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Augmented Reality and Mixed Reality in the Factory of the Future: A Bibliometric Analysis

Redney Monteiro
CeDRI,
Instituto Politécnico de Bragança,
5300-253 Bragança, Portugal
redneymonteiro@ipb.pt

Ana Mara Moreira
CeDRI,
Instituto Politécnico de Bragança,
5300-253 Bragança, Portugal
ana.mmoreira@ipb.pt

André Moreira
CeDRI,
Instituto Politécnico de Bragança,
5300-253 Bragança, Portugal
andre-moreira@ipb.pt

Jorge Laranjeira
Moldit,
Oliveira de Azeméis, 3720-903
Loureiro, Portugal
jorge.laranjeira@moldit.pt

José Barbosa
CeDRI, SusTEC,
Instituto Politécnico de Bragança,
5300-253 Bragança, Portugal
jbarbosa@ipb.pt

Pedro Filipe Oliveira
CeDRI, SusTEC,
Instituto Politécnico de Bragança,
5300-253 Bragança, Portugal
poliveira@ipb.pt

Carlos R. Cunha
CeDRI, SusTEC,
Instituto Politécnico de Bragança,
5300-253 Bragança, Portugal
crc@ipb.pt

Paulo Leitão
CeDRI, SusTEC,
Instituto Politécnico de Bragança,
5300-253 Bragança, Portugal
pleitao@ipb.pt

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***Abstract*—Mixed Reality (MR) and Augmented Reality (AR) – technologies which are part of the spectrum of Extended Reality (XR) – are considered emerging technologies and have gained increasing attention across multiple sectors, including Tourism and Healthcare, due to their versatility as tools for training, simulation, and education, as well as their potential to serve as innovative Human-Machine Interfaces (HMI). Simultaneously, other emerging technologies such as Internet of Things (IoT), Artificial Intelligence (AI), and Robotics have become central themes in R&D associated with the Fourth Industrial Revolution, commonly referred to as Industry 4.0, which emphasizes the digital transformation of industrial processes, through the integration of the new technologies. Beyond their relevance to Industry 4.0, XR technologies are also potential technologies in the emerging paradigm of Industry 5.0, which shifts the focus toward human-centric solutions and collaboration between humans and machines, this potential being based on the ability to enhance human interaction with complex systems. This paper presents the results of a bibliometric analysis of 634 peer-reviewed journal articles indexed in Web of Science and Scopus, spanning research from the past decade (2015 – 2025), as contribute to support future research and guide relevant stakeholders by identifying prevailing trends, leading contributors, and key publication sources in the domain of XR applied to industrial contexts.**

Keywords—Augmented Reality, Mixed Reality, Industry 4.0, Industry 5.0, Bibliometric Analysis

I. Introduction

Manufacturing systems have undergone considerable evolution due to the introduction of digital technologies. Among the various technologies that have been introduced, Augmented Reality (AR) and Mixed Reality (MR) demonstrate enormous potential to assist manufacturing systems and workers. The ability of these technologies to add a layer of information to the physical world, in an interactive and easy-to-use manner, will enable a reengineering that will revolutionize manufacturing systems.

The potential to empower workers is enormous, allowing them to gain better insight into manufacturing processes and be trained to perform the desired tasks. Similarly, MR, in particular, will enhance collaborative work between human operators and automated systems, thus expanding the operational and strategic possibilities of fully utilizing digital twins.

In this context, they present enormous potential that has not yet been fully explored, nor has it been widely adopted within the industry. Some barriers still exist to its full adoption, which are multidisciplinary and range from worker-related barriers to technology adoption, UI/UX challenges, and development and maintenance costs.

This paper explores these dynamics through a bibliometric analysis, identifying dominant trends, leading authors, and the main publication sources in the field of AR applied to industry. The goal is to provide a solid foundation for future research, supporting decision-makers and researchers in building smarter, more collaborative, and more humane factories.

II. Methodology

This bibliometric analysis was done with data captured from Scopus and Web of Science (WoS) in July 2025, with the goal of analyze the research over the last decade (2015-2025) in the field of Industry, more precisely, research which included the use of Mixed Reality (MR) and/or Augmented Reality (AR) towards the next industrial revolution.

The selection process (see Fig. 1) started with the definition of the query, requiring the use of MR or AR, and one of the common topics in the field of research (e.g., industry 4.0), being considered both Title, Keywords and Abstract. The principal topics of the query, MR and AR, are technologies which are part

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of the spectrum of Extended Reality (XR), being AR known as the technology which overlays the digital over the real word, similar to MR, however the later allows equal interaction with the digital, normally through the use of hand tracking or controllers, while AR has indirect interaction, this is, normally the user interacts with devices such as tablets or smartphones, triggering actions in the digital elements.

This query resulted in 742 articles from WoS and 782 from Scopus, which after merged through the use of the tool Zotero, resulted in a total of 1104 different articles, after which, the metadata (e.g., title) of the remaining articles was reviewed to exclude articles outside of this bibliometric analysis scope, resulting in the exclusion of 470 articles (42.57%). Aside from merging, Zotero also identifies retracted items, however none was detected.

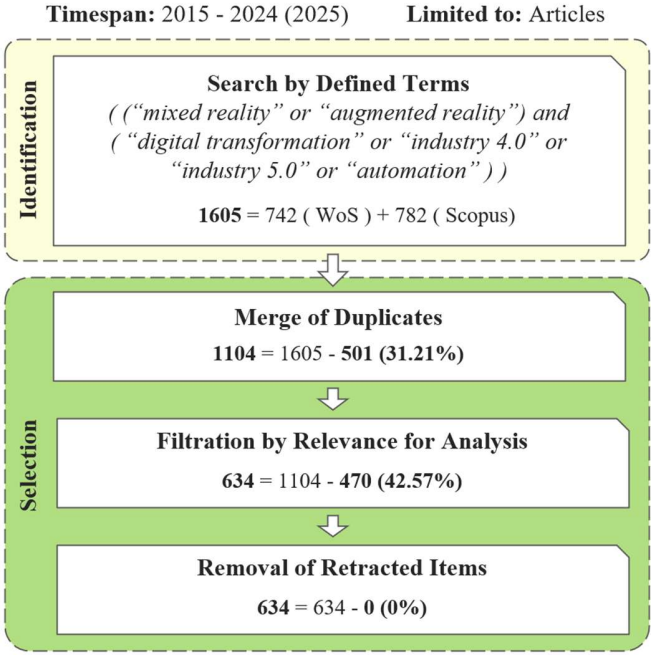

Fig. 1. Flowchart of the selection process

After done the process of selection, it was used the tools Bibliometrix [1] and VOSviewer [2] to generate and extract insights from the final articles selection.

III. Results and Discussion

Between 2015 and 2025, scientific production on Augmented Reality (AR) and Mixed Reality (MR) applied to industrial contexts has shown steady growth, with an Annual Growth Rate of 28.9%, as seen in Table I. The dataset comprises 360 scientific sources and contributions from 2,391 authors, underscoring the broad interest and collaborative nature of research in this field.

The analysis also reveals an average of 4.16 co-authors per article, suggesting a strong level of collaboration among researchers in this field. However, the number of single-authored documents (47 authors) is relatively low, reinforcing the trend towards multidisciplinary teamwork in this domain and the average age of the documents is 3.24 years, indicating that most of the scientific production in this area is recent.

The average number of citations per document is 50.27, a high value that highlights the impact and scientific relevance of the studies analyzed.

TABLE I. Data Overview

General Information		**Authors**	
Timepsan	2015:2025	Authors	2391
Sources	360	Authors of single-Authored Docs	47
Annual Growth Rate %	28.9		
Document Average Age	3.24	Co-Authors per Doc	4.16
Average Citations per Doc	50.27		

The annual scientific production (see Fig. 2) between 2015 and 2025 shows a marked upward trend until 2024, with some periods of fluctuation. In 2015, only 3 articles were published, a number that gradually increased, reaching 87 publications in 2020 and surpassing 100 articles from 2021 onwards. The peak of scientific output was recorded in 2024, with 118 articles published, highlighting the growing academic interest in AR/MR technologies applied to the Factory of the Future [3].

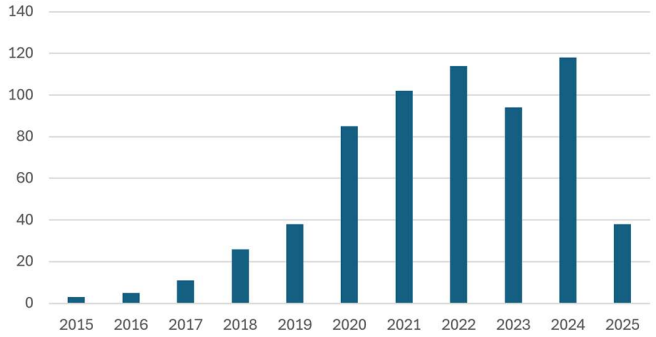

Fig. 2. Annual Scientfic Production (Bibliometrix)

In 2025 (as of the date of data collection), 38 articles have already been accounted for, which may indicate a tendency to maintain current levels of scientific production or even the possibility of a new peak by the end of the year. This evolution confirms that the topic continues to generate strong interest within the scientific community, reflecting its relevance in the context of Industry 4.0 and the transition to more advanced models of smart manufacturing.

A. Terms / Keywords

After the data cleaning and harmonization process (e.g., merging similar terms like "artificial intelligence" and "ai" and excluding principal keywords from de query like "augmented reality"), the WordCloud shown in Fig. 1 was generated.

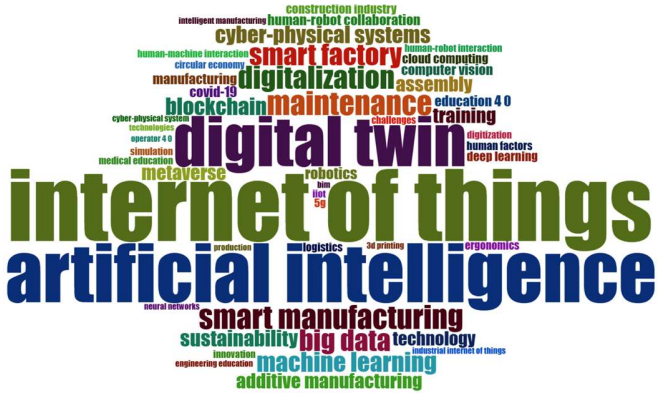

Fig. 3. Author's Keywords WordCloud (Bibliometrix)

A preliminary analysis reveals that "internet of things" and "artificial intelligence" are the most prominent terms, clearly reflecting the integration of technologies IoT and AI in the Industry 4.0 and onwards. In terms of the present research, it can be identified AR as being preferable over MR.

At a secondary level of relevance, keywords such as "digital twin", "smart manufacturing", "smart factory", "digitalization", and "maintenance" stand out, reinforcing the interest in immersive environments and digital representations of physical systems, along with concerns regarding technical structure and operational support.

Other important concepts include "artificial intelligence", "big data", "internet of things", and "integration", indicating how augmented and mixed reality are closely intertwined with other key technologies within the industry 4.0 ecosystem. Lastly, the presence of terms such as "cyber-physical systems" and "human–robot collaboration", although less frequent, may indicate emerging trends pointing toward the evolution into Industry 5.0, which is more human-centered and focused on collaboration and sustainability. Similarly, topics such as "sustainability" and "circular economy" point to research into the potential of these technologies for a greener industry.

In the Fig. 4 can be seen the co-occurrence of author's keywords, this graph was generated after defining a minimum of 10 co-occurrences and set the minimum line strength to 4. It is possible through this graph the common co-occurrence with topics like IoT and AI, as well the reaffirmation of the preference towards AR instead of MR, this being however of a possible consequence due to the popularity/misconception of terminologies, as well due to AR being present in R&D longer than MR.

It is also possible to note that the term "digital twin" is not present, being a consequence of settings defined for this graph generation, however the term "digital transformation" can be seen as topic frequently used with AR and Industry 4.0.

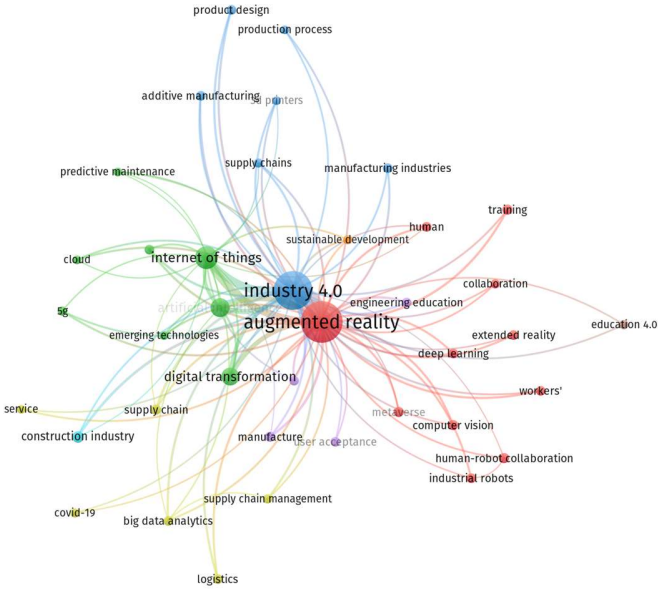

Fig. 4. Author's Keywords Co-Occurrence (VOSviewer)

B. *Countries*

Regarding scientific impact by country (see Table III), Mexico stands out as the most recognized, with a total of 216 citations, followed by India (203), Korea (189), and Italy (187). These figures highlight the growing importance of Latin American and Asian research centers in the production and dissemination of knowledge on the applications of AR and MR in the industrial sector.

TABLE II. MOST CITED COUNTRIES (BIBLIOMETRIX)

Country	Total Citations	Average Article Citations
Mexico	216	16.60
India	203	4.40
Korea	189	17.20
Italy	187	2.70
Singapore	180	45.00
Malaysia	172	13.20
Portugal	130	7.60
Greece	128	8.00
Spain	115	2.90
Hungary	90	15.00

Beyond the top four, countries such as Singapore (180 citations), Malaysia (172), and Portugal (130) also demonstrate significant academic impact, indicating a global and distributed advancement in immersive technology research. Greece (128 citations) and Spain (115) appear as well, reinforcing the relevance of Southern Europe as an emerging hub—although with slightly lower overall citation counts compared to the leading countries. Notably, Singapore presents the highest

average citation per article (45.00), suggesting a strong influence of fewer but highly impactful publications.

In terms of scientific production, the rank is leaded by Italy with 62 articles, followed by India (52) and China (42), however till 2022 these places were occupied by Spain and Germany.

C. Affiliations

The analysis of institutional affiliations reveals a geographically diverse distribution, reflecting the global and multidisciplinary nature of research related to the application of AR/MR in Industry 4.0. Among the most productive institutions are the Ministry of Education and Science of Ukraine and the University of Calabria (Italy), each with 17 published articles.

TABLE III. TEN MOST RELEVANT AFFILIATIONS (BIBLIOMETRIX)

Affiliation	Articles	Affiliation	Articles
Ministry Of Education And Science Of Ukraine	17	Uttaranchal University	10
University Of Calabria	17	Cranfield University	9
University Of Patras	15	Polytechnic University Of Turin	9
National University Of Singapore	11	Tianjin University	9
Universidade Da Coruna	10	University Of Naples Federico Ii	9

Next, the University of Patras (Greece) ranks third with 15 articles, establishing itself as one of the main research hubs in industrial engineering and applied computing in Southern Europe. The presence of Asian and Latin American institutions is also notable, such as the National University of Singapore (11 articles) and the University of A Coruña (Spain) (10 articles).

Other notable institutions include Uttaranchal University (India), Cranfield University (United Kingdom), Polytechnic University of Turin (Italy), Tianjin University (China), and the University of Naples Federico II (Italy), each with 9 articles.

In the Fig. 3 it can also be seen a diversity of collaborations between affiliations in this topic of research, being highlighted the collaboration between the Polytechnic University of Turin and the University of Naples Federico II, both in Italy.

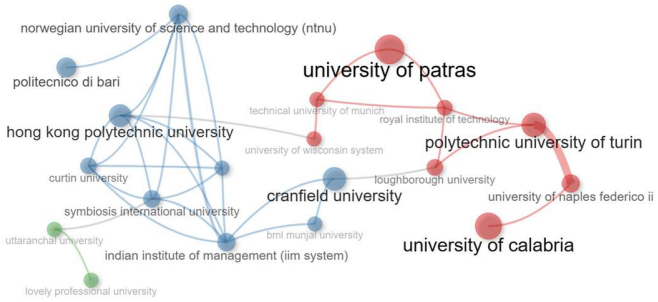

Fig. 5. Collaboration Network between Countries (Bibliometrix)

D. Authors

Regarding the most productive authors in the analyzed field of study, three researchers stand out with the highest number of publications to date: Dr. Tiago M. Fernández-Caramés, Dr. Paula Fraga-Lamas, and Dr. Dimitris Mourtzis, each with 8 articles. Dr. Fernández-Caramés and Dr. Fraga-Lamas, both affiliated with the University of A Coruña (Spain), are widely recognized for their contributions to the application of Industry 4.0 technologies, the Internet of Things (IoT), and augmented reality in smart industrial environments (Fraga-Lamas & Fernández-Caramés, 2019). Dr. Dimitris Mourtzis is affiliated with the University of Patras (Greece).

In second place, with 7 publications, is Dr. John Angelopoulos, also from the University of Patras, reinforcing the role of this institution as a key hub in scientific production on industrial digitalization.

Several other authors with 5 published articles each are also among the most prominent, including Dr. Fabio Bruno, Dr. Emanuele Marino, Dr. Tariq Masood, Dr. Bruno Simões, and Dr. Loris Barbieri, all of whom have made significant contributions in areas such as applied engineering, digital simulations, and human-machine interaction—central themes in the integration of immersive technologies into production systems. In addition, Dr. Oscar Blanco-Novoa stands out with 4 articles, often co-authored with Fernández-Caramés and Fraga-Lamas, further reinforcing the consistency of a well-established line of research.

TABLE IV. TEN MOST RELEVANT AUTHORS (BIBLIOMETRIX)

Author	Articles	Articles Fractionalized
Ernandez-Carames, Tiago M.	8	2.03
Fraga-Lamas, Paula	8	2.03
Mourtzis, Dimitris	8	2.83
Angelopoulos, John	7	2.50
Barbieri, Loris	5	1.07
Bruno, Fabio	5	1.07
Marino, Emanuele	5	1.07
Masood, Tariq	5	2.03
Simoes, Bruno	5	0.96
Blanco-Novoa, Oscar	4	0.95

E. Sources

Regarding sources (see Table V), *Applied Sciences–Basel* is the journal with the highest number of publications in the field, totaling 31 articles, followed by *Sensors* with 24 articles and *IEEE Access* with 18. Although ranked fifth in terms of number of publications, *Computers in Industry* stands out with the highest Impact Factor (IF 9.1) among the ten most relevant sources, reflecting their strong scientific influence and selectivity. Other high-impact journals include *Robotics and Computer-Integrated Manufacturing* (IF 11.4) and *Computers & Industrial Engineering* (IF 6.7), both of which also appear in the ranking despite publishing fewer articles.

These results suggest a balance between productivity and impact across the main sources, with a notable presence of multidisciplinary and applied engineering journals.

TABLE V. TEN MOST RELEVANT SOURCES (BIBLIOMETRIX)

Journal	Nº of Articles	Impact Factor (IF) by Journal Citation Reports 2024
Applied Sciences-Basel	31	2.5
Sensors	24	3.5
IEEE Access	17	3.6
Sustainability	17	3.3
Computers In Industry	14	9.1
International Journal Of Advanced Manufacturing Technology	14	3.1
Robotics And Computer-Integrated Manufacturing	12	11.4
Computers & Industrial Engineering	8	6.5
International Journal Of Computer Integrated Manufacturing	8	4.0
Electronics	7	2.6

F. Documents

Concerning article relevancy through global citations (see Table VI), the most cited publication is "Towards Aircraft Maintenance Metaverse Using Speech Interactions with Virtual Objects in Mixed Reality" [4] by Aziz Siyaev and Geun-Sik Jo, published in *Sensors* in 2021, with a total of 173 citations and an average of 34.6 citations per year. This article introduces combines AI, speech recognition and MR for education and training in aircraft maintenance.

The second most cited article is "Ubiquitous knowledge empowers the Smart Factory: The impacts of a Service-oriented Digital Twin on enterprises' performance" [5] by Francesco Longo, Letizia Nicoletti and Antonio Padovano, published in *Annual Reviews in Control* in 2019, with 115 citations and 16.43 citations per year. In this article is made a prototype combining Digital Twins and AR, for knowledge retrieval over a ontology-oriented knowledge structure, being tested in dedicated environments, showing improvements in time, costs and process quality.

At third place is "Operator 5.0: A Survey on Enabling Technologies and a Framework for Digital Manufacturing Based on Extended Reality" [6] by Dimitris Mourtzis, John Angelopoulos and Nikos Panopoulos, published in *Journal of Machine Engineering* in 2022, with 96 citations and an average of 24.00 citations per year. This article starts with identifying key technologies in the progress towards Industry 5.0 and the new human operator (Operator 5.0), followed by a proposal of a framework based on the use of MR for the training and support of shopfloor technicians.

TABLE VI. TEN MOST RELEVANT ARTICLES (BIBLIOMETRIX)

Paper (DOI)	Total Citations	Citations Per Year
SIYAEV A, 2021, SENSORS (10.3390/s21062066) [4]	173	34.60
LONGO F, 2019, ANNU REV CONTROL (10.1016/j.arcontrol.2019.01.001) [5]	115	16.43
MOURTZIS D, 2022, J MACH ENG (10.36897/jme/147160) [6]	96	24.00
HOREJSI P, 2020, IEEE ACCESS (10.1109/ACCESS.2020.2994650) [7]	58	9.67
SOLANES J, 2020, INT J ADV MANUF TECHNOL (10.1007/s00170-020-05997-1) [8]	52	8.67
DE A R, 2018, INT J INTERACT DES MANUF (10.1007/s12008-017-0451-7) [9]	43	5.38
BOTTANI E, 2021, COMPUT IND (10.1016/j.compind.2021.103429) [10]	39	7.80
JALO H, 2022, VIRTUAL REALITY (10.1007/s10055-022-00662-2) [11]	30	6.00
HUDA A, 2021, INT J INTERACT MOB TECHNOL (10.3991/ijim.v15i05.20905) [12]	27	5.40
MARTÍN-BARRIO A, 2020, SENSORS (10.3390/s20082181) [13]	26	4.33

IV. CONCLUSION

The present bibliometric analysis does an overview of the scientific production from 2015 to 2025 concerning the application of AR and MR in industrial contexts. The findings identify a growth in research activity, with an average annual growth rate of 28.9%, highlighting the increasing relevance of XR technologies in the digital transformation of the industrial sector. The analysis also revealed a strong collaborative nature among researchers, with an average of 4.16 co-authors per article. Also, the high average number of citations per article (50.27) underscores the scientific impact and maturity of the field. In terms of technological convergence, AR and MR are frequently studied alongside other Industry 4.0 pillars such as Artificial Intelligence, Internet of Things, and Digital Twins—confirming their central role in enabling smart and connected manufacturing systems, being AR more frequently used. It was also noted that research is globally distributed, with contributions from Latin America, Asia, and Southern Europe. Among the countries, Mexico and India stand out in terms of citations, while Italy and India lead in publication volume. The most cited documents demonstrate the diverse application potential of XR, from digital training environments to human-machine collaboration frameworks. These results collectively reinforce the strategic importance of AR/MR research in shaping the future of manufacturing, signaling strong opportunities for interdisciplinary innovation and technological integration in human-centered industrial systems.

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