Journal of Big Data

BRIEF REPORT Open Access

The state of metaverse research: a bibliometric visual analysis based on CiteSpace

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Abstract

Objective: To understand the current status of research in the field of metaverse, and to analyze the research progress and evolutionary trends in this field.

Methods: Based on the bibliometric analysis, a total of 921 papers were obtained by searching the Web of science core database for the keyword "metaverse". CiteSpace was used to visualize and analyze the current status and trends of metaverse research in China.

Results: Ireland is currently the country with the highest research impact. China is currently the country with the largest number of publications in this field, but the impact of the research is insufficient. The current research in the highly cited literature focuses on technical and history reviews of the metaverse as well as its development in the field of education. Artificial Intelligence and utaut2 are the underlying clusters of cited literature in this research area. Several research hotspots have been formed, such as virtual reality, augmented reality, mixed reality, digital twins and artificial intelligence.

Conclusion: The current research on metaverse in various fields is basically in its infancy, but has a great potential for future development and will gradually penetrate into many different directions with many challenges.

Keywords: Metaverse, Visual analysis, CiteSpace

Introduction

In the speculative novel named Snow Crash, the virtual parallel world in which users interact with characters is called the metaverse [1], which has also become the literary Origin of the metaverse mentioned by most scholars. In the virtual reality field, the initial version of the Metaverse was conceptualised as a network of virtual worlds where avatars could travel between them effortlessly. This idea was brought to life with Opensim's Hypergrid [2]. The second iteration of the Metaverse in mixed reality is presently being developed to establish a social and immersive VR platform that can function smoothly with massively multiplayer online games, open game worlds, and AR collaboration spaces. Users will be able to socialize and interact with one another as 3D holograms or avatars in physical or virtual spaces without any limitations, according to this

vision [3]. Damar defined the metaverse as a "3D virtual environment where augmented and virtual reality technologies enable all activities" in 2021 [4].

With the flattening of the Internet, the development of industrial intelligence, and the imagination of a super-intelligent society, the metaverse has become the current hotspot of industry and research [5]. As a product of the ultimate form of future society [6], the relationship between the virtual world constructed by the metaverse and the real world has become the focus of discussion. However, from the borrowing of literary ideas to the landing of industrial applications, the exploration of the metaverse is still in the early stages of chaos, and different experts have not formed a unified and clear understanding of the metaverse. Lee et al. [7] considered the metaverse as a virtual environment blending physical and digital facilitated by the development of Internet and Extend Reality, From the dual perspective of digital and physical world, they proposed three essential stages for the development of metaverse: Digital Twins (Our physical environments are digitised and thus own the capability to periodically reflect changes to their virtual counterparts), Co-existence of physical-virtual reality and Digital Natives. However, there is no high coverage of the applicable scene for the definition of the metaverse now, it is difficult to have a unified conclusion.

Although the business men focus on the extension of metaverse application scenarios, scholars pay more attention to the mechanism of metaverse in the process of data and manifestation of human thought and behavior [8]. Park et al. [9] proposed the basis of four elements: sense of reality, popularisation of access and identity, interactivity and extensibility. People can communicate in the metaverse through digital avatars [10, 11], and activities in the real world have a new activity space with the help of augmented or virtual reality services. Utility becomes a main idea for the design of the parallel space of the metaverse. Wang et al. [12] introduced the concepts of meta-enterprise and meta-city, which reflect the features of individuals, objects, institutions, places, among other elements found in actual enterprises and cities. Furthermore, they presented a simulation approach using metaiverse attributes to assess and improve decision scenes, which involves computational experimental methods. In addition, metaverse can also be used as the digital copy of enterprise marketing in the virtual world to realise the innovation of virtual platform, content service, consumer and business behaviour [13]. The study of the metaverse provides enlightenment for the future of human culture, scientific and technological advancements, and social progress, among other things. The current research progress and hot areas of the metaverse can be elucidated under the dual promotion of academic research and practical application. This provides an important theoretical guide towards better understanding key technologies and future development trends of the metaverse.

There are few bibliometric analysis articles available on the field of metaverse. Most of these articles use VOSviewer and Citespace softwares to conduct a basic knowledge graph analysis on a specific topic of metaverse research, such as metaverse in education [14] and research differences among different countries [15]. All previous bibliometric analysis of metaverse research was carried out in 2022. However, the relevant research on the metaverse has progressed very rapidly, and many changes are expected within one year. Therefore, this paper, which conducted research in 2023, has a significant advantage in terms of data update. The paper's innovation lies in selecting the Web of

Science core repository, which boasts high academic authority, as the data source after rigorous analysis of multiple databases. And this decision-making process is elaborately explained. This paper has also been analysed to identify the most influential articles and journals in the research literature related to the metaverse. Moreover, the paper uses the latest version of citespace to find the citation cluster dependency identification of citation trends previously unattainable in bibliometric analyses of the metaverse. Additionally, this paper examines the general direction of metaverse research and the obstacles that lie ahead, providing recommendations accordingly.

Based on the perspective of research correlation and trend of the metaverse, this paper reviews its literature, adopts CiteSpace software, based on bibliometric analysis method, takes the core data set of Web of Science as the literature data source, analyzes the latest research process and hot spots related to the metaverse from multiple dimensions, and analyzes its research trends and development trends. This paper aims to review the current research progress and trends in this field, as well as to highlight future research directions so as to gain a systematic understanding of the role played by the metaverse in the academic research.

Data and methodology

Data sources

Data retrieval for bibliometric analyses is of utmost importance. When comparing the three databases, namely Web of Science, Scopus, and Dimensions, Dimensions stands out as having the most comprehensive coverage of journals, while Web of Science is the most selective. Web of Science and Scopus mainly cover life sciences, physical sciences, and technology, whereas Dimensions has more coverage in the fields of social sciences, engineering, and arts and humanities [16]. It is worth noting that Web of Science has greater coverage in the social sciences and arts and humanities than Scopus, for WoS-exclusive journals in natural sciences, engineering, and the arts and humanities [17].

In this paper, citespace was chosen as the bibliometric analysis tool. This software has the most powerful features when takes WoS as the database. This paper has tried to use Scopus and Dimensions as a common data source for bibliometric analysis in the pilot phase of the econometric analysis and found that citespace has glitches and errors in performing institutional, country, and citation analyses. In addition, this paper intends to find out the hotspots of metacosmos related research as well as future trends through the bibliometric analysis, which mostly depends on the keyword analysis. After experimentation this paper found that the results of keyword analysis with WOS as a single data source and keyword analysis with WOS, Scopus, and Dimensions as a common data source did not differ much in predicting future trends. Therefore this paper selected WOS as the data source for this bibliometric analysis.

The core data set of Web of Science (WOS) includes tens of thousands of high-impact academic journals and conference documents worldwide, which has very high academic authority. WOS was chosen since it covers more extensive paper information, broader research areas, and a more extended time period than other databases.This paper takes the core data set of Web of Science as the data source. The scope of literature reading included key reports such as White Paper on China's Metaverse edited by Gon, and other reviews and research papers. We referenced to the previous literature on the metaverse

related research metrology analysis expression [15], the final determination of the search expression, to ensure that the search results can objectively reflect the research status of related fields. The retrieval formula of this subject was TS = (Metaverse OR Metauniverse OR Metauniverse OR Meta-cosmic OR Metacosmum). The search time was up to Dec 1, 2023, and the search type is article and review. A total of 921 academic journal articles were retrieved. The selected articles were downloaded in the format of "full records and cited references" and saved as plain text files as data samples for analysis.

In data retrieval, there is a trade-off between "completeness" and "accuracy". Usually, a high rate of accuracy is associated with a low rate of accuracy, and a high rate of accuracy is associated with a low rate of accuracy. The error of rejecting the truth caused by a low check rate is also known as a Type I error; the error of taking a falsehood caused by a low check rate is also known as a Type II error. According to Professor Chen Chaomei, the priority of bibliometric analyses using citespace is to ensure the completeness of the search results. The retrieved irrelevant data will be filtered out to a certain extent in the process of generating scientific knowledge maps. Apparently irrelevant branches can also be ignored when analysing the map [18]. In other words, between a Type I error and a Type II error, it is preferable to make a Type II error because there is still a chance that such an error can be corrected later in the analysis process. In order to improve the problem of low completeness in simple keyword or subject search, this paper improves the completeness of search results by "citation expansion" [19] and no longer manually removes papers of low relevance, as is the case in comparable bibliometric analyses.

Analysis methods

CiteSpace is a software developed by Professor Chen Chaomei's team at Drexel University in the United States. CiteSpace is based on co-citation analysis theory. It can display the structure, rule, and distribution of scientific knowledge in the form of a knowledge graph using a large amount of literature data within a certain subject field. Thus, it is a significant tool for visual bibliometric analysis. Based on bibliometric analysis, this paper used CiteSpace to visualize the authors, publishing institutions, countries and keywords of the selected articles, and drew co-occurrence maps of authors, institutions and countries, keyword co-occurrence, clustering and time line maps, as well as the highly cited journals and papers, the overlaying maps of the exerted and cited papers, so as to conduct a scientific and comprehensive analysis of the current status, hot spots and frontier trends of the metaverse related research. To further understand the overall research progress in the field of metaverse.

Results and discussion

Publication trend analysis

The results of the statistical analysis of the number of metaverse-related articles in the WoS core database are shown in Fig. 1. The results show that metaverse-related research started as early as 2005, only to remain in a state of being studied by a few until 2021. It was not until 2022 that the concept of metaverse was proposed by Zuckerberg and touted by commercial companies, and at a time when academia also began to pay extensive attention to metaverse, the number of core articles on metaverse-related research has shown a spurt of growth since 2022, and by Dec 1, 2023, the total number of core

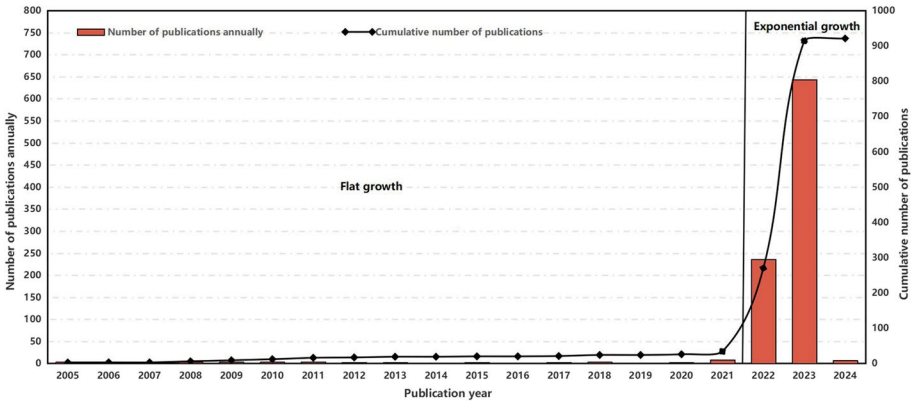

Fig. 1 Trends in the annual and cumulative number of publications on metaverse research

articles on metaverse-related research has increased from 34 to 921 in 2021 (7 of the papers are pre-published for 2024). Accordingly, the period 2008–2021 is described as the flat growth period of metaverse research development, and the period 2022 to the present as the exponential growth period.

In the literature searched, "Metaverse" first appeared in 2005 as the name of an immersive multi-projector system [20]. In fact, as early as 2008, scholars have begun to explore the concept of metaverse, and some scholars have begun to analyse the differences and links between the virtual world and the real world based on the MMORPG games [21], discussing the business opportunities and challenges of this virtual world ("Second Life"), and will study the impact of corporate social responsibility The focus is on ethical and political issues [22]. Online games are the main research entry point of the flat growth period of metaverse research development [23, 24]. The concept of the "metaverse" has, since its inception, had a strong science fiction connotation. The science fiction narrative of literary creation presents the cyber-virtual space in a highly figurative form, which is highly consistent with the technical characteristics and conceptual connotation of the current "metaverse" [25]. The digital cultural capital market has helped to popularise the concept of " metaverse ". In October 2021, Facebook founder Mark Zuckerberg announced that the company would change its name to "Meta", and in November the same year, Microsoft also announced that it would integrate virtual environment technology to create a "meta verse". Rob-lox identifies the eight elements of the metaverse as identity, sociability, immersion, low latency, diversity, location, economic system and civilisation. As a virtual world based on reality, video games provide a natural convenience for the formation of the technical space and conceptual connotation of the "metaverse". From this time onwards, research in this field entered a period of the exponential growth.

Cooperation network analysis

Country cooperation network analysis

Country was chosen as the node type, and the literature obtained from the WoS core collection database on metaverse(Fig. 2). The national collaboration network(Fig. 2) shows a relatively strong international collaboration between countries, with the highest number of publications coming from China (324), followed by the USA (161),

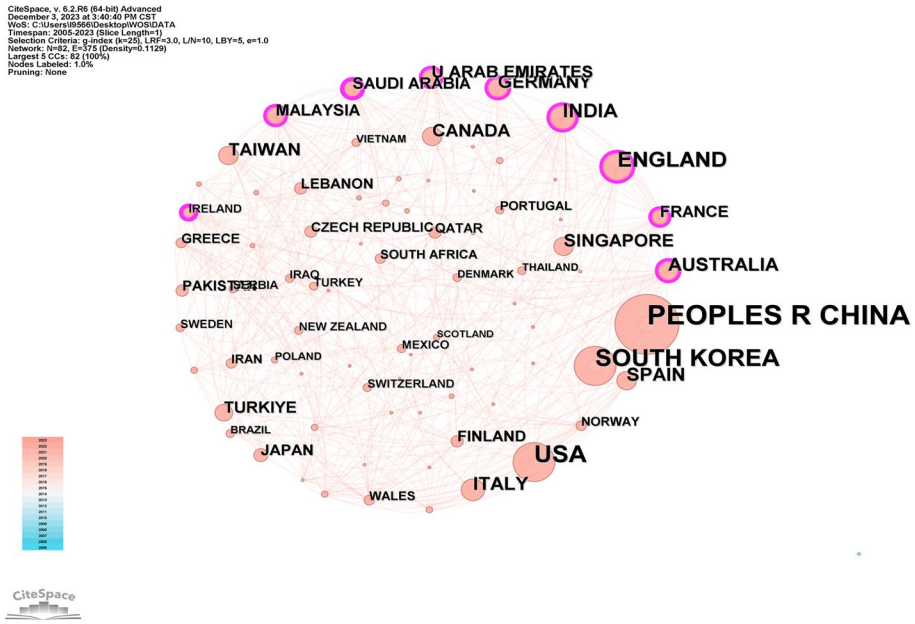

Fig. 2 International cooperative network of metaverse research

Table 1 Top 10 countries in terms of publications on metaverse research

No.	Countries & Region	Publications	Percentage (%)	Centrality
1	PEOPLES R CHINA	324	35.18	0.05
2	USA	161	17.48	0.09
3	SOUTH KOREA	158	17.16	0
4	ENGLAND	80	8.69	0.11
5	INDIA	56	6.08	0.19
6	ITALY	49	5.32	0.01
7	AUSTRALIA	41	4.45	0.18
8	SPAIN	41	4.45	0.03
9	GERMANY	36	3.91	0.1
10	TAIWAN	35	3.80	0.03

Korea (158), England (80) and India (56) (Table 1). The number of Chinese papers in metaverse research is much higher than that of other countries, indicating the high level of interest of Chinese researchers in this field. In addition, China has initiated collaborative exchanges with many other countries.

Nodes with purple outer circles in the graph have high median centrality values. Studies have shown that these nodes tend to identify cross-boundary potentials that may lead to transformative discoveries [26]. Ireland, Saudi Arabia, India, Australia, United Arab Emirates, France, Malaysia, England and Germany all have high median centrality values. The centrality of nodes in Ireland (centrality = 0.32) is much higher than in other countries (Saudi Arabia is 0.25 and India is 0.19), indicating a higher international influence in the field. During the exponential growth period of metaverse research, England, Germany, India and Australia have significantly higher

Fig. 3 Collaborative network of publishing institutions on metaverse research

Table 2 Top 10 institutions in terms of publications on metaverse research

No.	Institutions	Publications	Percentage (%)
1	Chinese Academy of Sciences	33	3.58
2	Nanyang Technological University	24	2.61
3	Institute of Automation	19	2.06
4	Sungkyunkwan University (SKKU)	17	1.85
5	Lebanese American University	14	1.52
6	Kyung Hee University	13	1.41
7	Beijing Institute of Technology	13	1.41
8	University System of Georgia	12	1.30
9	Symbiosis International University	11	1.19
10	University of Texas System	11	1.19

levels of international collaboration and publications than other countries on the whole.

Institution cooperation network analysis

A cooperation network analysis of institutions publishing articles on metaverse was performed using institution as the node type (Fig. 3; N = 223, E = 645, Density = 0.0261). During data processing, This paper compares "Nanyang Technological University & National Institute of Education (NIE) Singapore" with "Nanyang Technological "University" combined the calculated quantity, and the data result after processing is shown in Table 2. It can be seen from Table 2 that Chinese Academy of Sciences and Nanyang Technological University published more literatures in this

field, 57 in total, accounting for 6.19% of all literatures. The Chinese Academy of Sciences (CAS) is mainly based on inter-institutional cooperation within China with Nanjing University, Hunan University, Southern University of Technology and the University of Chinese Academy of Sciences. King Abdulaziz University, which has the highest level of intermediary centrality, also cooperates with CAS. Nanyang Technological University and National Institute of Education (NIE) Singapore, University of Waterloo, Hong Kong Polytechnic University and other institutions in the current cooperative research. And almost all institutional collaborations were conducted during the exponential growth period of metaverse research.

Author collaboration network analysis

The results of the author collaboration network analysis indicated that researchers in this field were more collaborative (Fig. 4). Larger circles indicate more occurrences of the node. The brighter the colour of the node, the more recent the year of occurrence. Among 231 authors, the authors with the most publications were Wang, Fei-Yue (13), Niyato Dusit (12), Deveci Muhammet (11), Dwivedi Yogesh K (10), Jamshidi Mohammad. In addition, articles by authors such as Dwivedi Yogesh K, Hughes Laurie, Raman Ramakrishnan, Pandey Neeraj, Dutot Vincent, etc. have relatively higher impact. Chinese authors generally publish more articles than foreign authors, but the overall impact of their articles is not as high as that of foreign authors. Foreign authors collaborate more closely in this field, but the collaboration between Chinese author teams is relatively loose. In the future, researchers from different countries should strengthen the cooperation and communication between different geographical areas in this field (Table 3).

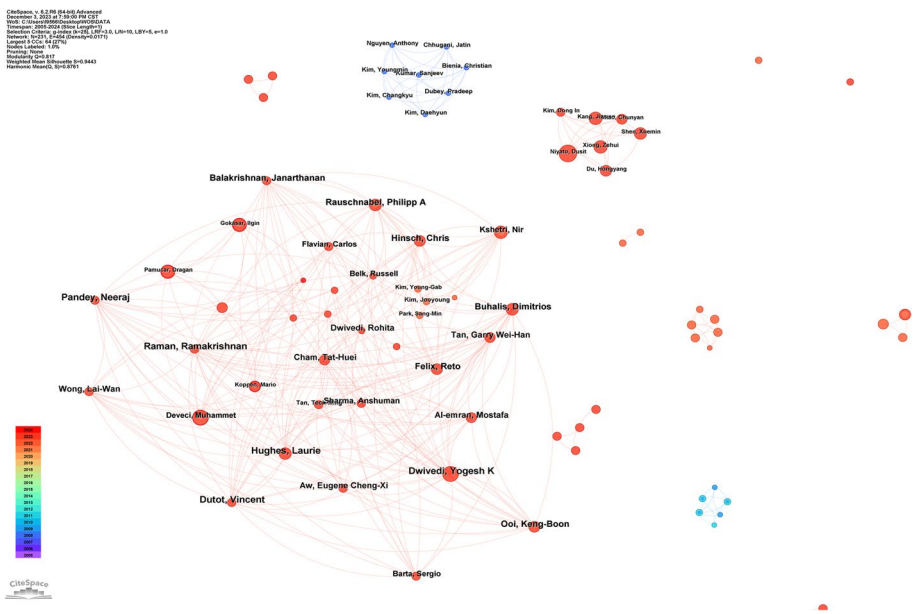

Fig. 4 Collaborative network of authors on metaverse research

Table 3 Top 10 authors in terms of publications on metaverse research

No.	Authors	Publications	Percentage (%)
1	Wang, Fei-Yue	13	1.41
2	Niyato Dusit	12	1.30
3	Deveci Muhammet	11	1.19
4	Dwivedi Yogesh K	10	1.09
5	Jamshidi Mohammad (Behdad)	10	1.09
6	Pamucar Dragan	8	0.87
7	Gokasar Ilgin	8	0.87
8	Kshetri Nir	7	0.76
9	Xiong Zehui	7	0.76
10	Kang Jiawen	7	0.76

According to Price's theory [27], the number of papers published by core authors is calculated according to formula (1).

$$N = 0.747(N_{max})^{1/2} \tag{1}$$

In the formula (1), N is the minimum number of papers the core author should publish; N_{max} is the number of papers by the most productive authors in the statistical year. According to formula (1), the number of papers published by core authors is at least about 2.69. Hence, this paper's core authors will be authors who have published at least two papers in the field of metaverse research. The statistics on the number of published papers indicate that there are 66 authors who have published at least three papers. So we can conclude the amount of core authors is 66.

Knowledge base and research fronts

Category distribution of research

According to Shneider's four-stage model, metaverse-related research is in its first stage. Therefore, an analysis of the category of disciplinary regarding the research literature is essential. In CiteSpace, clusters can be formed by a set of closely related documents and according to their interconnectivity. The label of clusters represents their nature, formed by choosing the most representative terms extracted from titles, abstracts, or keywords of the citing articles [30]. This facilitates the analysis of the clusters of disciplines to which the current basics of metaverse research belong, as shown in Fig. 5. As can be seen, current research related to the metaverse is spread across many disciplines, including business, engineering, computer science, environmental safety, healthcare, materials science, and more. Of these, the medical and engineering fields are currently the newest categories of research with the red color.

Overlaying maps of the exerted and citation cluster dependency

The research programme or paradigm of a field of study can be characterised by its knowledge base and research frontiers. The knowledge base is the collection of scholarly works cited by the corresponding research community, while the research frontiers are inspired by the works of the knowledge base. Multiple research frontiers may emerge

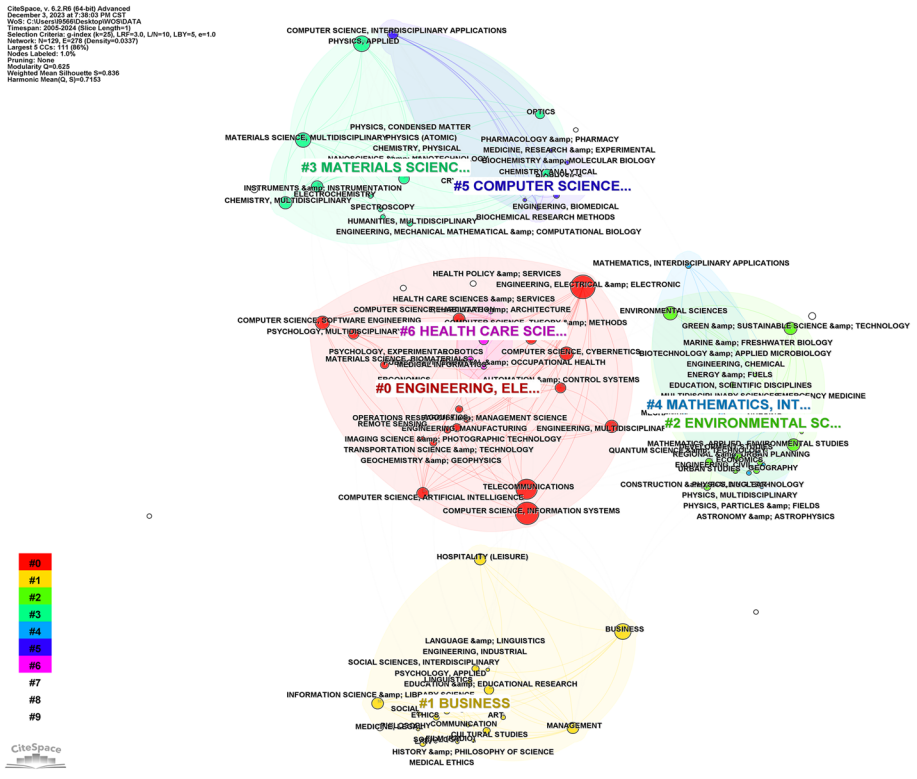

Fig. 5 Category clusters in metaverse research

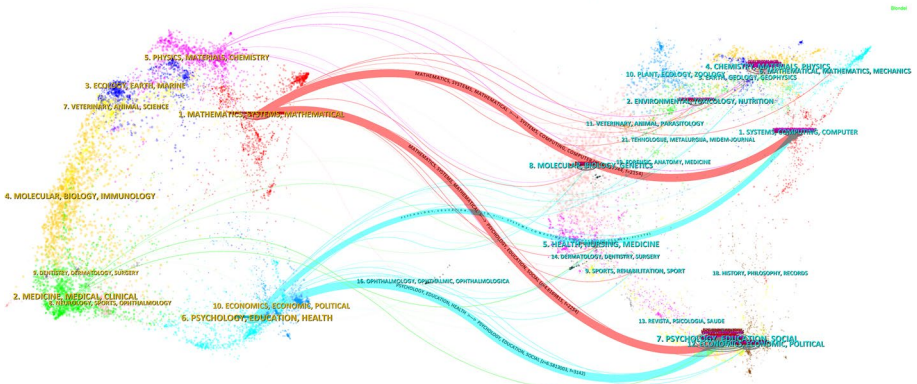

Fig. 6 A dual-map overlay of the metaverse literature

from a common knowledge base [18]. A dual-map overlay between the exerted and cited papers of the metaverse literature as shown in Fig. 6. And in Fig. 7, the dependencies between citation clusters can be seen.

A dual-map overlay of the literature on the metaverse presents the entire dataset within the context of a global science map, which is formed by over 10,000 journals indexed in the Web of Science [28]. The dual-map overlay shows that the knowledge base of metaverse papers focuses on the disciplines of computer science, economics,

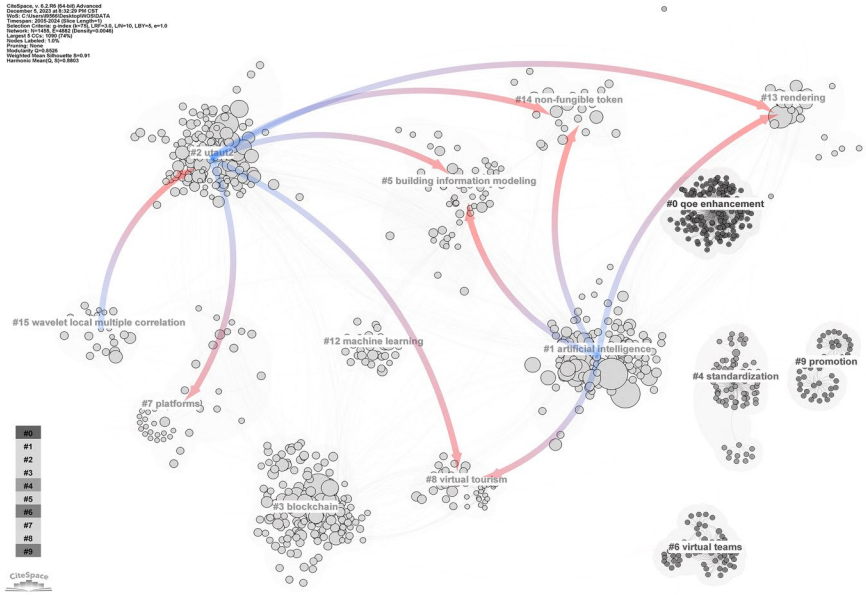

Fig. 7 Citation cluster dependency graph

Table 4 The characteristics summary of cited articles clusters

Cluster ID	LLR Lable(s)	Size	Silhouette	Mean Year
0	qoe enhancement	167	1	2002
1	artificial intelligence	158	0.721	2021
2	utaut2	150	0.918	2021
3	blockchain	145	0.794	2021
4	standardization	80	1	2009
5	building information modeling	59	0.921	2020
6	virtual teams	55	1	2006
7	platforms	43	0.923	2018
8	virtual tourism	41	0.975	2019
9	promotion	40	1	2005
12	machine learning	30	1	2020
13	rendering	28	0.969	2020
14	non-fungible token	24	0.971	2021
15	wavelet local multiple correlation	23	0.978	2022

politics, and sociology, while the research frontiers of metaverse papers focus on the disciplines of mathematics, economics, psychology and education (Fig. 6).

The cluster analysis of the citations yielded a total of some major cluster clusters, which can be seen in Table 4. Cluster ID is the number of the cluster, the larger the cluster size, the smaller the number. size represents the number of members contained in the cluster, Silhouette is a measure of the homogeneity of the members of the whole cluster, the larger the value, the higher the similarity of the members of the cluster. Mean year represents the average year of the literature. The silhouette values of each cluster are greater than 0.7, which indicates that these clusters are compelling for this study. Meanwhile, the dependency was set to the strongest as 75%, which enabled to obtain

the citation cluster dependency graph (Fig. 7), where the darker colour of the clusters indicates an earlier emergence. From the citation clustering dependency analysis, it can be seen that the development of clusters #5 building information modeling, #8 virtual tourism, #13 rendering, and #14 non-fungible token were jointly influenced by #1 artificial intelligence and #2 utaut2. Cluster #2 was influenced by #15 wavelet local multiple correlation and it also influenced #7 platforms.

Leading co-cited journals and articles analysis

Metaverse literature is drawn from various journals. The frequency of citations received by journals is a good way of assessing their influence and significance. An understanding of the distribution of core journals within the field is essential in forming a valid basis for a literature review. Co-citation analysis of journals enables the determination of the extent to which scientific publications within the study's domain have been influenced by them. The diagram in Fig. 8 illustrates the co-cited journals. And The nodes of journals with purple circles in the figure indicate that this journal has a high potential for cross-border development.

This paper has analysed the top 10 journals based on their citation frequency, as presented in Table 5. These findings are significant for researchers in the Metaverse field as it enables them to identify the most influential research journals. Through analysing co-cited journals, editors and authors can make informed decisions based on their research findings. This is advantageous for both the theoretical advancement and practical implementation of metaverse research.

What's more, this paper lists the top 10 cited articles as shown in Table 6. These articles are an important foundation for metaiverse research. It can be seen that the current research in the highly cited literature focuses on a technical review of the metaverse and its development in the field of education.

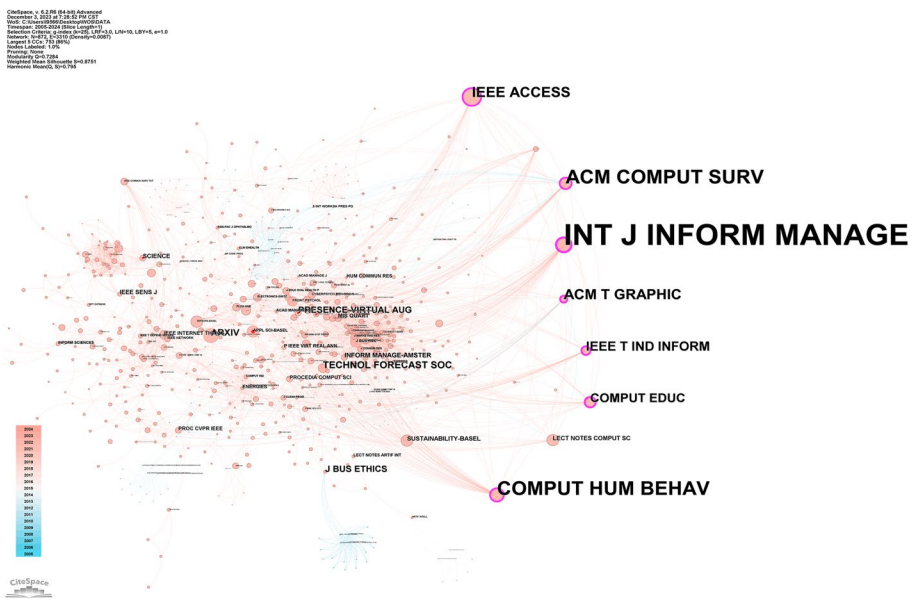

Fig. 8 Citation cluster dependency graph

Table 5 Top 10 leading journals in the metaverse literature

No.	Journal name	Frequency	Centrality	Publisher	IF(2022)
1	IEEE ACCESS	342	0.24	Institute of Electrical and Electronics Engineers Inc	3.9003
2	ARXIV	299	0.16	/	/
3	Computers in Human Behavior	216	0.03	Elsevier	9.8996
4	International Journal of Information Management	210	0.05	Elsevier	20.9994
5	Sustainability	198	0.01	MDPI (Basel, Switzerland)	3.9003
6	Lecture Notes in Computer Science	190	0.16	springer	1.546
7	Applied Sciences-Basel	184	0.02	MDPI (Basel, Switzerland)	2.7001
8	Sensors	178	0.05	MDPI (Basel, Switzerland)	3.9003
9	Journal of Business Research	174	0.02	Elsevier	11.2997
10	ACM Computing Surveys	151	0.24	Association for Computing Machinery (ACM)	16.6009

Table 6 Top 10 cited articles

No.	Author	Title
1	Park SM (2022)	A Metaverse: Taxonomy, Components, Applications, and Open Challenges
2	Mystakidis S (2022)	Metaverse
3	Dwivedi YK (2022)	Metaverse beyond the hype: Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy
4	Lee LH (2021)	All One Needs to Know about Metaverse: A Complete Survey on Technological Singularity, Virtual Ecosystem, and Research Agenda
5	Kye B (2021)	Educational applications of metaverse: possibilities and limitations
6	Haihan Duan (2021)	Metaverse for Social Good: A University Campus Prototype
7	Falchuk B (2018)	The Social Metaverse: Battle for Privacy
8	Gursoy D (2022)	The metaverse in the hospitality and tourism industry: An overview of current trends and future research directions
9	Xi NN (2023)	The challenges of entering the metaverse: An experiment on the effect of extended reality on workload
10	Tlili A (2022)	Is Metaverse in education a blessing or a curse: a combined content and bibliometric analysis

Popular research topics and trends

Keyword co-occurrence clustering analysis

In CiteSpace, a visual analysis of the keyword knowledge graph was performed on the retrieved documents. Firstly, the keywords are analysed for co-occurrence. In a co-occurrence network, the co-occurrence relationships between keywords are connected by connecting lines, and the greater the width of the line the greater the co-occurrence strength [29]. Keywords can summarise the research themes and contents of the literature in a concise manner. Keyword co-occurrence network analysis can reflect the development history and research hot topics of the relevant research fields, and can help researchers to quickly understand the dynamic evolution of each relevant knowledge unit in the field. In this study, the literature related to the metaverse in the WoS database was imported into CiteSpace and visualised and analysed with keywords as node types to obtain a keyword co-occurrence network spectrum (Fig. 9).

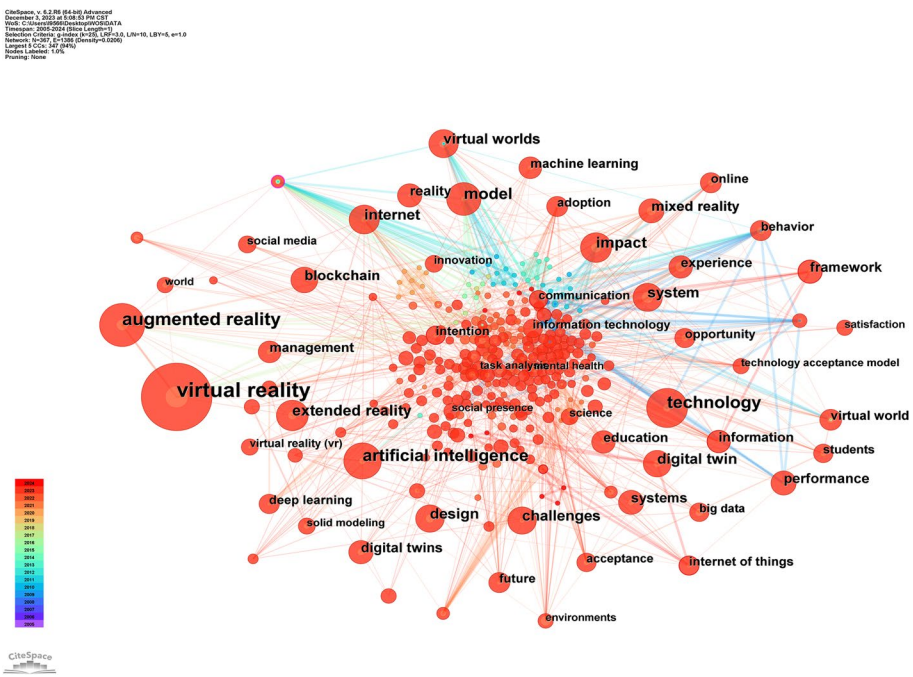

Fig. 9 Keyword co-occurrence network in the study of metaverse

Overall, the keyword co-occurrence network was very tightly structured, with the most frequent occurrence being "virtual reality" (213 times), followed by "augmented reality" (93 times), technology" (75 times), "artificial intelligence" (65 times), "model" (57 times) and "extended reality" (45 times) (Table 7). Keywords with co-occurrence network centrality greater than 0.1 was “second life”. Keywords such as "system", "online", "challenges", "intention", "technology", "model", and "impact" were repetitive and covered topics that were too broad to accurately determine the direction of research in related fields. However, the keywords "artificial intelligence", "extended reality", "mixed reality", "block chain" and "extended reality" identify hot spots for research on metaverse. In addition, the keywords"virtual reality", "augmented reality", "virtual worlds" and "digital twins" are the hot topics of research in this field.

Timeline visualization of keyword co-occurrence clustering analysis

According to the dataset, 10 most active and popular clusters of the metaverse research are shown in Fig. 10. Each cluster illustrates a different domain of knowledge. The first cluster (#0 artificial intelligence) is the largest and most dominant cluster in our dataset. The second largest cluster is #1 data models, and so on. Table 8 summaries the main features of each cluster. The structural characteristics of the clusters can be easily understood from the silhouette values of the clusters. The silhouette values of each cluster are greater than 0.7, which indicates that these clusters are compelling for this study.

In order to examine the historical growth patterns of clusters over time, a combined timeline network visualisation of keyword clusters was implemented, as shown in Fig. 11. The network reflects the positive development of most clusters from 2020 to 2023. The development and growth of other clusters may also increase over time. Timeline visualization contained 367 nodes and 1386 connected lines, and the cluster

Table 7 Top 20 keywords in terms of frequency for metaverse research

No.	Keywords	Frequency	Centrality
1	Virtual reality	213	0.01
2	Augmented reality	93	0.06
3	Technology	75	0.06
4	Artificial intelligence	65	0.02
5	Model	57	0.03
6	Extended reality	45	0.01
7	Impact	44	0.04
8	Internet	40	0.04
9	System	38	0.05
10	Challenges	37	0.01
11	Digital twin	37	0.01
12	Design	37	0.01
13	Virtual worlds	36	0.07
14	Blockchain	32	0.01
15	Mixed reality	30	0.07
16	Framework	28	0.04
17	Performance	28	0.03
18	Digital twins	27	0.01
19	Reality	27	0
20	Virtual reality	37	0.01

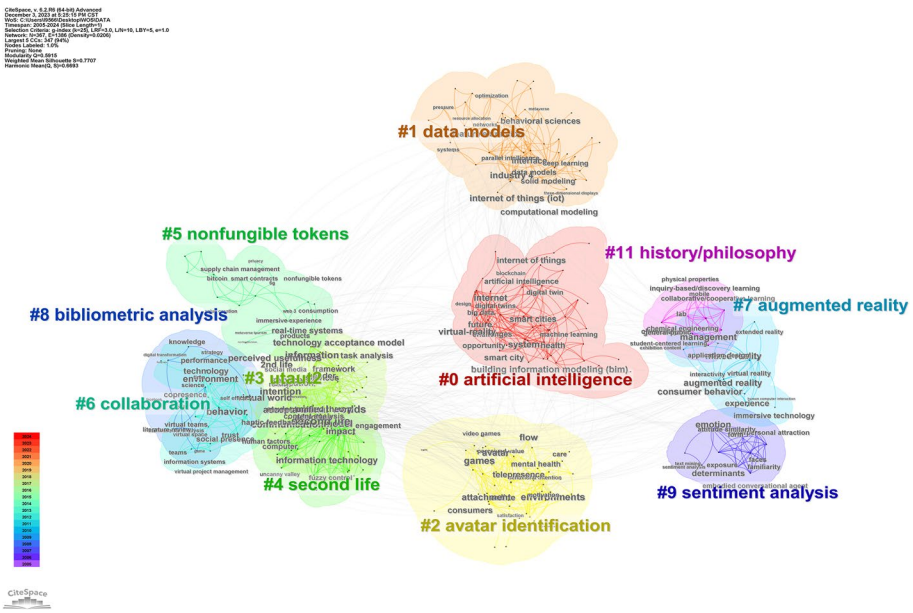

Fig.10 Keyword co-occurrence clustering analysis

analysis revealed that the research focus of metaverse differed at different time stages. The value of Modularity Q (0.5915) was greater than 0.3, indicating that the community structure divided by this keyword clustering will be significant. The value of Silhouette S (0.7707) was greater than 0.7, indicating that this keyword clustering

Table 8 The characteristics summary of keywords clusters

Cluster ID	LLR Lable(s)	Size	Silhouette	Mean Year
0	Artificial intelligence	61	0.704	2022
1	Data models	57	0.749	2022
2	Avatar identification	54	0.761	2022
3	Utaut2	49	0.791	2019
4	Second life	30	0.886	2014
5	Nonfungible tokens	17	0.961	2023
6	Collaboration	16	0.978	2010
7	Augmented reality	13	0.891	2019
8	Bibliometric analysis	11	0.857	2022
9	Sentiment analysis	11	0.987	2021

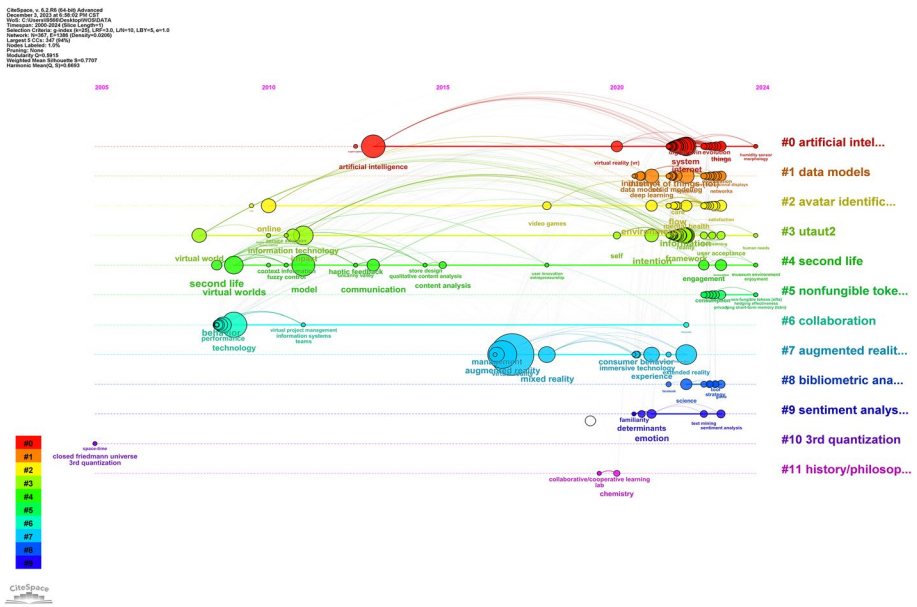

Fig. 11 Timeline visualization of keyword co-occurrence clustering analysis

is efficient. As can be seen from Table 6, 10 clusters have been formed in the current metaverse research literature. They are artificial intelligence, data models, avatar identification, utaut2, second life, nonfungible tokens, collaboration, augmented reality, bibliometric analysis and sentiment analysis. The initial development of each metaverse hotspot cluster can be traced back to the period from 2008 to 2010. Among them, researches on artificial intelligence, data models and avatar identification are hot trends. The research on social presence and second life is utaut2 and collaboration. The latest clustering to appear was nonfungible tokens, which was formed in 2023 and is growing rapidly. The fastest progress has been in artificial intelligence. It can also be seen that since 2021, all kinds of research on the metaverse have developed rapidly, and there are new directions in the field of artificial intelligence, such as security and evolution.

Keyword burst analysis

A burst is a surge in the frequency of occurrence of a keyword. In the figure, the light blue line segment indicates that an article has not yet been published, and the dark blue line segment depicts when an article was published. The start of the red line segment marks the beginning of the burst cycle, while the end of the red line segment marks the end of the burst cycle. The burst analysis of keywords can help to reveal the trend of hot topics in related research fields, and the higher emergence intensity, the higher attention of the academic community. The top 20 keywords in terms of burst strength were obtained through burst keywords detection, as shown in Fig. 12, where "Year" is the year of the original publication, "Strength" is the emergent strength, "Begin" and "End" are the start and end times of the burst keywords, and the red line is the time period when the burst keywords are active, which means that the burst keywords receive a lot of attention from researchers in that time period.

Of all the citation burst words, the one with the highest intensity is virtual worlds, which first appeared in 2008 and ended in 2018. And second life with higher intensity appeared in 2009 and ended in 2018 either. Between 2018 and 2021, scholars began to discuss important technologies related to the metaverse, such as mixed reality, VR, environments and experience. As the concept of the metaverse becomes more widely known in 2022, more keywords begin to appear from different fields, such as 5G, streaming media, system, integration, and green. But most of these words are short-lived in a period of rapid development.

Conclusion

Conclusion and limitations

The metaverse is a virtual social form that is idealised and can be edited and reconstructed independently by users [15]. It can ultimately coexist and interact with the real

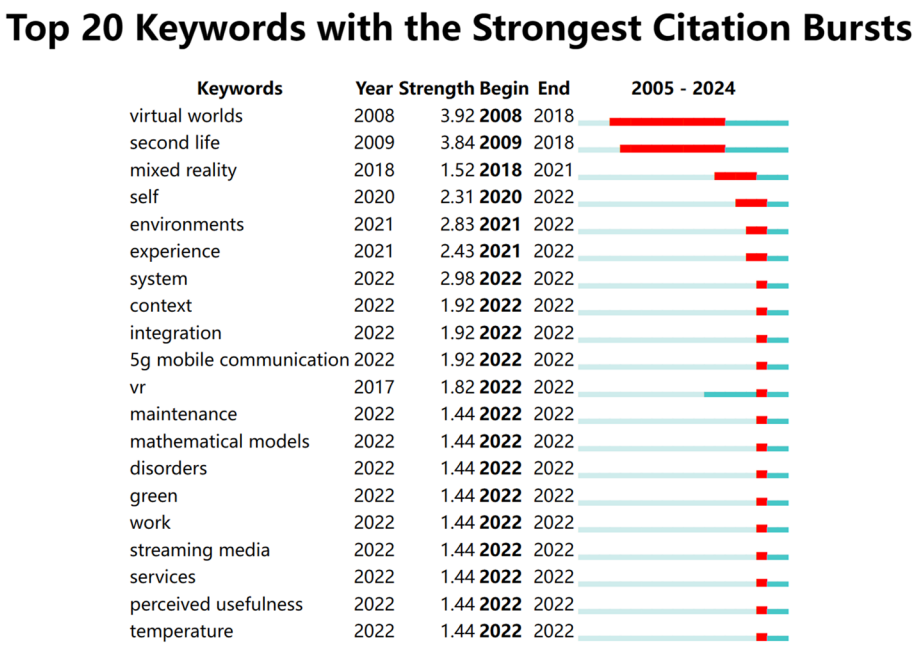

Fig. 12 Top 20 keywords with the strongest citation bursts on metaverse research

world. It is related to blockchain, digital twins, artificial intelligence, and many other technologies. In this study, we used CiteSpace to visualize and analyze the literature related to metaverse in the WoS core collection database and analyzed the collaboration between countries, institutions and authors in this field. Based on the above analysis, the researchers made the following conclusions:

Firstly, it can be observed from an analysis of scientific publications that the metaverse has gradually become an extensive area of research over the last 20 years. Currently, the stages of research and development in the metaverse can be categorised into a slow development period (2005–2021) and a fast development period (2022-present).

Secondly, in terms of international cooperation network, China has the largest number of publications, but the degree of international cooperation is still lower than England, the USA and other countries. The country with the most international influence in this field is Ireland. In the analysis of the network of published institutions, the research networks with the Chinese Academy of Sciences and Nanyang Technological University as the cores have been formed. Of the top five authors with the most published papers, only one is Chinese. This indicates that the study of the metaverse by Chinese research institutions and Chinese authors needs to be strengthened. In addition, there are 66 core authors in the field of metaverse research, less than 1/3 of the total number of authors.

Thirdly, this paper explores the knowledge base and research fronts of metaverse. Current research related to the metaverse is spread across many disciplines, including business, engineering, computer science, environmental safety, healthcare, materials science, and more. Of these, the medical and engineering fields are currently the newest categories of research. The knowledge base of metaverse literature focuses on the disciplines of computer science, economics, politics, and sociology, while the research frontiers of metaverse papers focus on the disciplines of mathematics, economics, psychology and education. The publishers of the most cited journals for the relevant literature are mainly Elsevier and MDPI. And the current research in the highly cited literature focuses on technical and history reviews of the metaverse as well as its development in the field of education. Artificial Intelligence and utaut2 are the underlying clusters of cited literature in this research area.

Finally, this paper explores the recent research hotspots and frontiers of the last 20 years based on an analysis of the evolution of topics in the field of knowledge. Through the scientific econometric analysis of keywords, it can be seen that virtual reality and artificial intelligence are the most popular research objects in the field of metaverse related research. The nonfungible token is the most recent and fastest growing research object in metaverse research. Generally speaking, research hotspots in the academic community mainly focus on virtual reality, augmented reality, mixed reality, digital twins and artificial intelligence. In addition, as the concept of the metaverse becomes more widely known in 2022, more keywords begin to appear from different fields, such as 5G, streaming media, system, integration, and green. But most of these words are short-lived in a period of rapid development.

Several significant limitations require consideration in this investigation. The methodological approach has some limitations as it only utilizes the WOS database, potentially leading to the exclusion of essential sources from other databases, such as Dimensions, Scopus, CORE, CiteSeerX and so on. Consequently, research findings related to

metaverses may have been overlooked. Moreover, the bibliometric analysis in this paper was conducted in Dec 2023. As the metaverse research is rapidly developing, it is possible that some of the latest research literature will not be included in the bibliographic database when this paper is published, which may result in the absence of cutting-edge literature. Furthermore, although this paper has taken some consideration of metaverse's search keywords, the lack of an authoritative definition of metacomes at present means that the research presented in this paper may lack some essential keywords, leading to the absence of some relevant documentation. Moreover, it is important to note that analyzing bibliometrics has limitations in several aspects, such as research objectives, perspectives, and methods. Currently, there are no verification methods for the precision or reliability of bibliometrics analysis results. It affects the robustness and rigour of research outcomes to some extent. In the future, we will widen our database search to uncover more objective and verifiable bibliometric methods and tools so that we can enhance the results of this paper.

Future research prospects

The areas of scientific research that are most active tend to have the highest levels of uncertainty [31]. The evidence revealed in this study suggests that metaverse is a Stage I specialty according to Shneider's four-stage model. Technological advancements in high-precision recognition models and deep learning-based naturally occurring models are contributing to the enhancement of the Metaverse through diverse factors such as mobile-based constant access and the utilization of virtual currencies to establish a connection with reality. The integration of improved social interactions and neural network methodologies necessitates a novel characterisation of the Metaverse [9].

Although prolonged attention and study in recent years, the metaverse still offers vast potential for research. The metaverse's study abounds in infinite possibilities and endless imagination. Despite the much existing literature, further research is necessary. This paper presents a new theoretical perspective for the study of the metaverse, based on the analysis of research hot topics and core evolutionary pathways, as well as related research articles and reviews. Currently, research on the metaverse encompasses three different ideas:

1. The cross-study of the metaverse with other fields. At present, combined research on the metaverse has emerged in various fields including education [32], entertainment [33], news [34], business [35], medicine [36], and other areas of study. Scholars have started to study the changes in the actual daily life of humans from the metaverse perspective. They have also explored ways and strategies to apply the concepts related to the metaverse to real-life situations. In the medical field [37, 38], medical professionals can use the metaverse to improve efficiency in diagnosis, education, and treatment. The interaction between medical staff and patients can be enhanced in the digital space [39]. The scope of emergency medicine in the virtual environment must be updated. Product marketing in the metaverse [40] alters consumer perception from a 2D product catalog to a 3D immersive virtual space. Such an environment better assists consumers in determining purchase factors and selecting well-designed products through digital advertising during the complete review

process [41]. People carry out various activities in real society, the core of social life. Researching other fields is vital to stimulate the creation of virtual individuals and communities in the current universe while addressing the division between virtual communities and real society. Virtual individuals and societies offer people concurrent and diverse identity validation and spatial–temporal experiences. Interdisciplinary studies facilitate developing several spaces in the metaverse. With a change of identity by the physical body, avatar or otherwise, people better emotional engagement and immersion [42, 43]. Simultaneously, research into the metaverse across various fields can also advance technological innovation in its practical applications. For instance, when safeguarding cultural inheritance [44], adopting the meta-ecology of cultural heritage as a research subject improves the likelihood of establishing a methodical process of building cultural heritage's meta-ecology, which could lead to more effective solutions for things like tourism guidance, site maintenance, heritage protection, among others.

2. Research on related technologies and supporting infrastructure of the metaverse. The development of the metaverse is inseparable from the progress of science and technology. At present, technologies such as blockchain, mixed reality, holographic transmission, software engines, hardware products and more are flourishing. The fundamental basis of the metaverse is blockchain technology [45], which gives creators complete digital ownership of their content. With traceable features that ensure data can't be tampered with, the mateverse creates a unique trusted mechanism. In August 2022, Canadian scientists successfully transmitted a person as a holographic image from Alabama to Ontario, marking the first international two-way holographic transmission. The immersive interactive virtual space, created using the virtual engine, allows users to move around highly intelligent virtual time and space freely, and adjust the space–time dimension and jump speed [46–48]. In January 2022, Nvidia released Omniverse, a software that empowers artists and creators to generate mateverse virtual worlds for free. That same year, Zuckerberg unveiled four VR prototypes [49]. These technologies have had gradual advancements, primarily during the swift progression of research on the mateverse. It is apparent that scientific research can accelerate the progress of technology. Additionally, the progress made in the related technology can provide feedback to the theoretical research on the mateverse, allowing for the exploration of new connotations and forms in the same. In the future, the leading-edge research on the mateverse will continue to move towards overcoming the technical limitations. These technologies could not only facilitate the mateverse's entry into the real world more effectively but also enhance the quality of people's lives. In the future, it is conceivable that there will be a new technological revolution, as the mateverse's content and structure continue to evolve.
3. Research on the technology ethics and governance policy of the metaverse. The application area of metaverse is expanding, and related technologies are rapidly advancing. Numerous technical hazards and ethical risks may arise as a result. The metaverse will present challenges that question existing legal and moral norms. To address this, not only research on the academic level but also anticipatory preparation during product development is essential. The risks of political parties [50], eco-

nomic fraud [51], loss of human subjectivity [52], excessive social entertainment [53] and technical safety problems [54] all demand attention. Furthermore, acceptable behaviours and privacy considerations require attention. There is a risk of disenfranchising those who lack access to the required infrastructure to enter the metaverse [5]. Scholars from around the globe have presented visionary ideas on regulating and governing metaverse applications in aspects like politics, economics, society, culture and technology [55]. Meta introduces the "Personal Boundary" feature, aiming to prevent sexual harassment in the metaverse. In the past two years, concerned authorities in China have introduced management strategies for digital collection trading, metaverse investments, and digital copyright. Ben Falchuk envisaged a novel control layer in 2018 to boost privacy safeguards in the metaverse, where all avatars possess similar capabilities and comply with the "rules of the game" [56]. From a future-oriented standpoint, Facebook research aims to use the peripheral nervous system and a brain-computer interface to input text. The ongoing advancements in brain-computer interfaces and Neuralink could manifest into a version that offers an encounter that is challenging to differentiate from veracity in the Metaverse [9]. In the future, there will be additional self-regulatory measures and technological standards for the multiverse industry. Hence, it is imperative to explore the mechanisms for regulating the development of the metaverse, guiding science and technology to create good, and promoting the autonomy of the metaverse industry through academic research

However, further research in metaverse also has certain limiting factors such as sustainability of metaverse users, hardware and software limitations and development huddle[9]. Operating the metaverse within XR demands different and greater resources and expenditures compared to the physical reality. Meanwhile, the user's learning expense for adapting to this new medium will also increase [57].

Acknowledgements
We would like to thank all contributors who supported the field work and the data collection and analysis.

Author contributions
HL: Visualization, Data curation, Writing-orginall draft preparation, and Software; BL: Conceptualization, Writing- Reviewing and Editing, Supervision, and Funding acquisition. All authors have read and agreed to the published version of the manuscript.

Funding
This research was funded by the Art Science Planning Project of Heilongjiang Province (2023A007), and Science and Technology Innovation Research Project for the Heilongjiang Science and Technology Association Think Tank (SKXZK0230012).

Availability of data and materials
The data used in this paper are all publicly accessible. The paper data in metaverse research can be downloaded via https://webofscience.clarivate.cn/wos/woscc/summary/1109da70-9aee-4091-b18d-a6a9a98a0c51-ba952668/relevance/1, accessed on 1 Dec 2023..

Declarations

Ethics approval and consent to participate
This article does not involve any animal or human testing and does not require the approval of the ethics committee.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

Received: 29 May 2023 Accepted: 4 January 2024
Published online: 10 January 2024

References

1. Joshua J. Information bodies: computational anxiety in Nealstephenson's snow Crash[J]. Interdisciplinary Literary studies. 2017;19(1):17–47.
2. Dionisio JDN, Burns WG, et al. 3D Virtual worlds and the metaverse. ACM Comput Surv. 2013;45:1–38.
3. Mystakidis S. Metaverse. Encyclopedia. 2022;2(1):486–97.
4. Damar M. Metaverse shape of your life for future: a bibliometric snapshot. J Metaverse. 2021;1(1):1–8.
5. Dwivedi YK, Hughes L, Baabdullah AM, et al. Metaverse beyond the hype: Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy. Int J Inf Manage. 2022;66: 102542.
6. Gao QQ, Liang XZ. Illusion and nothingness: a critical reflection on the phenomenon of metaverse. Academia. 2022;2:54–64.
7. Lee L H, Braud T, Zhou P, etal. All one needs to know about metaverse : A complete survey on technological singularity, virtual ecosystem, and research agenda. arXiv preprint arXiv:2110.05352, 2021.
8. Zhao X, Qiao L L, Ye Y. A review of metaverse research and applications. IRMJ 2022;12(4):12–23, 45.
9. Park SM, Kim YG. A metaverse: taxonomy, components, applications, and open challenges. IEEE Access. 2022;10:4209–51.
10. Davis A, Murphy J, 0wens D. Avatars, people, and virtual worlds: foundations for research inmetaverses. J Assoc Inf Syst 2009;10(2): 91-117.
11. Xu H, Li Z, Liz, et al. Metaverse native communication: A block chain and spectrum prospective. arXiv preprint arXiv: 2203.08355, 2022.
12. WangF Y, Qin R, Wang X, et al. Metasocieties in metaverse: metaeconomics and metamanagement for metaenterprises and metacities. IEEE Transact Comput Soc Syst. 2022;9(1):2–7.
13. Hollensen s, Kotler P, 0presnik M O. Metaverse: The new marketing universe. J Bus Strat 2022:1–7.
14. Chen W, Zhang J, Yu Z. A bibliometric analysis of the use of the metaverse in education over three decades. IJICTE. 2023;19(1):16.
15. Shen JL, Zhou XY, Wu W, et al. Worldwide overview and country differences in metaverse research: a bibliometric analysis. Sustainability. 2023;15(4):3541.
16. Singh VK, Singh P, Karmakar M, et al. The journal coverage of web of science, scopus and dimensions: a comparative analysis. Scientometrics. 2021;126(6):5113–42.
17. Mongeon P, Paul-Hus A. The journal coverage of Web of Science and Scopus: a comparative analysis. Scientometrics. 2016;106(1):213–28.
18. Chen C. Science mapping: a systematic review of the literature. J Data Info Sci. 2017;2(2):1–40.
19. Chen C, Hu Z, Liu S, et al. Emerging trends in regenerative medicine: a scientometric analysis in CiteSpace. Expert Opin Biol Ther. 2012;12(5):593–608.
20. Jaynes C, Steele RM, Webb S. Rapidly deployable multiprojector immersive displays. PRESENCE-Virt Augment Reality. 2005;14(5):501–10.
21. Papagiannidis S, Bourlakis M, Li F. Making real money in virtual worlds: MMORPGs and emerging business opportunities, challenges and ethical implications in metaverses. Technol Forecast Soc Chang. 2008;75(5):610–22.
22. Sarvary M. The metaverse: TV of the future? Harv Bus Rev. 2008;86(2):30.
23. Nevelsteen KJL. Virtual world, defined from a technological perspective and applied to video games, mixed reality, and the Metaverse. Comput Animat Virtual Worlds. 2018. https://doi.org/10.1002/cav.1752.
24. Estudante A, Dietrich N. Using augmented reality to stimulate students and diffuse escape game activities to larger audiences. J Chem Educ. 2020;97(5):1368–74.
25. Fu XX. "metaverse": technological trends and cultural syndromes in cyberspace [J]. Learn Pract. 2022;04:132–40.
26. Chen C, Chen Y, Horowitz M, Hou H, Liu Z, Pellegrino D. Towards an explanatory and computational theory of scientific discovery. J Informet. 2009;3(3):191–209.
27. Ding XD. Foundations of bibliometrics. Beijing: Beijing University Press; 1993.
28. Chen C, Leydesdorff L. Patterns of connections and movements in dual-map overlays: A new method of publication portfolio analysis. J Am Soc Inform Sci Technol. 2014;65(2):334–51.
29. Xu C, Yang T, Wang K et al. Knowledge graph analysis of coal and gas co-mining research based on Citespace. Coal Sci Technol 1–9.
30. Memon S, Li X, Memon KA, et al. The development trends and research fronts in orbital angular momentum technology: a bibliometric analysis. China Commun. 2023;20(2):289–310.
31. Chen C. Grand challenges in measuring and characterizing scholarly impact. Front Res Metr Anal. 2016. https://doi.org/10.3389/frma.2016.00004.
32. Kshetri N, Rojas-Torres D, Grambo M. The metaverse and higher education institutions. It Prof. 2022;24(6):69–73.
33. Lee UK. Tourism using virtual reality: media richness and information system successes. Sustainability. 2022;14(7):3975.
34. Wang X, Feng X, Zhao JY. Research on influencing factors and governance of disinformation dissemination on science and technology topics: an empirical study on the topic of "metaverse." Int Res. 2023. https://doi.org/10.1108/INTR-06-2022-0477.
35. Mancuso I, Petruzzelli AM, Panniello U. Digital business model innovation in metaverse: How to approach virtual economy opportunities. Inf Process Manage. 2023;60(5):103457.
36. Bansal G, Rajgopal K, Chamola V, et al. Healthcare in metaverse: a survey on current metaverse applications in healthcare. Ieee Access. 2022;10:119914–46.

37. Shao LJ, Tang W, Zhang ZQ, et al. Medical metaverse: technologies, applications, challenges and future. J Mech Med Biol. 2023. https://doi.org/10.1142/S0219519423500288.
38. Wu TC, Ho CTB. A scoping review of metaverse in emergency medicine. Austr Emerg Care. 2023;26(1):75–83.
39. Wu T, Hao F. Edu-Metaverse: concept, architecture, and applications. Interact Learn Environ. 2023. https://doi.org/10.1080/10494820.2023.2198567.
40. Dwivedi YK, Hughes L, Wang YC, et al. Metaverse marketing: How the metaverse will shape the future of consumer research and practice. Psychol Mark. 2023;40(4):750–76.
41. Shen BQ, Tan WM, Guo JZ, et al. How to promote user purchase in metaverse? A systematic literature review on consumer behavior research and virtual commerce application design. Appl Sci. 2021;11(23):11087.
42. Ritterbusch GD, Teichmann MR. Defining the metaverse: a systematic literature review. Ieee Access. 2023;11:12368–77.
43. Yang KD, Zhang ZY, Tian YL, et al. A secure authentication framework to guarantee the traceability of avatars in metaverse. IEEE Trans Inf Forensics Secur. 2023;18:3817–32.
44. Zhang X, Yang DL, Yow CH, et al. Metaverse for cultural heritages. Electronics. 2022;11(22):3730.
45. Huynh-The T, Gadekallu TR, Wang WZ, et al. Blockchain for the metaverse: a review. Future Gener Comput Syst. 2023;143:401–19.
46. Abu-Abed F, Zhironkin S. New game artificial intelligence tools for virtual mine on unreal engine. Appl Sci-Basel. 2023;13(10):6339.
47. Chia AA. The metaverse, but not the way you think: game engines and automation beyond game development. Crit Stud Media Commun. 2022;39(3):191–200.
48. Chu E, Zaman L. Exploring alternatives with Unreal Engine's blueprints visual scripting system. Entertain Comput. 2021. https://doi.org/10.1016/j.entcom.2020.100388.
49. Shen Y. Tsinghua University metaverse Development Research Report version 3.0. Tsinghua University School of Journalism and Communication metaverse Culture Laboratory. 2022, 11
50. Sun HY. Metaverse party politics: issues, risks and governance. J Shenzhen Univ. 2022;39(04):96–105.
51. Seo S, Seok B, Lee C. Digital forensic investigation framework for the metaverse. J Supercomput. 2023. https://doi.org/10.1007/s11227-023-05045-1.
52. Diao SF, Peng YS. The resolution and reconstruction of human subjectivity in the metaverse vision. J Changsha Univ Sci Technol. 2022;37(05):20–6+48.
53. Jian SY. Digitalization of entertainment: dynamics, risks and prospects of metaverse creation. J Shenzhen Univ. 2002;39(03):33–43.
54. Gupta A, Khan HU, Nazir S, et al. Metaverse security: issues, challenges and a viable ZTA model. Electronics. 2023;12(2):391.
55. Vidal-Tomas D. The illusion of the metaverse and meta-economy. IRFA. 2023. https://doi.org/10.1016/j.irfa.2023.102560.
56. Falchuk B, Loeb S, Neff R. The social metaverse: battle for privacy. IEEE Technol Soc Mag. 2018;37(2):52–61.
57. Xi N, Chen J, Gama F, et al. The challenges of entering the metaverse: an experiment on the effect of extended reality on workload. Inf Syst Front. 2022. https://doi.org/10.1007/s10796-022-10244-x.

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