The Past, Present and Future of the Metaverse Research: A Bibliometric Review

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ABSTRACT

Since the word "Metaverse" was first coined by the novelist Neal Stephenson in 1992, it has immediately shown endless charm and attracted many scientists, engineers, and geeks from all over the world to become its "vassals". In recent years, with the development of virtual reality, blockchain, and smart wearable devices, the idea of Metaverse seemed to be touchable and became a popular topic in academic literature. This study presents a comprehensive bibliometric analysis of 665 publications related to the metaverse. Using the Web of Science Core Collection database, the R-tool "Bibliometrix 4.0.0", and the software VOSviewer, we found that computer science is the predominant discipline, accounting for 40% of all publications. Sustainability emerged as the leading journal in the field since 2021. Geographically, China leads in research productivity, with the UK receiving the highest citations, and Korea showing significant governmental funding support. Through scientific mapping, we identified five crucial keyword clusters representing the multifaceted nature of metaverse research. Our findings highlight the importance of an interdisciplinary approach, particularly emphasizing the incorporation of social sciences into metaverse research.

Keywords: Metaverse, Bibliometric analysis, Literature review, Virtual reality, Augmented reality

INTRODUCTION

Technological advancements consistently reshape society, propelling us into the burgeoning era of the metaverse—a fusion of physical reality and digital simulation. In this realm, users, represented by avatars, engage within a virtual space reflective of the real world. The metaverse, spanning sectors from gaming and media to business and education, emphasizes a user-centric and immersive experience. Even in its infancy, the metaverse has witnessed impressive growth, with platforms like Decentraland, The Sandbox, Roblox, Somnium Space, and VoRtex emerging in response to heightened interest. Symbolic of a community, the metaverse operates on unique economic principles; NFTs and cryptocurrencies, for instance, serve as dominant currencies, and virtual assets range from intellectual property to digital collectibles and virtual real estate. Beyond merely being an application of computer science and engineering, the metaverse heralds a transformative phase in social civilization, with potential impacts on human behaviours, emotions, laws, and

ethics. Fundamentally, the metaverse represents a vision of the future internet society.

The academic community has exhibited a growing interest in metaverse research. Key research areas encompass the design of virtual environments (Cho et al., 2022), the conceptualization of avatars (Qi et al., 2022), the innovation in interaction technologies (Han et al., 2023), and the examination of social and economic dynamics (Shama et al., 2010) within virtual realms. Furthermore, scholars are delving into the ethical and legal ramifications of metaverses (Kshetri, 2022), addressing concerns related to privacy, ownership, and governance. Despite this flurry of activity, there remains a notable gap in bibliometric studies concerning the metaverse. A few have focused on niche areas, such as the application of the metaverse in education (Tas et al., 2022, Tlili et al., 2022), while others, due to their early publication dates, were limited by smaller dataset sizes of around 200 samples (Abbate et al., 2022, Feng et al., 2022). To address this gap, this paper offers a bibliometric examination of metaverse-centric literature, aiming to furnish a foundational schema for subsequent scholarly endeavours.

MATERIALS AND METHODS

For our study, we prioritized the Web of Science Core Collection (WoS) for data collection due to its high-quality metadata. Unlike Scopus, which stores the complete APA record within the manuscript, WoS provides detailed document information and pre-processes reference lists into discrete data points, such as first author, year, journal, and issue. On January 31st, 2023, we assembled a literature dataset using the search query "Topic=Metaverse*". This captured articles with the term "Metaverse" or "Metaverses" in the title, abstract, or keywords. Initially, we identified 705 relevant documents from the WoS. After excluding 24 non-English articles and certain non-academic articles like book reviews, news items, and art exhibit reviews, our dataset was refined to 665 documents. For basic descriptive analysis, we employed the open-source tool, Bibliometrix 4.0.0 (Aria et al., 2017). It facilitated the collection of statistical results which we then consolidated into concise tables and visually engaging figures. For our science mapping analysis, we utilized the free software VOSviewer (van Eck et al., 2010). This tool enabled us to explore in-depth relationships and co-occurrence networks. Specifically, we presented a keyword co-occurrence clustering network. Given the dynamic nature of the Web of Science database, which often undergoes retrospective updates, we deliberately captured a snapshot of Metaverse research from 1995 to January 2023 by setting specific parameters. As the field continues to evolve, we anticipate that future bibliometric analyses could provide a richer and modified perspective on the topic.

RESULTS

Table 1 provides descriptive statistics of our dataset spanning from January 1995 to 2023. Our dataset comprises 665 documents by 1,761 authors from 423 sources, with a total of 25,211 citations. There are 2,136 original author keywords, complemented by an additional 766 "keywords plus"

generated by Clarivate's algorithm. These "keywords plus" are sourced from common citation titles and can enhance bibliometric analysis accuracy. The average document is cited 5.135 times and has an age of 2.74 years, underscoring the metaverse's emergent research significance. Of the documents, 22.26% are single-authored, while 77.74% involve co-authors, averaging 3.44 co-authors per document. The international collaboration rate stands at 26.62%.

Table 1. Descriptive statistics.

Description	Results
Timespan	1995-2023
Documents	665
Sources (Journals, Books, etc.)	423
Authors	1761
References	25211
Keywords Plus	766
Author's Keywords	2136
Average Citations per Documents	5.135
Document Average Age	2.74
Single-authored Documents	148
Co-authored Documents	517
Co-authors per Documents	3.44
International Co-authorships %	26.62

Transitioning from the overall dataset characteristics, it's pivotal to emphasize the interdisciplinary nature of Metaverse research. While the Web of Science database can allocate a single article to multiple related research areas, a clear concentration emerges as shown in Table 2. Predominantly, Metaverse studies align with science and technology sectors. The leaders are computer science (40.75% of total publications), followed by engineering and telecommunications. Despite the dominance of technology sectors, the inclusion of fields like business, economics, educational research, chemistry, environment, and physics within the top ten areas accentuates the breadth of Metaverse exploration. Together, these top ten fields account for 76.09% of all Metaverse-related publications, as discerned from our WoS data analysis.

Table 2. Research areas.

Rank	Research Areas	Number of Documents	Ratio
1	Computer Science	271	40.75%
2	Engineering	178	26.77%
3	Telecommunications	63	9.47%
4	Business, Economics	60	9.02%
5	Science Technology Other Topics	45	6.77%
6	Education, Educational Research	38	5.71%
7	Chemistry	35	5.26%
7	Materials Science	35	5.26%
9	Environmental Sciences, Ecology	30	4.51%
10	Automation Control Systems	29	4.36%
10	Physics	29	4.36%

In tandem with the diverse range of research areas contributing to Metaverse studies, the sources of these studies are equally diverse. Although the Metaverse topic has notably gained traction in just a year, making citation metrics like h-index and g-index less compelling currently, total publications serve as our benchmark for core sources, authors, institutions, and funding bodies. For clarity, the h-index measures both the productivity and citation impact of publications, while the g-index gives more weight to highly cited papers.

Table 3. Publication sources.

Rank	Sources	Type	Publisher	TP	TC	H	G
1	Sustainability	Journal	MDPI	20	55	5	7
2	IEEE Trans. Syst. Man Cybern.	Journal	IEEE	17	0	N/A	N/A
3	IEEE Access	Journal	IEEE	14	86	3	9
4	IEEE VR 2022 Workshops	Conference	IEEE	14	1	1	1
5	Applied Sciences-Basel	Journal	MDPI	13	35	3	5
6	Sensors	Journal	MDPI	11	36	3	6
7	Electronics	Journal	MDPI	8	24	2	4
8	IEEE/CAA J. Autom. Sin.	Journal	IEEE	8	23	2	4
9	Frontiers In Psychology	Journal	Frontiers	8	6	2	2
10	Int.J.Environ. Res.PublicHealth	Journal	MDPI	7	9	2	3

(TP=Total Publication, TC=Total Citation, H=H-index, G=G-index.)

Table 3 elucidates the leading sources for Metaverse research based on productivity. Notable highlights include the journal Sustainability, leading in most bibliometric metrics with 20 publications and 55 citations, boasting an h-index of 5 and a g-index of 7. The 2022 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops stands out as the most prolific conference, featuring 14 papers. On the publisher front, MDPI and IEEE dominate, underlining their pivotal role in cutting-edge technology research sectors, including the Metaverse.

Many papers in our sample involve collaborations, sometimes between authors from different countries. Therefore, we examined the countries of 638 corresponding authors in our dataset, excluding 27 documents due to missing corresponding author information. Table 4 displays the top ten most productive countries of these corresponding authors. Evidently, China leads with 169 documents, making up 26.5% of total publications. The United States and Korea trail closely with 80 and 77 documents, each accounting for roughly an eighth of the total Metaverse-related publications. When considering international collaborations, European authors stand out. Germany boasts the highest rate of international co-publications at 50%, with the United Kingdom and Spain trailing at approximately 40% of their publications.

Table 4 also provides cumulative citation data by country or region. The United Kingdom's publications top the list with the highest total citations (1,611) and an average citation count of 35.02, indicating significant academic impact. The United States, South Korea, and China also excel in total citations, though their average per paper falls short when compared to the United Kingdom. The high average citation count for the United Kingdom suggests the superior quality of its scientific contributions.

Table 4. Country statistics.

Rank	Country	Total Publication	Rank	Country	Total Citation	Average Citation
1	China	169	1	UK	1611	35.02
2	USA	80	2	USA	523	6.54
3	Korea	77	3	Korea	366	4.75
4	UK	46	4	China	224	1.33
5	Turkey	23	5	France	64	5.82
6	Germany	22	6	Germany	56	2.55
7	Italy	21	7	Spain	50	2.63
8	Spain	19	8	Japan	48	3.69
9	Japan	13	9	Italy	46	2.19
10	Canada	12	10	Finland	38	7.60

Table 5. Funding agencies.

Rank	Funding Agency	Total Publication	Country/Region
1	National Natural Science Foundation of China	63	China
2	National Research Foundation of Korea	25	Korea
3	National Key Research and Development Program of China	12	China
4	Ministry of Science & ICT, Republic of Korea	10	Korea
5	Ministry of Education Moe, Republic of Korea	8	Korea
5	Science and Technology Development Fund Macau SAR	8	Macau
7	Ministry of Science & ICT Future Planning, Republic of Korea	7	Korea
8	European Commission	6	EU
8	Ministry of Education, Singapore	6	Singapore
8	National Research Foundation, Singapore	6	Singapore
8	National Science Foundation	6	USA

Table 5 lists the top ten funding agencies for Metaverse-related research in our dataset. The National Natural Science Foundation of China emerges as the leading sponsor, backing 63 documents, which account for 9.4% of total publications on the subject. It's closely followed by the National Research Foundation of Korea, which funded 25 documents, representing 3.8%. Remarkably, four of the top ten sponsors for Metaverse studies hail from Korea. This underscores a significant initiative by the Korean government, pointing to a concerted effort to collaborate with the industry and amplify the advancement of metaverse technologies and ecosystems for future generations.

To gain deeper insight into the relationships among keywords, we employed VOSviewer to create a network map and categorize them into distinct clusters. For this analysis, we combined both "author keywords" and "keywords plus" to form cohesive keyword clusters. Corresponding to Table 6, Figure 1 displays the interlinked keyword clusters, which coalesce into five distinct groups, each represented by a different colour.

Table 6. Keywords clusters.

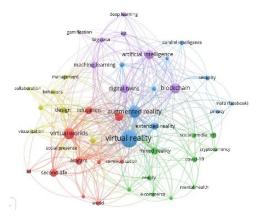| Cluster	Keywords
1 (red)	3D; Avatars; Communication; Education; Internet; Second Life; Students; Virtual Environments; Virtual Words; World
2 (green)	Covid-19; Cryptocurrency; E-Commerce; Environments; Mental Health; Mixed Reality; NFT; Reality; Social Media; Telepresence
3 (blue)	Augmented Reality; Extended Reality; Games; Meta (Facebook); Parallel Intelligence; Privacy; Security; Solid Modeling; Virtual Reality
4 (yellow)	Behaviors; Collaboration; Design; Immersion; Management; Performance; Social Presence; Visualization
5 (purple)	Artificial Intelligence; Big Data; Blockchain; Deep Learning; Digital Twins; Gamification; IOT; Machine Learning

Figure 1: Keywords clusters.

Cluster one, highlighted in red, delves into avatars and the sociology of metaverses. On one hand, avatars in the metaverse represent human users (Qi et al., 2022). They have evolved from mere emblematic symbols, akin to the two-dimensional profile photos commonly used online today, into three-dimensional virtual "puppets" that mirror users' body language, gestures, tone, and even attitudes (Cho et al., 2022). This provides a depth to interactions in the metaverse, making them richer than those on the traditional internet and more akin to real-life interactions. Conversely, the virtual communities formed by these avatars also mirror characteristics of human society (Bibri, 2022). Within this space, users can engage in a plethora of activities ranging from work and education to communication and commerce. This includes buying virtual real estate, running schools, selling virtual goods, and even establishing families in the virtual realm. Personal spaces can be designed and constructed, friends invited over for games and social interactions. And with the advancement of 3D technology, facial expressions and body language of avatars can be discerned in detail, making interactions more vivid and lifelike.

The second research stream, highlighted in green, delves into the business and financial models within the metaverse. Central to this cluster

are keywords such as "cryptocurrency", "non-fungible token (NFT)", and "e-commerce". Within the metaverse's electronic business model, cryptocurrencies function as the circulating currency (Vidal-Tomas, 2022). Asset rights are solidified in the form of NFTs. The blend of blockchain and NFT technologies paves the way for near-indisputable, traceable, and distributed ledgers. Within these ledgers, crypto-tokens and smart contracts are orchestrated to function seamlessly (Dai, 2022). The recorded transactions pertaining to the transfer of cryptocurrencies not only indicate ownership chains of specific virtual assets, such as art and land, but also validate the transaction's authenticity on the blockchain. This equips e-commerce platforms with enhanced tools to fortify user security and privacy. Essentially, the metaverse can be conceptualized as a vast, accessible digital realm where individuals can acquire and safeguard virtual assets.

The third cluster, highlighted in blue, explores the nexus between the metaverse and reality, coupled with the ethical dimensions within the metaverse. The metaverse is recognized as a simulation, enhancement, and reimagining of the tangible world. Central to the metaverse's framework is augmented reality (AR), a technology that melds virtual elements with the real world, typically facilitated by electronic devices, like smartphone or tablet apps (Rauschnabel et al., 2022). A common application infuses the real-world environment with added information, entertainment, or experiences to elevate the user's sensory journey. Pokémon Go stands as a testament to AR's successful deployment. Conversely, virtual reality seeks to employ computer algorithms to sculpt an enveloping virtual realm for uninhibited exploration. Broadening the scope, extended reality encompasses an array of metaverse technologies, including virtual reality, augmented reality, and mixed reality, with a vision to fuse the physical and virtual domains. Beyond technological innovations, it's imperative to mull over ethical and legal implications. Foundational to the metaverse should be robust privacy and security measures. Historically, momentous technological leaps invariably usher in a cascade of societal and legal challenges (Kshetri, 2022). Prospective metaverse research might pivot to harnessing novel technologies to fortify individual user security and privacy. Clear directives from governing bodies on the collection, utilization, and ownership of voluminous data are essential.

The fourth cluster, highlighted in yellow, delves into the abstract philosophies underpinning the metaverse. Emphasizing terms such as "behaviour", "collaboration", "design", "management", and "social presence", this grouping encapsulates a user-centric design ethos. With the rising ubiquity of the metaverse, both researchers and product managers are pivoting towards tailoring virtual landscapes and interactions to human inclinations and patterns. This entails drawing insights from a myriad of social science fields including anthropology, psychology, sociology, and management. Through a deep dive into human behavioural ecology, scholars are equipped to unravel the intricacies of human comportment, subsequently enabling them to digitally replicate these behaviours (Shen et al., 2021). Probing the dynamics of human collaboration paves the way for pioneering interfaces, tools, and algorithms that bolster remote teamwork and elevate efficiency. Furthermore, understanding the nuances of human social interactions offers the

potential to craft logical social frameworks that promote mutual engagement and synergy amongst users (Zhang et al., 2022). This paradigm champions the ethos of user-centric design, underscoring the premium on user experience and enriching the genuineness of human-computer interfaces.

The fifth cluster, represented in purple, delves into the interplay between big data, machine learning, artificial intelligence (AI), and the metaverse. Employing big data technologies, vast volumes of data, spanning user behaviours to transactional records, can be culled from the metaverse's milieu (Zhou, 2022). Leveraging this treasure trove of information, software experts are pioneering deep learning architectures, such as intricate neural networks tailored for virtual spaces and applications (Cho et al., 2022). Riding on this big data wave, AI algorithms are honing their prowess in natural language processing and computational aptitude through deep learning. Currently, AI's foray into domains like voice and facial recognition, content genesis, and board games like chess has reached a notable degree of maturation. The research trajectory is poised to veer towards intricate endeavours, such as logic-driven problem-solving. These cutting-edge technological evolutions are primed to propel the metaverse into arenas as diverse as mathematics, finance, computing, and defence.

CONCLUSION

In a comprehensive bibliometric analysis of metaverse-related literature, this study found that computer science dominates, accounting for 40% of publications. The journal "Sustainability" has distinguished itself since 2021 in terms of volume and h-index, becoming indispensable for metaverse stakeholders. While China leads in research output, the UK has the most citations, and the Korean government provides significant funding support. Our scientific mapping delineated five keyword clusters that encapsulate the metaverse's multifaceted essence. These clusters weave together technological innovations, societal dynamics, ethical concerns, and commerce. Key areas include the sociology of avatars, the economics of virtual assets, advancements in AR, VR, MR, and XR, legal considerations for user safety and privacy, and the human-centric design philosophy. Furthermore, the nexus of big data, machine learning, and artificial intelligence with the metaverse highlights the importance of an interdisciplinary approach, especially the incorporation of social sciences.

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