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Original Article

Bibliometric Analysis of Augmented Reality in Software Development

Análisis Bibliométrico de Realidad Aumentada en el desarrollo de software

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Abstract

Introduction: augmented reality (AR) technologies provide immersive and enriched experiences. In the context of software development, these technologies can enhance interactivity, improve the visualization of software under development, and positively impact usability, productivity, and user experience.
Objective: the aim of this study is to conduct a bibliometric analysis of the application of augmented reality technologies in software development processes.
Methodology: the methodology involved searching for articles related to the topic in the Scopus search engine. The Bibliometrix tool was then applied to perform the bibliometric analysis.
Results: the results highlight the most relevant works based on an analysis of sources, authors, documents, and collaboration networks.
Conclusions: the bibliometric analysis provides a comprehensive view of research on the use of augmented reality in software development, highlighting key trends, influential authors, and emerging areas of interest.

Keywords: augmented reality; bibliometrics; software development; technology.

Resumen

Introducción: las tecnologías de realidad aumentada (RA) ofrecen experiencias inmersivas y enriquecidas. En el contexto del desarrollo de software, estas tecnologías pueden mejorar la interactividad, la visualización del software en desarrollo y, en general, impactar positivamente en la usabilidad, productividad y experiencia del usuario.
Objetivo: el objetivo de este trabajo es realizar un análisis bibliométrico sobre la aplicación de tecnologías de realidad aumentada en los procesos de desarrollo de software.
Metodología: la metodología consistió en realizar búsquedas de artículos relacionados con el tema en el motor de búsqueda Scopus. Posteriormente, se aplicó la herramienta Bibliometrix para llevar a cabo el análisis bibliométrico.
Resultados: los resultados revelan los trabajos más relevantes en el área, basados en un análisis de fuentes, autores, documentos y redes de colaboración.
Conclusiones: el análisis bibliométrico proporciona una visión integral de la investigación sobre el uso de la realidad aumentada en el desarrollo de software, destacando las principales tendencias, autores influyentes y áreas de interés emergentes.

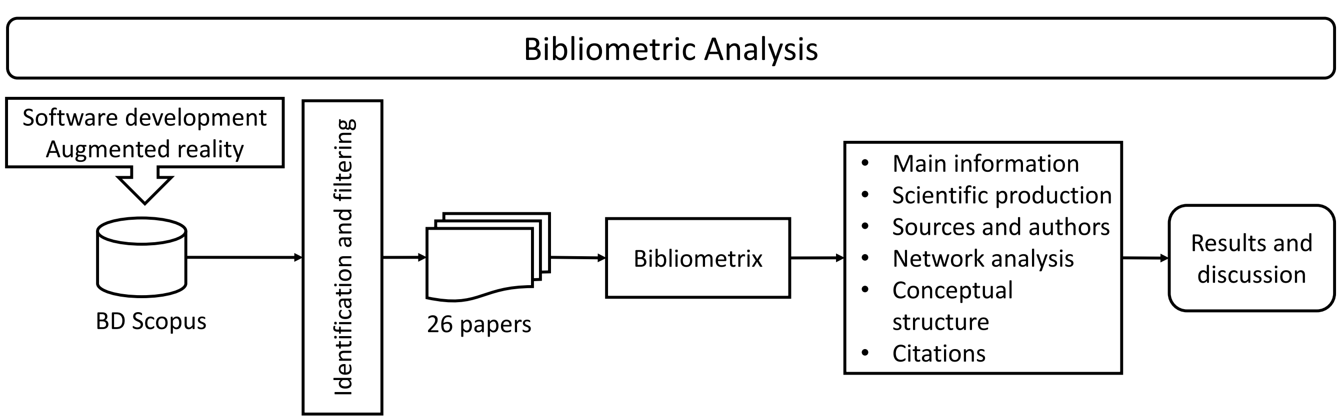
Palabras clave: bibliometría; Desarrollo de software; Realidad aumentada; Tecnología.

Contribution to the literature

Why was it conducted?
The study was conducted with the aim of bibliometrically analyzing the application of augmented reality technologies in the software development process. The aim was to evaluate scientific production in this area, identify collaborations between researchers, and determine emerging research areas. The study conducted responds to the need to improve the interactivity, visualization, and usability of software in development through immersive technologies such as augmented reality.

What were the most relevant results?
The most relevant results of the study show that the application of augmented reality technologies in software development is a growing area of research, but still in consolidation. 26 articles are identified in the Scopus database, indicating that the topic is relatively recent. The annual growth rate of publications is 13.99%, with most of the works published in conferences and not in specialized journals. No dominant bibliographic source was found, suggesting that the research is dispersed in different scientific communities.

What do these results contribute?
The results provide a global overview of the current state of research at the intersection of augmented reality and software development. The study identifies underexplored areas that may be opportunities for future research, highlights the recognition of key trends and devices, helping researchers and developers to focus on the most widely used technologies and perform an analysis of scientific collaboration, facilitating the identification of potential partnerships and work networks.



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Introduction

The complexity of software has increased enormously in the last decades, which has led to the development of new processes, technologies, roles and tools that facilitate and support the development and maintenance of software products. The process perspective allows defining a coherent set of policies, organizational structures, technologies, procedures and artifacts that are necessary to conceive, develop, install and maintain a software product (1).

Software processes can be divided into the following categories (2): primary processes (main processes oriented to software development, operation and maintenance); support processes (applied throughout the life cycle to support the primary processes); organizational processes (training, process measurement analysis, infrastructure management, process improvement and software life cycle model management); and cross-project processes (involving more than one software project in an organization).

The need for both developers and software project managers to use contextual information, in real time and during the software process, is more of a priority than ever (3). One of the technologies that can help meet this need is augmented reality.

Augmented reality (AR) research aims to develop technologies that enable real-time fusion of computer-generated digital content with the real world (4). AR can superimpose computer-generated information on real-world views, amplifying human perception and cognition in new and surprising ways (5). With AR, digital information appears to become part of the real world, at least from the user's perception (6). AR allows the user to see the real world and complement reality without completely immersing the user in a synthetic environment. AR technologies have three characteristics: combining the real and virtual world, having real-time interaction with the user, and being registered in a 3D space (7).

A taxonomy of devices used for the development of AR applications is organized in several levels (8). At a first level are "Wearable devices" (helmets, glasses and headsets) and "Non-portable devices", which are divided at a second level, into two subcategories: 1) stationary devices (TVs, PCs, games, etc.). and 2) mobile devices (cell phones, tablets, laptops, etc.).

The software process can use augmented reality technologies to increase user interactivity with the software being developed, improve the visualization of the software under development and impact aspects such as usability, productivity and user experience.

The introduction of AR into the software development process involves the incorporation of specific components and functionalities that leverage the sensory and visualization capabilities of mobile devices, such as cell phones and tablets, as well as specific devices such as smart glasses. This approach transforms the way users interact with the software being developed, enabling a more intuitive and contextualized interaction with the physical environment that may include workspaces, specific development tools, documents and/or models.

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Some studies have shown that immersion within 3D environments provides multiple cognitive and behavioral advantages (9, 10). AR as an immersive technology leverages the possibilities of natural human perception: spatial memory, motion, manipulation and feedback for a better understanding of the software product under development (11). In addition, engineering, introspection, and intelligence have been highlighted as three important dimensions of software engineering that can benefit from the use of these immersive technologies (12).

The objective of this paper is to perform a bibliometric analysis about the application of augmented reality technologies during the software development process. The bibliometric analysis will allow to evaluate the scientific production in this area of knowledge, identify collaborations between researchers and determine emerging research areas.

The article is organized as follows. The first section presents the introduction. The second section shows the methodology applied. The third section presents the results of the bibliometric analysis. The fourth section presents a discussion of the results. Finally, the conclusions of the study are presented.

Method

The methodology used to perform the bibliometric analysis is presented in Figure 1, with its different phases of identification, filtering, analysis and reporting.

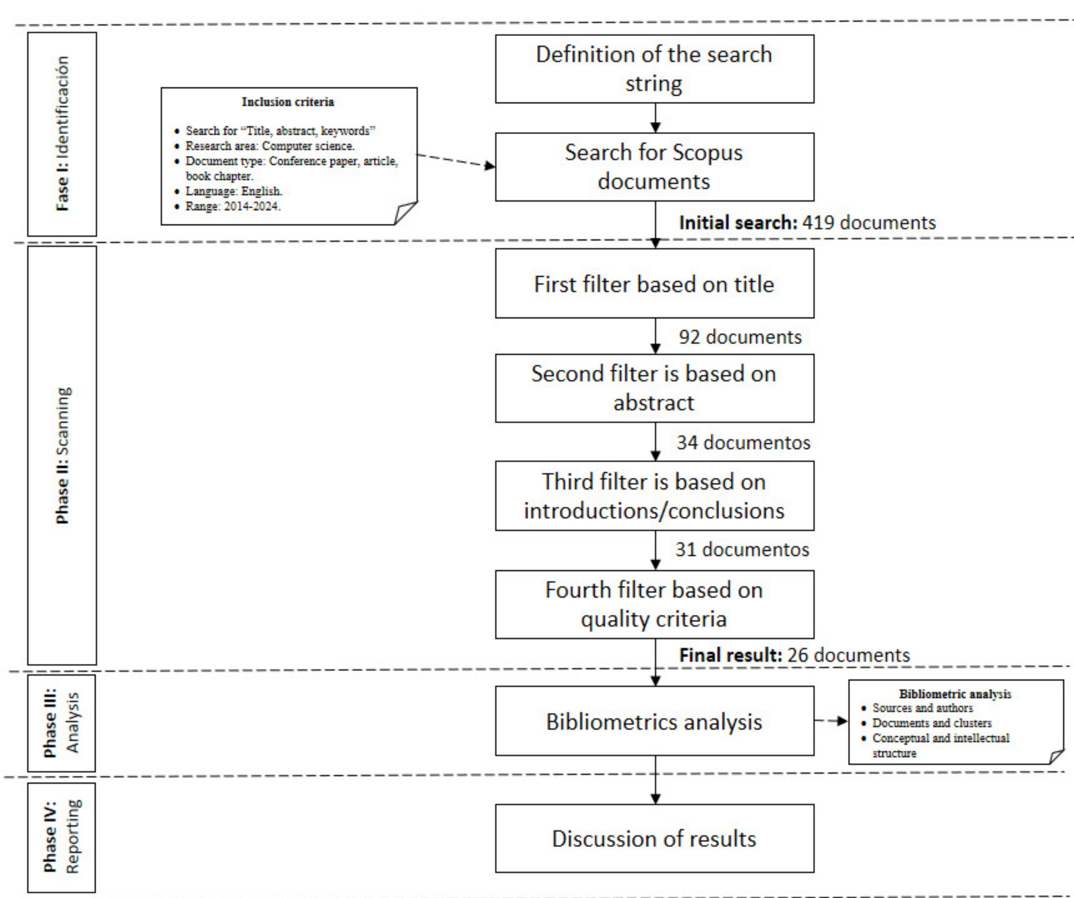

Figure 1. Overview of the methodology used during the bibliometric analysis.

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The work started with the definition of the following search string:

"augmented reality" AND ("software process" OR "software engineering" OR "software construction" OR "software analysis" OR "software design" OR "software testing" OR "software requirements")

The search string involves the term "augmented reality" together with the term "software process" and its different synonyms and specific phases of the process. This search string was then entered into the Scopus bibliographic engine with the following inclusion criteria:

- Search for "Title, abstract, keywords".
- Research area: Computer science.
- Type of document: conference paper, article, book chapter.
- Language: English.
- Interval: 2014-2024.

An initial result of 419 articles was obtained. Then, four filters were applied based on: document title, abstract, introduction/conclusions and, finally, a filter based on the following quality criteria:

- Is the article related to the research topic?
- Is the context of the research clear?
- Is the research methodology clearly described?
- Is the data collection process clearly explained?
- Is the AR application/technology well described?
- Are the results obtained clear?

The final amount obtained was 26 articles, which was exported to a csv file. This file was used as a data source in the Bibliometrix tool, which allowed generating a bibliometric analysis based on sources, authors, documents, groupings, conceptual structure and intellectual structure. The 26 final articles selected are presented in Table 1.

Table 1. Final articles used in the bibliometric analysis.

Year	Study	Year	Study
2016	(13, 14)	2020	(24, 25)
2017	(15)	2022	(26, 27, 28, 29, 30, 31)
2018	(12, 16, 17, 18)	2023	(32, 33, 34, 35, 36)
2019	(19, 20, 21, 22, 23)		

Results

After the final selection of 26 articles from the Scopus bibliographic database, they were analyzed using the Bibliometrix tool. Table 2 shows the general information on the data collected.

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Table 2. Overall results of the bibliometric analysis

Description	**Results**
1. Main Information	
Time interval	2014-2024
Sources	24
Documents	26
Annual growth rate %	13,99
Average age of documents	3,88
Average citations per document	6,692
References	659
2. Contents of the document	
Keywords	263
Author keywords	74
3. Authors	
Authors	71
Authors with single-authored documents	0
4. Collaboration of authors	
Single-authored documents	0
Co-authors per paper	3,42
International co-authorship %	19,23
5. Document types	
Journal articles	2
Conference paper	24

The total number of articles found was 26, which is a low number that shows that the research topic is relatively recent. The bibliographic sources were 24 for the 26 papers found. Therefore, there is no relevant source that focuses on the researched topic related to the application of augmented reality to the software development process. The growth rate is positive and high, and the average age of the documents is less than four years. The average citations per paper is 6,692, showing that the articles are not yet widely referenced: although the research topic is welcomed by the research community and is still under development.

The total number of authors was 71. The works were carried out in groups since none of them was carried out by a single author. In addition, the works are carried out with local groups with low international participation (19.23%). On average there are 3.41 co-authors per paper. The vast majority of the papers are conference articles (92.3%).

Figure 2 shows the production of articles by year. Articles were found from 2016 onwards. The production had a rise from 2017 to 2019, then a decline until 2021, then increasing and peaking in 2022.

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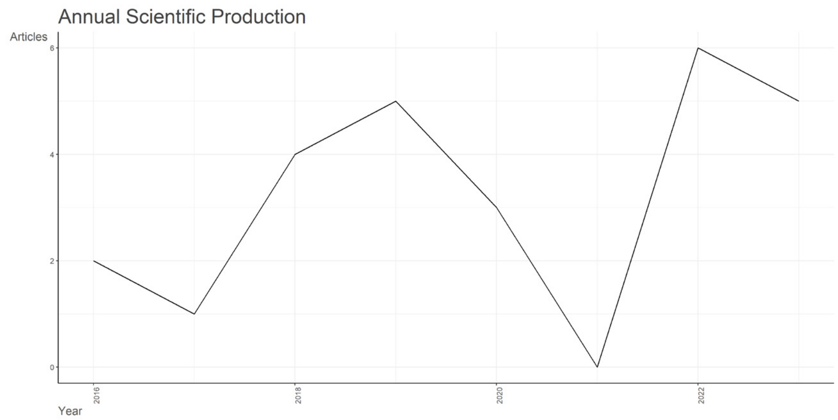

Figure 2. Annual scientific production.

The most relevant sources are shown in Figure 3. There is no relevant bibliographic source for the research topic. The two most referenced sources were: CCIS - Communications in Computing and Information Science, and ICSE - Proceedings of International Conference on Software Engineering. The first source is a series dedicated to the publication of computer science conference proceedings from the Springer publishing house (37). The second source is the world's leading software engineering conference (38) organized by ACM.

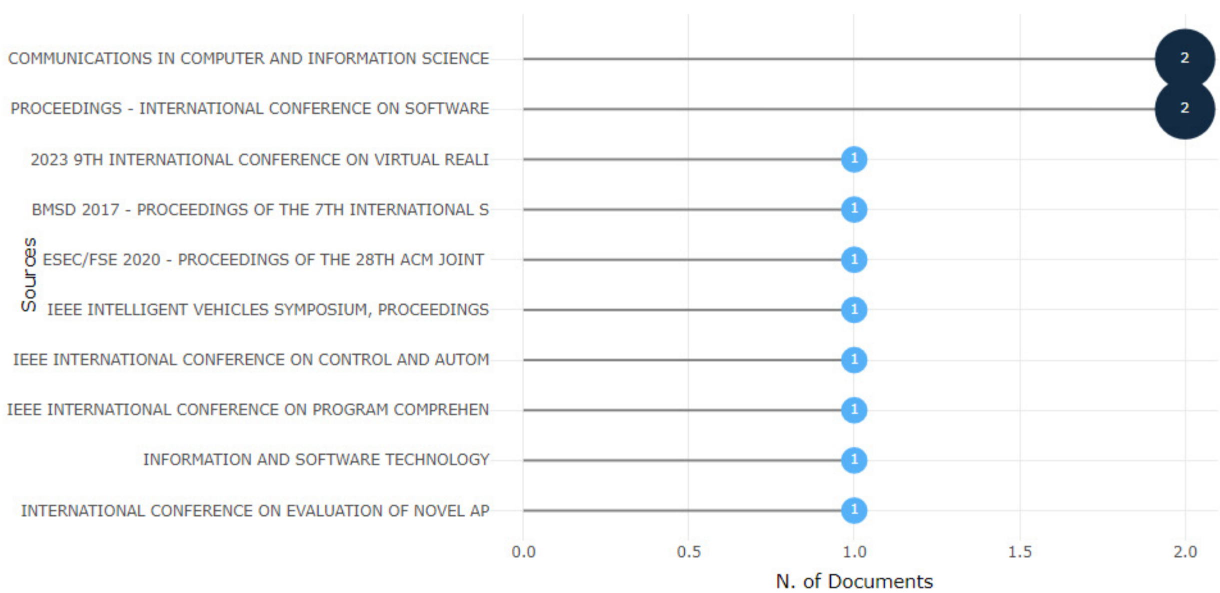

Figure 3. Most relevant sources

Scientific production by country is shown in Figure 4. The countries with the highest frequency of academic production in the area of research were India and Germany. They are followed in descending order by China, the United States and, to a lesser extent, Greece, Turkey, Australia, Brazil, France and Denmark.

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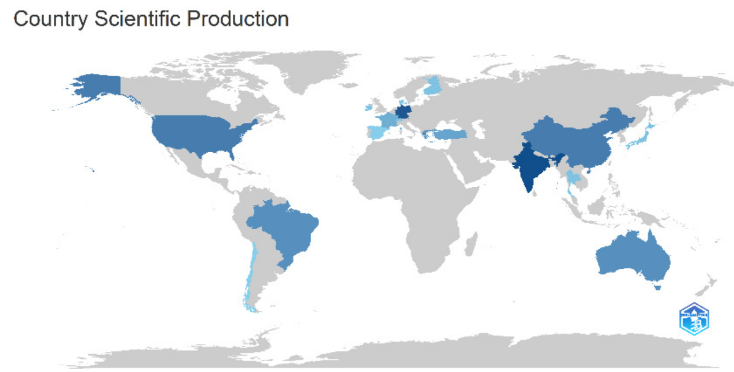

Figure 4. Scientific production by country.

The most relevant affiliations are presented in Figure 5. The University of Patras, in Greece, is the university with the highest number of affiliations of researchers in the subject under study with a total of seven researchers. This is followed by the National Taiwan University with five affiliations. This is followed by the universities of Monash (Australia) and Cankaya (Turkey) with four affiliations. The University of Kiel finishes with the highest number of affiliations with three. The University of Dublin (Ireland), the Federal University of ABC (Brazil), Tung-Fan Design University (Taiwan) and the University of Potsdam (Germany) have two affiliations. The remaining studies have only one affiliation.

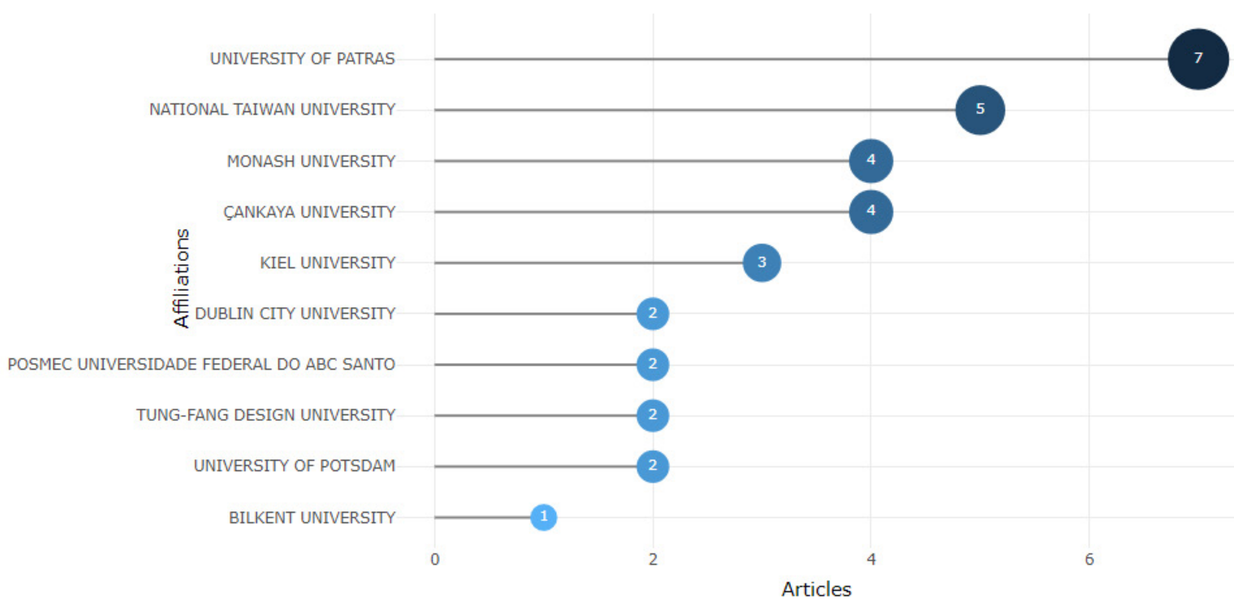

Figura 5. Afiliaciones más relevantes

Figure 6 shows the most cited papers globally. The most widely cited paper is (17) with 38 global citations. This study investigates software visualization. It is followed in order by (12), (26), (33) and (13) with 19, 15 and 14 and 10 citations, respectively. The remaining studies contain fewer than 10 references.

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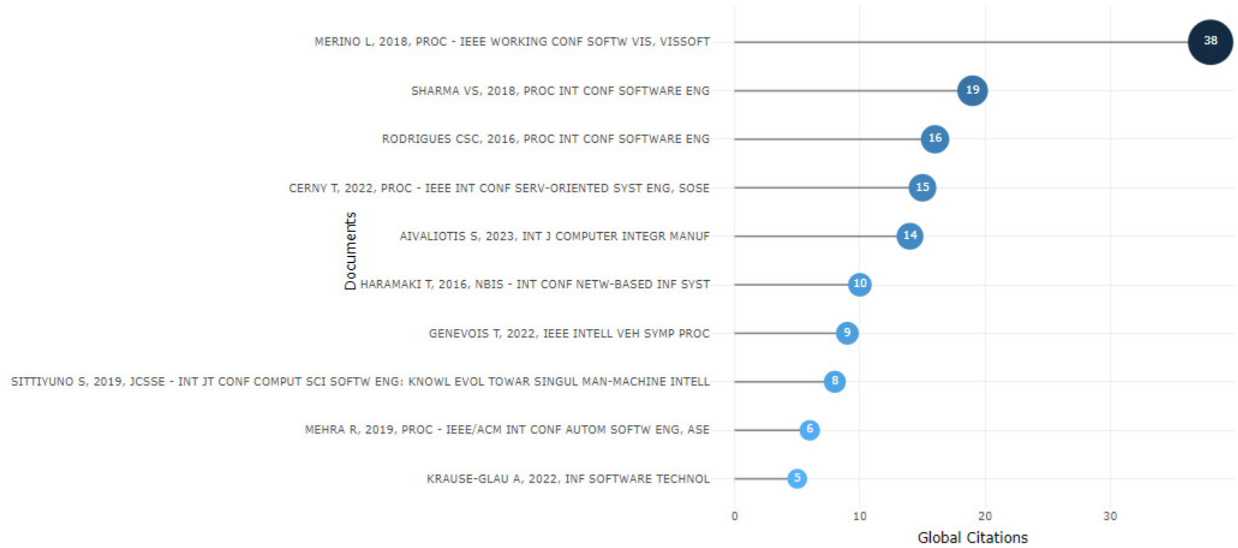

Figure 6. Most cited documents globally

Figure 7 shows the word cloud with the terms that appear most frequently in the studies collected. The most widely referenced words are “Augmented reality”, followed by “Software design”, “Software engineering”, “Visualization”, “Virtual reality” and “Application programs”. It stands out that augmented reality studies applied to the software development process are mainly oriented to the design stage, the presentation and visualization of information and application programs.

Figure 7. Word cloud.

A clustering map is presented in Figure 8. Five clusters were identified: a) Augmented reality, visualization and application software; b) Augmented reality, industrial robots and mixed reality; c) Accessibility, augmented reality and computer software; d) Augmented reality and Industry 4.0; and e) Augmented reality, data visualization and microservices.

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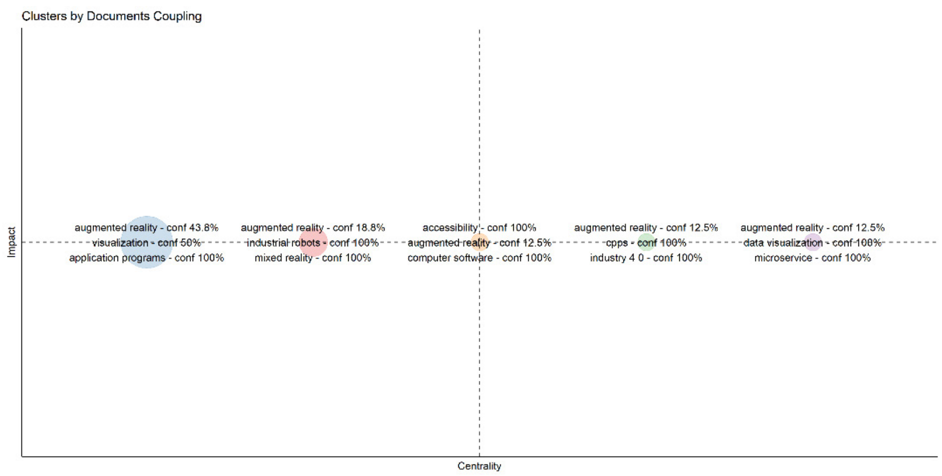

Figure 8. Clustering map.

All five clusters have the same level of impact. The first cluster "Augmented reality, visualization and application software" has the highest number of papers. Clusters 3 and 4 are the most developed topics: augmented reality, industry 4.0, data visualization and microservices.

Figure 9 presents the network of co-occurrences. The main and central cluster gathers terms related to augmented reality, establishing its application in specific stages of software development such as: design, testing, programming and concrete applications such as internet of things, robotics and information systems. The other groupings are related to the topics of processes, visualization, education and human-machine interaction. An isolated topic with low connection is industrial robots and their programming.

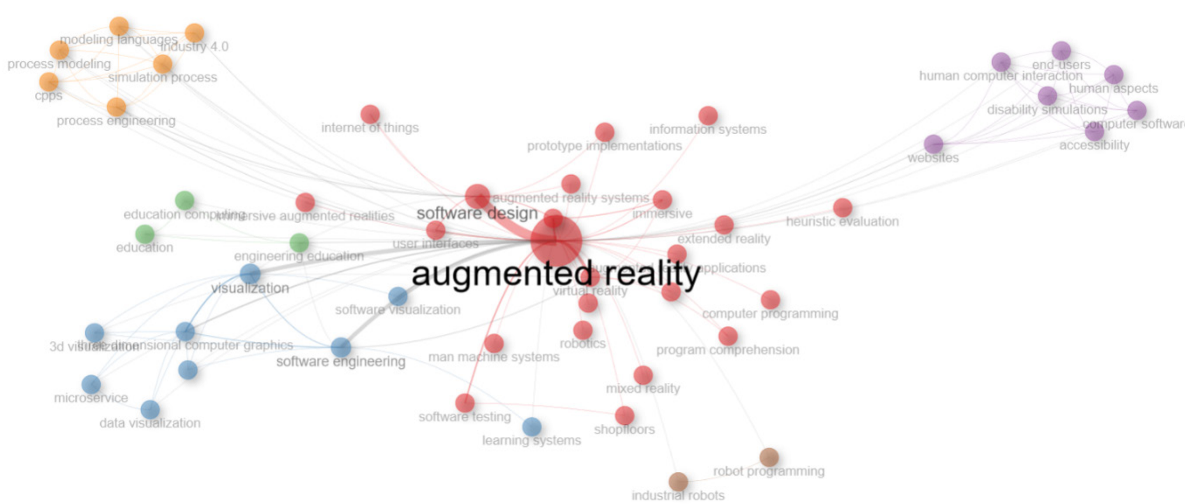

Figure 9. Network of co-occurrences

Figure 10 shows the thematic map of the studies investigated. The figure shows four zones:

Basic topics: their degree of relevance is high but not their degree of development. In this area are the augmented reality topics related to software engineering and, in particular, to the software design stage. These are the main topics on which the object of study of the research is based.

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Motor topics: their degree of relevance and degree of development are high. In this area are located the topics of education, visualization, computer graphics, software testing, human-machine interaction and robot programming.

Niche topics: their degree of development is high but not their degree of relevance. This area features topics related to websites, industry 4.0 and process engineering.

Emerging or declining topics: user interfaces, robotics and immersive augmented reality.

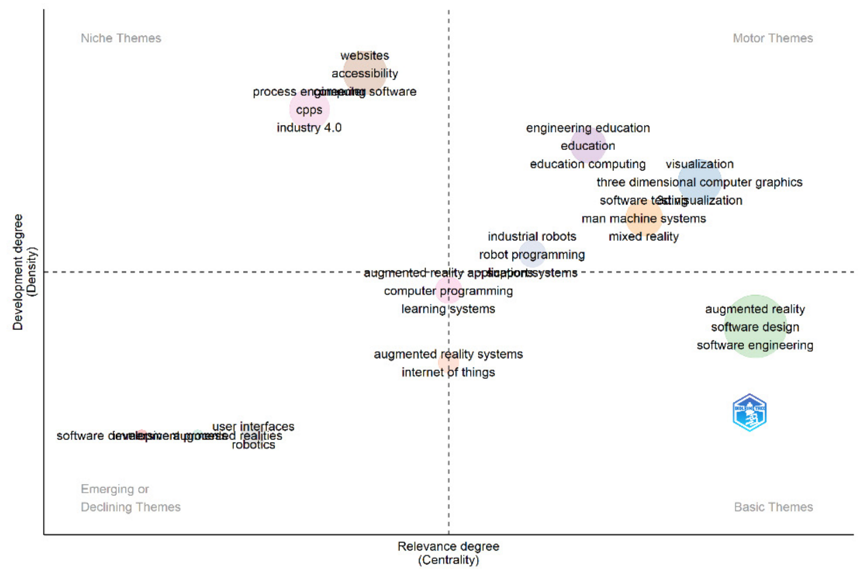

Figure 10. Thematic map.

At a medium level of development and relevance are augmented reality applications, learning systems and computer programming. With a medium degree of development and slightly less relevance are applications oriented to the Internet of Things.

The co-citations network is presented in Figure 11. The co-citations network is a graphical representation of the relationship between the studied documents based on the frequency with which they are cited to each other. Six clusters are presented but three of them have quite a lot of centrality due to the number of articles that are cited among them. The most referenced article is (39), followed by (40), (11) and (41).

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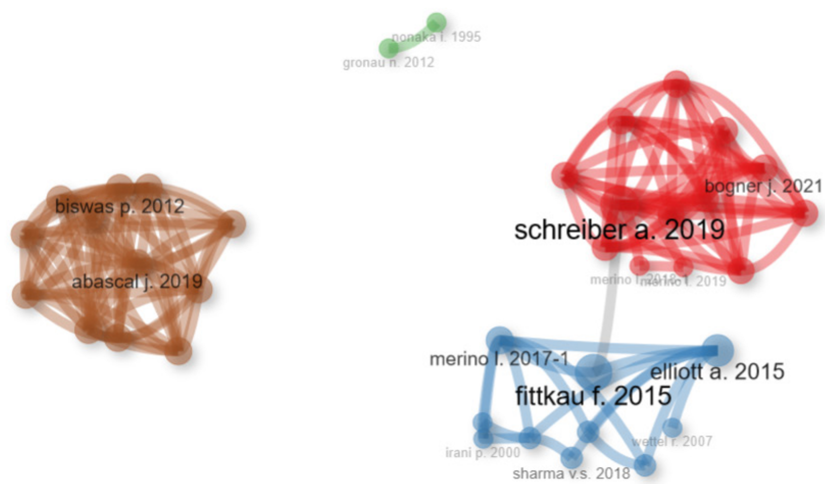

Figure 11. Network of co-citations.

The most referenced research topics are related to software visualization using various media such as graphs and arcs, and metaphors such as cities, buildings, islands, etc.

Table 3 presents the main AR devices used during software development.

Table 3. AR devices used in software development.

Devices	Studies
Helmets	Microsoft Hololens (12, 17, 20, 21, 25, 31, 33, 34, 39); Oculus (19)
Smartphones and tablets	(23, 28, 32, 36)
Smart glasses	Epson Moverio BT-300 (15); Nreal Light (31); HTC VIVE (22); others (16)
Projectors	Panasonic PT-VZ575N (29); Short focus (13)
Cameras	Monocular (27), web camera (14)
Unspecified	(18, 24, 26, 30, 35)

AR helmets: AR helmets are the most widely used devices. These helmets sit on the user's head and cover their eyes with high-resolution displays, providing an immersive experience. In particular, the Microsoft Hololens stand out. These devices are primarily used for immersive visualization; however, they are also available for real-time interaction (34), providing instructions (33), enabling intuitive interactions (20, 31, 34), expanding the worksite (20), inserting scenic elements or superimposed images (17, 21, 25), interacting hands-free with voice commands and head control (39), and projecting contextual information and relevant notifications (12). Only (19) uses a different helmet, Oculus, allowing interaction with objects and immersive experiences.

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Smartphones and tablets: Traditional devices such as mobile phones and tablets are widely used to implement AR systems due to their popularity and widespread use. Their use allows for more accessible and practical AR integration in educational environments (28). Mobile devices' screen size can impact systems comprehension (23, 32). However, some studies presented combinations: in (36) a smartphone acts as a client, responsible for capturing image data from AR glasses and sending them to the server, which is implemented on a personal computer to process the image data.

Smart glasses: Smart glasses were also widely used, although no specific brand had the highest use rate. These glasses are worn like lenses and provide visual information on the screen, allowing hands-free interactions and data visualization. Smart glasses were generally used for contextual information display (31), enhanced interaction (15), intuitive interaction (31), transparent display (15), and high accuracy in positioning virtual objects in three-dimensional space (22) and interaction with 3D models (16).

Other devices: Devices that were not as widely used were: projectors (13, 29), used to present spatially supporting information; cameras (14, 27), intended for optical tracking, image recognition, gesture recognition and body tracking; and sensors (27), to generate scene visualization.

Discussion

Software development can use these types of technologies to help successfully develop software product building activities during the execution of software development projects.

The bibliometric study found that publications are mainly at conferences, the highest frequency of publications is in India and Germany, and the most relevant affiliations are in Asia and Europe.

The most cited papers globally are oriented to the topics of: software visualization, immersive project management, robot programming, and computer programming education.

In the topic of visualization, studies focus on: presenting software in graphical form using graphs (12, 20, 21), visualizing aspects such as software architecture (25) or specific architectures such as microservices (32).

In the topic of project management, works related to virtual meetings and remote team management are included (25, 36).

In the topic of robot programming, studies are aimed at facilitating the programming of industrial robots (29, 33), and establishing robot arm paths or robotic trajectories to meet specific objectives (34).

Finally, in the area of computer programming education, the papers present applications developed to learn object-oriented programming (19) and engineering education (13, 18).

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Other topics addressed not so extensively, but equally important, are: software documentation (24), software validation (27), process modeling (15, 16), UML modeling (14), and web site usability (30, 31).

No articles were found oriented to investigate aspects related to other primary software processes such as requirements analysis and software testing. Despite the fact that software maintenance is one of the fundamental activities within the software development life cycle, the bibliometric analysis did not identify specific studies that addressed the application of augmented reality in this process. One possible explanation for this absence is that the search string used did not explicitly include the term “software maintenance”. This could have limited the retrieval of relevant studies in this field. However, the low representation of maintenance-related research in the set of articles analysed also suggests that, in general terms, the scientific community has focused augmented reality on previous phases of development, such as design, visualisation and programming. This leaves open an opportunity for future research exploring how augmented reality could improve specific maintenance tasks. These tasks include understanding legacy code, detecting and correcting defects, restructuring software and visually documenting system changes.

Collaborative networks exist, but are scarce, demonstrating that the topic is relevant but still lacks a consolidation of research networks with events, publications and concrete books in this research area.

The results indicate that AR helmets, particularly Microsoft HoloLens, are the most widely used devices in software development. This is due to their immersive capabilities and hands-free interaction. These helmets enable real-time visualization, intuitive controls, and contextual information projection, making them highly effective for complex AR tasks. The presence of Oculus in a single study suggests that alternative devices may have potential but are less commonly adopted.

Smartphones, tablets, and smart glasses also play a significant role in AR development. Mobile devices are favored for accessibility, though screen size may impact usability. Some studies explored hybrid approaches, using smartphones as clients for AR glasses, pointing to an emerging trend in distributed AR processing. Meanwhile, smart glasses provide hands-free interactions and precise 3D visualization, though no single brand dominates the market, highlighting a fragmented landscape.

Other AR devices, such as projectors, cameras, and sensors, are less frequently used but serve essential supporting roles. These technologies assist with spatial visualization, gesture recognition, and body tracking, complementing primary AR interfaces. Their lower adoption rate suggests they function more as auxiliary tools rather than core development platforms. However, further integration with mainstream AR devices could enhance their utility.

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Conclusions

Software development is an area that requires extensive knowledge, not only of the business domain, but of technologies, processes and people. In the technology domain, augmented reality can offer advantages and benefits that facilitate the successful execution of the various tasks involved in building a software product.

This study conducted a bibliometric analysis of papers about research oriented to the application of augmented reality to facilitate the software development process. The topic investigated is quite promising since, although studies addressing the subject were found, there are still many efforts to consolidate this area of research.

Current research niches are the visualization of code structure, which facilitates code analysis tasks and helps in learning programming concepts; the programming of industrial robots supporting the establishment, execution and validation of robotic routes and trajectories; and project management from a perspective of virtual meetings and remote work management.

The emerging topics in this area are oriented to cover in a more global way the development process, including the activities of the primary processes of software development: analysis, design, coding, testing and maintenance, as well as specific applications in specific domains where industry 4.0, web development, accessibility aspects and user interaction stand out.

CRediT authorship contribution statement

Conceptualization - Ideas, Data Curation, Formal analysis, Investigation, Methodology, Project Management, Resources, Software, Supervision, Validation, Visualization - Preparation, Writing - original draft - Preparation, Writing - revision and editing - Preparation: Leonardo Bermon Angarita

Financing: does not declare

Conflict of interest: does not declare.

Etics Implications: does not declare.

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