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Impact of BIM-based virtual and augmented reality interfaces on health and safety in construction projects: protocol for a systematic review

Adeeb Sidani [a]; J. Duarte [b]; Fábio Dinis [c]; J. Santos Baptista [d]; João Poças Martins [e]; Alfredo Soeiro [f]

[a]Civil Engineering, University of Porto, PT (adeeb.sidani@hotmail.com); [b]*LAETA*, Faculty of Engineering, University of Porto, PT (jasduarte@fe.up.pt) ORCID: 0000-0002-5856-5317.; [c]Civil Engineering, University of Porto, PT (fabiodinis@fe.up.pt); [d]*LAETA*, University of Porto, PT (jsbap@fe.up.pt) ORCID: 0000-0002-8524-5503; [e]Civil Engineering, University of Porto, PT (jppm@fe.up.pt); [f]Civil Engineering, University of Porto, PT (avsoeiro@fe.up.pt);

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Abstract

The construction sector is notable for its interdisciplinary knowledge and complex interactions between different parties and the sector has been gradually adopting new methodologies to improve work and collaboration practices, such as the case of Building Information Modeling (BIM). A protocol for a systematic review is proposed to evaluate the effectiveness of virtual reality techniques in the Architectural, Engineering, Construction and Operations sector. 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 of virtual reality tools implemented in construction projects at the same time it will try to estimate the cost of the equipment and the implementation of the intervention and if any other mentioned cost might be related to risk reduction or better performance. This protocol is registered in PROSPERO under the code of PROSPERO CRD42018085845.

1. INTRODUCTION

It is necessary to provide efficient interaction and proper collaborative workflows, the construction sector is notable for its interdisciplinary knowledge and complex interactions between different parties, during a construction project delivery (Liu, Van Nederveen, and Hertogh 2017). The Architectural, Engineering, Construction and Operations (AECO) sector has been gradually adopting new methodologies to improve work and collaboration practices, such as the case of Building Information Modeling (BIM) (Smith 2014).

However, BIM is still not entirely embraced by all segments (Liu, Van Nederveen, and Hertogh 2017) stressing the need for technological adaptations to improve collaboration and inclusiveness. An effective collaborative workflow addressing BIM capabilities for sharing construction information and simultaneously adapted to the actual work of the different teams involved in a construction project is still in demand (Kerosuo et al. 2015).

Immersive Virtual Reality (IVR) interfaces have been matter of research and interest by the AECO sector in the last few years (Paes, Arantes, and Irizarry 2017, Kunz et al. 2016, Maffei et al. 2016), demonstrating the potential of the technology to improve 3D spatial perception (Paes, Arantes, and Irizarry 2017) as well as to provide a more natural approach to interact with virtual models (Dinis and Poças Martins 2016).

Furthermore, BIM-based Virtual Reality (VR) interfaces may provide feasible conditions to streamline the development of plausible virtual environments.

Although, limitations have been found such as interoperability issues between software tools (Monteiro 2013), current studies describe viable applications of integrating BIM and VR (Yan, Culp, and Graf 2011, Wu and Kaushik 2015, Rüppel and Schatz 2011, Du et al. 2018).

To date, no systematic review has been conducted on the VR's effect on health and safety in the construction industry. This research protocol for a systematic review aims to provide the interfaces and up to date technology used in the construction industry to overcome health and safety risks. This will allow the investigation and the studying of new VR interfaces, that might elevate the health and safety status in the construction industry, as well as comparing the effectiveness and assessing different interfaces.

Objectives

The aim of this research protocol is to evaluate the effectiveness of VR techniques in in the AECO sector, targeting occupational safety and health. Therefore, the proposed systematic review will specifically answer the following questions:

1. What are the VR techniques that are implemented in construction projects?
2. At which stage of the Projects lifecycle are the VR techniques implemented?
3. How effective are the Virtual reality techniques in reducing construction risks?
4. How are these interfaces being assessed in terms of effectiveness and usability?

2. METHODS

2.1. Eligibility criteria

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

Type of studies

The research will mostly be including experimental and theoretical studies, case studies or field 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 the information for the technology and tools will also be used.

Participants

The study will include articles that mention workers and participants that have used VR or were a part of the implemented process, experience levels of the participants will not be an issue for end users. It will also include 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. Nevertheless, any type of project or site condition will be included.

Interventions

The interventions targeting VR are of interest in general. In addition to the studies targeting Augmented Reality (AR), the study might include training practices, site monitoring, 4D visualizations and walkthrough. Any BIM-Based virtual 3D models if found relevant.

Timing

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

Setting

There are no setting restrictions.

Language

The study will consider articles in English only.

Exclusion Criteria

The study will exclude discussion papers, conference papers and unpublished work. As well all studies before 2007.

Information sources

The research strategy will include electronic databases which will provide easy access found in Index and E-journals such as: *"Academic Search Complete, Current Contents, Web of Science, SCOPUS, INSPEC, ScienceDirect, Cambridge Journals Online, Directory of Open Access Journals (DOAJ), Emerald Fulltext, Informaworld (Taylor and Francis), Oxford Journals, SAGE Journals Online, SciELO - Scientific Electronic Library Online, SpringerLink, Wiley Online Library, ACM Digital Library, ASME Digital Collection, CE Database (ASCE), IEEE Xplore, IOP Journals, ScienceDirect (eJournals), SIAM"*. The search targeted only published journal articles that were written in English, the search will target articles from 2007 onwards, this is due to the integration of BIM with construction safety.

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

2.2. Search strategy

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

1. Construction + "Virtual Reality" + Safety
2. Construction + "Virtual Reality" + BIM
3. Construction + "Augmented Reality" + Safety
4. Construction + "Augmented Reality" + BIM
5. Construction + "Virtual Reality" + "Accidents Prevention"
6. Construction + "Virtual Reality" + "Building Information Modeling "
7. Construction + "Augmented Reality" + "Accidents Prevention"
8. Construction + "Augmented Reality" + Building Information Modeling"

The search will be made by 2 independent authors. At the beginning of the search every combination of the key words will be inserted in SCOPUS, with no study type, language or date limit will be defined to the search. The number of articles will be recorded in a 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 screening criteria, which will start by the date, language, subject area, and then the source.

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

2.3. STUDY RECORDS

Data management

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

Selection process

First step is done by three authors, it will include screening the titles of the articles. After that the abstracts will also be screened from the studies that showed relation between the title and the research questions. 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 three 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.

Data collection process

Quantitative 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 questions and the research objectives. 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.

Data items

The data extracted in the review will be considering 4 main items: 1) the implementation of the intervention, 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, and operation methods). 3) the outcome including (risk prevention, improving the quality of work, cost and time effectiveness). 4) record the objectives mentioned in the article and classify them. As well as mentioning the authors future proposals and limitations.

Outcomes and prioritization

The primary outcomes: The primary outcome of this study is to assess the effectiveness of virtual reality tools implemented in construction projects. Furthermore, this study will evaluate the improvement of the safety and the type of tools and techniques used in each stage of the design project as well as evaluating the risk reduction. Nevertheless, Participants involved in the interventions will be mentioned as well.

Secondary outcome: The secondary outcomes are cost related; the study will try to estimate the cost of the equipment and the implementation of the intervention and if any other mentioned cost might be related to risk reduction or better performance. In addition, 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, could be in developing the models, or testing it.

Risk of bias in individual studies

Risk of bias in qualified articles will be evaluated by three independent reviewers. The quality of the studies will be evaluated using the Cochrane collaboration tool for assessing 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 forth reviewer will be assigned to settle any further disagreements.

2.4. DATA

Synthesis

If the given data from the studies were standardized (Applicability, usability, effectiveness, goals participants, intervention, methods of implementation and outcomes). If possible, a meta-analysis will be conducted using a random effect model. If meta-analysis is not possible all analysis will be made in a qualitative way. The results might include several intervention designs or implementation methods, if so the results will be categorized to several groups. These groups will be identified according to the project's life cycle stage.

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 discussion to assume it and include it in the data collection.

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

Meta-aggregation

Narrative synthesis will be based on a previously prepared table to summarize and fill extracted information. Therefore, providing a clear relation between the collected articles and their applied interventions in a head to head trials comparison. At the same time compare them with before trial condition. As for the outcomes a narrative synthesis will give a clear comparison of the effect of the intervention on the construction safety with the state of safety without the application of the intervention, and the interventions effect with each other, in a text form.

Meta-bias

If the extracted articles showed the possibility of formulation a meta-analysis a Meta-Bias will be amended later. Outcome reporting in trial (orbit) might be considered.

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' CONTRIBUTIONS

Development of study design and conduct: AS, FMD, JD. Coordination of study conduct: AS. Title-/ abstract screening: AS, FMD. Full text screening: AS, FMD, JD. Data extraction: AS, FMD, JD. Critical appraisal: AS, FMD, JD. Data analysis and interpretation: AS, FMD, JD.

Support in data analysis and interpretation: FMD, JD. Draft of the document: AS. Support in draft of the manuscript: FMD, JD, SB, JP, AS. All authors read and approved the final version.

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Appendix

– Table 1 for data records

Confirm.	0	Summary of Total Rejected Items						Data Base Type	Data Base Category	Data Base Name	Keywords 1:							
Summary of articles collected	Summary of Selected Articles	Date	Type of Article Review	Source	Language	Off topic	"Other (to define)"				Number of selected articles	Total number of articles collected	Number of articles excluded after introduction of criteria					
													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	Multidisciplinar	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		Engineerin	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 for analysis

Author	Title	Year	Source/ Journal	Abstract	Aim	Population	Methodology	Target Group	Risks	Outcome Measures	Results	Problems/ Limitations	Conclusion/ Future Developmen	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 research objective 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.