Systematic review on virtual environments in the collaborative design process

Revisão sistemática sobre ambientes virtuais no processo de colaboração em projetos

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ABSTRACT
Virtual environments have become increasingly used tools in collaborative design processes related to Architecture, Engineering, and Construction (AEC) However, in order to promote greater engagement of lay users in decision-making, it becomes necessary to employ tools that stimulate and encourage their participation in the early stages of the project. Due to the constant evolution of technology, conducting an analysis of these tools over the years can provide an important contribution to collaborative design practice. The aim of this article is to analyze studies focused on the use of virtual environment technologies in collaborative design processes over the past 10 years through Systematic Literature Review (SLR). The results allow the analysis of research areas, the evolution of publications and the similarity of keywords. Finally, the terms and concepts related to the discussed subject are examined, contributing to discussions and recommendations for future SLR research.

Keywords: design process, virtual reality, augmented reality, mixed reality, collaborative design, participatory design, co-design.
RESUMO
Os ambientes virtuais estão se tornando instrumentos cada vez mais utilizados em processos de colaboração em projetos relacionados à Arquitetura, Engenharia e Construção (AEC). Entretanto, para promover um maior engajamento dos usuários leigos nas tomadas de decisões, torna-se necessário a utilização de ferramentas que estimulem e incentivem sua participação nas etapas prévias do projeto. Devido à constante evolução da tecnologia, realizar uma análise destas ferramentas ao longo dos anos pode apresentar uma importante contribuição na prática projetual colaborativa. O objetivo deste artigo é analisar os estudos voltados à utilização de tecnologias de ambientes virtuais nos processos de colaboração em projeto nos últimos 10 anos através da Revisão Sistemática de Literatura (RSL). Os resultados possibilitam analisar quais são as áreas de pesquisa, a evolução das publicações e a similaridade das palavras-chave. Por fim, são analisados os termos e conceitos utilizados referentes ao assunto abordado, contribuindo com discussões e recomendações para futuras pesquisas sobre a RSL.

Palavras-chave: processo de projeto, realidade virtual, realidade aumentada, realidade mista, projeto colaborativo, projeto participativo, co-design.

1 INTRODUCTION
Collaboration among groups and individuals has become a decisive process to produce innovation, quality and reliability in the development of systems and products in several areas. In the field of Architecture, Engineering and Construction (AEC), it is important to ensure and encourage users participation in the design process, as the designed building needs to satisfy the specified needs to present an adequate architectural quality, preceded by understanding the perspective, goals and desires of clients and future users (Voordt & Wegen, 2013). Although ongoing discussions about design collaboration, the practice of collective creativity has existed for approximately 40 years under the name of participatory design (Sanders & Stappers, 2008). New terms have been adopted throughout history and are now known and consolidated by designers. Concepts such as collaborative design, user-centered design and co-design are used by several authors to explain user collaboration in different design stages.

With the aim of aiding the communication between architects and users and ensuring clear and understandable information, several alternatives involving virtual environment technologies are being explored, such as Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR). According to Moura and Campagna (2018), although design tradition transmits an invaluable heritage rich in principles, digital innovation not only offers quantitative but also qualitative advantages by allowing the development of new paradigms, enriching the complexity of the information embedded in designed products and providing new levels of
interaction between the designed environment and the user. Furthermore, using these technologies from the early stages of the design can allow consecutive learning cycles about possible solutions and generate relevant discussions between architects and users (Marins & Bittencourt, 2019; Loup-Escande, Burkhardt, Christmann & Richir, 2014).

The use of these digital tools in the design process, now more popular and accessible, has opened up enormous operational possibilities: enable alternative design solutions more quickly, enable effective procedure, facilitate the understanding and evaluation of all stages of the process and provide users with intelligible and interactive tools to perform specific design tasks (Maurya, Arai, Moriya, Arrighi & Mougenot, 2019; Van Leeuwen, Hermans, Jylhä, Quanjer & Nijman, 2018; Moura & Campagna, 2018).

Therefore, the present research aims to analyze studies focused on the use of virtual environment technologies in the collaboration processes in design involving different stakeholders over the past 10 years, through a Systematic Literature Review (SLR).

2 METHODOLOGY

To conduct the research and analysis of the proposed theme, the SLR method was adopted. A research protocol was proposed, where the objective, analysis criteria and papers selection were established. The search was conducted in the following international and interdisciplinary bibliographic databases: Scopus (http://www.scopus.com) and Web of Science (http://www.webofknowledge.com).

To collect the papers for this review, a search string was created based on the predefined terms and concepts by the authors, following the protocol guidelines, considering the four fields shown in Table 1.

In the first field, the word ‘Design’ was defined to focus the research in the design area. The second field aimed to limit the research by the roles of agents involved in the design process. The third field restricted the types of virtual interface tools used in the studies and the fourth field refined the application format of the technologies used. The boolean operator ‘AND’ was used between each field, and the boolean operator ‘OR’ was used between the words within each field. Finally, a restricted search between 2010 and 2019 was established to determine the most up-to-date papers.
Table 1 – Search String

<table>
<thead>
<tr>
<th>Terms used in the search (Title, Abstract or Keywords)</th>
<th>1º field</th>
<th>2º field</th>
<th>3º field</th>
<th>4º field</th>
</tr>
</thead>
<tbody>
<tr>
<td>design</td>
<td>“participat* design”</td>
<td>“virtual reality”</td>
<td>simulat*</td>
<td></td>
</tr>
<tr>
<td>“collab* design”</td>
<td>“augmented reality”</td>
<td>evaluat*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>“co-design”</td>
<td>“mixed reality”</td>
<td>prototyp*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>codesign</td>
<td>“immersive environment”</td>
<td>model*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: prepared by the authors

The publications from the consulted databases were imported into the StArt\(^1\) software, which aided in organizing and systematizing the literature review, resulting in 261 publications (full papers and non-duplicates)\(^2\) available in English. In order to conduct a thorough analysis of research related to AEC, all publications underwent a second filter based on the inclusion and exclusion criteria established by the authors in the initial protocol (Table 2), where the titles, abstracts and keywords were read. Through this filtering process, 71 publications in the AEC field were identified.

Table 2 - Inclusion/exclusion criteria

<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>INCLUSION</th>
<th>EXCLUSION</th>
</tr>
</thead>
<tbody>
<tr>
<td>● Address the theme directly in the title;</td>
<td>Only one condition was necessary to exclude the text:</td>
<td></td>
</tr>
<tr>
<td>● Be included in the keywords or abstract;</td>
<td>● Fall outside the three main aspects of the research (design process / project participatory / simulation);</td>
<td></td>
</tr>
<tr>
<td>● Discuss design evaluation;</td>
<td>● Present concepts outside the AEC field;</td>
<td></td>
</tr>
<tr>
<td>● Discuss Architecture, Engineering, and Construction;</td>
<td>● Unable to find the full paper;</td>
<td></td>
</tr>
<tr>
<td>● Address virtual simulation in the design process;</td>
<td>● Unable to find bibliographic data.</td>
<td></td>
</tr>
<tr>
<td>● Approach collaboration in the design process (Participatory / Collaborative / Co-design).</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: prepared by the authors

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\(^1\) http://lapes.dc.ufscar.br/tools/start_tool

\(^2\) Link to access SLR article titles: https://drive.google.com/file/d/1rf3mdBdqjPsRxh-sNwfWNvQ9ICAg_rKU/view?usp=sharing
The general outline of the research is delineated in figure 1.

Figure 1 – Outline of the bibliographical survey

3 ANALYSIS OF PUBLICATIONS FOUND

From the reading the titles, abstracts and keywords of the 261 publications found, seven major research area groups were identified, as shown in the Graph 1.

Graph 1 - Publications in the last 10 years (2010-2019) according to research áreas

Source: prepared by the authors
The results obtained from the bibliographic databases made it possible to identify the areas that have been using virtual environment tools in the collaboration process in design projects over the past 10 years. It is evident that publications have been found in diverse fields, focusing not only on design/projects (‘AEC Design’, ‘Product Design’, ‘Fashion Design’), but also in other research areas (‘Education’, ‘Health’, ‘Computer Science’).

Among all research areas, the AEC sector has the highest number of total publications (27% of research). This is mainly due to the growth of research that occurred in the last 5 years, as it is possible to analyze in Graph 2.

Significant increases in the number of publications have been observed within the AEC design context over the past 10 years. The first increase occurred between 2012 and 2014, possibly due to the launch of important VR tools (Oculus Rift in 2012 and Google Cardboard in 2014). Another notable increase occurred from 2015 until the present day, with a strong focus on research in this field.

This can be attributed to the appearance of new technologies and the popularization of game programs in immersive environments, such as Unity 3D and Unreal Engine. Therefore, it can be inferred that research in this sector demonstrates an increased use of virtual environment technologies as tools to support users in design collaboration processes.

4 ANALYSIS OF PUBLICATIONS RELATED TO AEC

After applying the inclusion/exclusion criteria, 71 publications related to AEC were selected. To identify the relationship between the terms from these publications, an analysis of
the keywords provided by the authors was conducted using VOSViewer\(^3\) software, a bibliometric analysis tool. This software carried out the construction of a relationship network of terms and made it possible to identify the similarity and occurrences of these words. Figure 2 presents the keyword network of the 71 publications in the AEC sector.

![Figure 2 – Keyword network of the 71 AEC publications](image)

Source: prepared by the authors

Through the selection of the most recurrent keywords, the software created clusters of similarity among them. Analyzing Figure 2, we can identify six main clusters, with the following prominent keywords: ‘Virtual Reality’, ‘Collaborative Design’, ‘Augmented Reality’, ‘Participatory Design’, ‘Virtual Environment’ and ‘User Centered Design’. These keywords stand out due to their frequency of occurrence in the publications. The other keywords were positioned according to the proximity of the themes found in the publications.

It is observed that ‘Virtual Reality’ serves as a connecting term between all the other clusters, demonstrating its protagonism over the other words. In some cases, ‘Virtual Reality’ is directly linked to ‘Augmented Reality’ and ‘Mixed Reality’, indicating a complementarity of the tools used in virtual environments.

\(^3\) [https://www.vosviewer.com/](https://www.vosviewer.com/)
About collaboration processes in design, the term ‘Collaborative Design’ stands out, being close to words such as ‘Design’, ‘Creativity’, ‘Collaboration’, ‘Virtual Worlds’ and ‘Protocol Analysis’, which are terms used for collaboration and design analysis between designers. The term ‘Participatory Design’ is very close to the words ‘User Experience’ and ‘User Centered Design’, demonstrating the importance of user involvement and experience in participatory design processes. The term ‘Co-Design’, although within the ‘Virtual Environment’ and ‘Architecture’ cluster (red cluster), is directly linked to words such as ‘Human-Computer Interaction’ and ‘Design Process’, indicating that Co-Design can perform user interaction through computational tools.

As some initially considered important terms did not receive significant prominence in the keywords, we chose to examine their occurrence in titles and abstracts as well, enabling more precise analyses. When considering virtual environment technologies, their evolution over the past decade was analyzed according to Graphs 3 and 4.

Graph 3 – Technologies of virtual environments used in collaborative processes in AEC

Source: prepared by the authors
The graphs indicate that ‘Virtual Reality’ is the most frequent technology in collaborative design processes (30%), followed by ‘Augmented Reality’ (19%). Terms such as ‘Virtual Environment’ and ‘Virtual Worlds’ appear because they are commonly used in relation to these technologies. Terms such as ‘BIM’ and ‘CAVE’ occasionally appear, suggesting that they are being used less and possibly losing importance in this context of use in the design process. One term that shows potential growth in searches is ‘Game Engine’ (8%), as it significantly increased in participation between the years 2016 and 2019. This fact can be explained by the development and popularization of game tools in recent years.

From another perspective, when analyzing the terms related to the type of collaboration processes in design in the AEC field, four recurring terms were found in the collaborative environment: ‘Collaborative Design’, ‘Participatory Design’, ‘Co-Design’ and ‘User Centered Design’ (Graphics 5 and 6).
Analyzing Graphs 5 and 6, a strong occurrence of the term ‘Collaborative Design’ (54%) was identified in relation to the others, as well as a recurrent use over the past 10 years. It was also observed that the terms ‘Co-Design’ (20%), ‘Participatory Design’ (19%) and ‘User Centered Design’ (7%) were utilized, but with a lower number of occurrences.

Based on these results, it can be inferred that Collaborative Design can be considered a more qualified methodology for the use of virtual environment technologies in collaborative design processes in the AEC field.

5 CONCLUSIONS AND FUTURE RESEARCH

This research aimed to analyze the directions of studies focused on the use of virtual environment technologies in collaborative design processes over 10 years. It was possible to conclude that, despite the Search String’s definition being focused on searching for publications in AEC, this restriction was not effective in filtering only research related to design processes, as
approximately 50% of the publications are outside this research environment. However, the AEC sector has a higher number of total publications in 10 years (27% of the research), making it an expanding research area on the topic.

Another aspect analyzed was the scope of the term ‘Design’, which is usually associated with several fields of research. It was possible to analyze that the isolated term does not have many occurrences (as shown in Figure 2), gaining more prominence only when associated with other complementary words, such as ‘Urban Design’, ‘Collective Design’, ‘Interior Design’, ‘Parametric Design’, ‘Design Cognition’ and ‘Design Conversation’.

The analysis of the keywords provided by the authors did not generate effective data, as some important terms were only detected after a broader analysis through reading titles and abstracts. In some cases, terms related to the research are indirectly approached or not considered extremely important by the authors.

Regarding collaboration process methodologies in design, a significant difference was observed in the number of occurrences of the words ‘Collaborative Design’, ‘Participatory Design’, ‘Co-Design’ and ‘User Centered Design’. Further investigation is required to ascertain how these terms are being used in AEC research, as well as their definitions within design processes and their relationship when applied in virtual environment technology research.

The use of basic terms led to the emergence of other terms that were not part of the initial search string. These new words demonstrate other lines of research that can be addressed in future studies, such as ‘Game Engine’, ‘BIM’ and ‘User Centered Design’. The research also revealed underutilized terms in recent publications, such as the word ‘CAVE’.

Therefore, the discussion on the use of virtual environment technologies in collaborative design processes is evident in current research, and further investigation is needed regarding the relevance of the user's role. The literature review indicates that virtual technologies are tools employed both in the initial stages of defining requirements and in the final reviews of design solutions, indicating a trend in the use of these instruments that requires further in-depth studies, as they were not the focus of this paper.
REFERENCES


