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BIM-based sensor technologies implemented in the construction site: protocol for a systematic review

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Abstract

Building Information Modelling (BIM) is used in construction projects to improve efficiency. In general, it improves project management and monitoring, reduces time and costs, strengthens collaboration among stakeholders, and reduces risks and injuries. Sensor technologies with various functionalities are being implemented in the construction site. Technologies such as tracking workers and transmitting real-time site inspections to support the BIM tools in various fields are being used. To evaluate sensor technologies' usability and effectiveness in Architecture, Engineering, Construction and Operations (AECO) sector, a literature review adapting PRISMA Statement is proposed. Consequently, this document represents a complementary manuscript as a PRISMA Protocol (PRISMA-P). Relevant articles were collected from top electronic databases in the construction field. This review aims to investigate the sensor connected BIM models and the technologies being utilized in the AECO sector, investigating the targeted groups, construction field, and the system architectures being used. Furthermore, the study will examine the implemented sensors' case studies to evaluate each technology's effectiveness. Finally, the reliability of the tools and future proposals is projected.

1. INTRODUCTION

Construction industries tend to have a dynamic and complex working environment. Thus, safety and work efficiency are often inadequate (Zhang, Teizer, Pradhananga, & Eastman, 2015). Construction safety is an international concern, with many injuries occurring in construction sites worldwide (Zhang, Teizer, Lee, Eastman, & Venugopal, 2013).

In line with the Occupational Safety and Health Administration (OSHA), the construction industry was responsible for 199,200 injuries and illnesses in 2019. According to the U.S. Bureau of Labour Statistics, construction had 9.5 fatalities per 100,000 full-time workers. According to OSHA, as of 2020, "*one in five worker deaths last year were in construction*".

Falls, struck-by-objects, electrocution, and stuck-in are considered the fatal four construction accidents and were responsible for more than half of the construction workers deaths at 58.6% in 2020 (U.S. Department of Labor; Bureau of Labor Statistics, 2019).

According to Heinrich (Chi & Han, 2013), accidents are defined as an event that is uncontrolled and unplanned, in which an act or effect of a particular person, object, material, or radiation results in injuries (Abdelhamid & Everett, 2000). A literature review was done by Hosseinian explaining the theories behind why accidents occur on the construction site (Hosseinian and Torghabeh 2012). Hosseinian illustrated the most common accident causation theories in his work, highlighting people variable, management aspects, and physical characteristics of hazards. The review concludes that accidents in workplaces can be prevented if human errors are eliminated, adding that the strategies are needed to be revised to manage the risks and elevate the workers' awareness. It also proposes a model that focuses on the link between the accident likelihood and the managerial activities in these hazards.

A more recent case study done by Kadiri of some selected multinational construction companies found that negligence was the primary cause of construction sites' accidents (Kadiri et al., 2014). Kadiri proposed that management must implement and focus on regular supervision and inspection and highlighted the importance of constant training on the use of tools and equipment and proper use of safety equipment to ensure a safer and accident-free construction site.

Furthermore, in a study conducted by Chim on the Causes and Preventive Approaches to Mitigate Accident Rate, Chim reassured that the company and the workers' negligence is the leading cause for accidents on the construction site (Chim, Chun, & Wah, 2018). Chim mentioned that accidents could be avoided if the construction company management is careful with supervision during the construction process. According to Abdelhamid and Everett (2000), three factors trigger accidents: not identifying a dangerous situation related to a specific task, ignoring a hazardous condition, and proceeding with the activity, or acting unsafe whatever the current environment was. Thus, the construction site requires regular and advanced monitoring and supervision; besides, new workers must be trained carefully before going to the construction site to avoid unsafe actions, and further special training should be considered for specific tasks or activities that could impose risks on engineers or workers. Consequently, manual monitoring and supervision are prone to error due to the complex and dynamic environment. Subsequently, to assist the supervisors and visual inspection of the on-site risks, automated safety monitoring such as using Building Information Modelling (BIM) is being adopted by the Architecture, Engineering and Construction (AEC) industry (Eleftheriadis, Mumovic, & Greening, 2017). The implementation of BIM looks promising and could also assist the continuous advancements in the construction processes. BIM could provide essential decision-support tools for engineers throughout the design stage, improving workers' safety and performance and enriching on-site training (Wang & Chong, 2015).

However, BIM as a stand-alone tool cannot acquire real-time data, identify hazardous zones, monitor construction site, and help with the inspection. Particular technologies such as sensors and tracking devices are being deployed on-site to acquire real-time data (Carbonari, Naticchia, Giretti, & De Grassi, 2009). Several sensors with various functionalities are being implemented such as Radio Frequency Identification Devices (RFID), magnetic field, Laser Detection and Ranging (LADAR), Radio Detection and Ranging (RADAR), ultra-wideband (UWB) (Teizer, Lao, and Sofer 2007) ultrasonic, infrared heat and magnetic sensors, sonar, Inertial Measurement Unit (IMU), Bluetooth, Global Positing System (GPS) Global Navigation Satellite System (GNSS), laser, video and static camera including Vision Cameras (V.C.), electrocardiogram (ECG/EKG), traffic management, Audio Technology and electromyography (EMG), galvanic skin response (GSR) (Villarejo, Zapirain, & Zorrilla, 2012), accelerometers, gyroscopes, and magnetometers and light sensors (Wahlström, 2013).

In addition to site monitoring, further usages of sensors are being put into work, such as schedule and material flows, the equipment uses and movement (Dong, Li, & Yin, 2018). Grau et al. (2009) compared traditional and automated identification and localization of engineered components and demonstrated significant productivity gains. In recent years, the sensors are being integrated to deliver a digital and realistic copy of the site, representing an information-rich model with comprehensive analytical capability. The concept is called Digital twins, combining artificial intelligence, machine learning, and data analytics. Achieving a dynamic digital model that can be continuously updated and self-learning from the actual construction from multiple information sources representing several types of sensors (Lu, Xie, Parlikad, Schooling, & Konstantinou, 2020).

To elevate on-site health and safety management and reduce risks. Three aspects need to be improved: identifying hazardous areas, monitoring/inspection, and training (Dong et al., 2018). Numerous research topics are being conducted in digitalizing the construction site, including (Teizer, Lao, and Sofer 2007), which developed an algorithm to track workers' movement and identify the dangers along their paths. In another study (Teizer, Allread, Fullerton, & Hinze, 2010), a real-time warning system works on RFID technology. Every time a worker gets close to a dangerous area, the system will warn the worker. Training (Teizer, Cheng, & Fang, 2013) also integrated the warning system with a 3D virtual reality to train workers in steel erection tasks.

Recently, no review has been conducted on BIM sensors and the Digital Twin models in the construction industry. This PRISMA Protocol (PRISMA-P) intends to provide the interfaces and up to date technology used in the construction industry to improve the BIM deployment. This review will clarify the types of sensors connected to BIM models used in the construction site. Comparing the effectiveness among different sensors connected to BIM models and categorizing the fields and user groups for these technologies. Moreover, illustrating the architectural framework of these tools. Consequently, paving the way for further investigation in this area, allowing the development of state-of-the-art sensors to target the Architectural, Engineering, Construction and Operations (AECO) sector's worker's health and safety of the workers.

Objectives

This research protocol aims to identify the new trends of sensors used in AECO. Hence, the proposed systematic review will exclusively answer the following questions:

1. What types of sensors are being developed and implemented in the construction site?
2. What are the common usages of sensors that are implemented in construction projects?
3. What are the main target groups for the sensors involve?
4. In which fields of the construction process are the technologies being applied?
5. How effective is the use of sensing technology?
6. What are the typical system Architectures for the Sensor technologies?
7. What is the relation between sensor application and health and safety?

2. METHODOLOGY

This protocol follows the PRISMA-P checklist (Shamseer et al., 2015). The following sections will illustrate the PRISMA methodology.

2.1 Eligibility criteria

The criteria are The Preferred Reporting Items for Systematic Review and Meta-Analysis PRISMA (Moher et al., 2009) PRISMA checklist will be adopted to manage the selection and synthesis of the articles.

<u>Type of studies</u>

Controlled site trials, case studies, among others. Any article with sufficient data to measure the effectiveness, identify the techniques and methods of implementation and the significance of the result. Other studies providing information about the intervention will also be utilized.

Participants

Any mention stakeholder who has used BIM-based sensors or participated in the implemented process will be considered. Safety and facility managers, architects, engineers (surveying, mechanical, electrical and civil) are the main participants. The study will similarly include both the female and male population, with no age restrictions.

Interventions

The interventions targeting any BIM-based sensors implemented in the AECO industry are of the systematic review's interest. The research might include training practices, site monitoring, worker's tracking and inspections.

Timing

The studies will select any applied technique of sensors in any phase of the construction process.

Setting

No setting restriction will be considered.

Language

Only English published journal articles will be considered.

Exclusion Criteria

The review will exclude conference papers, review papers, discussion papers, and unpublished work. All articles before 2010 will be excluded. Studies that are not related to the engineering field, specifically construction, will be rejected.

2.2 Information sources

The investigated approach will include the top electronic databases in the field of construction and sensors. Such as: *"ScienceDirect, INSPEC, Current Contents, SCOPUS, and Web of Science"*. The search will be from 2010 since BIM application was becoming evident, and sensors and other technologies were linked to BIM around 2010. The study will also follow the snowballing technique looking through the articles' references to see any relevant studies (Wohlin, 2014).

2.3 Search strategy

Several keywords are considered for the search strategy: "construction, sensors, Digital Twins, Global Positioning Systems, tracking devices, Building information modelling". The next step is considering several synonyms for the keywords to avoid missing any term; these include: "BIM, GPS". A combination of keywords was formulated to initiate the search. The keywords are in the area of BIM-based sensors in the construction site. The combination is as follows:

1. Construction and sensors and "Building Information modelling" and Digital Twins.
2. Construction and "tracking devices" and "Building Information modelling" and Digital Twins.
3. Construction and "Global positioning systems" and "Building Information modelling."
4. Construction and GPS and Safety and "Building Information Modelling" and Digital Twins.

Two independent authors will conduct the search. The research will initiate by inserting every keyword combination in one of the electronic databases; no language date or study type will be limit. The total number of articles will be recorded in found in (Appendix Table 1) for qualitative and quantitative studies. Keeping track of every study from the initial number of articles and the number of the excluded articles with each limitation will start by the date, language, subject area, and then source.

The final search strategy will be examining the collected articles' references to check for any relevant study that might be included in the review.

2.4 Study records

Data management

When all the possible articles are collected and recorded the studies will be transferred to "Mendeley" a software for screening, allowing another check for duplication and managing the records. Titles and abstracts of the gathered articles will be screened. After filtering the results, the article's full text will be collected and assessed. Two independent authors will perform all the mentioned steps.

Selection process

The first step will include screening the articles' titles and will be done by the two authors. The second step, abstracts, will be screened from the articles showing a relation between the research questions. Full text will be collected after the studies meet the inclusion criteria. Any doubts that arise in the first and second step concerning the article's relevance will be considered relevant and included in the review. After combining the independent results, any conflict between the two authors will be solved through discussion between them. A third author will resolve any arisen conflicts. The exclusion of any study after the screening of the full text will be justified and recorded.

Data collection process

Qualitative data will be extracted from the studies and recorded in the review using a pre-structured table for data extraction based on “The consumers and communication review groups data extraction” template (Montgomery & Shepard, n.d.). The information obtained will include data related to the BIM-based sensory technologies, populations, implementation methods, hardware and software used, results of the studies and problems they faced with future recommendations. Two authors formulated the table to collect the data to answer the research question and research objective specifically. Two reviewers will fill the table. Then, the results will be combined. Any disagreement will be solved by discussion. A third author will solve any further disagreements.

Data items

The data extracted in the review will be considering three main items: 1) the name and description of the interventions. 2) The intervention type, including tools, type, description, stakeholders targeted, system architecture, and implementation methods. 3) The case studies will be analyzed for targeted fields, effectively improving work quality, cost and time effectiveness, and technology readiness level. Finally, mentioning the author's future proposals and study limitations.

Outcomes and prioritization

Primary outcomes:

The primary outcome of the review is to assess the effectiveness of BIM-based sensors implemented in construction projects. Furthermore, this study will examine the stakeholders, implementation stages and fields, and the advantages of these technologies. Nevertheless, the system architecture, data collection, and communication techniques between the sensors and the BIM databases will be revealed.

Secondary outcome:

The secondary outcomes are readiness related; the study will assess the intervention's effectiveness, hardware, and software. It will also state the intervention's time consumption, expressly:" If it took more time than allocated and if it impacted the building schedule negatively or positively". The role of other stakeholders in the intervention could be in developing the models or testing them.

Risk of bias in individual studies

Two independent reviewers will evaluate the risk of bias in qualified articles. The studies quality will be evaluated using the Cochrane Collaboration tool for assessing the risk of bias found in the appendix (Montgomery & Shepard, n.d.). The following components of the studies will be assessed: stakeholders, implementation of the intervention, tools and equipment used, and data analysis. The quality of each of these components will be graded as high, moderate, or low. If a disagreement arises, it will be resolved by discussion. A third reviewer will be assigned to settle any further disagreements.

2.5 Data

Synthesis

A meta-analysis would be conducted using a random effect model if the studies' given data were standardized (population, intervention, implementation methods, and outcomes). The results might include several intervention designs or implementation methods. If so, the results will be categorized into several groups. These groups will be identified according to the project's life cycle stage.

Suppose any missing data, the authors of the studies will be contacted to retrieve any wanted information. If missing data cannot be obtained, authors will build up the discussion to assume it.

Sensitivity analysis will be performed to check if outcomes are affected by any changes in the methods or data used.

Meta-aggregation

For this type of study, a Meta-Analysis would not be applicable. If the extracted articles showed the possibility of formulation a meta-analysis, a Meta-aggregation would be amended later.

Meta-bias

For this type of study, a Meta-Analysis would not be applicable. If the extracted articles showed the possibility of formulation a meta-analysis, a Meta-Bias would be amended later. Outcome reporting in the trial (orbit) might be considered.

2.6 Confidence in cumulative evidence

The Systematic Review is in the engineering field, and the expected findings will not be appropriate for a Meta-Analysis. Consequently, confidence in cumulative evidence will not be applicable as well.

In case the results of the studies showed relevance for a Meta-Analysis, the GRADE (Grading of Recommendations Assessment, Development and Evaluation) system will be used to assess the final evidence and recommendations' quality and strength.

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