papers published by Xiong et al. [11], Ma et al. [3] and, Gavrilovic and Haukaas [16]. The papers published by Ghahremani et al. [8] and Ren et al. [13] supported two different applications of BIM; the modeling of concrete structures and finite element analysis. The usage of structural integrity monitoring was only mentioned in the study by Zhen et al. [12]. The topic of urban modeling was discussed in Vogelbacher et al. [9], and the simulation and quantification of fire and smoke in the study by Xu et al. [14]. The paper by Lu et al. [15] also addressed two different applications of BIM usage on simulation and quantification of fire and smoke, as well as virtual reality simulation. Finally, the study conducted by Zakeri et al. [10] was not part of the review due to its classification as a systematic review of the literature itself.

3.3 Simulation Models

The analysis of the 10 selected papers on the SLR shows that the most popular simulation is the 3D dimensions. This could be explained by acknowledging that 3D is a popular type of simulation that has been utilized for a longer period of time, when compared with the five dimensional method (5D). The 5D dimension method is newer and was only observed in a study published in 2020 as seen in Figure 6.

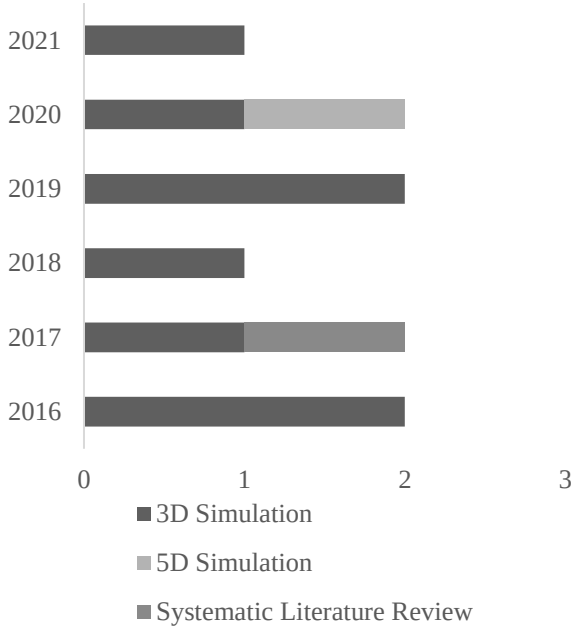

Figure 6. Type of simulation applied over the years

There is a lack in studies that analyze advanced levels of simulations, hence narrowing access to a higher degree of accuracy and even more innovative features. The studies of Vogelbacher et al. [9], Ma et al. [3], Xu et al. [14], Ghahremani et al. [8], Xiong et al. [11], Ren et al. [13], Lu et al. [15], and Gavrilovic and Haukaas [16] reviewed the application of 3D simulation. As per articles addressing the use of 5D simulation, we refer to the studies of Zhen et al. [12] and the systematic literature review of Zakeri et al. [10].

4 Conclusions

BIM presents itself as a promising path for the analysis of concrete structures, in terms of both, representation and prevention of non-occurring events. It is also favorable to the process of reconstruction through the simulation of events that have already occurred, such as: terrorists attacks, earthquakes, etc. Simulation allows us to predict and understand the structural behavior as well as to develop appropriate plans of action. The simulation process is basically a test that is performed through the use of a digital model.

This review gave evidence to the existence of only few studies on the subject. However, this can be seen as an encouraging factor to promote the development of new research exploring a topic that will contribute to the insertion of multi-professionals into this new job market.

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