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Impact of BIM-based augmented reality interfaces on construction projects: protocol for a systematic review

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Abstract

Building Information Modelling (BIM) has been adopted in construction projects to increase efficiency. In general, improving project management and monitoring, reducing time and cost, strengthen the collaboration between stakeholders, in addition to Risk and injury reduction. To assist the BIM tools, Augmented Reality (AR) is being implemented, as a promising technology that clarifies the construction process. To evaluate the usability and effectiveness of AR tools in the Architectural, Engineering, Construction and Operations (AECO) sector, a protocol for a systematic review is proposed, adapting the PRISMA Statement Protocol (PRISMA-P). The search will be carried out in the reference databases for the field. One of the main outcomes of this study is to assess the effectiveness and usability of AR tools implemented in construction projects. Furthermore, this study identifies the BIM dimensions covered and the related tools and techniques. In addition, to the assessment and evaluation methods adopted by the authors to evaluate their studies, the reliability of the tools and their impact were also analysed. The secondary outcomes are objective oriented, the study points out why the AR technology was implemented and at which construction stage. Moreover, it assesses the technology's capability of replacing traditional approaches in the construction projects, by mentioning the time and cost consumption and the role of the stakeholders.

1. INTRODUCTION

Azuma (1997) describes Augmented Reality (AR) as a variation of Virtual Reality (VR), excelling itself for complementing a real environment with the integration of virtual objects. Also, the author designates that AR systems hold three main characteristics: the combination of real and virtual; real-time interaction; and 3D presentation.

In a study by Kodeboyina and Varghese (2016) the fundamental requirements to develop AR systems are input devices, sensors, processor and display which are mostly integrated on modern handheld equipment such as smartphones and tablets. Chi, Kang and Wang (2013) and Wang et al. (2013) determine that AR technology evolved from marker-based applications towards markerless systems, although more recent advances in context-aware tools such as Wikitude, Google's Project Tango, and more recently ARCore, may expedite the technology used on mobile devices. Indeed, there is a rising trend towards the use of mobile AR (Rankohi & Waugh, 2013) given the increasing processing power of handheld devices.

More recently, AR is evolving from static information connected to an object entity to context-aware systems able to recognize the surrounding environment (Wang, Kim, et al., 2013). From the 1996 AR system to construction inspection and architecture renovation proposed by Webster *et al.* (1996) to the more recent HMD (Head-mounted display) applications (e.g., Microsoft Hololens), several research studies have demonstrated the generalized interest towards the use of AR systems in the domains of the Architectural, Engineering, Construction and Operations (AECO) sector. Furthermore, AR applications enriched with BIM information have reported positive effects to different applications amongst this industry. In fact, AR technology has been targeted as one of the main BIM-related research fields (Li, Wu, Shen, Wang, & Teng, 2017).

However, limitations may be found while managing higher amounts of data, such as the case of BIM-based AR systems (Love et al., 2013; Gheisari & Irizarry, 2016; Patti et al., 2017; Wang, 2013). Additionally, research has documented limitations that still hamper the implementation of AR for construction-related activities such as the accuracy of tracking technologies (Rankohi & Waugh, 2013; Bae, Golparvar-Fard, & White, 2014; Kodeboyina & Varghese, 2016), and precise alignment (Agarwal, 2016).

With regards to the potential benefits from the use of AR towards the AECO industry, comparisons between studies are oftentimes hampered by the variety of methods and data treatment techniques.

As such, the proposed systematic review will provide a full-fledged appraisal on the most recent methods, reasoning, tools (hardware and software), target groups, and assessment methods used to develop AR applications connected to BIM parametric information.

Objectives

The objective of this research protocol is to evaluate the effectiveness and usability of BIM-Based AR techniques in the Architecture, Engineering, Construction and Operations sector. Therefore, the proposed systematic review will specifically answer the following questions:

1. What are the AR techniques that are implemented in construction projects?
2. Why is AR implemented in the construction site, what is the objective of the implementation?
3. At which stage of the Projects lifecycle are the AR techniques implemented?
4. How effective are the AR techniques in reducing construction risks?
5. Are the AR techniques improving traditional approaches?
6. How are these interfaces being assessed in terms of effectiveness and usability? (qualitative, quantitative, comparative assessments, case study based, user, centered?)

2. METHODS

2.1 Eligibility criteria

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

Type of studies

Controlled site trials, prospective and retrospective studies will be considered, as well as cross-sectional studies, case-control studies and comparative cohort studies. Any study with sufficient data to measure the effectiveness, and identifying the techniques and methods of implementation, in addition to the significance of the result. Other studies providing information for the technology and tools will also be used.

Participants

The study will include articles that mention workers and participants that have used AR or were a part of the implemented process. It will also include students, architects, engineers (site, mechanical, electrical and civil), as well as safety managers. The study will likewise include both female and male population, with no age restrictions.

Interventions

The interventions targeting AR are of interest in general. The study might include training practices, site monitoring, 4D visualizations and walkthrough. Any BIM-Based AR 3D models if found relevant.

Timing

The studies will select any implemented method of AR in any stage of the project lifecycle. From the conceptual phase including the occupation and maintenance after the project's execution.

Setting

There are no setting restrictions.

Language

The study will consider English articles only.

Exclusion Criteria

The study will exclude discussion papers, conference papers and unpublished work.

2.2 Information sources

The research strategy included the top electronic databases in the field of construction and AR which provided easy access to databases found in Index such as: *"Academic Search Complete, Current Contents, SCOPUS, Web of Science, and ScienceDirect"*. The search targeted only published journal articles that were written in English, the search will be from the year 2016.

The study will also look through the references of the articles to see if there are any included relevant studies.

2.3 Search strategy

For the search strategy, several keywords are considered: "construction, Augmented Reality, BIM". The next step is the consideration of several synonyms for the keywords to avoid missing any term, these include: "Building information modelling, AR". Before initiating the search, the combination of the keywords was formulated in a sense that included the usage of Virtual Reality in construction and which might include BIM and Safety. The combination is as follows:

1. Construction + "Augmented Reality" + BIM
2. Construction + "Augmented Reality" + "Building Information modeling "
3. Construction + AR + BIM
4. Construction + AR + "Building Information modeling"

The search will be made by two independent authors. At the beginning of the search, every combination of the keywords will be inserted in *the search*, with no study type, language or date limitation to the search. The number of articles will be recorded in Table 1 found in the appendix, for both qualitative and quantitative studies. This will keep track of every study from the initial number of articles and the number of the excluded articles with each limitation, which will start by the date, language, subject area, and then the source.

The final step in the search strategy will be searching in the references of the collected articles to see if there are any included relevant studies.

3. STUDY RECORDS

3.1 Data management

After finishing the search and recording the number of the collected articles in Table 2 found in the appendix, selected articles from the databases will be exported to "Mendeley" software for screening, check for duplicates and management of the retrieved records. Titles and abstracts of the compiled articles will be screened. After filtering the results, the studies will be combined for obtaining the full-text copies of possibly appropriate articles will be assessed. All the mentioned steps will be performed by three independent authors.

3.2 Selection process

The first step is done by five authors, it will include screening the titles of the articles. After that, the abstracts will also be screened from the studies that showed the relation between the title and the research question. Full-text will be collected after the title and the abstract meet the inclusion criteria. Any doubts in the title or the abstract will be considered as a relevant article and the full text will be collected to be screened. After combining the separate results, any conflict between the five authors will be solved through discussion between them. A fourth author will resolve any further conflicts. The exclusion of any article after the full-text screening will be justified and recorded.

3.3 Data collection process

Qualitative data will be extracted from papers included in the review using a pre-structured table for data extraction based on the (Cochrane consumers and communication review groups data extraction template). The data extracted will contain information related to the interventions, populations, methods of implementation, tools used and results and problems they faced with future recommendations. The table is formulated by three authors, aimed to collect the data which will specifically answer the research question and research objective. Three reviewers will fill the table and then the results will be combined. Any disagreement will be solved by discussion, and a fourth author will solve any further disagreements.

3.4 Data items

The data extracted in the review will consider three main items: 1) the implementation of the intervention (objective, construction phase, field) in which stage of the project life cycle and what kind of participants it included. 2) the type of the intervention including (tools, type, risk it targeted, BIM and AR relation, BIM dimensions and operation methods). 3) the outcome including, risk prevention, assessment methods, improving the quality of work, cost and time effectiveness. Furthermore, the author's future proposals and limitations will be registered.

3.5 Outcomes and prioritization

Primary outcomes

The primary outcome of this study is to assess the effectiveness and usability of AR tools implemented in construction projects. Furthermore, this study will check the BIM related tools and techniques used and the BIM-dimensions they covered. In addition, to the assessment and evaluation process, the authors made to evaluate their studies and the impact it had on the construction project. Nevertheless, the participants involved in the intervention will be referred to.

Secondary outcome

The secondary outcomes are objective-related. The study will point out why was the AR technology used and at which construction stage, in addition to the applicability and capability of replacing the traditional approaches in the construction projects. Furthermore, it will state the time consumption of the intervention, specifically: "If it took more time than allocated and if it impacted the building schedule negatively or positively". And mention the role of other stakeholders that took part in the intervention that was developed or while it is being tested.

3.6 Risk of bias in individual studies

Risk of bias in qualified articles will be evaluated by two independent reviewers. The quality of the studies will be evaluated using the Cochrane Collaboration tool for assessing the risk of bias found in the appendix. The following components of the studies will be assessed: stakeholders, implementation of the intervention, tools and equipment used; and data analysis of the results. 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 and a third reviewer will be assigned to settle any further disagreements.

4. DATA

4.1 Synthesis

If the given data from the studies were standardized (population, intervention, methods of implementation and outcomes), a meta-analysis will be conducted using a random effect model. 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.

If 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.

4.2 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 will be amended later.

4.3 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 will be amended later. Outcome reporting in the trial (orbit) might be considered.

4.4 Confidence in cumulative evidence

The GRADE (Grading of Recommendations Assessment, Development and Evaluation) system will be used to help assess the quality and strength of the final evidence and recommendations.

Authors` contribution

Development of study design and conduct: AS, FD, JD. Coordination of study conduct: AS. Title-/ abstract screening: AS, FD. Full-text screening: AS, FD, LS, JD, DC. Data extraction: AS, FD, LS, JD, DC. Critical appraisal: AS, FD, JD. Data analysis and interpretation: AS, FD, JD. Support in data analysis and interpretation: FD, JD. Draft of the document: AS. Support in the draft of the manuscript: FD, JD LS, DC, JPM, AS

All authors read and approved the final version.

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Appendix

Table 1. Data records

Confirm .	0	Summary of Total Rejected Items						Data Base	Data Base	Data Base Name	Keywords 1:							
													Number of articles excluded after introduction of criteria					
Summary of articles collected	Summary of Selected Articles	Date	Type of Article	Source	Language	Off topic	"Other (to define)"				Number of selected articles	Total number of	Date:	Type of Article:	Subject Area	Language:	Off Topic	Other
0	0	0	0	0	0	0	0				0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	Index	Multidisciplinary	Academic Search Complete	0							
0	0	0	0	0	0	0	0			Current Contents	0							
0	0	0	0	0	0	0	0			Web of Science	0							
0	0	0	0	0	0	0	0			SCOPUS	0							
0	0	0	0	0	0	0	0		Engineering	INSPEC	0							
0	0	0	0	0	0	0	0			ScienceDirect	0							
0	0	0	0	0	0	0	0	E-Journal	Multidisciplinary	Cambridge Journals Online	0							
0	0	0	0	0	0	0	0			Directory of Open Access Journals	0							
0	0	0	0	0	0	0	0			Emerald Fulltext	0							
0	0	0	0	0	0	0	0			Informaworld (Taylor and Francis)	0							
0	0	0	0	0	0	0	0			Oxford Journals	0							
0	0	0	0	0	0	0	0			SAGE Journals Online	0							
0	0	0	0	0	0	0	0			Scientific Electronic Library Online	0							
0	0	0	0	0	0	0	0			SpringerLink	0							
0	0	0	0	0	0	0	0			Wiley Online Library	0							
0	0	0	0	0	0	0	0		Engineering	ACM Digital Library	0							
0	0	0	0	0	0	0	0			ASME Digital Collection	0							
0	0	0	0	0	0	0	0			CE Database (ASCE)	0							
0	0	0	0	0	0	0	0			IEEE Xplore	0							
0	0	0	0	0	0	0	0			IOP Journals	0							
0	0	0	0	0	0	0	0			ScienceDirect (eJournals)	0							
0	0	0	0	0	0	0	0			SIAM	0							

Table 2. Data analysis

Author	Title	Year	Source/ Journal	Abstract	Aim	Population	Methodology	Target Group	Risks	Outcome Measures	Results	Problems/ Limitations	Conclusion/ Future Development	Chapters overview

– Cochrane collaboration tool for assessing risk of bias

Domain	Support for judgement	Review authors' judgement
Selection bias		
Random sequence generation	Describe the method used to generate the allocation sequence in sufficient detail to allow an assessment of whether it should produce comparable groups.	Selection bias (biased allocation to interventions) due to inadequate generation of a randomized sequence.
Allocation concealment	Describe the method used to conceal the allocation sequence in sufficient detail to determine whether intervention allocations could have been foreseen in advance of, or during, enrolment.	Selection bias (biased allocation to interventions) due to inadequate concealment of allocations prior to assignment.
Performance bias		
Blinding of participants and personnel. Assessments should be made for each main outcome (or class of outcomes).	Describe all measures used, if any, to blind study participants and personnel from knowledge of which intervention a participant received. Provide any information relating to whether the intended blinding was effective.	Performance bias due to knowledge of the allocated interventions by participants and personnel during the study.
Detection bias		
Blinding of outcome assessment. Assessments should be made for each main outcome (or class of outcomes).	Describe all measures used, if any, to blind outcome assessors from knowledge of which intervention a participant received. Provide any information relating to whether the intended blinding was effective.	Detection bias due to knowledge of the allocated interventions by outcome assessors.
Attrition bias		
Incomplete outcome data. Assessments should be made for each main outcome (or class of outcomes).	Describe the completeness of outcome data for each main outcome, including attrition and exclusions from the analysis. State whether attrition and exclusions were reported, the numbers in each intervention group (compared with total randomized participants), reasons for attrition/exclusions where reported, and any re-inclusions in analyses performed by the review authors.	Attrition bias due to amount, nature or handling of incomplete outcome data.
Reporting bias		
Selective reporting	State how the possibility of selective outcome reporting was examined by the review authors, and what was found.	Reporting bias due to selective outcome reporting.
Other bias		
Other sources of bias	State any important concerns about bias not addressed in the other domains in the tool. If questions/entries were pre-specified in the review's protocol, responses should be provided for each question/entry.	Bias due to problems not covered elsewhere in the table.