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Global Research Trends in Augmented Reality: Scientometric Mapping Based On Wos Database

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Abstract

Purpose: This study seeks to conduct a Bibliometric analysis of publications pertaining to "Augmented Reality." In the contemporary era dominated by Information Technology, Augmented Reality (A.R.) has emerged as an immersive data source, blending authentic and digital images to enhance knowledge development. As a result, there is a significant research focus on Augmented Reality to uncover its potential in advancing knowledge.

Methodology: The research paper examines and underscores bibliographic data from articles in the Web of Science (WoS) using a pertinent search query. The study investigates the chronological progression of research publications, highly cited works, countries contributing significantly, leading journals, prolific authors and institutions, co-authorship networks among authors and countries, and an analysis of keywords. Open-source tools like VOSviewer, Biblioshiny, and Google Sheets were employed for conducting the analysis

Findings: The study reveals that a maximum number of publications on research in “Augmented Reality” are in the form of articles. The global participation of 103 countries, with the USA, China, and South Korea leading in publications, emphasizes the widespread engagement in AR research. The analysis of journals indicates the centrality of "IEEE Transactions on Visualization and Computer Graphics" in disseminating AR research. This journal's high productivity and citation count make it a crucial platform for AR scholars. Examining institutions, the dominance of the University of Central Florida, National University of Singapore, and Stanford University, with high publication shares, reflects their pivotal role in shaping AR research. The concentration of output in a few key institutions suggests their leadership and expertise in the field

Originality/ Value: The study's originality and value lie in providing a precise idea of the work done globally, establishing a network of co-authorship, and offering insights into the impact of publications. The detailed analysis presented in the study serves as a valuable resource for researchers and stakeholders, aiding them in obtaining rigorous bibliographic knowledge and guiding future research and development (R&D) activities.

Keywords: Augmented Reality, Bibliometric Analysis, Web of Science, VOSviewer, Biblioshiny, Citation Analysis.

Introduction

Augmented Reality (AR), a transformative technology that overlays digital information onto the physical world, has witnessed exponential growth in both technological advancements and research interest. As AR continues to permeate various sectors, including education, healthcare, and industry,

understanding the trajectory of research in this field becomes paramount. The ever-evolving landscape of technology, economy, education, and sociology continually reshapes the fabric of human society. Technological advancements, in particular, play a pivotal role in driving change across various domains, with each sector influencing and reinforcing the others. Among the notable innovations in today's technological realm, augmented reality (AR) stands out as a transformative force (**Altinpulluk, 2018**).According to **Czerkawski and Berti (2021**), augmented reality holds significant potential for educators and students in the field of education, positioning itself as an emerging and innovative technology with transformative capabilities. As we delve into the literature, the conceptual definitions of AR technology reveal a multifaceted understanding, with various perspectives contributing to the richness of its conceptualization.Augmented reality, at its core, involves the integration of digital information into the physical world, providing users with an enhanced and interactive experience. The diverse angles from which scholars approach the concept highlight its versatility and broad applicability. From enhancing educational experiences to impacting various sectors, AR's potential seems boundless.

Augmented Reality (AR) stands at the forefront of technological innovation, offering interactive experiences that bridge the gap between the analog, physical, or real-world environments and the virtual realm. Unlike virtual reality, which immerses users in entirely digital or artificial environments, AR enriches the existing physical surroundings with virtual elements, creating a blended and enhanced experience **(Hollerer and Feiner, 2004).Yuen, Yaoyuneyong, and Johnson (2011)** further refine the definition of AR, describing it as a technology that allows users to engage in activities within the real-world environment while interacting with digital content and applications generated through computer processes, all contingent upon specific locations. This definition emphasizes the seamless integration of digital overlays onto the physical world, enriching users' perception and interaction with their surroundings.In essence, AR serves as a technological bridge between the tangible and the virtual, enhancing the real-world experience by overlaying it with digital information. The dynamic nature of AR enables users to engage with computer-generated content in real-time, fostering an interactive and immersive encounter with their environment.**Richey (2018)** adds another layer to the understanding of AR by describing it as a technology that completes the real world with digital information through a visual interface. This completion of reality occurs through the integration of digital elements, such as graphics, text, or multimedia, into the user's visual field. The result is a composite view that combines the physical and the virtual, offering a richer and more contextualized experience. Augmented Reality (AR) represents a convergence of real-world and digital images, creating an immersive data source that enhances and solidifies knowledge. This transformative technology is defined as the synchronous view of a real setting, either directly or indirectly, augmented by virtual computer-enhanced technologies **(Carmigniani and Furht, 2011).** AR unfolds across three dimensions, each contributing to its dynamic and interactive nature.

Firstly, AR possesses the capability to seamlessly combine both virtual and real elements within the environment. This integration allows users to experience a blended reality where digital overlays enhance their perception of the physical world. Whether it's layering information onto historical landmarks or projecting virtual characters into real spaces, AR introduces a new layer of engagement. **Secondly**, AR facilitates real-time communication between the user and the augmented environment. This dynamic interaction enables instant responsiveness to changes in the physical space, creating an adaptive and fluid experience. This real-time element is crucial for the effectiveness of AR applications, ensuring that the digital enhancements align seamlessly with the user's context. **Thirdly,** AR offers

precise applications to both real and virtual instances. The technology goes beyond mere visual augmentation, allowing users to interact meaningfully with the augmented elements. This precise application enhances the utility of AR across various fields, from education and healthcare to gaming and industrial training. Importantly, AR preserves the integrity of the real environment. The augmentation is not intrusive but rather establishes real-time communication between the physical world and virtual instances **(Erbas and Demirer, 2014**). This coexistence ensures that the user's engagement remains grounded in reality while benefiting from the enhancements offered by the digital overlays.American inventor Louis Rosenberg significantly contributed to the development of AR by creating virtual fixtures for the US Airforce. These fixtures marked a pioneering step in the application of AR, particularly in military and industrial contexts. The concept of virtual fixtures involves overlaying digital information onto the physical world, providing users with additional contextual data or interactive elements.

In recent years, AR technology has emerged in various scientific fields such as science, mathematics, chemistry, and others because it can increase learning interactions **[Yusof c s 2020].** The combination of virtual items with reality offers real-time interaction through the presentation of 3D objects, which is an essential element of the technology of reality itself and can offer a distinct learning experience. In different research, further benefits of technology for greater reality are emphasized, such as increased student involvement, self-directed learning [**Aric F 2019**], self-guided for virtual tour [8], motivation in learning geometry **[A. Kondlo et al. 2020** and others. Increased media learning reality technology also promotes an approach to learning through constructive and genuine learning, so that students become more engaged in a learning environment.

Among all the emerging technologies, there is one that is gaining ground in different areas of life, such as gaming, travel, leisure, business, medicine, and education, and that is augmented reality (AR) (Yakubova et al., 2021). For Berryman (2012), one of the first steps in the field of AR was taken by Morton Heiling, who in 1962 built the Sensorama, a prototype of what he saw as an immersive cinematic experience and the device received a patent. Later, in 1968, Sutherland built what is recognised as the first AR system, using his head-mounted display (HMD) (Vaughan-Nichols, 2009). In 1995, Caudell designed a digital HMD to help workers wire aircraft by showing schematics of an aircraft in the factory (Vaughan-Nichols, 2009). After that, Strickland (1996) conducted pioneering research using an HMD device, similar to the one designed by Sutherland in 1968, to work on street crossing skills for autistic students. Escobedo et al. (2012) also pioneered work in AR by using a mobile assistance application called Mobile Social Compass (MOSOCO) to help autistic students. This application used AR and other visual supports to facilitate students to practice their social skills in real-world conditions by guiding them through the six basic social skills of the social compass curriculum. At the end of the 1990s, the first definition of AR emerged, which is associated with the creation of an educational game (Carmigniani et al., 2011). Also, in later years, Google's AR glasses have been used so that autistic students can practice emotion recognition in the classroom (Sahin et al., 2018).

Literature Review

Numerous research works have delved into applications of Augmented Reality (A.R.) across various domains. However, only a limited number of studies have been identified that specifically focus on an extensive bibliometric exploration of A.R. research. This review examines relevant journal articles that

concentrate on the bibliometric analysis of A.R. applications in education, science education, medicine, sports and physical education, and knowledge building.

To chronologically investigate research on Virtual Reality (V.R.) and A.R., Cipresso et al. (2018) performed a cluster analysis on Web of Science (WoS) indexed publications. The study primarily focused on network analysis and centrality indices concerning elements such as country, author, institutions, and keywords. The literature analysis, employing network and cluster approaches, provided a panoramic view of the alterations and evolution in research since its inception.

Arici et al. (2019) conducted a bibliometric study examining research trends in the application of A.R. in science education, utilizing WoS data. The study identified keywords commonly used in abstracts, such as education, knowledge, science education, experiment, and effectiveness, and incorporated findings from content analysis.

Karakus et al. (2019) evaluated available literature on A.R. application in education using bibliometric parameters, focusing on bibliographic coupling of countries, institutions, journals, publications, authors, and co-occurrence of author keywords. Bibliographic visualization techniques, including VOSviewer, were employed to depict publication specifications, addressing research trends and productivity concepts in A.R. education.

Moreno et al. (2020) explored the emergence of A.R. in physical education through bibliometric parameters. The study utilized WoS data, applying quantitative and qualitative parameters to analyze research output. VOSviewer was employed for network visualization, density, and overlay. The study also involved the calculation of quality indexes and co-authoring and co-keyword analyses.

Bardhan's (2020) unique study investigated the application of A.R. and V.R. in commerce (retail) using bibliometric methods and tools. The study, based solely on WoS data, examined both quantitative and qualitative indexes, with a specific focus on keyword analysis.

Various studies have explored A.R.'s application in knowledge building. Cadavieco et al. (2020) conducted a comprehensive investigation, employing quantitative analysis to determine the number of documents across different forms and subject areas. Qualitative analysis assessed educational potentials, opposing views, and A.R. app analyses.

Yeung et al. (2021) analyzed scientific publications on V.R. and A.R. applications in medicine using WoS data and tools like VOSviewer and Biblioshiny. The study investigated quantitative bibliometric parameters, popular research topics, key authors, institutions, countries, journals, and thematic exploration of medical conditions.

Avila-Garzon et al. (2021) analyzed A.R. in education from 1995 to 2020 using Scopus data. The study employed Bibliometrix and VOSviewer to examine author contributions, content, citations, and keywords, providing insights into the research landscape. Virtual Reality (VR) and Augmented Reality (AR) are the two sides of the same coin of emerging technologies sharing some of characteristics mostly but also they have some distinguished features. According to Maunder (2018) website, integration of VR and AR in education market is expected to reach 19.6 billion with annual growth rate equals 16.2% by 2023.According to Krüger et al. (2019), Kim et al. (2018) and Javornik (2016), Virtual reality main characteristics represented in imaginary space, immersion in virtual space, sensory feedback and interactivity while augmented reality includes contextuality, which means combination of virtual and actual world simultaneously, interactivity at the same time and spatiality in the 3D world. These features enabled virtual and augmented reality in learning and created new significant educational approaches during outbreak of Covid-19 pandemic. Recently, virtual and augmented reality have gained increasing

popularity due to a quantum leap in the development of VR and AR technologies (Beck, 2019; Chen et al., 2017; Gudoniene & Rutkauskiene, 2019).

Methodology

The study follows the established procedures of Bibliometric evaluation to analyze the global trend of research publications in AR The WoS , is a popular and most prominent abstract and citation database in terms of content, including bibliographic and citation information for all traditional, transdisciplinary and interdisciplinary areas. WoS is considered to be the best database for investigating the goal of this study. Because of its extensive and updated coverage, data from this source is regarded as the most reliable for a bibliometric investigation to expect precise and accurate results. Moreover, numerous studies have been done using the data from this database. The search strategy was developed by using the following key terms in the "ALL" field of the database: "Augmented Reality" OR "Mixed Reality" OR "virtual reality" initially. The total number of documents retrieved using the search strategy was 3999 The refined results were extracted in an MS-Excel spreadsheet for further analysis using Biblioshiny (Aria and Cuccurullo, 2017), VOSviewer (Van Eck and Waltman, 2010 which facilitate analysis of data for quantitative indexes, network visualization and mapping, respectively.

Objectives : This study is governed by the following objectives:

1. What is the chronological growth pattern (revealing the number of publications) of publications in augmented reality indexed in WoS?
2. Which of the articles on augmented reality were highly cited during the period of study?
3. Which countries produced the highest publications in augmented reality?
4. Which are the productive journals?
5. Which were the most productive authors and research institutions?

Data analysis and network visualization

TABLE I. MAIN DATASET INFORMATION

Description	Results
Timespan	2009:2023
Documents	3999
Annual Growth Rate %	18.92
Document Average Age	3.53
Average citations per doc	19.18
References	130150
Keywords Plus (ID)	4061
Author's Keywords (DE)	9544
Authors	13717
Authors of single-authored docs	198
Single-authored docs	210
Co-Authors per Doc	4.65
International co-authorships %	25.21
article	3657

article; book chapter	14
article; early access	181
article; proceedings paper	144
article; retracted publication	3

In the period from 2009 to 2023, an extensive and dynamic landscape of research in the domain of Augmented Reality has unfolded, as reflected in the collected data. Over these years, a total of 3,999 documents were published, as shown in Table 1 showing a remarkable annual growth rate of 18.92%, indicative of the growing significance and relevance of this field. The relatively low average document age of 3.53 years suggests that researchers are actively producing fresh content, keeping the knowledge base up to date.One of the most noteworthy findings is the considerable impact and engagement in this research area. The average citations per document stand at 19.18, indicating the influence of the research within the scientific community. With a staggering 13,150 references cited across these documents, it is evident that Augmented Reality research is deeply rooted in the broader body of scientific literature.Keyword analysis reveals the diversity and complexity of the research landscape, with 4,061 Keywords Plus (ID) and 9,544 Author's Keywords (DE). This extensive terminology highlights the multifaceted nature of Augmented Reality and the multitude of topics being explored.The collaborative nature of this research is apparent with 13,717 authors contributing to these documents, out of which 198 authored single-authored documents, emphasizing the significance of individual contributions. A substantial number of co-authors per document (4.65) signifies the importance of teamwork and collaboration in advancing Augmented Reality research. International collaboration plays a substantial role, with 25.21% of documents involving co-authorship between researchers from different countries. This indicates that Augmented Reality is a globally connected research field, benefiting from a diverse range of perspectives and expertise. The majority of the documents are articles (3,657), with some also taking the form of book chapters, early access releases, proceedings papers, and a small number of retracted publications. This diversity in document types demonstrates the wide-ranging avenues of exploration within the field.

Figure 1. Annual scientific production

The data provided, showcasing the number of articles on augmented reality (AR) published each year, reflects a compelling trend in the growth and increasing significance of AR research. Over the past decade, there has been a remarkable surge in the volume of AR-related publications, indicating a burgeoning interest and investment in this field.The most recent years, particularly 2023, 2022, and 2021, stand out with the highest number of articles—713, 710, and 624, respectively. This suggests a current peak in research activity, possibly driven by advancements in AR technologies, increased applications across various domains, and a growing recognition of its potential impact.The upward trajectory is evident when examining the progression from 2009 to 2023, with a noticeable acceleration in research output starting around 2016. This period coincides with the rapid evolution of AR technologies and their integration into diverse sectors, including education, healthcare, and industry. The consistent rise in the number of articles underscores the sustained interest and commitment of the research community to explore, innovate, and contribute to the expanding domain of augmented reality. It signifies the maturation of AR as a research area and hints at the continuous evolution and relevance of AR technologies in shaping the future of human-computer interaction and immersive experiences. Researchers, practitioners, and stakeholders in AR can draw valuable insights from this trend to guide their contributions and stay abreast of the dynamic developments in the field.

Top 10 highly productive institution in research on "augmented reality

In total, 392 institutions have been found to have participated unevenly in global research on "Augmented Reality." The productivity of the top 10 institutions varied from 10 to 13 publications per institution,. Again, the organization wise distribution of global research output is highly skewed. For example, the top 10 institutions together contributed 40% (2100) global publication shares. The scientometric profile of the top 10 extremely fruitful institutions is depicted in Table 2. Further analysis based on publication, TP and TC reveals that 10 organizations, namely, University cent Florida, National University Singapore, and Stanford University are the most productive institutes. The data suggests that Augmented Reality research is dominated by a select group of institutions, with the University of Central Florida, National University of Singapore, and Stanford University being among the most influential contributors to the field. This concentration of research output in a few key institutions may indicate their leadership and expertise in AR research. Researchers, policymakers, and industry stakeholders interested in AR should take note of these leading institutions when seeking collaborations or insights in this rapidly evolving field.

Institutes	TP	TC
University cent Florida	52	1885
National University Singapore	50	2203
Stanford University	47	940
Shanghai Jiaotong university	42	1051
Tech Univ.Munich	41	716
Univ. Politeon valonica	34	1268
Chinese acd. University	32	791
University Valencia	30	708
John hopkins university	29	559
Zehejiang university	29	350

Table 2.(TP=Total publications, TC=Total Citation

Top 10 most productive countries global publication output, citation impact in "augmented reality" research.

In total, 103 countries participated in global research on "Augmented Reality," Table 3 summarizes the publication and citation effect of the top 10 countries in A.R. research. The table clearly shows that the USA dominates with almost 939 publications. The countries like China and South Korea are taking good shares in the TP following the USA numbering 629 and 346. he global landscape of Augmented Reality (AR) research involves a diverse participation of countries, with a total of 103 nations contributing to the body of knowledge in this field. Table 3 provides valuable insights into the publication and citation impact of the top 10 countries engaged in AR research.The most striking observation is the dominant role played by the United States. With almost 939 publications, the USA emerges as a formidable leader in AR research. This extensive research output underscores the country's significant commitment to advancing AR technology and applications.Furthermore, countries such as China and South Korea are noteworthy for their substantial contributions, with 629 and 346 publications, respectively. These nations have firmly established themselves as key players in AR research, with a growing presence in the field.The data presented in Table 3 underscores the global nature of AR research, with multiple countries actively engaged. However, it also highlights the clear leadership of the USA, while China and South Korea are emerging as influential contributors. This diverse international collaboration enriches the AR research landscape and promises exciting developments in the field in the future. Researchers, policymakers, and industry stakeholders should take note of these trends to foster further collaboration and innovation in the world of Augmented Reality.

Country	TP	TC	TLS
USA	939	25428	5982
China	629	8719	3716
South Korea	346	5591	2046
Germany	313	6549	2622
Spain	291	6920	2296
England	276	7393	2314
Italy	171	5882	1784
Australia	185	5630	1622
Taiwan	184	3276	1285
Canada	151	2812	1262

Table 3.(TP=Total publications, TC=Total Citation ,TLS=Total link strength)

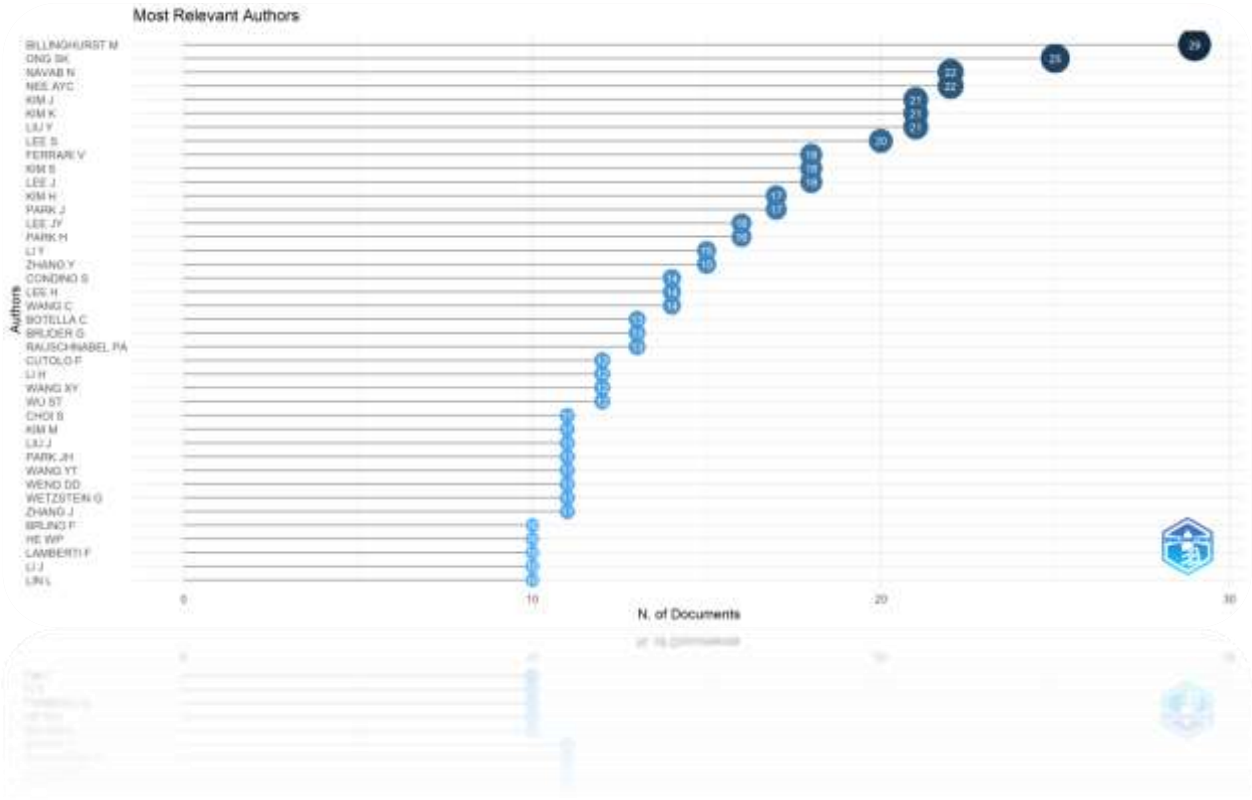

Figure 2. profile of top 10 extremely fruitful authors in research on "augmented reality

In all, 13717 authors have been found to have unevenly participated in global research on "Augmented Reality." BILLINGHURST M is most productive author with 29 articles followed by ONG SK . The landscape of global research on Augmented Reality (AR) is marked by a significant number of contributing authors, totaling 13,717 individuals. Among these authors, two prominent figures stand out in terms of their exceptional productivity in the field. Notably, M. Billinghurst has demonstrated remarkable dedication to AR research, with a staggering 29 published articles to their name. Following closely, Ong S.K. has also made a substantial contribution, further enriching the body of knowledge with their work.

Table4. Top 9 highly cited papers in research on "augmented reality

The most influential research publications are displayed in Table 4 The total number of citations to a research publication is the most important factor in global citation analysis, whereas the number of citations inside a specific bibliometric dataset is the most important factor in local citation analysis. The Virtual reality:Applications and implications for tourism published in the journal of Tourism Management(Impact factor 12.7) With citation score of 838 followed by Affordances and Limitations of Immersive Participatory Augmented Reality Simulations for Teaching and Learning published in the journal of Science Education and Technology(Impact factor 4.4) with 736 citations . These publications have garnered substantial attention and citations, indicating their significant impact in the field. Table 4 underscore the substantial influence and recognition of these research publications within the global AR and VR research community. The high citation scores indicate that they have been widely referenced and have played a pivotal role in shaping and advancing the understanding of AR and VR technologies

and their applications. Researchers, scholars, and practitioners in the field would likely find these publications to be valuable resources for their work, given their demonstrated impact and relevance.

Table4. Top 9 highly cited papers in research on "augmented reality"

Article title	Authors	Source title	TC	IF	DOI
Affordances and Limitations of Immersive Participatory Augmented Reality Simulations for Teaching and Learning	Matt Dunleavy, Chris Dede & Rebecca Mitchell	journal of Science Education and Technology	736	4.4	10.1007/s10956-008-9119-1
Virtual reality:Applications and implications for tourism	Daniel A. Guttentag	Tourism Management	838	12.7	10.1016/j.tourman.2009.07.003
Skin-integrated wireless haptic interfaces for virtual and augmented reality	Xinge Yu et.al	Nature	536	64	10.1038/s41586-019-1687-0
Holographic near-eye displays for virtual and augmented reality	AndrewMaimone, Andreas Georgiou and Joel S. Kollin	ACM Transactions on Graphics	454	6.2	10.1145/3072959.3073624
Augmented reality applications in design and manufacturing	A.Y.C. Nee et.al	CIRP Annals	585	4.1	10.1016/j.cirp.2012.05.010
The effectiveness of virtual and augmented reality in health sciences and medical anatomy	Christian Moro et.al	Anatomical Sciences Education	425	5.9	**https://doi.org/10.1002/ase.1696**
Toward Interconnected Virtual Reality: Opportunities, Challenges, and	Ejder Bastug et.al.	IEEE Communications Magazine	375	11.2	10.1109/MCOM.2017.1601089

Enablers					
Pose Estimation for Augmented Reality: A Hands-On Survey	Eric Marchand	IEEE Transactions on Visualization and Computer Graphics	355	5.2	10.1109/TVCG.2015.2513408
The Past, Present, and Future of Virtual and Augmented Reality Research: A Network and Cluster Analysis of the Literature	Pietro Cipresso et al.	Frontiers in Psychology	494	3.8	10.3389/fpsyg.2018.02086

Figure 3 . Top 34 most productive journals and impact in research on "augmented reality

The communication pattern in the field of Augmented Reality (AR) research involves scholars publishing their work in a diverse range of journals from around the world. The data indicates that the total research output is spread across 160 different journals, reflecting the global nature of AR research.Among these journals, Figure 3 highlights the ten journals that have published the highest number of papers in the field. Notably, the "IEEE Transactions on Visualization and Computer Graphics" stands out as the most productive journal, with a significant publication output of 171 papers and an impressive citation count of 4,362. This indicates that this particular journal is a central hub for AR research, with a substantial body of work and a high level of recognition in terms of citations.The prominence of "IEEE Transactions on Visualization and Computer Graphics" underscores its importance as a platform for disseminating and sharing AR research findings. Scholars and researchers in the field of AR likely consider this journal as a key outlet for their work due to its high productivity and substantial impact, as indicated by the substantial citation count. It serves as a vital resource for those interested in staying up-to-date with the latest advancements and research in Augmented Reality.

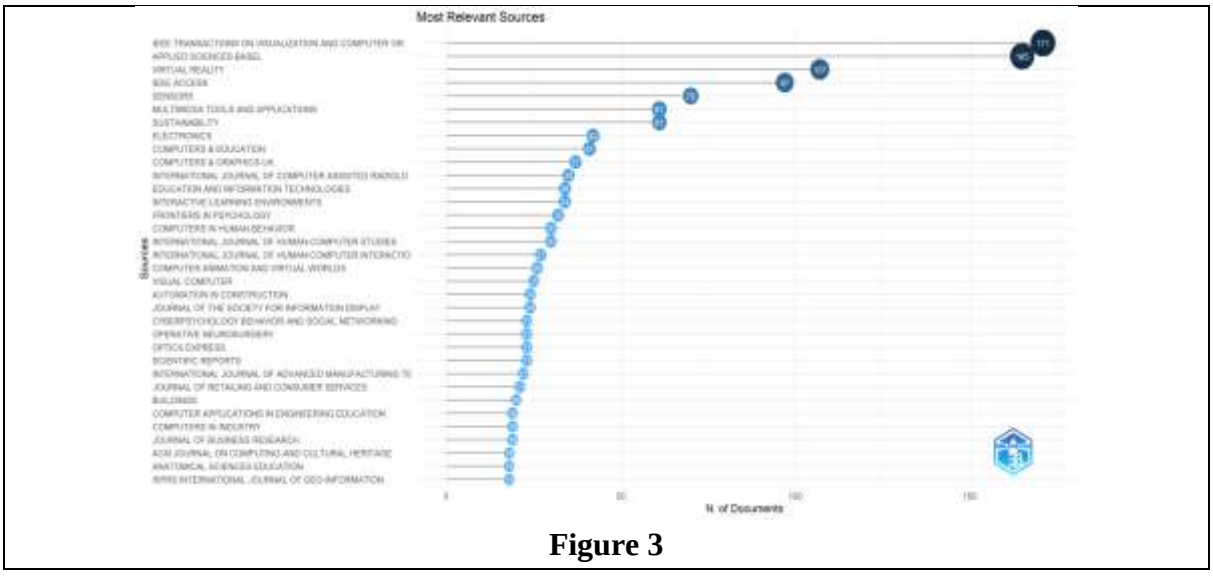

Figure 3

Table 5. Significant keywords appearing in the global publications in "augmented reality" research

The provided term frequency data offers insights into the prevalence of specific terms in the context of augmented reality (AR) and virtual reality (VR) research.**Dominance of Augmented and Virtual Reality**: "Augmented reality" and "virtual reality" are the most frequently occurring terms, indicating their central role in AR and VR research. These technologies are at the core of the field, with a combined frequency of over 1,196.**Key Technological Aspects**: Terms such as "system," "design," "technology," and "performance" are indicative of the technical and functional aspects of AR and VR. These terms highlight the focus on building, optimizing, and evaluating AR and VR systems.**Educational Applications**: "Education" is a significant term, reflecting the emphasis on using AR and VR for educational purposes. It signifies the growing interest in leveraging these technologies to enhance learning experiences.**Simulation and Experience**: "Simulation" and "experience" are key terms, suggesting that AR and VR research often involves creating immersive simulations to enhance user experiences.**Healthcare and Surgery**: Terms like "surgery," "navigation," and "perception" point to the application of AR and VR in healthcare, particularly in surgical procedures and medical training.**Challenges and Management**: The presence of "challenges" and "management" underscores the recognition of the complexities and issues associated with AR and VR implementation. Researchers are actively addressing these challenges.**Mixed Reality**: "Mixed reality" is gaining attention, indicating the evolving landscape of AR and VR, which includes hybrid experiences that blend physical and digital environments. The term frequency analysis highlights the multidisciplinary nature of AR and VR research, encompassing technology, education, healthcare, and more. It also reflects the growing interest in addressing challenges and optimizing user experiences. These terms provide a snapshot of the key themes and priorities within the field of augmented and virtual reality research.

Terms	Frequency	Terms	Frequency
augmented reality	654	model	130
virtual-reality	542	surgery	119
system	300	information	104
education	250	visualization	97
design	232	navigation	87
technology	232	challenges	85
performance	155	students	80
simulation	151	mixed reality	78
impact	147	management	76
experience	139	perception	74
reality	136	framework	69
environments	134	environment	67

Table 5

Figure 4. Trending topics in research on "Augmented Reality" research

The analysis presented in Figure 4, utilizing Biblioshiny, offers valuable insights into the occurrence of

keywords in augmented reality (AR) research over different years. This approach provides a dynamic perspective on the evolving trends and hot topics within the discipline.The focus on keyword occurrence from 2011 onwards allows for tracking the scientific development of AR research. The prominence of certain keywords in 2021, such as "augmented reality" (654 occurrences), "virtual-reality" (542 occurrences), and "system" (300 occurrences), indicates their heightened usage and relevance in contemporary research.These keyword frequencies suggest a continued emphasis on the core technologies of augmented and virtual reality, underscoring their sustained significance in the field. The prevalence of "system" highlights a focus on the technical infrastructure and framework supporting AR applications.By comparing the most recent keyword occurrences with those from earlier years, the study identifies emerging trends and shifting priorities. This method serves as a fundamental approach to understanding the trajectory of AR research, offering valuable insights for researchers, practitioners, and stakeholders in the field.Overall, the analysis provides a comprehensive snapshot of the current state of AR research, revealing the dominant keywords and their evolution over time. Researchers can leverage this information to stay abreast of developing trends and contribute to the ongoing scientific advancements in augmented reality.

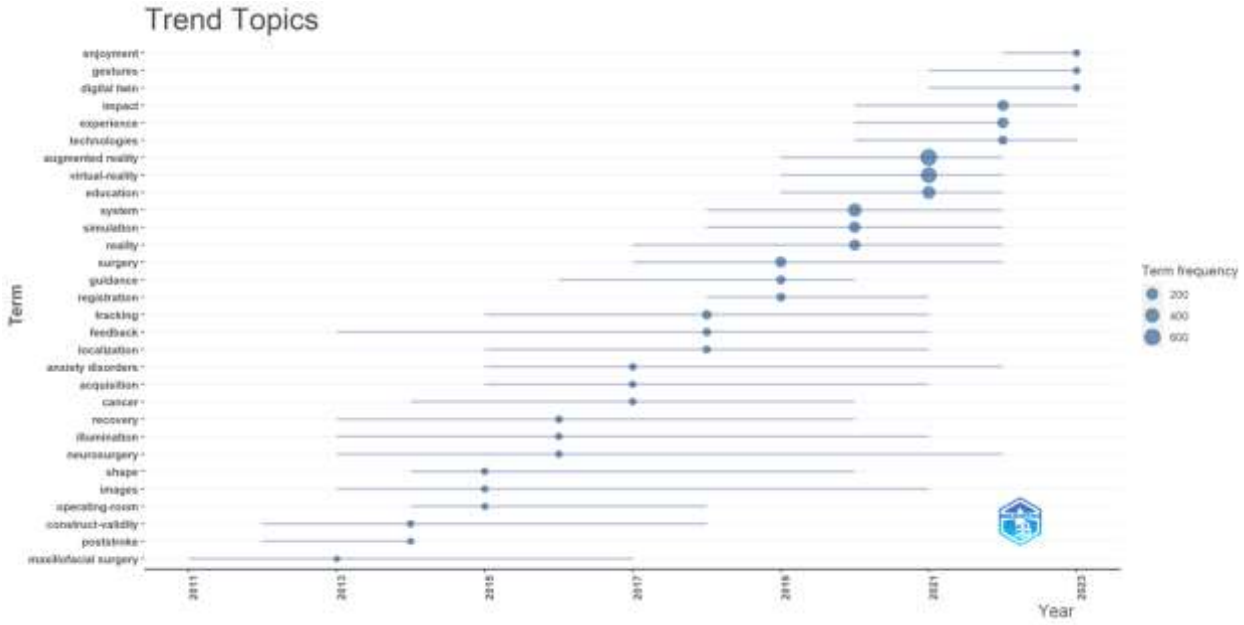

Figure 5. Three field plots

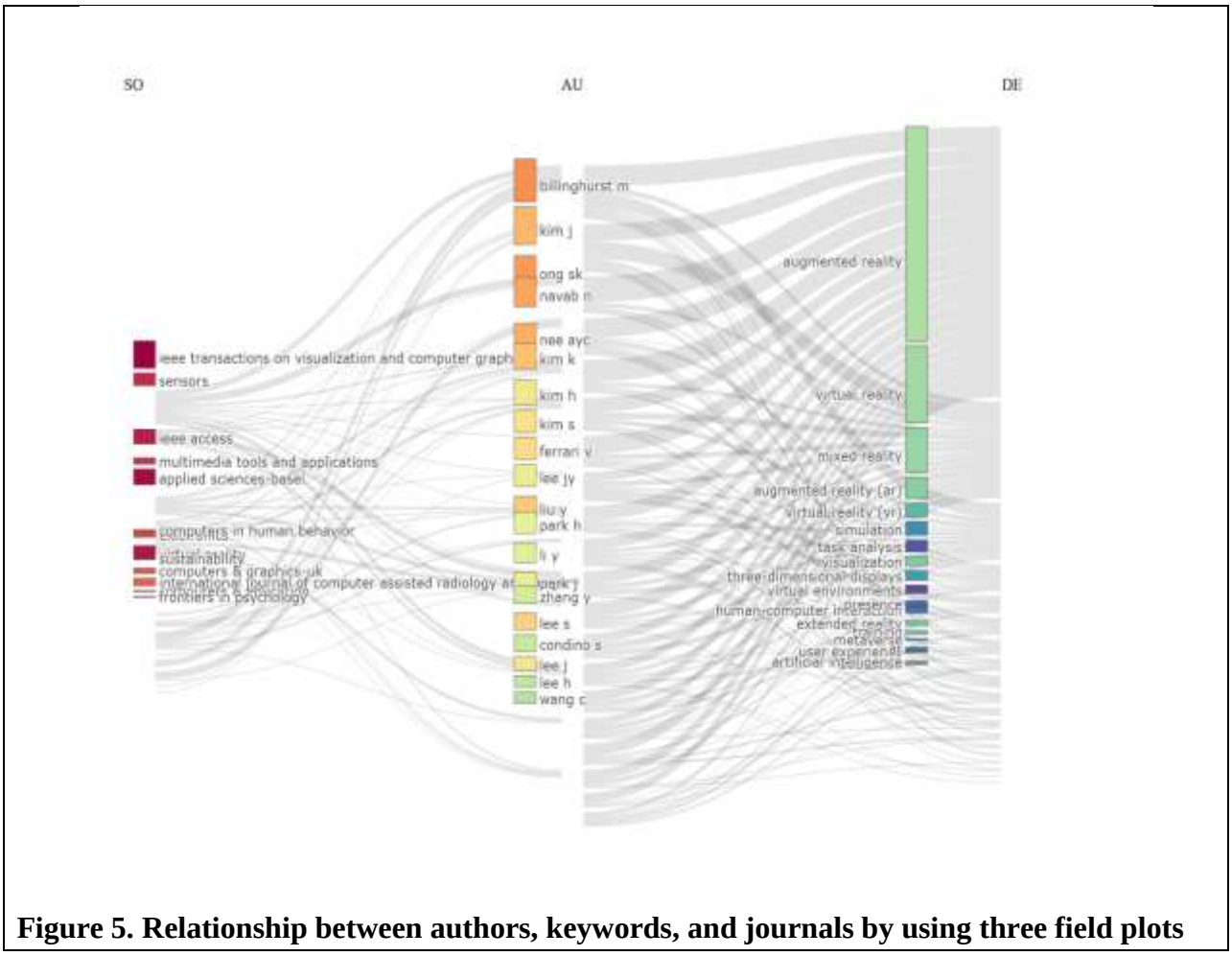

Figure 5. Relationship between authors, keywords, and journals by using three field plots

The use of a three-field plot to identify authors and journals publishing on specific topics is common practice. Figure 5 displays a Sankey plot illustrating the interrelation between the most significant keywords, prominent authors, and leading journals. These plots are created by selecting three key metadata fields. The left-field bar size denotes the journals , the middle-field bar size represents author and their frequency, and the right-field bar size shows the cited areas. The figure indicates that publications heavily rely on journals such as the *Ieee transactions on visualization and computer graphics and iee access* .Some notable authors who have conducted research published on Augmented reality are Billingurst M and Kim j .The research conducted in this area primarily focuses on Augmented reality and virtual reality. The Sankey plot provides a visual representation of how these three key metadata fields (journals, authors, and cited areas) are interconnected and influential in the field of Augmented Reality research. It helps researchers and readers identify the most important journals, authors, and key topics in the field

Figure 6 . Co-authorship networks of the top countries

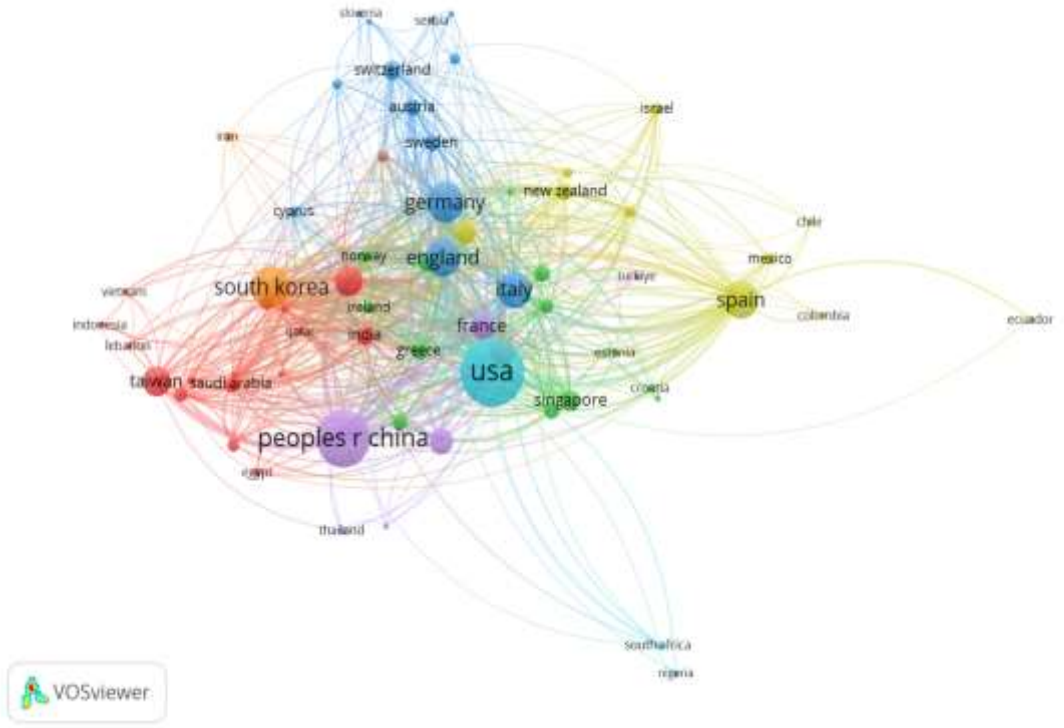

Figure 6 . Co-authorship networks of the top countries based on the total number of articles. Note: A threshold of 5 was applied for these 3999 articles, which resulted in a total of 65 countries. The bubble size in yellow color refers to the total number of articles

Where an author works is indicated by their nationality. The research work will also be counted as the research output of that organization and the nation in where the organization is located, for example, if they work for a research institute and publish papers under a specific organization. In terms of joint research output, 50 different nations have each contributed at least one publication to AR research. About 65 countries have contributed to the collaborative effort, if two contributions are taken into account. To examine the patterns of collaboration, we set the minimum number of documents for a country in the current study at five.A map of international co-authorship networks with countries is shown in **Figure 6**. The size of the circle symbolizes the amount of research activity in each country, which produces a particular number of papers. A circle is drawn between the two nations that have joined forces for cooperative projects. The extent and quantity of the cooperating nations are shown in this graph by the line thickness. The top countries conducting collaborative research *on Augmented* reality *are* USA (939 Documents 25428 citations), China (629 Documents 6819 citations) according to data from VOSviewer software when the minimum number of papers is set to five. 34 nodes (circles) make up country co-authorship networks, which VOSviewer divides into 9 clusters. This information provides insights into the international nature of research in Augmented Reality, highlighting the leading countries in terms of research output and collaboration. The visualization of co-authorship networks helps to understand how nations are working together in this field.

FIGURE 7. Co-authorship network of the top organization

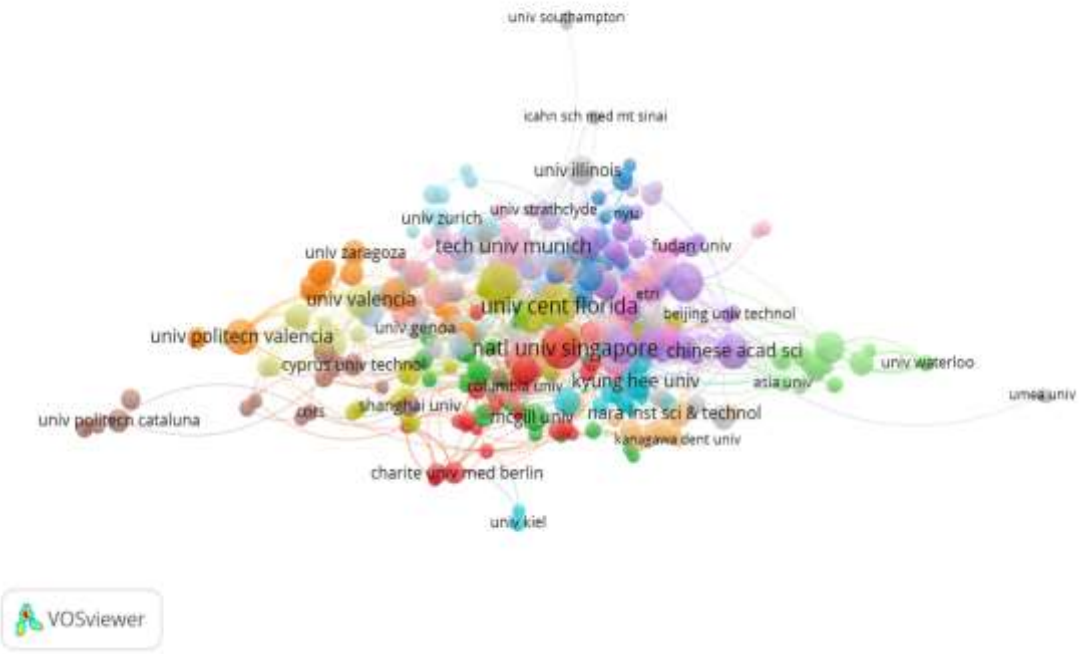

FIGURE 7. Co-authorship network of the top organization based on the total number of published articles. Note: A threshold of 5 was applied for these 1581 articles, which resulted in a total of 3939 organization ,392 organization were selected . The bubble size refers to the total number of articles, while line thickness and color refer to link strength and clustering, respectively

A co-authorship analysis provides a snapshot of scholarly communication among different institutions working in any research domain. Figure 7 shows the top organization with a minimum of five collaborative papers. Also represented is useful bibliometric parameters like citations, and total link strength (TLS). University cent Florida with 52 papers and citation of 1885, National university Singapore with 50 papers and citation of 2203 , are the leading organizations making significant contributions to collaborative research on Augmented reality .. As shown in Figure 5, VOSviewer has divided the co-authorship analysis of organizations into 23 clusters which include 380 organizations represented in different colors. This information helps identify the prominent organizations and their contributions to collaborative research in Augmented Reality, as well as the collaborative network structure among these institutions. It appears that the University of Central Florida and the National University of Singapore are among the top contributors in this research domain.

Discussion

The integration of scientometric analysis, bibliometrics, and visualization techniques provides a powerful and dynamic approach to understanding the landscape of research in "Augmented Reality." The use of tools like VOSviewer allows for the creation of visual maps that not only capture the structural relationships within the knowledge domain but also depict the evolutionary process of the fied

(Van Eck and Waltman, 2010; Gu et al., 2019) This method goes beyond traditional systematic review works by leveraging theories and techniques from information science, computer science, and applied mathematics. The resulting visualizations offer a comprehensive and insightful representation of the current status and potential future developments in Augmented Reality research. The examination of leading countries, prolific authors, chronological growth, and co-authorship networks provides a holistic view of the global research landscape. It enables researchers, policymakers, and industry stakeholders to identify key contributors, influential publications, and emerging trends, facilitating informed decision-making and fostering collaboration. In essence, the combination of bibliometric analysis and visualization techniques serves as a reliable tool for navigating the complexities of Augmented Reality research, offering a nuanced understanding of its dynamics and contributing to the advancement of knowledge in this evolving field.

The comprehensive bibliometric analysis of Augmented Reality (AR) research from 2009 to 2023 reveals a dynamic and rapidly evolving landscape. The substantial annual growth rate of 18.92% and the low average document age of 3.53 years signify the field's vibrancy, with researchers actively producing fresh content to keep the knowledge base current. The remarkable average citations per document (19.18) and the extensive international collaboration (25.21%) highlight the global impact and interconnected nature of AR research. The diversity of 4,061 Keywords Plus and 9,544 Author's Keywords underscores the multifaceted exploration within AR. Examining institutions, the dominance of the University of Central Florida, National University of Singapore, and Stanford University, with high publication shares, reflects their pivotal role in shaping AR research. The concentration of output in a few key institutions suggests their leadership and expertise in the field. The global participation of 103 countries, with the USA, China, and South Korea leading in publications, emphasizes the widespread engagement in AR research. The high citation counts and total link strength further validate the impact of these contributions. Noteworthy authors like Billinghurst M and Ong S.K stand out in a community of 13,717 researchers, emphasizing individual contributions to AR literature. Additionally, the top-cited papers underscore the significant influence of select publications, guiding future research directions. The analysis of journals indicates the centrality of "IEEE Transactions on Visualization and Computer Graphics" in disseminating AR research. This journal's high productivity and citation count make it a crucial platform for AR scholars. The term frequency analysis showcases the dominant themes in AR research, spanning technology, education, healthcare, and challenges. The focus on "augmented reality" and "virtual reality" underscores the foundational concepts, while emerging terms like "mixed reality" indicate evolving trends. The exploration of trending topics through keyword occurrences offers valuable insights, with 2021 showing heightened emphasis on core terms like "augmented reality" and "virtual-reality."Co-authorship networks reveal international collaboration, with the USA and China leading in collaborative efforts. The University of Central Florida and the National University of Singapore emerge as key contributors, fostering a collaborative network.

Conclusion

The extensive analysis not only paints a detailed picture of the Augmented Reality (AR) research landscape but also serves as a compass for those navigating this dynamic field. By highlighting key contributors, influential publications, global collaboration patterns, and emerging trends, this wealth of information empowers researchers to make informed decisions, policymakers to shape strategic initiatives, and industry stakeholders to stay ahead of the curve. Understanding the nuances of AR

research is crucial in harnessing the full potential of this technology. The concentration of output in specific institutions and countries, the impact of prolific authors, and the significance of certain journals provide a roadmap for future exploration. The collaborative nature of AR research, evident in international partnerships and co-authorship networks, emphasizes the global interconnectedness of knowledge creation in this domain. Moreover, the analysis not only captures the current state of AR research but also projects future developments. The identification of trending topics and the evolution of keyword occurrences over time offer insights into the trajectory of the field. This foresight is invaluable for anticipating technological advancements, educational applications, and challenges that may shape the future of Augmented Reality. In essence, this comprehensive analysis acts as a beacon, illuminating the path forward in the ever-evolving landscape of Augmented Reality. It's not just a compilation of data; it's a guidebook for researchers and stakeholders to navigate the complexities, seize opportunities, and contribute meaningfully to the continued growth and innovation in AR research.

Limitations of the study

Although this study contributes to the domain of knowledge significantly but simultaneously it has few limitations. The study only adopted the WoS database to source data. Researchers may conduct similar studies taking data from databases like Google Scholar, Scopus, which also hold large amount of bibliographic information. With this study, we tried to shed light on progress and trend of the publications on AR in general.

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