ISSN 2007-9737

Augmented Reality and its Influence on Sporting Events: A Systematic Literature Review

Jesús Minaya-Isique[1], Javier Gamboa-Cruzado[2], Ángel Núñez-Meza[3], Blanca Cecilia López-Ramírez[4,*]

[1] Universidad Nacional Federico Villarreal, Facultad de Ingeniería Industrial y de Sistemas, Lima, Peru

[2] Universidad Nacional Mayor de San Marcos, Facultad de Ingeniería de Sistemas e Informática, Lima, Peru

[3] Universidad Nacional Daniel Alcides Carrión, Facultad de Ingeniería de Sistemas, Pasco, Peru

[4] Tecnológico Nacional de México/IT de Roque, Celaya, Mexico

2022032376@unfv.edu.pe, jgamboa65@hotmail.com, anunezm@undac.edu.pe, bllopez@itroque.edu.mx

Abstract. Augmented reality is vigorously emerging across various domains, merging digital elements with the physical environment to create an interactive and enriched experience; its rise within the realm of sports events is particularly notable. The primary objective is to identify the state of the art in research on augmented reality in sports events over the past seven years. A systematic literature review was conducted, meticulously examining bibliographic sources such as Web of Science, Science Direct, ProQuest, Scopus, EBSCOhost, and IEEE Xplore. Through an exhaustive search strategy, initially 5,018 relevant publications were identified. Subsequently, exclusion criteria based on the PRISMA Flow Diagram were applied, resulting in the selection of 60 highly relevant papers for detailed review. The results of the systematic review indicate that Web of Science, Scopus, and IEEE Xplore are the most prolific sources in terms of the number of papers published during the study period. Furthermore, it was observed that the year 2022 recorded the highest production of papers, while the year 2020 had the lowest production. These findings are valuable as they provide relevant information for making comparisons in future research across different contexts and situations.

Keywords. Augmented reality, virtual reality, sports events, competitions, systematic literature review.

1 Introduction

Augmented reality (AR) stands as a disruptive technology that amalgamates virtual elements with the tangible environment, forging profoundly enriching interactive experiences. Its cross-sector adoption has been exponential, particularly in the sports events industry, where it has opened new horizons to enhance spectator experiences, elevate athlete performance, and transform the marketing of these events. AR facilitates the embedding of complementary information, such as instant metrics, interactive visualizations, and three-dimensional recreations, into the visual interfaces and mobile devices of the audience. Concurrently, it provides competitors and trainers with sophisticated tools for scrutinizing and enhancing performance, emulating competitive scenarios, and obtaining instant feedback. According to authors [3, 5, 24, 29], AR and virtual reality (VR) are enhancing the way spectators experience sports events, achieved through the overlay of real-time statistics and data directly within the viewing environment, as has been

implemented in sports like hockey with technologies such as FoxTrax and in augmented Dodgeball games.

In sports training, AR and VR offer simulated environments that replicate competitive conditions, allowing athletes to train more effectively. This includes systems that enable gymnasts to interact with digital avatars and environments that simulate actual competitions [2, 4, 31, 47].

In the same vein [20, 21, 55], it is expressed that virtual reality (VR) is fundamental in developing training programs for referees, providing controlled environments where they can improve their decision-making and precision in play assessment and reveal how VR simulations allow referees to experience intense game situations, assessing their ability to make correct decisions under pressure.

As indicated by [16, 32, 53, 56], Augmented Reality (AR) and Virtual Reality (VR) are transforming the way sports events are broadcast, offering spectators real-time visualizations that range from performance data to aerial views provided by drones; these technologies enable a richer and more detailed viewing experience, making spectators feel as if they are at the event. Using AR and VR, coaches and athletes can analyze performance details through real-time data capture.

This is especially useful in sports requiring high precision such as table tennis or fencing, where the technology provides immediate feedback on techniques and strategies [31, 36, 37, 47]. Research explores how the interactivity provided by AR and VR influences user motivation and overall flow experience, with studies indicating that these media can significantly amplify user immersion and satisfaction [17, 19, 42, 49].

Prototyping and evaluation of new AR and VR applications are crucial for understanding how these technologies can be best implemented in the sports arena. Studies discuss the importance of developing flexible prototypes that can be tested outside of deployment locations to ensure their effectiveness and acceptance by users [26, 27, 28, 29]. While AR and VR applications in sports offer numerous opportunities, they also face significant challenges, including technical issues, implementation costs, and the need for user feedback-based adjustments to enhance the experience and accessibility [24, 25, 60].

AR and VR technologies are specifically being applied to enhance training in sports requiring specific skills and coordination. For instance, they are used to simulate environmental and physical conditions athletes might face in real competitions, such as in cycling, where resistance, temperature, and altitude are simulated [30, 39, 58]. Research that explores how VR environments affect user interaction and space perception.

These studies are fundamental for understanding how collaborative and competitive experiences in VR can be designed to enhance performance and user experience [23, 34, 38, 46]. Applications using AR and VR to perform detailed analysis and assessments of sports skills, like motion tracking in combat sports or technique analysis in precision sports.

These studies show how technology can help identify and enhance specific aspects of sports performance [12, 13, 35, 40]. Research on how AR and VR are being used to transform major sports events, from enhancing spectator experiences to including technologies that allow greater audience interaction and participation. Studies include the implementation of technologies during live events and the audience response to these innovations [50, 51, 52, 53].

Work in the development and implementation of new AR and VR platforms that allow users to experience sports in innovative ways. These studies address everything from the creation of virtual environments for competitions to the development of tools that facilitate the analysis and broadcasting of sports events [54, 55, 57, 59].

The use of AR to enrich the spectator experience in stadiums is gaining ground. These studies focus on how the integration of contextual information and augmented visualizations can enrich the experience during the event [25, 43, 44, 60]. According to [61, 71], extended reality (XR), which includes augmented reality (AR) and virtual reality (VR), is being explored in sports to analyze future trends and potential development. Although still in its early stages, XR could be useful in sports training, particularly for perceptual and cognitive skills. It is crucial to assess the representativeness level of XR tools before their implementation to minimize negative transfer effects and validate

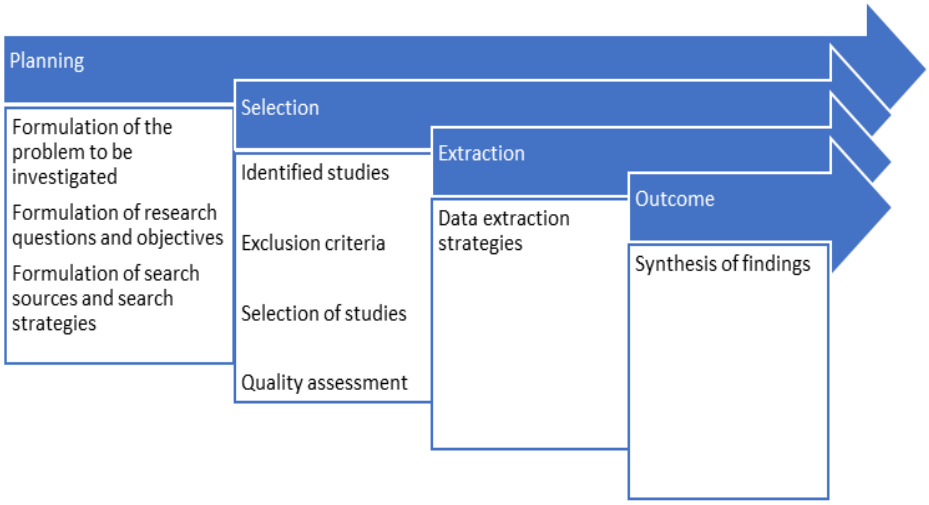

Fig. 1. Stages of the SLR3.1 research problems and objectives

their use. Virtual reality (VR) is used in sports to educate users, assist in the medical field, train in psychology, analyze performance, and train skills and fitness.

The most common VR tools include StandAlone VR, Mobile VR, and PC VR, with the latter being the most used. This diverse use underscores the importance of VR in developing complex sports skills and its potential in different application areas [65]. Two AR applications using the vision-based tracking method stand out for their accessibility and home use: the AR Baseball Presentation System and the Interactive AR Bowling System [66, 67].

The application of augmented reality (AR) in sports sciences is discussed, urging more research to harness the potential of this technology in fields such as health and sports education [68, 69]. Consequently, a significant gap is noted in the literature concerning augmented reality and its impact on sports events. The scarcity of systematic reviews and meta-analyses prevents proper comparison regarding the volume and quality of publications in this thematic area.

Without a broader corpus of studies, it is complex to assess the appropriateness of search strategies employed, the correct configuration of search equations, or the implementation of bibliometric analyses and citation networks, among other critical methodological aspects.

2 Theoretical Background

2.1 Augmented Reality

Augmented Reality (AR), often referred to as Virtual Augmented Reality, uses computational technology to superimpose virtual elements onto physical reality through a visual interface. This allows users to observe computer-generated objects embedded in the real environment while simultaneously viewing their tangible surroundings. AR is characterized by three main attributes: a "seamless" fusion of real and digital data, synchronous interactivity, and the amalgamation of real and virtual spaces [8].

AR is defined as interfaces that integrate digital content directly into the user's field of vision. The experience of attending live sports events is potentially enhanced with this innovation, by enhancing user engagement and leveraging spectators' familiarity with the overlay of graphics on video feeds during broadcasts [11].

In 2021, approaches for route selection and mobility assistance for people with disabilities were studied. Additionally, the state of augmented reality and mobility systems was analyzed from five dimensions: data collection, data management and open standards, needs modeling, accessibility in maps and applications, and user-centered services [70].

Table 1. Research problems and objectives

Research Question	Objective
RQ1: In which quartiles are the journals that publish studies on the effect of augmented reality in sports events classified?	Find out the quartile levels of journals where research on the influence of augmented reality in sports events has been published.
RQ2: What are the criteria for measuring user satisfaction with augmented reality in sports contexts?	Identify the criteria for measuring user satisfaction with augmented reality in sports events.
RQ3: What are the most frequent and relevant keywords in studies about augmented reality in sports events?	Recognize the most used and relevant keywords by the number of papers in research on augmented reality and its influence on sports events.
RQ4: Which researchers frequently collaborate as co-authors in studies on augmented reality in sports events?	Detail the authors who frequently are co-authors in research on the influence of augmented reality in sports events.
RQ5: Which paper titles exhibit high and moderate similarities in research related to augmented reality in sports events?	Identify papers whose titles show high and moderate similarity in research on augmented reality in sports events

Table 2. Search descriptors and their synonyms

Descriptor and Synonyms
augmented reality/ virtual reality/ mixed reality/ extended reality/ assisted reality
sports events/ sporting event/ athletic event/ sports competitions/ competitions/ athletic contests/ sports tournaments/ sports games/ sports activities/ sports/ live sports/ sport games/ sports jousting

Table 3. Information sources and search equation

Source	Search Equation
Web of Science	((TI=(("augmented reality" OR "virtual reality" OR "mixed reality" OR "extended reality" OR "assisted reality") AND ("sports events" OR "sporting event" OR "athletic event" OR "sports competitions" OR competitions OR "athletic contests" OR "sports tournaments" OR "sports games" OR "sports activities" OR sports OR "live sports" OR "sport games" OR matches OR "sports jousting"))) OR AB=(("augmented reality" OR "virtual reality" OR "mixed reality" OR "extended reality" OR "assisted reality") AND ("sports events" OR "sporting event" OR "athletic event" OR "sports competitions" OR competitions OR "athletic contests" OR "sports tournaments" OR "sports games" OR "sports activities" OR sports OR "live sports" OR "sport games" OR matches OR "sports jousting"))) OR AK=(("augmented reality" OR "virtual reality" OR "mixed reality" OR "extended reality" OR "assisted reality") AND ("sports events" OR "sporting event" OR "athletic event" OR "sports competitions" OR competitions OR "athletic contests" OR "sports tournaments" OR "sports games" OR "sports activities" OR sports OR "live sports" OR "sport games" OR matches OR "sports jousting"))
Science Direct	Title, abstract, keywords: ("augmented reality" OR "virtual reality" OR "mixed reality") AND ("sports events" OR "sporting event" OR "athletic event" OR "sports competitions" OR competitions OR sports)
ProQuest	title(("augmented reality" OR "virtual reality" OR "mixed reality" OR "extended reality" OR "assisted reality") AND ("sports events" OR "sporting event" OR "athletic event" OR "sports competitions" OR competitions OR "athletic contests" OR "sports tournaments" OR "sports games" OR "sports activities" OR sports OR "live sports" OR "sport games" OR matches OR "sports jousting")) OR abstract(("augmented reality" OR "virtual reality" OR "mixed reality" OR "extended reality" OR "assisted reality") AND ("sports events" OR "sporting event" OR "athletic event" OR "sports competitions" OR competitions OR "athletic contests" OR "sports tournaments" OR "sports games" OR "sports activities" OR sports OR "live sports" OR "sport games" OR matches OR "sports jousting"))
Scopus	TITLE-ABS-KEY ("augmented reality" OR "virtual reality" OR "mixed reality" OR "extended reality" OR "assisted reality" AND "sports events" OR "sporting event" OR "athletic event" OR "sports competitions" OR competitions OR "athletic contests" OR "sports tournaments" OR "sports games" OR "sports activities" OR "live sports" OR "sport games" OR matches OR "sports jousting")
EBSCOhost	TI (("augmented reality" OR "virtual reality" OR "mixed reality" OR "extended reality" OR "assisted reality") AND ("sports events" OR "sporting event" OR "athletic event" OR "sports competitions" OR competitions OR "athletic contests" OR "sports tournaments" OR "sports games" OR "sports activities" OR sports OR "live sports" OR "sport games" OR matches OR "sports jousting")) OR SU (("augmented reality" OR "virtual reality" OR "mixed reality" OR "extended reality" OR "assisted reality") AND ("sports events" OR "sporting event" OR "athletic event" OR "sports competitions" OR competitions OR "athletic contests" OR "sports tournaments" OR "sports games" OR "sports activities" OR sports OR "live sports" OR "sport games" OR matches OR "sports jousting")) OR AB (("augmented reality" OR "virtual reality" OR "mixed reality" OR "extended reality" OR "assisted reality") AND ("sports events" OR "sporting event" OR "athletic event" OR "sports competitions" OR competitions OR "athletic contests" OR "sports tournaments" OR "sports games" OR "sports activities" OR sports OR "live sports" OR "sport games" OR matches OR "sports jousting"))
IEEE Xplore	(("Publication Title": "augmented reality" OR "Publication Title": "virtual reality" OR "Publication Title": "mixed reality" OR "Publication Title": "extended reality" OR "Publication Title": "assisted reality") AND ("Publication Title": "sports events" OR "Publication Title": "sporting event" OR "Publication Title": "athletic event" OR "Publication Title": "sports competitions" OR "Publication Title": competitions OR "Publication Title": "athletic contests" OR "Publication Title": "sports tournaments" OR "Publication Title": "sports games" OR "Publication Title": "sports activities" OR "Publication Title": sports OR "Publication Title": "live sports" OR "Publication Title": matches OR "Publication Title": "sports jousting")) OR (("Abstract": "augmented reality" OR "Abstract": "virtual reality" OR "Abstract": "mixed reality" OR "Abstract": "extended reality" OR "Abstract": "assisted reality") AND ("Abstract": "sports events" OR "Abstract": "sporting event" OR "Abstract": "athletic event" OR "Abstract": "sports competitions" OR "Abstract": competitions OR "Abstract": "athletic contests" OR "Abstract": "sports tournaments" OR "Abstract": "sports games" OR "Abstract": "sports activities" OR "Abstract": sports OR "Abstract": "live sports" OR "Abstract": matches OR "Abstract": "sports jousting")) OR (("Author Keywords": "augmented reality" OR "Author Keywords": "virtual reality" OR "Author Keywords": "mixed reality" OR "Author Keywords": "extended reality" OR "Author Keywords": "assisted reality") AND ("Author Keywords": "sports events" OR "Author Keywords": "sporting event" OR "Author Keywords": "athletic event" OR "Author Keywords": "sports competitions" OR "Author Keywords": competitions OR "Author Keywords": "athletic contests" OR "Author Keywords": "sports tournaments" OR "Author Keywords": "sports games" OR "Author Keywords": "sports activities" OR "Author Keywords": sports OR "Author Keywords": "live sports" OR "Author Keywords": matches OR "Author Keywords": "sports jousting"))

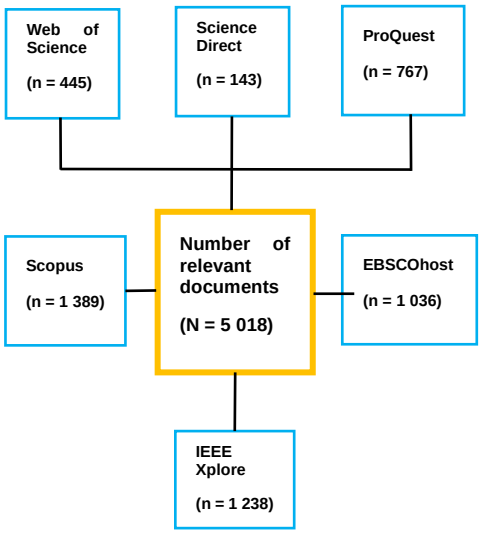

Fig. 2. Number of relevant sources

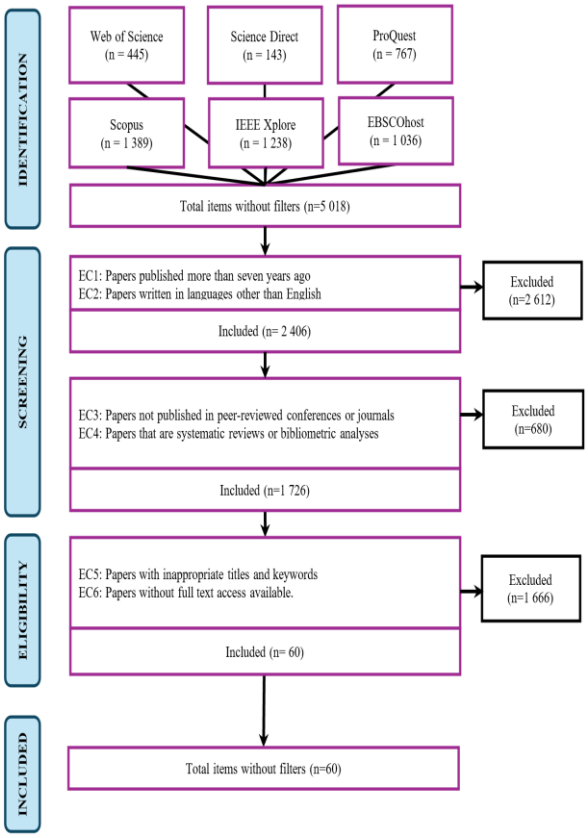

Fig. 3. PRISMA flow diagram

2.2 Sports Events

Sports events are organized competitions or meetings that involve the participation of athletes or teams across various sports disciplines. These events are held at local, national, and international levels, and often attract a large number of spectators and followers. Sports events can include individual or team competitions, such as championships, tournaments, Olympic games, marathons, and matches in football, basketball, tennis, among others. These events not only offer exciting sporting contests but also promote a spirit of competition, camaraderie, and entertainment for fans and viewers.

The use of information and communication technologies (ICT), specifically cross-platform mobile applications, can significantly promote physical activity, leading to a notable increase in exercise among users. These findings suggest that mobile applications represent a promising tool for addressing various social issues [62].

3 Review Method

A hybrid approach inspired by the Systematic Literature Review (SLR) methodology was adopted for the review, based on the guidelines provided by B. Kitchenham, thus tailored to the specific needs of this study. With this approach, a rigorous scrutiny of the influence of Augmented Reality in Sports Events was undertaken, seeking precise answers to the research questions posed. This process is articulated in various essential phases, detailed and outlined in Figure 1.

3.1 Research Problems and Objetives

In this research, a search strategy focused on augmented reality applied to sports events is established. This strategy facilitates the effective extraction of data from selected studies, providing a solid foundation for performing an objective analysis and gathering crucial information as a primary resource. The research questions (RQs) play a fundamental role in this process. Seven RQs are formulated, each with its specific objectives, detailed in Table 1.

Table 4. Quality assessment criteria

	Quality Criteria (QA)
QA1	Is the study purely research-based?
QA2	Are the tools used for data collection cited?
QA3	Is the full text of the paper available?
QA4	Is the research area clearly specified?
QA5	Is the context in which the research was conducted described?
QA6	Are the experimental results clearly presented and detailed?

Table 5. Quality evaluation results

Ref.	Type	QA1	QA2	QA3	QA4	QA5	QA6	Score	Ref.	Type	QA1	QA2	QA3	QA4	QA5	QA6	Score
[1]	Journal	2	3	2	3	3	3	16	[31]	Journal	2	2	3	3	3	2	15
[2]	Conference	2	1	1	2	3	2	11	[32]	Conference	2	1	1	2	3	3	12
[3]	Conference	3	2	3	3	3	3	17	[33]	Journal	2	3	3	3	3	2	16
[4]	Journal	2	1	2	3	3	2	13	[34]	Journal	2	3	1	3	3	2	14
[5]	Journal	3	2	2	2	3	2	14	[35]	Journal	2	2	3	2	3	2	14
[6]	Journal	2	2	3	3	3	2	15	[36]	Journal	2	2	3	2	3	2	14
[7]	Journal	2	2	3	3	2	2	14	[37]	Journal	2	3	3	3	3	3	17
[8]	Journal	2	2	3	2	2	2	13	[38]	Journal	2	2	3	2	3	2	14
[9]	Conference	2	3	3	3	2	2	15	[39]	Journal	3	2	3	3	3	2	16
[10]	Journal	2	3	3	2	2	2	14	[40]	Journal	2	2	2	2	2	3	13
[11]	Journal	3	2	2	2	2	2	13	[41]	Journal	2	3	1	3	2	3	14
[12]	Journal	2	2	2	2	2	3	13	[42]	Journal	2	2	2	3	3	3	15
[13]	Conference	3	1	1	2	2	3	12	[43]	Conference	3	2	3	3	3	3	17
[14]	Conference	2	3	2	3	2	3	15	[44]	Journal	2	2	3	3	2	2	14
[15]	Conference	2	2	1	2	2	3	12	[45]	Journal	3	3	3	3	3	2	17
[16]	Journal	2	2	3	2	2	2	13	[46]	Journal	2	2	1	3	2	3	13
[17]	Journal	2	3	2	3	2	3	15	[47]	Journal	3	2	3	2	3	3	16
[18]	Conference	1	2	1	3	3	2	12	[48]	Journal	2	2	1	3	3	3	14
[19]	Journal	2	2	3	2	2	2	13	[49]	Journal	2	2	3	2	3	3	15
[20]	Journal	2	3	3	2	3	2	15	[50]	Journal	2	3	3	2	2	3	15
[21]	Journal	2	2	3	2	2	2	13	[51]	Journal	2	3	3	3	3	3	17
[22]	Conference	2	1	1	3	3	2	12	[52]	Journal	2	3	2	2	3	2	14
[23]	Journal	2	3	3	3	2	3	16	[53]	Journal	3	2	3	2	3	3	16
[24]	Journal	3	3	3	2	2	2	15	[54]	Journal	2	2	3	2	3	2	14
[25]	Conference	2	2	1	2	3	2	12	[55]	Conference	3	2	3	3	3	3	17
[26]	Conference	2	2	2	2	2	2	12	[56]	Conference	1	2	3	3	3	2	14
[27]	Conference	2	2	1	2	2	2	11	[57]	Journal	2	3	3	3	3	3	17
[28]	Journal	3	2	3	2	3	2	15	[58]	Journal	2	2	3	3	3	3	16
[29]	Conference	2	3	3	2	2	2	14	[59]	Journal	3	3	2	2	2	2	14
[30]	Journal	3	2	2	2	2	3	14	[60]	Conference	3	2	3	3	3	3	17

3.2 Information Sources and Search Strategies

For the search of relevant research papers, various bibliographic databases were utilized. These include IEEE Xplore, Web of Science, Science Direct, ProQuest, Scopus, and EBSCOhost. The search strategy was based on the use of keywords, which are detailed in Table 2.

The search was conducted using a set of relevant terms that facilitated the search and information extraction process.

This set of terms is referred to as a search equation, the composition of which varies depending on the information source used, as shown in Table 3.

3.3 Identified Studies

Once the search was concluded in each information source, the number of identified studies was compiled, which is presented in Figure 2.

3.4 Selection Criteria

Exclusion criteria were established to precisely evaluate the quality of the retrieved literature. Six exclusion criteria were used to determine the eligibility of the papers, which are described below:

EC1: Papers published more than seven years ago.

EC2: Papers written in languages other than English.

EC3: Papers not published in peer-reviewed conferences or journals.

EC4: Papers that are systematic reviews or bibliometric analyses.

EC5: Papers with inappropriate titles and keywords.

EC6: Papers without full text access available.

3.5 Selection Process

Initially, 5,018 papers were identified through a search using relevant keywords for the study. The steps of selection and filtering used are detailed in Figure 3. As a result of this process, 60 papers were selected for detailed review and analysis.

3.6 Quality Assessment

Regarding Quality Assessment, it is crucial to examine and assess the quality of the papers selected for the final sample. During this phase, the chosen papers were analyzed using six quality criteria. This final stage of selection and filtering culminates with the preparation of the official list of papers included in this study, following the quality assessment. The goal is to ensure that the research described in each paper is understandable and reliable.

The quality criteria used to evaluate the papers are detailed in Table 4.

For each paper, a detailed reading was conducted, and six criteria were applied to assess its quality using a scoring scale ranging from 1 to 3 (1 being "Not good", 2 "Good", and 3 "Very Good"). A minimum inclusion threshold of 11.5 points was established. All the 60 evaluated papers reached or exceeded this threshold, thus meeting the established quality criteria. This meticulous evaluation definitively determined the number of publications that would be included in the study. The results of this quality assessment are documented in Table 5.

3.7 Data Extraction Strategies

In this phase, after consolidating the final collection of papers, the necessary information to answer the research questions was extracted. Information extracted from each paper included elements such as the paper title, URL, source, year of publication, country, ISSN, type of publication, name of the journal or conference, authors, institutional affiliation, publication quartile, H-index, number of citations, methodology used, abstract, and keywords. It is relevant to mention that not all papers provided complete answers to all the research questions. Mendeley Desktop was used for the management of these data.

3.8 Synthesis of Findings

Relevant information was compiled to address each of the research questions, from RQ1 to RQ5, presenting it in the form of quantitative and qualitative data. Using these data, statistical comparisons were conducted among the findings associated with each research question. Through this statistical analysis, it was possible to identify research patterns and discern the prevailing trends over the last seven years.

4 Results and Discussion

4.1 Overview of the Studies

The systematic literature review constitutes an exhaustive methodology that adheres to a structured process, including defining research questions, identifying and selecting information

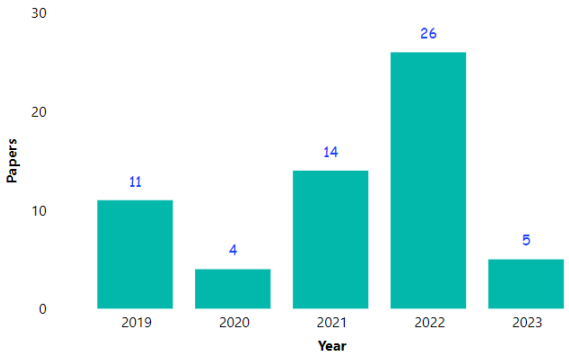

Fig. 4. Number of papers per year

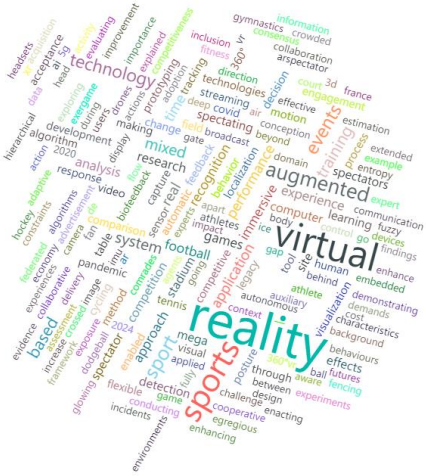

Fig. 5. Word cloud of titles by paper

sources, extracting and synthesizing data, and analyzing the results.

After gathering the relevant studies, data extraction was conducted to collect detailed information from each study, such as title, authors, publication year, among other relevant data. Figure 4 illustrates the distribution of papers published annually.

There is a notable increase in the publication of papers from 2019 to 2022, suggesting a growing interest in the area of study. The highest peak of publications was recorded in 2022, with 26 papers, indicating a possible catalyzing event or a significant advancement in that year.

The drop to 5 papers in 2023 could imply a saturation of research or a shift in focus towards new subfields. The year 2020 shows the fewest publications, which could be related to the global effects of the COVID-19 pandemic.

Figure 5 shows a variety of keywords from research sources, which are explained below. The word cloud shows a strong presence of terms "reality", "sports", and "virtual", indicating that augmented reality in sports events is a central focus area in recent literature. The diversity of words related to "technology", "training", "experience", and "performance" reflects the breadth of augmented reality applications in sports and interest in how this technology can enhance the experience for athletes and spectators.

The variety of specific sports terms like "cycling", "fencing", and "running" demonstrates the application of augmented reality across a range of sports disciplines. Additionally, the inclusion of terms such as "cooperative", "context", and "behavior" signals interest in the social and contextual aspects of augmented reality in sports. According to Zhao et al. [61], the most used terms in titles referring to augmented reality are “physical education” followed by “deep learning” and “mixed reality”.

The concentration of research around augmented reality and sports underscores the need to delve deeper into how these technologies can optimize performance and the sports experience. Understanding the prevalent terminology in titles can influence keyword strategy for future research and assist in enhancing the visibility and impact of studies in academic databases.

In Table 6, number of citations, and number of papers by source are presented. The data in the table suggest that Science Direct dominates in terms of the number of citations, especially for papers with 15 citations or more.

Although Web of Science, Scopus, and IEEE Xplore have a similar number of published papers, the number of citations from Web of Science and Scopus is significantly higher, which could indicate a selection of more influential studies for the scientific community.

The presence of papers with fewer than five citations in all sources except Science Direct shows a broad spectrum of influence, from emerging papers to well-established works. The fact that ProQuest has no papers with 15 or more citations and a low total number of citations

Table 6. Number of citations, and number of papers by source

Range Citations	**<5**		**≥15**		**≥ 5 and < 15**		**Total**	
Source	Tot Papers	N° Citations	Tot Papers	N° Citations	Tot Papers	N° Citations	Tot Papers	N° Citations
Web of Science	10	10	3	115	2	17	15	142
IEEE Xplore	9	5	1	25	2	24	12	54
Scopus	6	16	2	110	4	31	12	157
EBSCOHost	6	7	1	18	1	11	8	36
Science Direct	0	0	4	392	3	28	7	420
ProQuest	6	4	0	0	0	0	6	4
Total	**37**	**42**	**11**	**660**	**12**	**111**	**60**	**813**

Table 7. Criteria for evaluating user satisfaction with augmented reality

Criterion	**Reference**	**Qty. (%)**
Interaction	[1][2][6][8][9][11][12][14] [15][17][18][19][21][22][23] [24][25][26][27][28][30][31] [32][33][34][35][36][38][39] [42][44][45][46][47][49][50] [51][54][56][57][58][59]	42 (51,3)
Quality	[6][7][8][10][12][14][16][17] [19][21][22][27][28][31][34] [35][37][40][47][48][53][56] [57][58][59]	25 (30.4)
User experience	[7][10][17][19][21][25][28] [32][43][46][49][52][56][59] [60]	15 (18.3)

suggests that it may be a less prominent source for high-impact papers in this field.

Science Direct is noted as the source from which the most studies on augmented reality and its influence on sports events are cited. According to [61], Scopus has the highest number of citations related to augmented reality in sports events. Conversely, [63] maintains that Science is the source with the highest number of citations referring to papers on the described topic.

Similarly, [64] mentions Science Direct as the source with the highest number of citations related to augmented reality and its influence on sports events.

Regarding publications, both [65] and [67], and [68] agree that IEEE Xplore is the leading platform in terms of the production of papers on augmented reality related to sports events. The prominence of Science Direct in terms of citations indicates that researchers might prioritize this source for disseminating their works to maximize visibility and impact. Finally, the table indicates areas of opportunity for new research to gain traction in sources where high numbers of citations are less common.

Various countries have undertaken significant efforts in research and development in this area, resulting in a sustained increase in knowledge. An analysis was conducted to determine the most

productive countries in this field, using various sources such as scientific publications and conferences to track studies and research conducted by each nation.

Figure 6 shows the distribution of the number of papers by country. The heatmap reflects a concentration of productive research on the topic in the United States, China, and Australia, indicating strong investment and a possible concentration of experts in the region. Europe and Asia exhibit a moderate level of research activity, which may reflect a diversification in global research. Canada and Africa, shown in red, have a lower production of papers, which could point to barriers related to funding, infrastructure, or access to international academic networks.

The United States leads the production of studies on augmented reality and its influence on sports events. According to [61], the United States, followed by China, are the countries with the highest production of papers in this field. Neuman et al. [63] also highlight the prominence of the United States in generating publications on this topic. Similarly, Mesias Da Silva and others [64] point to the United States as the leader in the production of related papers.

Lastly, Makalesi [69] confirms that the United States has made the most contributions in the field of augmented reality. Understanding each country's participation in research provides a comprehensive view, reveals opportunities and gaps, stimulates collaboration, and assists in the strategic planning of future research.

It is crucial to obtain accurate data on author affiliations and to perform thorough analysis to garner relevant and significant insights into each country's contribution.

4.2 Responses to Research Questions

This report provides answers to the research questions posed in the study, considering relevant feedback, discussions held, and implications for future research.

RQ1: In which quartiles are the journals that publish studies on the effect of augmented reality in sports events classified?

The quality and impact of scientific research are reflected in the academic journals where they are published. The quartile level of a journal is a measure that ranks its importance and visibility within the academic field. It is essential to identify the quartile levels of journals that have disseminated studies on best practices and their impact on decision-making, with the goal of assessing the quality and impact of such research. Figure 7 illustrates the quartile levels of the papers based on the journals in which they have been published.

The Sankey Diagram shows that the most prominent information sources for publishing studies on augmented reality in sports events include databases such as Scopus, Web of Science, and IEEE Xplore. These sources are

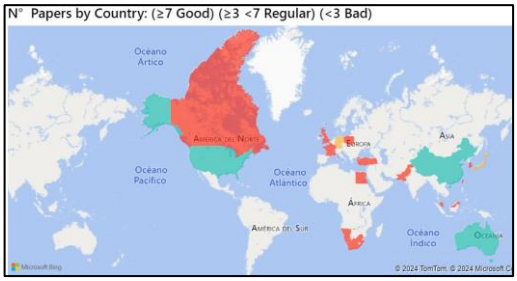

Fig. 6. Heatmap of the number of papers by country

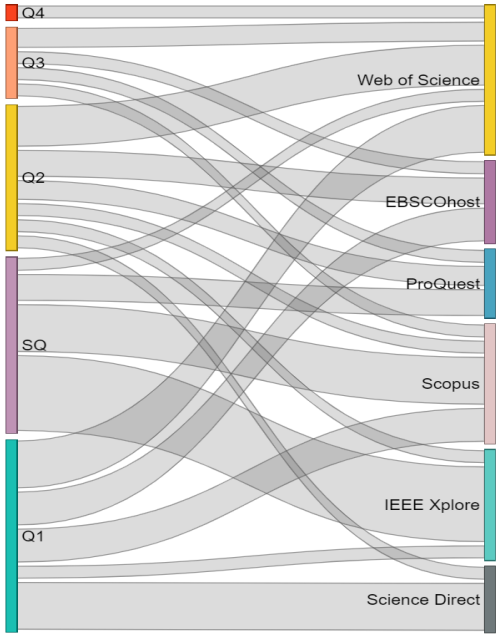

Fig. 7. Quartile levels of papers in relation to sources

primarily associated with high-impact publications in the Q1 and Q2 quartiles, reflecting a commitment to research excellence.

Additionally, there is an interesting presence of studies in Q3 and Q4 through EBSCOhost and ProQuest, indicating that studies are also being published in journals with a more specific or specialized audience. In this particular review, no papers were found that explicitly deal with the similarity between the titles of the selected research. This uniqueness highlights the originality of the present study in relation to existing literature.

The absence of prior research on title similarity implies that this aspect has not been widely explored or analyzed in the specific context of the topic addressed. Therefore, this research has the opportunity to fill a gap in knowledge and offer new perspectives. Research on augmented reality in sports events is being recognized for its quality and relevance in the scientific community.

The fact that publications span across various quartiles of journals provides opportunities for emerging researchers to publish in journals with a lower impact factor while working towards more prestigious publication goals.

RQ2: What are the criteria for measuring user satisfaction regarding augmented reality in sports contexts?

Table 7 presents the criteria used to assess satisfaction concerning augmented reality. As part of the research, three specific criteria were identified to measure user satisfaction with the application of augmented reality in sports events.

Three primary criteria are identified for assessing user satisfaction in augmented reality applied to sports events: interaction, quality, and user experience. With 51.3% of the references, interaction emerges as the most significant factor, followed by quality and user experience, with 30.4% and 18.3% respectively.

This specific review indicates that interaction is a central aspect of user satisfaction, suggesting that designers of augmented reality applications should focus on improving the interface and usability. The quality of content and the fluidity of the user experience provide a solid foundation for evaluating and enhancing augmented reality applications to enrich the experience of sports fans.

RQ3: What are the most frequent and relevant keywords in studies on augmented reality in sports events?

Common metrics exist to determine the importance of a keyword in the context of research. Here are two widely used approaches:

– Term Frequency (TF): This metric calculates how often a word appears in a text. The formula for calculating term frequency is: $\mathrm{TF} = (\text{Number of times the word appears}) / (\text{Total number of words})$. This measure shows how frequently a keyword appears in relation to the total words in the text:

– Inverse Document Frequency (IDF): This measure assesses the relative importance of a keyword across a set of documents. The formula for calculating inverse document frequency is: $\mathrm{IDF} = \log((\text{Total number of documents in the set}) / (\text{Documents containing the word}))$. Inverse document frequency is used to assign greater weight to keywords that appear in fewer documents compared to those that appear in many documents. These measures can be combined to calculate a relevance score for the keywords. Subsequently, visualization algorithms, such as spatial arrangement and font size, can be used to create a keyword cloud.

Keywords are crucial for identifying and categorizing research topics. By examining the most used and relevant keywords in studies on AR and its impact on sports events, valuable insights are gained about the main themes and concepts that have been extensively explored in this field. Figure 8 illustrates the most frequently used keywords, organized by the number of papers in which they appear.

The keyword cloud clearly shows that "augmented reality" and "virtual reality" are the dominant terms, emphasizing their relevance in current research on sports events. Other terms such as "competition" and "COVID-19" suggest a focus on how augmented reality can enhance competition and offer alternatives during disruptive events like a pandemic. According to Zhao et al. [61], the most used keywords are "sports", "virtual reality", "visualization".

ISSN 2007-9737

Fig. 8. Keyword cloud of most used keywords

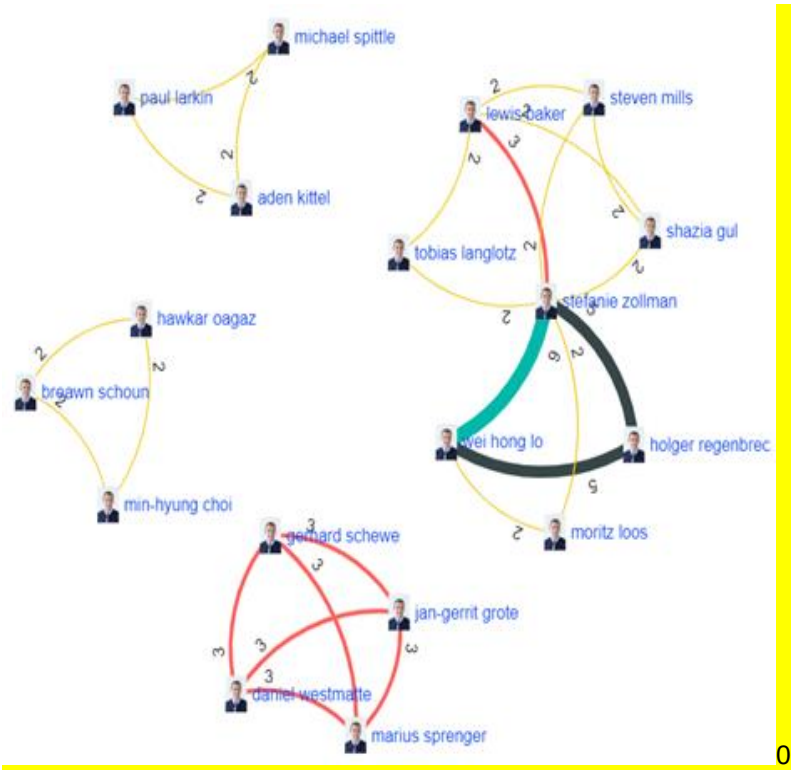

Fig. 9. Bibliometric network of co-authoring authors

The appearance of "COVID-19" indicates the adaptability of augmented reality in the face of challenges of physical events, while terms like "competition" suggest a focus on improving the competitive experience. These terms guide researchers towards areas of growing interest and

the need for immersive technologies to enhance participation and enjoyment of sports events, both in normal times and during global crises.

RQ4: Which researchers frequently collaborate as co-authors on studies about augmented reality in sports events?

To calculate title similarity among research, initial text processing is performed to remove stopwords, punctuation, and apply normalization techniques.

Creation of Term Vectors: From the preprocessed titles, term vectors are constructed. Each term in the title is represented as a dimension in the vector, and a numerical value representing its frequency or importance is assigned.

Cosine Similarity Calculation: Once the term vectors for the titles of the research are ready, the cosine similarity between them is calculated using the following formula:

$$\text{Cosine Similarity}\,(\mathrm{A}, \mathrm{B}) = (\mathrm{A} \cdot \mathrm{B}) \,/\, (||\mathrm{A}|| \times ||\mathrm{B}||),$$

where A and B are the term vectors of the research titles, (A · B) represents the dot product between vectors A and B, and ||A|| and ||B|| represent the norms (lengths) of vectors A and B. The dot product (A · B) is calculated by multiplying corresponding components of vectors A and B and summing the results. The norm of a vector is calculated by taking the square root of the sum of the squares of its components.

The result of the cosine similarity calculation is a value between 0 and 1, where 1 indicates total similarity and 0 indicates no similarity. This mathematical model based on cosine similarity is a common way to measure the similarity between the titles of research.

Analyzing authors who frequently collaborate as co-authors on research helps identify relationships and joint efforts in knowledge generation in this area. Figure 9 shows a bibliometric network illustrating the connections between authors who have collaborated as co-authors.

The provided information reveals exclusive participation between authors Wei Hong Lo and Stefanie Zollman with 9 joint participations in various papers. Similarly, Wei Hong Lo has a notable co-production of papers with Holger Regenbrec with up to 5 joint papers. We also see participation from Marius Sprenger, Jan-Gerrit Grote, Gerhard Scheve, and Daniel Westmatt in up to three papers.

We interpret that for the researched topic, researchers frequently collaborate on joint research and by affinity produce a final work. In this specific review for this question, no papers were found that explicitly deal with authors who are co-authors of the selected research. This uniqueness highlights the originality of the present study in relation to the existing literature. Therefore, this research has the opportunity to fill a knowledge gap and offer new perspectives.

Knowing the most influential publications in the field can help authors establish connections with other researchers and establish an academic network. By citing and referencing these publications in their own work, they can engage in dialogue with other researchers and contribute to the ongoing academic conversation.

RQ5: Which paper titles show high and moderate similarities in research related to augmented reality in sports events?

Similarity in paper titles can reveal recurring themes and approaches within a specific field of research, facilitating the identification of common areas of interest and promoting deeper development in aspects that still require further exploration. Figure 10 presents an analysis of title similarity, illustrating the connections and common themes among various studies.

The figure reveals pertinent information about the similarity between the titles of the analyzed research. Five significant similarities are identified. Title pairs marked in red indicate a notable similarity, with a percentage greater than 61%.

This suggests that these titles share a large number of words or key concepts, demonstrating a significant connection between the corresponding research. On the other hand, titles with a yellow background reflect a moderate similarity of 60% or less. In this specific review, no papers were found that explicitly deal with the similarity between the titles of the selected research.

This uniqueness highlights the originality of the present study in relation to the existing literature. The absence of prior research on title similarity implies that this aspect has not been widely

ISSN 2007-9737

Similarity of Titles

Ref1	Title1	Ref2	Title2	Similitud
[60]	ARSpectator: Exploring Augmented Realit...	[43]	Localisation for Augmented Reality at Sport Eve...	1,00
[27]	From off-site to on-site: A Flexible Frame...	[26]	Flexible XR Prototyping – A Sports Spectating E...	0,69
[7]	Virtual Reality Experience of Mega Sports ...	[6]	Innovation for Positive Sustainable Legacy From...	0,68
[38]	The effects of competitiveness and challe...	[23]	Evaluating the effects of collaboration and com...	0,64
[57]	Application of Adaptive Virtual Reality wit...	[39]	The Conception of Application of Computer Virt...	0,61
[52]	Application of virtual reality technologies ...	[50]	The show must go on - virtualisation of sport ev...	0,60
[46]	Does Winning or Losing Change Players' ...	[15]	Collaborative and Competitive Futures for Virtu...	0,59
[22]	Procedural Marine Landscape Synthesis f...	[15]	Collaborative and Competitive Futures for Virtu...	0,58
[5]	On ice or on air?: how an egregious glowi...	[1]	From the field of play to the laboratory: Recreati...	0,57
[51]	The Performance-Result Gap in Mixed-Re...	[30]	A Fully Immersive Virtual Reality Cycling Trainin...	0,57
[43]	Localisation for Augmented Reality at Sp...	[5]	On ice or on air?: how an egregious glowing ho...	0,56
[60]	ARSpectator: Exploring Augmented Realit...	[5]	On ice or on air?: how an egregious glowing ho...	0,56
[37]	Performance Improvement and Skill Trans...	[36]	Real-time posture feedback for effective motor l...	0,55
[43]	Localisation for Augmented Reality at Sp...	[11]	Mitigating crowded transportation terminals ne...	0,54
[60]	ARSpectator: Exploring Augmented Realit...	[11]	Mitigating crowded transportation terminals ne...	0,54
[31]	Immersive feedback in fencing weapon pr...	[18]	Effects of Visual Biofeedback on Competition Pe...	0,54
[39]	The Conception of Application of Compu...	[8]	Importance of National Fitness Sports Relying o...	0,52
[5]	On ice or on air?: how an egregious glowi...	[4]	Localization and tracking of stationary users for ...	0,51
[38]	The effects of competitiveness and challe...	[22]	Procedural Marine Landscape Synthesis for Swi...	0,50
[29]	From Lab to Field: Demonstrating Mixed ...	[1]	From the field of play to the laboratory: Recreati...	0,49
[58]	Virtual reality sports auxiliary training syst...	[13]	Research on Taekwondo State Recognition Syste...	0,48
[23]	Evaluating the effects of collaboration an...	[22]	Procedural Marine Landscape Synthesis for Swi...	0,48
[28]	Stats on-site — Sports spectator experien...	[19]	The impact of virtual reality (VR) technology on ...	0,48
[23]	Evaluating the effects of collaboration an...	[18]	Effects of Visual Biofeedback on Competition Pe...	0,47
[59]	Design of Athlete's Running Information ...	[2]	Virtual Reality-Based Gymnastics Visualization U...	0,46
[55]	Re-enacting Football Matches in VR using...	[20]	Using 360° virtual reality as a decision-making a...	0,46
[38]	The effects of competitiveness and challe...	[18]	Effects of Visual Biofeedback on Competition Pe...	0,45
[48]	Sports Video Augmented Reality Real-Ti...	[5]	On ice or on air?: how an egregious glowing ho...	0,44
[24]	The Ball is in Our Court: Conducting Visua...	[14]	Expert Sample Consensus Applied To Camera Lo...	0,43
[44]	Analysis and Research on the Timeliness ...	[42]	Decision-Making in Virtual Reality Sports Games...	0,43
[10]	Development of Computer Vision-enable...	[5]	On ice or on air?: how an egregious glowing ho...	0,42
[48]	Sports Video Augmented Reality Real-Ti...	[32]	A Low-cost Approach Towards Streaming 3D Vi...	0,41
[43]	Localisation for Augmented Reality at Sp...	[1]	From the field of play to the laboratory: Recreati...	0,41
[60]	ARSpectator: Exploring Augmented Realit...	[1]	From the field of play to the laboratory: Recreati...	0,41
[28]	Stats on-site — Sports spectator experien...	[9]	Reimagining the Stadium Spectator Experience ...	0,41
[45]	A Multi-Method Analysis of Sport Spectat...	[19]	The impact of virtual reality (VR) technology on ...	0,41
[56]	Paper Research on the Application of Virt...	[19]	The impact of virtual reality (VR) technology on ...	0,40
[56]	Paper Research on the Application of Virt...	[11]	Mitigating crowded transportation terminals ne...	0,40
Total				**144,51**

Fig. 10. Title similarity

explored or analyzed in the specific context of the topic addressed. Therefore, this research has the opportunity to fill a knowledge gap and offer new perspectives. This information is valuable for several reasons.

Firstly, it helps to identify trends in research, as observing the frequency with which certain themes or approaches are repeated in the titles of papers can provide clues about the most relevant and popular areas of interest in the field.

Additionally, identifying papers with similarities in their titles allows researchers to detect potential gaps in knowledge. If there is a limited presence of studies on certain specific aspects or approaches in the titles of the papers, this may indicate a need for additional research to cover those areas that have not yet been thoroughly explored.

5 Conclusions and Future Research

This study conducted a meticulous systematic review that shed light on the prominence and evolution of augmented reality within the context of sports events. Through a detailed analysis of 60 selected publications, the study elucidated the

research trajectory in this field over the past seven years, showing a notable acceleration in research activity starting in 2019, with a peak in publications in 2022.

This growth can be attributed to an increase in interest and investment in this technology, as well as the need for innovative solutions in response to challenges such as the COVID-19 pandemic, which limited participation in physical sports events.

The responses to the research questions are particularly revealing. The first question (RQ1) focused on the quartiles of the journals where studies related to augmented reality and sports events are published. The findings demonstrated that publications are distributed across a broad spectrum of journals, from high-impact (Q1 and Q2) to specialized (Q3 and Q4), indicating a comprehensive recognition of the scientific value of this research.

The second question (RQ2) explored the criteria for assessing user satisfaction with augmented reality in sports. The results indicated that interaction is the predominant criterion, followed by quality and user experience. These criteria highlight the fundamental areas that augmented reality designers must prioritize to enhance user experiences.

The fourth question (RQ4) centered on author collaboration in the field, revealing co-authorship networks that underline the importance of interdisciplinary collaborations in advancing research. Finally, the fifth question (RQ5) uncovered a high degree of similarity between paper titles, suggesting thematic convergence and the possibility of future research collaborations and developments in areas not yet saturated.

It has been established that terms used as synonyms for both variables should not exceed seven years to ensure the inclusion of novel papers. Additionally, it has been revealed that the years with the most publications on this topic, according to scientific paper contributions, are mainly 2021 and 2022.

Another highlighted aspect is the journals that have the most influence on research, as well as the most used keywords in each of them. Moreover, it has been possible to determine that there are successes and failures compared to other authors when analyzing review papers. Given that the influence of virtual reality is a current topic being employed in various fields of sports and sports events, it is suggested to encourage collaboration between different areas and facilitate the exchange of knowledge and experiences.

This can enrich research and generate new perspectives. The present study provides a guide for future researchers interested in exploring virtual reality in the field of sports, and will contribute to the understanding and continuous improvement of this highly relevant field of study.

References

1. **Adams, K., Kiefer, A., Panchuk, D., Hunter, A., MacPherson, R., Spratford, W. (2019)**. From the field of play to the laboratory: Recreating the demands of competition with augmented reality simulated sport. Journal of Sports Sciences, Vol. 38, No. 5, pp. 486-493. DOI: 10.1080/02640414.2019.1706872.
2. **Artlip, M., Chen, J., Li, B. (2022)**. Virtual reality-based gymnastics visualization using real-time motion capture suit. EEE 19th International Conference on Mobile Ad Hoc and Smart Systems, pp. 728–729. DOI: 10.1109/MASS56207.2022.00112.
3. **Azuma, S., Hertzog, C., Sakurai, S., Hirota, K., Nojima, T. (2019)**. Augmented Dodgeball AR viewer for spectators. International Conference on Artificial Reality and Telexistence Eurographics Symposium on Virtual Environments, pp. 25–26. DOI: 10.231 2/egve.20191300.
4. **Baker, L., Ventura, J., Langlotz, T., Gul, S., Mills, S., Zollmann, S. (2024)**. Localization and tracking of stationary users for augmented reality. The Visual Computer, Vol. 40, No. 1, pp. 227–244. DOI:10.1007/s00371-023-02777-2.
5. **Brousseau, M., Kelp-Stebbins, K. (2020).** On ice or on air?: How an egregious glowing hockey puck crossed the line into augmented reality. Sport in Society, Vol. 25, No. 5, pp. 908–926. DOI: 10.1080/17430437.2020. 1807956.
6. **Byers, T., Hayday, E. J., Mason, F., Lunga, P., Headley, D. (2021)**. Innovation for positive

sustainable legacy from mega sports events: Virtual reality as a tool for social inclusion legacy for Paris 2024 Paralympic games. Frontiers in Sports and Active Living, Vol. 3, p. 625677. DOI: 10.3389/fspor.2021.625677.

7. **Capasa, L., Zulauf, K., Wagner, R. (2022)**. Virtual reality experience of mega sports events: A technology acceptance study. Journal of Theoretical and Applied Electronic Commerce Research, Vol. 17, No. 2, pp. 686–703. DOI: 10.3390/jtaer17020037.
8. **Chen, L., Zhu, H. (2022)**. Importance of national fitness sports relying on virtual reality technology in the development of sports economy. Computational Intelligence and Neuroscience, Vol. 2022, No. 1, pp. 1–13. DOI: /10.1155/2022/4128981.
9. **Cheng, K., Koda, K., Masuko, S. (2022)**. Reimagining the stadium spectator experience using augmented reality and visual positioning system. 2022 IEEE International Symposium on Mixed and Augmented Reality Adjunct, pp. 786–787. DOI: 10.1109/ISMAR-Adjunct57072.2022.00167.
10. **Doskarayev, B., Omarov, N., Omarov, B., Ismagulova, Z., Kozhamkulova, Z., Nurlybaeva, E. (2023)**. Development of computer vision-enabled augmented reality games to increase motivation for sports. International Journal of Advanced Computer Science and Applications, Vol. 14, No. 4. pp. 245–252. DOI:10.14569/IJACSA.2023.0140428.
11. **Elkhouly, R., Tamaki, E., Iwasaki, K. (2023)**. Mitigating crowded transportation terminals nearby mega-sports events. Behaviour & Information Technology, Vol. 42, No. 7, pp. 904–920. DOI: 10.1080/0144929X.2022.2048890.
12. **Gao, Y., Ma, G. (2021)**. Human motion recognition based on multimodal characteristics of learning quality in football scene. Mathematical Problems in Engineering, Vol. 2021, No. 1, pp. 1–8. DOI: 10.1155/2021/7963616.
13. **Gong, H. (2022)**. Research on Taekwondo state recognition system based on fuzzy control algorithm. 2022 International Conference on Artificial Intelligence and Autonomous Robot Systems, Vol. 2022, pp. pp. 387–390. DOI: 10.1109/AIARS57204.2022.00093.
14. **Gul, S., Baker, L., Boult, R., Mills, S., Zollmann, S. (2021)**. Expert sample consensus applied to camera localization for AR sports spectators. 2021 36th International Conference on Image and Vision Computing New Zealand, pp. 1–6. DOI: 10.1109/IVCNZ54163.2021.9653307.
15. **Hamilton, R. (2019)**. Collaborative and competitive futures for virtual reality music and sound. 2019 IEEE Conference on Virtual Reality and 3D User Interfaces pp. 1510–1512. DOI: 10.1109/VR.2019.8798166.
16. **Hu, F., Deng, Y., Aghvami, A. H. (2021)**. Cooperative multigroup broadcast 360 video delivery networks: A hierarchical federated deep reinforcement learning approach. IEEE Transactions on Wireless Communications, Vol. 21, No. 6, pp. 4009–4024. DOI: 10.1109/TWC.2021.3126147.
17. **Kang, S. (2020)**. Going beyond just watching: The fan adoption process of virtual reality spectatorship. Journal of Broadcasting & Electronic Media, Vol. 64, No. 3, pp. 499–518. DOI: 10.1080/08838151.2020.1798159.
18. **Kennard, M., Zhang, H., Akimoto, Y., Hirokawa, M., Suzuki, K. (2020)**. Effects of visual biofeedback on competition performance using an immersive mixed reality system. 2020 IEEE International Conference on Systems, Man, and Cybernetics, pp. 3793–3798. DOI: 0.1109/SMC42975.2020.9283022.
19. **Kim, D., Ko, Y. J. (2019)**. The impact of virtual reality (VR) technology on sport spectators' flow experience and satisfaction. Computers in Human Behavior, Vol. 93, pp. 346–356. DOI: 10.1016/j.chb.2018.12.040.
20. **Kittel, A., Larkin, P., Elsworthy, N., Spittle, M. (2019)**. Using 360 virtual reality as a decision-making assessment tool in sport. Journal of Science and Medicine in Sport, Vol. 22, No. 9, pp. 1049–1053. DOI: 10.1016/j.jsams.2019.03.012.
21. **Kittel, A., Lindsay, R., Larkin, P., Spittle, M. (2022)**. The application of 360 VR for training sports officials: a constraints-led approach.

Managing Sport and Leisure, pp. 1–9. DOI: 10.1080/23750472.2022.2126995.

22. **Li, W. (2022)**. Procedural marine landscape synthesis for swimming exergame in virtual reality. 2022 IEEE Games, Entertainment, Media Conference, pp. 1–8. DOI: 10.1109/GEM56474.2022.10017505.
23. **Liang, H. N., Lu, F., Shi, Y., Nanjappan, V., Papangelis, K. (2019)**. Evaluating the effects of collaboration and competition in navigation tasks and spatial knowledge acquisition within virtual reality environments. Future Generation Computer Systems, Vol. 95, pp. 855–866. DOI: 10.1016/j.future.2018.02.029.
24. **Lin, T., Chen, Z., Beyer, J., Wu, Y., Pfister, H., Yang, Y. (2023).** The ball is in our court: conducting visualization research with sports experts. IEEE Computer Graphics and Applications, Vol. 43, No. 1, pp. 84–90. DOI: 10.1109/MCG.2022.3142448.
25. **Lo, W. H., Regenbrecht, H., Zollmann, S. (2022)**. A context-aware interface for immersive sports spectating. 2022 IEEE International Symposium on Mixed and Augmented Reality Adjunct, pp. 605–610. DOI: 10.1109/ISMAR-Adjunct57072.2022.00125.
26. **Lo, W. H., Regenbrecht, H., Zollmann, S. (2022)**. Flexible XR prototyping–a sports spectating example. 2022 IEEE International Symposium on Mixed and Augmented Reality Adjunct, pp. 167–170. DOI: 10.1109/ISMAR-Adjunct57072.2022.00038.
27. **Lo, W. H., Zollmann, S., Regenbrecht, H. (2021)**. From off-site to on-site: A flexible framework for XR prototyping in sports spectating. 2021 36th International Conference on Image and Vision Computing New Zealand, pp. 1–6. DOI: 10.1109/IVCNZ54163.2021.9653277.
28. **Lo, W. H., Zollmann, S., Regenbrecht, H. (2022)**. Stats on-site—sports spectator experience through situated visualizations. Computers & Graphics, Vol. 102, pp. 99–111. DOI: 10.1016/j.cag.2021.12.009.
29. **Lo, W. H., Zollmann, S., Regenbrecht, H., Loos, M. (2019)**. From lab to field: demonstrating mixed reality prototypes for augmented sports experiences. Proceedings of the 17th International Conference on Virtual-Reality Continuum and its Applications in Industry, pp. 1–2. DOI: 10.1145/3359997.3365728.
30. **Imran-Bin, M., Azmi-Bin, M. Y., Nazrita-Binti, I., Eze-Manzura-Binti, M. M., Ng, H. H. (2023)**. A fully immersive virtual reality cycling training (vProCycle) and its findings. International Journal of Advanced Computer Science and Applications, Vol. 14, No. 2. pp. 347–353. DOI: 10.14569/IJACSA.2023.0140242.
31. **Malawski, F. (2022)**. Immersive feedback in fencing training using mixed reality. Computer Science, Vol. 23, No. 1. DOI: 10.7494/csci.2022.23.1.4570.
32. **Marty, K., Rajasekaran, P., Sun, Y., Fuchs, K. (2020)**. A low-cost approach towards streaming 3D videos of large-scale sport events to mixed reality headsets in real-time. 2020 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops, pp. 254–261. DOI: 10.1109/VRW50115.2020.00053.
33. **Mascret, N., Montagne, G., Devrièse-Sence, A., Vu, A., Kulpa, R. (2022)**. Acceptance by athletes of a virtual reality head-mounted display intended to enhance sport performance. Psychology of Sport and Exercise, Vol. 61, p. 102201. DOI: 10.1016/j.psychsport.2022.102201.
34. **Meghji, M., Balloch, A., Habibi, D., Ahmad, I., Hart, N., Newton, R. (2019)**. An algorithm for the automatic detection and quantification of athletes' change of direction incidents using IMU sensor data. IEEE Sensors Journal, Vol. 19, No. 12, pp. 4518–4527. DOI: 10.1109/JSEN.2019.2898449.
35. **Nadeem, A., Jalal, A., Kim, K. (2021)**. Automatic human posture estimation for sport activity recognition with robust body parts detection and entropy markov model. Multimedia Tools and Applications, Vol. 80, pp. 21465–21498. DOI: 10.1007/s11042-021-10687-5.
36. **Oagaz, H., Schoun, B., Choi, M. H. (2022)**. Real-time posture feedback for effective motor learning in table tennis in virtual reality.

International Journal of Human-Computer Studies, Vol. 158, p. 102731. DOI: 10.1016/j.ijhcs.2022.102731.

37. **Oagaz, H., Schoun, B., Choi, M. H. (2021)**. Performance improvement and skill transfer in table tennis through training in virtual reality. IEEE Transactions on Visualization and Computer Graphics, Vol. 28, No. 12, pp. 4332–4343. DOI: 10.1109/TVCG.2021.3086403.
38. **Parton, B. J., Neumann, D. L. (2019)**. The effects of competitiveness and challenge level on virtual reality rowing performance. Psychology of Sport and Exercise, Vol. 41, pp. 191–199. DOI: 10.1016/j.psychsport.2018.06.010.
39. **Ren, Y., Li, J. (2021)**. The conception of application of computer virtual reality technology in sports training. Journal of Physics: Conference Series, IOP Publishing, Vol. 1861, No. 1, p. 012110.
40. **Ritter, Y., Droste, M., Bürger, D., Pastel, S., Witte, K. (2022)**. Comparison of response behavior in karate kumite between real world and virtual reality. Sports Engineering, Vol. 25, No. 1, p. 14. DOI: 10.1007/s12283-022-00378- 1.
41. **Schmidt, A. (2022)**. A comparison of gate detection algorithms for autonomous racing drones. 2022 IEEE Aerospace Conference, pp. 1–13. DOI: 10.1109/AERO53065.2022.9843561.
42. **Seong, B. H., Hong, C. Y. (2022)**. Decision-making in virtual reality sports games explained via the lens of extended planned behavior theory. International Journal of Environmental Research and Public Health, Vol. 20, No. 1, p. 592. DOI: 10.3390/ijerph20010592.
43. **Skinner, P., Zollmann, S. (2019)**. Localization for augmented reality at sport events. 2019 International Conference on Image and Vision Computing New Zealand, pp. 1–6. DOI: 0.1109/IVCNZ48456.2019.8961006.
44. **Tan, Q., Baek, S. S. (2021)**. Analysis and research on the timeliness of virtual reality sports actions in football scenes. Wireless Communications and Mobile Computing, Vol. 221, No. 1, pp. 8687378 DOI: 10.1155/2021/8687378.
45. **Uhlendorf, K., Uhrich, S. (2022)**. A multi-method analysis of sport spectator resistance to augmented reality technology in the stadium. Journal of Global Sport Management, pp. 545–574. DOI: /10.1080/24704067.2022.2155210.
46. **Ventura, R. B., Richmond, S., Nadini, M., Nakayama, S., Porfiri, M. (2021)**. Does winning or losing change players' engagement in competitive games? Experiments in virtual reality. IEEE Transactions on Games, Vol. 13, No. 1, pp. 23–34. DOI: 10.1109/TG.2019.2928795.
47. **Wan, H. (2022)**. Sensor action recognition, tracking, and optimization analysis in training process based on virtual reality technology. Wireless Communications and Mobile Computing, Vol. 2023, No. 1. DOI: 10.1155/2022/1564390.
48. **Wang, H., Wang, M., Zhao, P. (2021)**. Sports video augmented reality real-time image analysis of mobile devices. Mathematical Problems in Engineering, Vol. 2021, No. 1, p. 9963524. DOI: 10.1155/2021/9963524.
49. **Westmattelmann, D., Grotenhermen, J. G., Sprenger, M., Rand, W., Schewe, G. (2021)**. Apart we ride together: The motivations behind users of mixed-reality sports. Journal of Business Research, Vol. 134, pp. 316–328. DOI: 10.1016/j.jbusres.2021.05.044.
50. **Westmattelmann, D., Grotenhermen, J. G., Sprenger, M., Schewe, G. (2021)**. The show must go on-virtualisation of sport events during the COVID-19 pandemic. European Journal of Information Systems, Vol. 30, No. 2, pp. 119–136. DOI: 10.1080/0960085X.2020.1850186.
51. **Westmattelmann, D., Stoffers, B., Sprenger, M., Grotenhermen, J. G., Schewe, G. (2022)**. The performance-result gap in mixed-reality cycling–evidence from the virtual tour de France 2020 on Zwift. Frontiers in Physiology, Vol. 13, 868902. DOI: 10.3389/fphys.2022.868902.
52. **Woyo, E., Nyamandi, C. (2022)**. Application of virtual reality technologies in the comrades' marathon as a response to COVID-19

pandemic. Development Southern Africa, Vol. 39, No. 1, pp. 20–34. DOI: 10.1080/0376835X.2021.1911788.

53. **Wu, C. W., Shieh, M. D., Lien, J. J. J., Yang, J. F., Chu, W. T., Huang, T. H. (2022)**. Enhancing fan engagement in a 5G stadium with AI-based technologies and live streaming. IEEE Systems Journal, Vol. 16, No. 4, pp. 6590-6601. DOI: 10.1109/JSYST.2022.3169553.
54. **Xiao, Y., John, C., Ren, X., Zhang, P. (2019)**. A method for predicting background advertisement exposure parameters in sporting events: Televised football game approach. Plos One, Vol. 14, No. 10, p. e0223662. DOI: 10.1371/journal.pone.0223662.
55. **Xu, W., Alarab, I., Lloyd-Buckingham, C., Bowden, S., Noer, B., Charles, F. (2022)**. Re-enacting football matches in VR using virtual agents' Realistic Behaviours. 2022 IEEE International Conference on Artificial Intelligence and Virtual Reality, pp. 119–123. DOI: 10.1109/AIVR56993.2022.00024.
56. **Yuxin, M. (2021)**. Paper research on the application of virtual reality panoramic news communication technology in sports events. IEEE, 2021 2nd International Conference on Education, Knowledge and Information Management, pp. 670–673. DOI: 10.1109/ICEKIM52309.2021.00152.
57. **Zhang, Y., Tsai, S. B. (2021)**. Application of adaptive virtual reality with Ai-enabled techniques in modern sports training. Mobile Information Systems, Vol. 2021, pp. 1–10. DOI: 10.1155/2021/6067678.
58. **Zhou, J. (2021)**. Virtual reality sports auxiliary training system based on embedded system and computer technology. Microprocessors and Microsystems, Vol. 82, p. 103944. DOI: 10.1016/j.micpro.2020.103944.
59. **Zhu, C. (2022).** Design of athlete's running information capture system in space-time domain based on virtual reality. Scientific Programming, Vol. 2022, pp. 1–10. DOI: 10.1155/2022/9415286.
60. **Zhao, J., Mao, J., Tan, J. (2022)**. Global trends and hotspots in research on extended reality in sports: A bibliometric analysis from 2000 to 2021. Digital Health, Vol. 8. DOI: 10.1177/20552076221131141.
61. **Velasque, A. B., Esparza, R. E., Gamboa-Cruzado, J. (2021).** Aplicaciones móviles multiplataforma para la promoción de la actividad física en tiempos de Covid-19: Un estudio de caso en la Ciudad de Trujillo. Revista Ibérica de Sistemas e Tecnologías de Informação. pp. 474–487.
62. **Neumann, D. L., Moffitt, R. L., Thomas, P. R., Loveday, K., Watling, D. P., Lombard, C. L. (2018)**. A systematic review of the application of interactive virtual reality to sport. Virtual Reality, Vol. 22, pp. 183–198. DOI: 10.1007/s10055-017-0320-5.
63. **Messias-da-Silva, A. M., Albuquerque, S. G., Alencar-de-Medeiros, F. P. (2021)**. A Review on Augmented Reality Applied to Sports. IEEE 16th Iberian Conference on Information Systems and Technologies, Vol. 2021, pp. 1–6. DOI: 10.23919/CISTI52073.2021.9476570.
64. **Malachi, E. G., Tunggara, R., Cahyadi, Y. (2023)**. A systematic literature review of virtual reality implementation in sports. 2023 IEEE International Conference on Artificial Intelligence in Information and Communication, pp. 382–385. DOI: 10.1109/ICAIIC57133.2023.10067095.
65. **Wang, T., Du, Z., Wang, F., Wang, S. (n.d.)**. Augmented reality in sports event videos: A qualitative study on viewer experience.
66. **Uematsu, Y., Saito, H. (2008)**. Visual enhancement for sports entertainment by vision-based augmented reality. Advances in Human-Computer Interaction, Vol. 2008. No. 1, DOI: 10.1155/2008/145363.
67. **Luoto, A. (2018)**. Systematic literature review on user logging in virtual reality. Proceedings of the 22nd International Academic Mindtrek Conference (pp. 110-117).
68. **İmamoğlu, M., Erbaş, Ç., Dikmen, C. H. (2022)**. Trend analysis of augmented reality studies in sports science. Kastamonu Eğitim Dergisi, Vol. 30, No. 3, pp. 502–511. DOI: 10.24106/kefdergi.739231.

69. Castro-Espichan, J., Espinoza-Flores, J., Niño, M. J., Gamboa-Cruzado, J., Oseda, G. D., Mendivel, G. R. (2021). Visión artificial con realidad aumentada para el desplazamiento de personas con discapacidad visual: Una revisión sistemática de la literatura. Revista Ibérica de Sistemas e Tecnologías de Informação, pp. 346–357.

70. Le-Noury, P., Polman, R., Maloney, M., Gorman, A. (2022). A narrative review of the current state of extended reality technology and how it can be utilized in sport. Sports Medicine, Vol. 52, No. 7, pp. 1473–1489.

Article received on 07/06/2024; accepted on 15/09/2024.
**Corresponding author is Blanca Cecilia López-Ramírez.*