Data Science and Management 7 (2024) 129–143

Contents lists available at ScienceDirect

Data Science and Management

journal homepage: www.keaipublishing.com/en/journals/data-science-and-management

Research article

Topic prevalence and trends of metaverse in healthcare: a bibliometric analysis

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ARTICLE INFO

Keywords:
Metaverse
Health informatics
Text mining
Bibliometric analysis

ABSTRACT

Metaverse technology is an advanced form of virtual reality and augmented technologies. It merges the digital world with the real world, thus benefitting healthcare services. Medical informatics is promising in the metaverse. Despite the increasing adoption of the metaverse in commercial applications, a considerable research gap remains in the academic domain, which hinders the comprehensive delineation of research prospects for the metaverse in healthcare. This study employs text-mining methods to investigate the prevalence and trends of the metaverse in healthcare; in particular, more than 34,000 academic articles and news reports are analyzed. Subsequently, the topic prevalence, similarity, and correlation are measured using topic-modeling methods. Based on bibliometric analysis, this study proposes a theoretical framework from the perspectives of knowledge, socialization, digitization, and intelligence. This study provides insights into its application in healthcare via an extensive literature review. The key to promoting the metaverse in healthcare is to perform technological upgrades in computer science, telecommunications, healthcare services, and computational biology. Digitization, virtualization, and hyperconnectivity technologies are crucial in advancing healthcare systems. Realizing their full potential necessitates collective support and concerted effort toward the transformation of relevant service providers, the establishment of a digital economy value system, and the reshaping of social governance and health concepts. The results elucidate the current state of research and offer guidance for the advancement of the metaverse in healthcare.

1. Introduction

Owing to the rapid development of the digital economy, the development of the metaverse has received widespread attention (Kim, 2021). The metaverse is considered a basic infrastructure for the next-generation Internet. It is not merely a virtual reality (VR) platform but rather a digital space. In this digital space, users can create, interact, and share information by engaging in business, socialization, and entertainment activities. After Facebook rebranded itself as Meta to fully develop the metaverse in October 2021, many large technology companies have expedited their efforts to investigate metaverse-based business models. However, an improper understanding of the metaverse renders it difficult for developers to overcome the associated challenges and achieve sustainable development (Lee, 2021).

The metaverse, which first appeared in Neal Stephenson's science fiction novel *Snow Crash* in 1992, is assumed to be synchronized with the real world and is a derivative of the current social media. Facebook's transformation has redefined the conventional concepts of communication, connectivity, news reporting, e-commerce, and social interaction (Hassouneh and Brengman, 2015). The metaverse is characterized by social existence and social and technological exchange, thus further highlighting the ability of virtual-world construction (Owens et al., 2011). Online health communities and telemedicine are essential in facilitating digital health. Digital health provides benefits to multiple stakeholders such as doctors, patients, healthcare provider organizations, online platforms, and pharmaceutical companies. The metaverse enables novel applications of artificial intelligence (AI)-based medical practices, health self-management, precision medicine, and drug innovation (Lou and Wu, 2019; Wang et al., 2022).

The metaverse in healthcare is designed to elevate virtual care from a

Peer review under responsibility of Xi'an Jiaotong University.
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https://doi.org/10.1016/j.dsm.2023.12.003
Received 12 September 2023; Received in revised form 24 December 2023; Accepted 24 December 2023
Available online 30 December 2023

two-dimensional to a three-dimensional (3D) experience to revolutionize health informatics. In a 3D immersive manner, the applications of the metaverse in healthcare include remotely monitoring critically ill patients, analyzing clinical patient data, monitoring blood glucose and heart rate, enhancing physical fitness tracking capabilities, and providing other unimaginable medical and health services. Peer-to-peer support is becoming increasingly important during interactions between medical professionals and patients in digital health (Aanestad and Jensen, 2011; Fürstenau et al., 2019). Professional clinical advice and treatment are considered the gold standards in healthcare. Therefore, efficient immersive medical and health services in a 3D virtual space must be provided based on medical-domain knowledge. Early metasaverse applications primarily focused on games and entertainment (Papagiannidis et al., 2008; Sun et al., 2023). Paying for the experience offered by healthcare service providers in metaverse is garnering the interest of multiple stakeholders.

However, challenges remain in terms of healthcare in metaverse (Andrulli and Gerards, 2023). First, patient privacy and safety in metaverse are issues of concern (Cheung, 2020). The metaverse in healthcare significantly alters medical practices from many perspectives. Owing to its numerous users and innovative connections, the metaverse inevitably results in various issues, e.g., personal, public, and national security issues (Leenes, 2007). The inappropriate management of mental health activities may endanger the health of the users. Because the metaverse may gamify healthcare applications, related constraints and regulations are necessary (Bochennek et al., 2007). Builders in the metaverse should carefully define the value of digital health; otherwise, multiple stakeholders in healthcare ecosystems may be confronted with severe consequences. Similar to the Roblox platform, which shares 30% of its revenue with developers, the metaverse in healthcare should allow developers to create value and use extended virtual technology to attract users (Sweeney, 2019). In the early days, stakeholders who pioneered the construction of the metaverse in healthcare included large technology companies in non-medical and health industries. The professional crisis caused by the gamification and entertainment of medical experts poses a significant challenge. Identifying the opportunities and challenges of the metaverse in healthcare offers theoretical and practical significance for the digital transformation of health services.

The bibliometric mapping approach involves a quantitative analysis of dynamic changes in emerging research topics over time (Hawkins, 1977). In recent years, visualization tools were used in bibliometric mapping research to enhance the understanding of topic trends (Olmeda-Gómez and de Moya-Anegón, 2016). For example, Özköse (2023) performed bibliometric analysis to understand the Internet of things (IoT), which enhances human life by providing an extensive description of the interrelationships and relationships among humans. Anas et al. (2023) performed a comprehensive bibliometric analysis of the evolution and trends in research pertaining to online purchasing experiences. They effectively outlined the emerging knowledge structure within the field investigated. Bibliometric techniques have been used to review studies pertaining to key account management (Kumar et al., 2019). Academic studies concerning AI and sustainability were analyzed to reveal the main trends and propose a robust agenda to accommodate future related studies (Bracarense et al., 2022). Bibliometrics effectively decrease the bias of topic trends through large-scale literature and subject analysis.

We aim to revise the literature pertaining to the metaverse in healthcare using a bibliometric mapping approach. This study investigates the promises of the metaverse in healthcare using various text-mining methods based on more than 34,000 publications published over 22 years as well as available news sources. We present a groundbreaking concept known as the health metaverse and its corresponding research framework. Using a series of quantitative methods, we identify future challenges and research directions, thereby adding substance and clarity to our proposed method. Furthermore, we analyze the metadata of related studies obtained from scientific databases and news sources from the Internet and then analyze the research trends based on four perspectives: knowledge, socialization, digitation, and intelligence. Based on the analysis results, we effectively identified the conceptual definition, topic distribution and differences, research trends, challenges, and applications of the healthcare metaverse.

RQ 1: How can a taxonomy be developed to capture the metaverse's emerging topics using a bibliometric mapping approach?
RQ 2: What are the opportunities and challenges of the metaverse in healthcare?

The remainder of this paper is organized as follows: Section 2 provides a review related studies. Section 3 introduces the materials and methods used for taxonomy construction. In Section 4, we elaborate on the results of topic distribution and trends; additionally, we discuss the application of the metaverse in healthcare. Section 5 provides a comprehensive discussion of the opportunities and challenges associated with the metaverse in healthcare. Finally, Section 6 presents the conclusions of this study.

2. Literature review

2.1. Metaverse

The application of metaverse technologies is prevalent in the industry; nonetheless, its academic discourse remains limited. The metaverse comprises a diverse array of technologies, such as AI, IoT, digital twins, and extended reality (XR) (Damar, 2022). The rapid evolution of digital medical transformation has been propelled by the progress of these technologies. The metaverse engages in collaborative efforts to enhance access to healthcare services across multiple disciplines, augment medical education and training, and optimize the provision and reception of medical services, thus aligning with the clinical requirements of patients (López-Ojeda and Hurley, 2023).

Thomason (2021) investigated the application of metaverse technology to reshape the health service paradigm and posited a potential value across five domains: collaborative work, education, clinical care, healthcare, and monetization. To investigate the latest developments in the healthcare metaverse, Bansal et al. (2022) scrutinized seven key areas: telemedicine, clinical care, education, mental health, physical health, veterinary medicine, and pharmaceuticals. The application of the metaverse in medicine encompasses diverse functionalities. For example, it enables remote surgeries spanning thousands of miles, thus creating physical separation between patients and surgeons (Massetti and Chiariello, 2023). Additionally, surgeons can visually access real-time clinical data, including diagnostic images.

Bashir et al. (2023) advocated for the use of metaverse technology in healthcare for applications such as medical diagnosis, patient monitoring, medical education, infectious disease management, and drug discovery, particularly in the context of federal learning support. Similarly, Wang et al. (2022) asserted that the amalgamation of metaverse technology with medical technology and AI is highly promising. This potential extends to fostering the development, prototype design, evaluation, supervision, transformation, and enhancement of medical practices grounded in AI, with emphasis on medical image-guided diagnosis and treatment. Meanwhile, Ali et al. (2023) proposed the integration of AI and blockchain in the metaverse.

The application of the metaverse in personalized medicine is promising for enhancing the quality and efficiency of individualized medical services. Nonetheless, various challenges, notably those pertaining to patient data security and privacy, impede the widespread adoption of the meta-verse in healthcare. Hence, Zhang et al. (2023) enhanced a model-sharing framework and advocated for the implementation of a decentralized autonomous organization blockchain network to ensure equitable distribution of shared benefits from models in cases involving imbalanced medical resource data. Ali et al. (2023) established metaverse environments facilitated by blockchain technology, where doctors and patients engage in interactions, thus ensuring data security, protection, and privacy. Shah and Khang (2023) investigated the transformative effect of the IoT on healthcare, with specific focus on telemedicine and remote patient monitoring.

Existing studies pertaining to the application of the metaverse in the health domain are primarily based on a conceptual and framework-oriented perspective, i.e., bibliometric analyses are scarce. Our objective is to systematically categorize and quantitatively assess meta research in the health domain. We aim to comprehend the prevailing challenges in applying meta to medical services and identify potential research directions for the future.

2.2. Bibliometric analysis

The concept of bibliometrics was introduced by Alan Pritchard in 1969 and is defined as "the application of mathematical and statistical methods to illustrate the processing of textual information, involving the calculation and analysis of different levels of textual information, as well as the nature and trend of discipline development" (Blažun Vošner et al., 2017). Bibliometric analysis, which is based on the concept of metrology, involves the use of mathematical and statistical methods for the analysis and measurement of information (Merigó and Yang, 2017).

Wider et al. (2023) conducted a preliminary analysis of the metaverse reported in the extant literature using bibliometric methods to elucidate the present and future prospects of this domain. Damar (2021) conducted a bibliometric evaluation of metaverse technology, which revealed the paucity of studies pertaining to the historical trajectory of the metaverse. Furthermore, the application of the metaverse has been intensively investigated using VR and augmented reality (AR) technologies, owing primarily to interest from the education sector (Muktiarni et al., 2023; Tlili et al., 2022). A systematic literature review regarding the application of metaverse in the education industry was conducted using quantitative analysis methods, which fortified the application of the metaverse in global education (Tlili et al., 2022). Muktiarni et al. (2023) conducted a bibliometric analysis of Metaverse's educational trend theme within the Google Scholar database and highlighted that researcher should scrutinize the relationship between the educational meta-universe and the digitization of education in the future.

In the field of health education, Ağaç et al. (2023) performed bibliometric analysis to acquire the research trends and models as well as to evaluate the cooperation networks associated with the application of the metaverse. The metaverse is a unique educational tool that may realize interactive digital courses, thus enabling detailed studies pertaining to the anatomy and anatomical devices (Massetti and Chiariello, 2023). Although metaverse technology is important in the field of education, complete and systematic bibliometric analyses of its technological applications in the healthcare are scarce. This study focuses on the use of bibliometric analysis for the current investigation into the application of the metaverse in healthcare.

3. Materials and methods

A flowchart of the current study is shown in Fig. 1. First, we determined the relevant keywords and designed search strategies based on three categories: (RC1) metaverse, (RC2) metaverse in the healthcare sector, and (RC3) health metaverse applications. Second, based on meticulously selected keywords, we used the Web of Science database to retrieve relevant publications for analysis. Third, trend and topic analyses of health metaverse publications based on four perspectives were performed using visualization tools. Finally, we present our understanding regarding the concepts, research framework, future challenges, and research directions associated with the health metaverse.

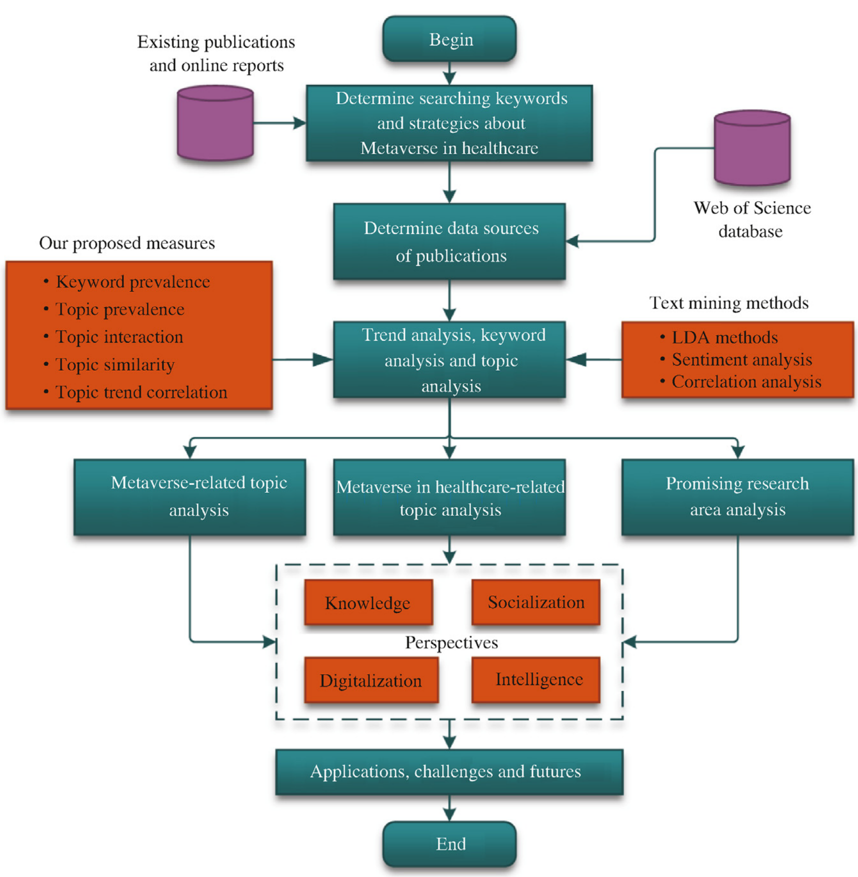

Fig. 1. Flowchart of bibliometric analysis.

3.1. Data sources

Metaverse-related studies from the Web of Science database were selected for bibliometric analysis. These studies were published over a span of 22 years from January 2000 and December 2021.

First, the literature and reports were classified into three research categories (RC1, RC2, and RC3) to determine the comprehensive definition of the metaverse. The keywords in the Web of Science database for the three categories were determined, as shown in Table 1. We analyzed the keyword occurrences for the RC1 type. Relevant keywords for the RC2 and RC3 types were determined empirically based on a comprehensive analysis of metaverse topics.

Second, the relevant publications for each category were retrieved from the database. The number of publications were 106, 7,950, and 26,619 for RC1, RC2, and RC3, respectively. Finally, the papers were analyzed using various methods to provide insights into the various levels of the health metaverse. To avoid the coverage limitation of the database, we conducted additional search on the Internet to obtain metaverse-related news and blogs. In addition, we obtained complete coverage of topics pertaining to the health metaverse from public news.

3.2. Trend analysis

Time-trend analysis was performed to examine the evolution of the metaverse and its applications in the healthcare sector over the past 22 years. Initially, we scrutinized publication trends containing the keyword "metaverse" over the past two decades. Notably, research activity increased modestly between 2007 and 2012, whereas it increased significantly beginning from 2020.

By retrieving bibliometric data, we identified a set of crucial keywords related to the health metaverse. These keywords, along with the corresponding numbers of retrieved studies, included VR, AR, mixed reality (MR), digital health, online health community, and telemedicine. We discovered that metaverse-related studies in the healthcare sector constituted a significant proportion after 2021. To identify trends in the health metaverse within three years following 2021, a timeline view of the bibliometric data is shown in Fig. 2. The initial application of the metaverse in healthcare focused on medical education using AR and VR technologies. Metaverse application in healthcare was extended to areas of physical therapy and care using AI technology in 2022. Currently, the metaverse is considered an effective tool for medical services and activity recognition that helps improve patients' user experiences. The recent three-year trend indicates a positive transition of metaverse applications in healthcare.

3.3. Keyword analysis

We examined metaverse-related studies by employing an overlay visualization of keyword occurrences based on four distinct perspectives. First, we identified essential keywords with strong correlations to the retrieved bibliometric data. Second, we realized an overlay visualization of these studies using the core dataset of the Web of Science to assess the utilization of the metaverse. Third, we analyzed bibliometric data categorized by topic to comprehensively understand the health metaverse. Fourth, we summarized topics derived from keyword clusters to highlight the key health attributes. The number of unique author keywords and keywords combined are listed in Table 2.

Table 1
Summary of search keywords used in Web of Science database.

Research category	Keywords
(RC1) Metaverse itself	Virtual reality, augmented reality, mixed reality, virtual worlds, avatar, 3d worlds, hyper reality, digital economy, social network, gaming, immersive experience
(RC2) The metaverse in the healthcare sector	Telemedicine, virtual reality in health, augmented reality in health, medical information standards, online health community, digital health, mobile health
(RC3) Metaverse perspectives	Digital transformation, digital economy, blockchain, artificial intelligence, digital twin, wearable devices, multimodal data

3.4. Topic analysis

The topic-analysis steps undertaken to advance the emerging concept of the health metaverse are outlined below. First, we examined the distribution of the research areas within the retrieved bibliometric data. Fig. 3 shows the distribution of fields associated with publications featuring various subject terms. The darker cells indicate a higher concentration of studies within the corresponding field. The primary research domains were related to the metaverse, include science and technology, life sciences, and social sciences. Second, we subjected the raw text of abstracts from the bibliometric data to latent Dirichlet allocation (LDA) topic modeling. Third, we investigated the framework for the health metaverse by considering four key perspectives: knowledge, socialization, digitization, and intelligence.

3.4.1. Knowledge perspective

The knowledge perspective delves into the foundational knowledge required to facilitate the development of the health metaverse. Owing to the pivotal role of medical information standards in healthcare informatics, our approach involves identifying the current utilization of these standards and evaluating the necessary adaptations to satisfy the user requirements associated with the health metaverse. This analysis is based on keywords sourced from academic publications and public resources.

3.4.2. Digitization perspective

A set of keywords pertaining to the digitization perspective is employed to discern the attributes of the participants within the health metaverse. Digital manifestations encompass a range of stakeholder roles, including those of patients, physicians, administrators, and healthcare providers. The integration of multimodal information is instrumental in creating comprehensive avatars within the metaverse. This perspective focuses on investigating the effect of digitization on metaverse users.

3.4.3. Socialization perspective

Based on publications pertaining to social networks and platforms, we introduce a framework for establishing social connections among users within the health metaverse. This framework begins with the identification of several research avenues associated with the socialization perspective. Subsequently, we provide an overview of its current applications. Finally, we conduct a comparative analysis between conventional social platforms and the metaverse platform.

3.4.4. Intelligence perspective

We perform a comparative analysis between conventional clinical decision support systems and the health metaverse. Next, we outline the advantages and disadvantages of implementing AI in healthcare Management. In addition, we identify specific application scenarios within the health metaverse to promote innovative AI utilization in the healthcare sector. Moreover, we devise strategies for establishing connections between real-world users and AI-driven avatars within the health metaverse.

3.5. Measures of topic difference

To facilitate the comprehension of topic distribution and disparities revealed by the topic-modeling results, we used the keyword prevalence (KP), topic prevalence (TP), topic interaction (TI), topic similarity (TS), and topic trend correlation (TTC) as indicators based on the topic and

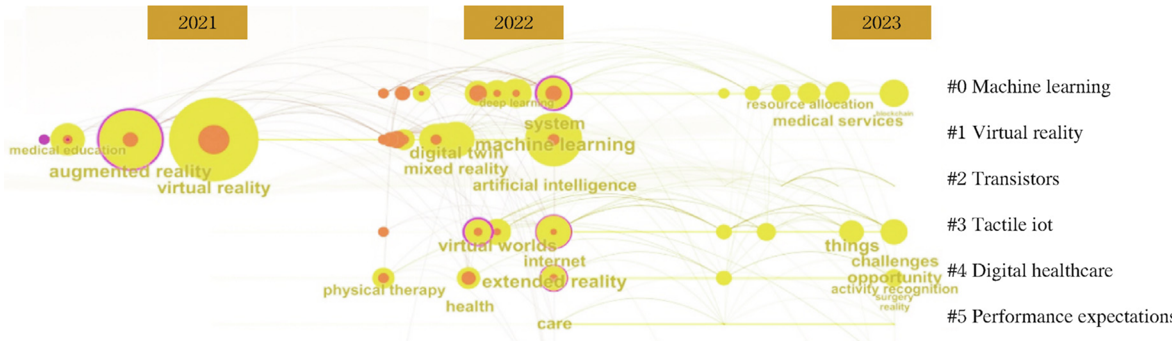

Fig. 2. Timeline view of bibliometric data related to health metaverse.

Table 2
Numbers of unique author keywords and keywords plus from our search.

Research category	Keyword	Number of author keywords	Number of keywords Plus®
RC1	Metaverse	371	68
RC2	Medical artificial intelligence	11,057	5,842
	Medical information standards	2,937	1,924
	Social network	1,811	1,380
	Virtual reality and health	5,216	3,989
RC3	Artificial intelligence	15,806	9,865
	Blockchain	12,130	3,590
	Digital economy	6,118	1,669
	Digital transformation	8,834	2,956
	Digital twin	6,667	2,519
	Multimodal data	4,918	2,724
	Wearable device	9,881	4,351

keyword weights from the obtained topic models.

3.5.1. KP

Assuming that W is a keyword, K the number of topics in the LDA model, Mi the number of keyword occurrences in the i-th topic, $wt(i)$ the weight of the i-th topic and, $w(i,j)$ the keyword weight of the j-th keyword in the i-th topic, one can express the KP as follows:

$$KP(W) = \sum_{i=1}^{K} w_{t(i)} \sum_{j=1}^{M} w(i,j)/N, \tag{1}$$

where N is the number of keyword occurrences in all topics.

3.5.2. TP

Based on the KP expressed in Eq. (1), we propose the TP indicator. Suppose that a topic defined in $T = [W_1, W_2, \ldots, W_M]$ and W_i is the i-th keyword in the topic; hence, the TP is expressed as:

$$TP(T) = \sum_{i=1}^{M_T} KP(W_i) \tag{2}$$

where M_T denotes the number of keywords in the topic. Using the KP and TP indicators in Eqs. (1) and (2), we can divide the news into a series of datasets by year and thus obtain the measured value change of the TP. Finally, we can examine the TP trends based on the topics.

3.5.3. TI

A TI analysis method is proposed for these two topics. Suppose that a topic distribution comprises a series of topics defined in $F = \{T_1, T_2, \ldots, T_k\}$, the keyword distribution in each topic (T_k) is defined in $T_k = [w_1, w_2, \ldots, w_m]$, and two topic distributions exist, i.e., (F_i, F_j). Therefore, the TI measure is expressed as follows:

$$TI(F_i, F_j) = \sum_{i=1}^{N_c} w_{W \in \forall T_i, W \in \forall T_j} \tag{3}$$

where N_c denotes the number of mutual keywords between F_i and F_j. The TI measure in Eq. (3) can be used to easily estimate the degree of interaction between two topics in terms of shared keywords.

3.5.4. TS

To understand the similarity between two topics in terms of shared keywords, we propose using the TS indicator to obtain the similarity between two different topics via the longest common subsequence (LCS) method. Assuming that two topics T_1 and T_2 have keyword distributions of $[w_i]$ and $[w_j]$, respectively, the TS indicator can be estimated as follows:

$$TS(T_1, T_2) = 1 - \frac{|LCS(T_1, T_2)|}{\max(|T_1|, |T_2|)} \tag{4}$$

where LCS in Eq. (4) includes shared keywords; and $|T_1|$ and $|T_2|$ are the numbers of keywords in T_1 and T_2, respectively. Subsequently, the TS between the two topics can be estimated.

3.5.5. TTC

We propose a TTC to estimate the correlation between two topic trends by combining temporal information based on the Pearson correlation coefficient. Suppose that two types of TP exist, defined as $TS_1 = [TP_1^1, TP_1^2, \ldots, TP_1^n]$ and $TS_2 = [TP_2^1, TP_2^2, \ldots, TP_2^n]$. Therefore, the TTC value between TS_1 and TS_2 is expressed as

$$corr(TS_1, TS_2) = \frac{\sum_{i=1}^{n} (TP_1{}^i - \overline{TP}_1)(TP_2{}^i - \overline{TP}_2)}{\sqrt{\sum_{i=1}^{n} (TP_1{}^i - \overline{TP}_1)^2} \sqrt{\sum_{i=1}^{n} (TP_2{}^i - \overline{TP}_2)^2}} \tag{5}$$

where TP_k^i represents the k-th time series of the TP in the i-th year.

Using the indicators in Eqs. (1)–(5), we can estimate the TP and topic differences from different perspectives based on a deeper understanding.

3.6. Visualization tools

Visualization tools were used to conduct a bibliometric analysis of the acquired data. We used the citation-analysis tool available through the online Web of Science database to acquire raw publication data and generate fundamental statistics. In addition, we used VOSViewer (Van Eck and Waltman, 2011) to visualize the search results as critical information and trends within the retrieved bibliometric data pertaining to the evolution of metaverse-related studies in the healthcare sector. Furthermore, we extensively used other tools such as CiteSpace (Chen et al., 2010) and the Python package (*biblio-laws*) under development to leverage the metrics for a comprehensive examination of the data

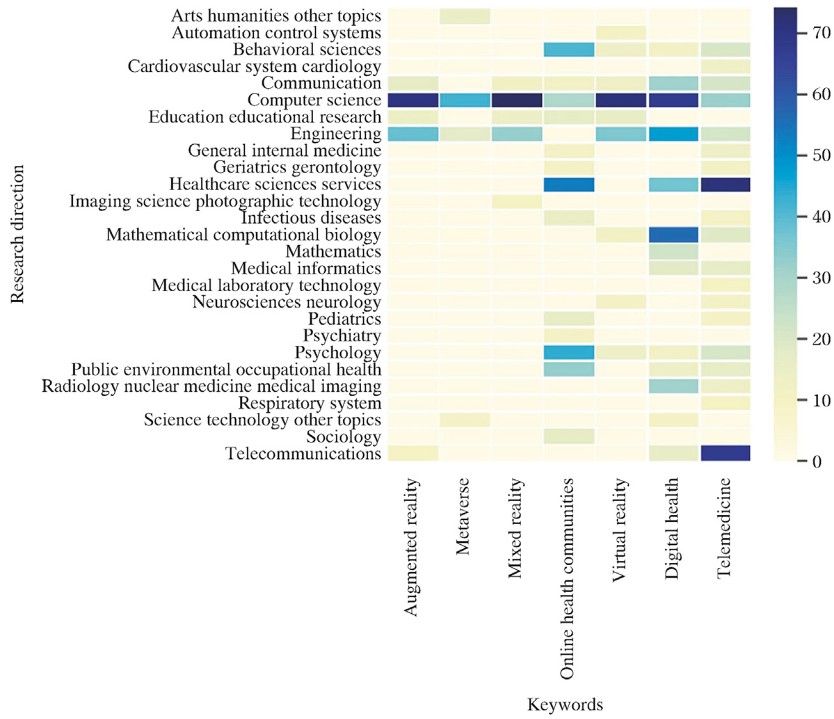

Fig. 3. Heat map of research directions and keywords pertaining to health metaverse.

characteristics and topic trends.

4. Results

Based on bibliometric data, we systematically examined the construction of the health metaverse. We considered the conceptual definition, framework, and existing applications, which serve as valuable references for the transformation of the healthcare industry into the metaverse.

4.1. Conceptual definition

Health services typically revolve around human interactions. Patients initiate conversations with physicians regarding their health condition. Physicians assess symptoms by considering various physiological factors, such as emotional responses, physical reactions, and clinical data. Subsequently, physicians formulate the most suitable treatment plan for patients. Table 3 summarizes the scholarly perspectives regarding the use of the metaverse in healthcare.

Previously, researchers have investigated digital health technologies to address personal health concerns (Anderson and Agarwal, 2011; Wiederhold and Riva, 2022; Yang et al., 2022). The global pandemic has accelerated this trend, thus promoting the adoption of health services, wearable devices, and telemedicine. In the metaverse, healthcare informatics users are no longer confined to a single stakeholder (Koohang et al., 2023). Rapid technological advancements are reshaping the existing health informatics systems into comprehensive ecosystems (Pang et al., 2018). However, various challenges remain, including those pertaining to technology (exchangeability and mobility), laws and regulations, and human elements (skills, resistance, and distrust).

The health metaverse is constructed based on computer science, telecommunications technology, healthcare services, and computational biology. In addition, existing studies in fields such as behavioral science, psychology, and education are crucial in advancing the health metaverse (Koohang et al., 2023). In contrast to the broader conceptual definition of the metaverse, we define the health metaverse from the perspectives of knowledge, digitization, socialization, and intelligence. Interoperability is extremely important in digital healthcare, as service providers and stakeholders in this expansive domain increasingly require the seamless sharing of portable and compatible data across diverse systems, institutions, platforms, and international boundaries (Dwivedi et al., 2022).

The health metaverse represents a virtual healthcare platform that exists parallel to the real world but operates independently of it. This virtual realm is constructed based on authoritative knowledge within the healthcare sector and the fusion of multimodal health informatics. Its primary objective is to promote the development of intelligent multimodal medical informatics applications. Unlike the current cumbersome online tools, next-generation virtual health services based on the health metaverse aim to immerse users in a more interactive and human-like environment, realized through AR, VR, MR, and other virtualization technologies (Muktiarni et al., 2023).

4.2. Topic distribution

To obtain insight into the topic distributions and disparities among various categories of studies pertaining to the health metaverse, we conducted a comprehensive topic-modeling analysis. In particular, we employed advanced LDA methods and a novel approach to aggregate topic and keyword weights using our proposed indicators, i.e., KP, TP, TI, TS, and TTC. Table 4 summarizes the top keywords obtained from each research category.

Fig. 4 presents a comparative analysis of the cumulative weights assigned to the research perspective for each research category. This graph illustrates the distinct distributions of the four perspectives. For example, AI-related research focuses on the knowledge perspective, whereas blockchain-related research predominantly focuses on the socialization perspective. This disparity in cumulative weights allows researchers to obtain clarity regarding their primary research focus when addressing health problems.

Fig. 5 presents a comparative assessment of TI among the categories, with emphasis on the topic distribution. The TI strength indicator

Table 3
Scholarly perspectives regarding conceptual definition of metaverse in healthcare.

Authors	Definition of metaverse in the healthcare sector
Thomason (2021)	The areas include collaborative working, education, clinical care, wellness and monetization.
Damar (2022)	Virtual reality or augmented reality are important in medical metaverse, changing scientific research, health services, and health-related process.
Yang et al. (2022)	The metaverse in healthcare should manage the patient disease and psychosocial models through rigorous evidence-based medicine, ensure availability, confidentiality, integrity, and controllability of the system.
Musamih et al. (2022)	Potential applications include telemedicine and telehealth, medical education and training, medical marketing, healthcare supply chain, healthcare facilities and fitness and wellness.
Ali et al. (2023)	The metaverse consists of three environments, namely, the doctor's environment, the patient's environment, and the metaverse environment.
Xu, et al. (2022)	The scenarios or paths include clinical surgery, medical robots, medical teaching, drug and medical device research and development.
Song and Qin (2022)	Heath related technology in Metaverse include augmented reality, virtual reality and digital twin.
Bansal et al. (2022)	The latest development includes telemedicine, clinical care, education, mental health, physical fitness, veterinary and pharmaceuticals.
Wiederhold and Riva (2022)	Three current major technological trends include telepresence, digital twinning, and blockchain while pervasive societal issues including discrimination, privacy violation, lack of transparency, and public safety will always occur.
Shah and Khang (2023)	The IoT in the metaverse changes healthcare with two areas, telemedicine and remote patient monitoring, which improves healthcare's accessibility and convenience.
López-Ojeda and Hurley (2023)	It increases access to health services among supplement medical education and training, and delivering and receiving medical care to meet patient needs.
Wang et al. (2022)	Medical technology and AI can facilitate the development, prototyping, evaluation, regulation, translation, and refinement of AI-based medical practices, especially medical imaging-guided diagnosis and therapy.
Chengoden et al. (2023)	It ensures immersive, intimate, and personalized patient care, and also provides adaptive intelligent solutions that eliminates the barriers between healthcare providers and receivers.

quantifies the extent to which keywords are shared between two research categories. The interaction strength between blockchain and AI was the most pronounced. Notably, blockchain has received significant attention in other domains such as medical AI, wearable devices, multimodal data, and healthcare VR.

Table 5 presents a comparison of topic similarities based on topic models generated using LDA methods. This comparison underscores the interconnectedness of the metaverse with existing research categories, such as the digital economy, digital transformation, wearable devices, digital twins, and AI.

Based on the results of topic models from news reports, the similarity between metaverse and health-metaverse topics was estimated to be 0.776. From a knowledge perspective, the total keyword weight of metaverse in healthcare is greater than that of metaverse topics, whereas it is less well known than the metaverse from socialization and digitalization perspectives. From an intelligence perspective, they are approximately identical. Based on our analysis results from the news, keywords such as VR, virtual world, immersive, gaming, and AR have greater weights than other keywords associated with metaverse topics.

Segmented into primary categories (metaverse, metaverse in healthcare, and metaverse perspective), the publication datasets were meticulously examined to facilitate a comparison of the TP and topic distinctions. Our analysis revealed that the interaction of topics between the metaverse and metaverse in healthcare was significantly stronger than those in other comparative scenarios. In terms of the knowledge and socialization perspectives, the metaverse perspectives exhibited more pronounced keyword weights compared with the metaverse in healthcare. Conversely, in the domains of digitalization and intelligence, the metaverse in healthcare demonstrated significantly stronger cumulative keyword weights. In terms of TS, the metaverse exhibited similarity scores of 0.634 and 0.416 with respect to the metaverse perspective and metaverse in healthcare, respectively. Additionally, the metaverse perspective indicated a similarity score of 0.600 with respect to the metaverse in healthcare.

4.3. Research trends

Developing a health metaverse requires technologies such as remote communication and VR. Additionally, knowledge pertaining to healthcare is essential. This forms the basis for creating a virtual community that encompasses both patients and medical professionals. We propose a research framework based on bibliometric data. This framework emphasizes innovative research directions in healthcare informatics and promising applications in health management. Four perspectives are focused on, i.e., knowledge, socialization, digitization, and intelligence. Fig. 6 provides a comparative analysis of the TTC across the four perspectives. The correlation between the knowledge and socialization perspectives emerged is the strongest among the comparisons. All correlations within this comparison were significant ($p < 0.0l0$).

Based on Zipf's law (Wyllys, 1981), Fig. 7 presents a comparison of keyword distributions across the three categories. The high-frequency keywords are highlighted in the subfigures. Studies regarding the virtual world, second life, avatars, and VR are dominant in the subject area of the metaverse. Meanwhile, studies regarding rehabilitation, health, simulation, stroke, exercise, disorders, virtual patients, and head injuries are prevalent in the health metaverse.

Research directions for metaverse include wearable devices, accelerometers, sensors, activity recognition, biomedical monitoring, and

Table 4
Summary of top keywords from different research categories.

Research category	Top keywords
Artificial intelligence	System, datum, model, algorithm, study, performance, application, power, paper, area, network, computer, process, technique, innovation
Blockchain	Datum, technology, system, network, service, security, transaction, privacy, article, application, device, user, model, challenge, management
Digital economy	Economy, value, business, datum, research, innovation, model, development, technology, solution, country, level, finger, sign language, sensor
Digital transformation	Transformation, technology, business, model, health, process, system, industry, management, value, service, datum, firm, strategy, book
Multimodal data	Datum, emotion, model, system, analysis, modality, patient, recognition, method, sensor, result, multimodal, interaction, correlation, research
Wearable device	Device, feedback, force, user, system, display, study, experiment, method, design, sensor, interaction, datum, patient, result
Medical artificial intelligence	Model, datum, dementia, image, system, method, application, patient, health, technology, study, disease, algorithm, diagnosis, result
Medical information standards	System, datum, health, trial, CTIM, NLP, method, process, result, imaging, information, study, data, guideline, conclusion
Social network	Health, network, study, group, participant, result, analysis, professional, method, intervention, user, internet, conclusion, research, application
Virtual reality and health	Health, participant, group, study, intervention, virtual reality, VR, game, training, result, method, patient, exercise, child, student

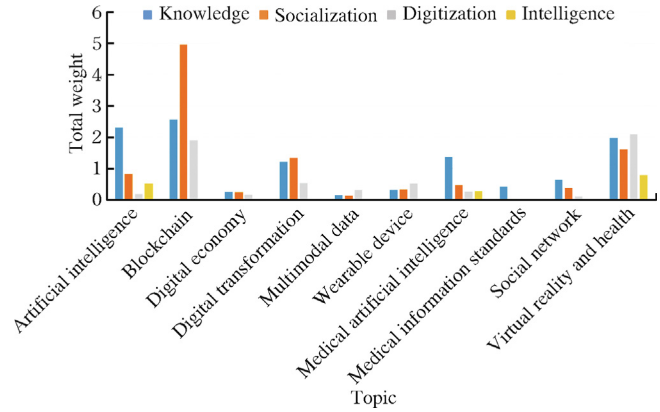

Fig. 4. Comparison of total weight change for different topics.

mobile handsets. The results showed high-quality keywords related to our research topics. For more detailed cluster topics, please refer to Table S1 in the Supplementary data.

Table 6 shows the estimated parameters of Brookes' equation based on Bradford's law (Brookes, 1968). First, we estimate $R(n) = \alpha n^{\beta}, 1 \leq n < c$ and then establish $R(n) = K \ln(n/S)), c \leq n \leq N$, where n is the journal rank number, N is the total number of journals, and the remaining are parameters. A higher value of S in the table indicates a greater scope of research related to the corresponding keywords. In the table, α suggests the number of relevant papers in high-rank journals.

Notably, research areas such as medical information standards, social networks, and blockchain exhibit relatively larger value of S, thus implying that these research fields encompass a greater scope than others. The results offer a quantitative estimation of the trends and maturity levels within each research area and provide valuable insights into this bibliometric analysis.

Lotka's law (Lotka, 1926) was applied to examine the scientific productivity of keyword-related research areas. This method quantitatively estimates the relationship between publications and authors by fitting the equation $lnf(x) + aln(x) = lnC,$ where x represents the number of papers, $f(x)$ represents the number of authors who published x papers, and the remaining are parameters. Parameter a is an indicator of imbalance in the distribution of authors of scientific papers. A smaller a value represents a higher degree of scientific research cooperation. Table 7 indicates that blockchain-related studies exhibited a higher degree of scientific research cooperation. Conversely, larger values of a indicate that the publications are closely intertwined with the fields of technology, society, and humanities.

4.4. Theoretical framework

Fig. 8 presents the theoretical framework for metaverse applications in the healthcare sector. The framework includes four perspectives, namely, knowledge, socialization, digitalization, and intelligence, which represent multimodal medical information standards, medical and social data fusion, telemedicine and online health management, and medical AI, respectively.

Table 5
Topic similarity between different metaverse topics.

Category comparison	Topic similarity
(metaverse, digital economy)	0.923
(digital economy, digital transformation)	0.902
(digital economy, wearable device)	0.829
(metaverse, digital transformation)	0.821
(metaverse, wearable device)	0.817
(digital transformation, wearable device)	0.806
(digital transformation, digital twin)	0.800
(artificial intelligence, medical artificial intelligence)	0.791
(digital twin, multimodal data)	0.770
(digital economy, digital twin)	0.731
(multimodal data, medical artificial intelligence)	0.729
(digital transformation, multimodal data)	0.715
(medical information standards, social network)	0.707
(digital economy, multimodal data)	0.700
(multimodal data, wearable device)	0.673
(digital twin, wearable device)	0.655
(medical artificial intelligence, medical information standards)	0.645
(metaverse, digital twin)	0.638
(digital twin, medical artificial intelligence)	0.635
(artificial intelligence, multimodal data)	0.635

4.4.1. Medical information standards: knowledge perspective

Applications of medical informatics are based on expert knowledge. Medical information standards contribute significantly in facilitating the sharing, exchange, and integration of medical information. Noteworthy applications of medical information standards include tasks such as medical text analysis, the coding of laboratory test results, and the standardization of medical images. These standards have been instrumental in advancing the precision and effectiveness of clinical-decision support systems, as illustrated in the overlay visualization of their publications (refer to Fig. S1 in the Supplementary data).

Medical information standards employed for encoding medical text include notable systems such as the International Classification of Diseases (ICD) (Chen et al., 2020), the Systematized Nomenclature of Medicine-Clinical Terms (SNOMED CT) (Lee et al., 2014), and the Unified Medical Language System (UMLS) (Amos et al., 2020). The ICD is a disease-classification standard that is widely adopted in more than 100 countries and facilitates the reporting of coded patient data to the World Health Organization. The use of ICD-coded patient medical records enables global disease monitoring, statistical analyses, data sharing, reimbursement billing, and annual appropriation planning. Similarly, SNOMED CT is pivotal in encoding electronic health records in numerous member states. In healthcare, the metaverse virtualizes a comprehensive array of medical knowledge and services. This critical endeavor is intricately correlated with medical information standards and serves as their foundational framework. Without this foundation, the content contributed by users in the metaverse may be devoid of the essential medical

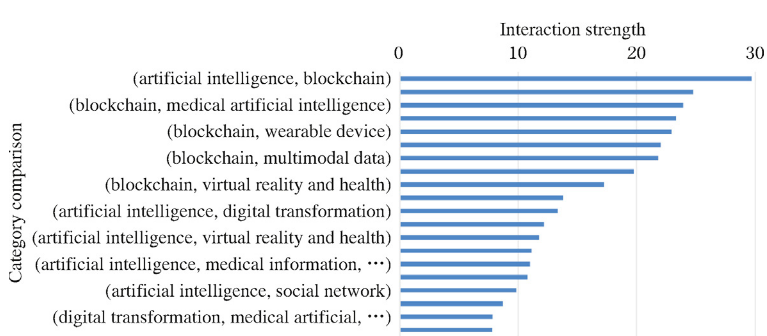

Fig. 5. Topic interaction strength of different categories.

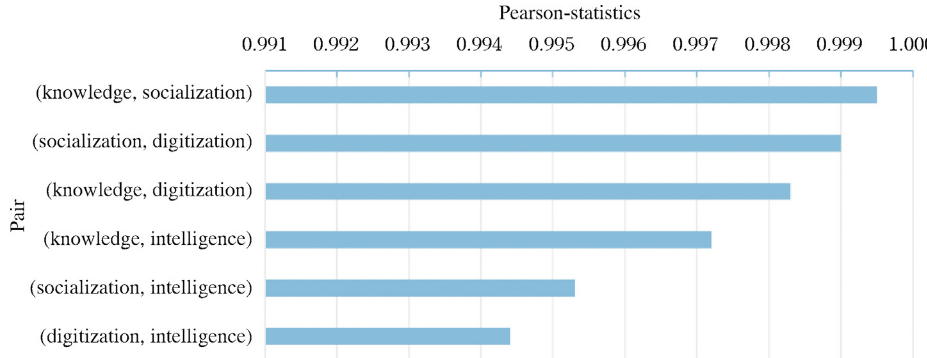

Fig. 6. Comparison of topic trend correlation over time among four topic perspectives.

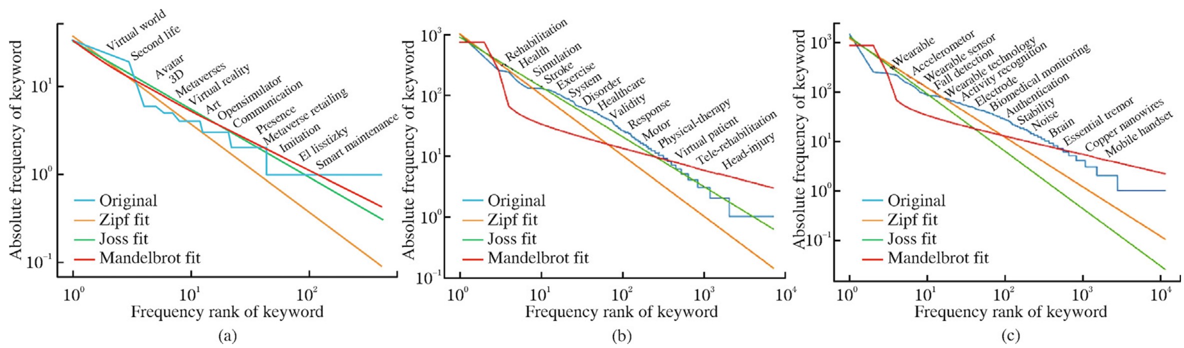

Fig. 7. Zipf distribution of keywords related to metaverse. (a) Metaverse, (b) metaverse in healthcare, and (c) metaverse perspectives.

Table 6
Estimated parameters of Brookes' equation based on Bradford's law.

Keywords of research field	α	β	*S*	*K*	Total year
Medical artificial intelligence	1349.363	0.282	0.041	423.370	12
Medical information standards	55.230	0.540	5.399	175.129	7
Social network	54.122	0.526	2.596	109.595	12
Virtual reality and health	849.172	0.249	0.010	203.939	12
Artificial intelligence	1523.286	0.368	0.000	106.689	22
Blockchain	391.000	0.461	7.772	902.554	6
Digital economy	833.457	0.248	0.017	212.502	22
Digital transformation	1092.483	0.277	0.027	340.614	21
Digital twin	754.921	0.276	0.067	253.502	18
Multimodal data	854.084	0.211	0.000	133.451	22
Wearable device	1603.496	0.254	0.001	295.218	22

Table 7
Estimated parameters related to relationships between author and paper numbers using Lotka's law.

Keywords	*a*	*C*
Medical artificial intelligence	3.72	0.91
Medical information standards	4.36	0.94
Social network	4.33	0.94
Virtual reality and health	3.67	0.90
Artificial intelligence	3.69	0.90
Blockchain	2.77	0.80
Digital economy	4.08	0.93
Digital transformation	3.37	0.88
Digital twin	3.27	0.87
Multimodal data	3.48	0.89
Wearable device	3.29	0.88
Metaverse	3.27	0.88

factual basis from the natural world. Consequently, satisfying the specific demands of users within a secure virtual environment becomes challenging.

Enhancing existing medical information standards, as catalyzed by the integration of multimodal data contexts, is instrumental in fostering the innovative evolution of medical information applications. This process enables patients to engage with avatars meticulously crafted from individual patient data in a 3D environment. This immersive experience empowers patients to observe the progression of disease, access visual diagnoses, predict treatments, and obtain better visual understanding regarding the effect of treatment options on their bodies. The utilization of multimodal medical information standards is paramount for facilitating high-precision medical VR applications customized to patient conditions.

In the future, disease coding will transition from the conventional text-based encoding, such as ICD codes, to the utilization of 3D virtual entities to precisely represent each category of information (Sébastien et al., 2009). An important challenge in creating these virtual entities is the complexity of managing and standardizing multimodal medical information (Baltrušaitis et al., 2018).

The application of medical information standards in the health sector can significantly enhance medical education. The health metaverse can create simulated medical environments for training medical students, thereby reducing the likelihood of errors in real-world scenarios. Existing gamified medical training programs typically rely on medical information standards. Nevertheless, a substantial proportion of experienced medical professionals are aged over 50 years and may not possess innate digital fluency, thus rendering it difficult to satisfy the literacy requirements for engaging with the health metaverse.

4.4.2. *Medical and social data fusion: socialization perspective*

The health metaverse serves as a platform that leverages virtualization technology to seamlessly connect various medical and healthcare stakeholders, thereby establishing a highly efficient virtual multimodal

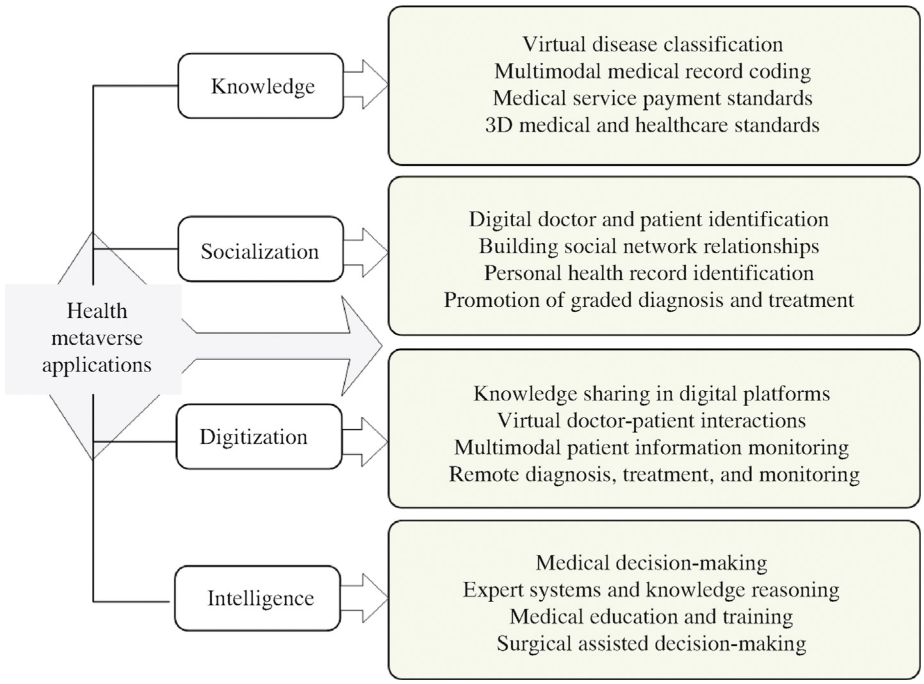

Fig. 8. Theoretical framework of metaverse applications in healthcare sector.

world. In contrast to conventional social networks, which digitize the roles of participants such as doctors, patients, and service providers, the health metaverse integrates all users while incorporating their existing social relationships through the amalgamation of multimodal user data (Fig. S2 in Supplementary data).

In the health metaverse, virtual hospitals can embody the roles of avatars representing doctors, patients, nurses, and managers, thus mirroring the existing administrative hierarchy. Fig. 9 provides insights into the evolution of TP across different perspectives over the years, using KP and TP as indicators. As shown, the TP increased consistently across all four perspectives. Notably, socialization-related topics increased significantly since 2018, whereas knowledge-related topics increased gradually before stabilizing. Similarly, intelligence-related topics increased gradually, albeit with a smaller magnitude of TP compared with those of the other three perspectives.

The socialization aspect of the health metaverse enhances interactions between medical professionals and patients. In the typical healthcare settings, doctors communicate with hospital patients, which is typically inefficient. In regions with limited medical resources, patients may encounter prolonged waiting times to access high-quality medical care. In addition, existing online health communities typically offer limited real-time communication options with remote doctors via text messaging and voice communication (Zhao et al., 2020). The health metaverse offers a virtualized platform in which patients can engage in face-to-face communication with doctors. This platform employs VR technology to visualize disease data and treatment plans during the communication process, thereby enhancing the quality of medical services and the efficiency of doctor–patient interactions (Zhao et al., 2020).

Metaverse applications related to personal health are undergoing a transformation toward socialization. For instance, consider current sports training applications that establish online training communities by sharing users' training results, which is characteristic of personal health social applications. In the health metaverse, users can congregate remotely, engage in healthy exercises with other users, and share their workout outcomes in a visually immersive virtual environment. This allows individuals to experience the excitement of interacting with others while exercising comfortably in their own homes. Personal health entertainment and socialization are promising for the development of the health metaverse and are particularly advantageous for fostering personal health. Metaverse-based personal exercise extends beyond sports-performance metrics, i.e., it involves the acquisition of multimodal data and a comprehensive assessment of personal health conditions.

4.4.3. Telemedicine and online health management: digitalization perspective

Telemedicine and online health management are pivotal applications in the health metaverse. Unlike socialization and openness, these applications prioritize the privacy of personal diagnosis and treatment data. Key terms associated with the digitalization perspective, such as VR, mental health, education, rehabilitation, and physical activity, were identified (Fig. S3 in Supplementary data). These keywords are particularly pertinent to studies focusing on stress, anxiety, pain, depression, obesity, and stroke.

In telemedicine, physicians and patients interact in secure environments (Chen et al., 2019a, 2019b; Ryskeldiev et al., 2018). In the metaverse, telemedicine can be used to establish a virtual environment. This environment uses three types of technologies to facilitate the presentation of the personal health conditions of patients via intuitive visualization techniques. It can visually depict the effects on a virtual body before

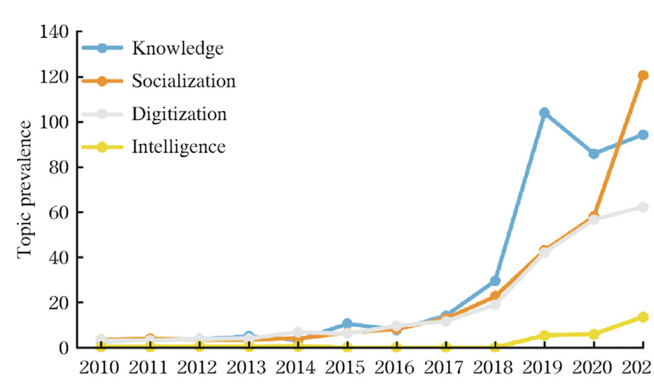

Fig. 9. Topic prevalence change by year for different perspectives.

and after treatment or medication. These applications may encompass the remote monitoring of critically ill patients, enhanced analysis into clinical-outcome data, and the comprehensive acquisition and monitoring of multimodal health information.

Users can seek access to their health data for personal health management in the metaverse. This inevitably entails the incorporation of essential digital components, such as virtual currency and personal credit assessment. Current efforts by technology companies predominantly revolve around games, entertainment, and e-commerce, and are typically motivated by commercial interests. However, the value system of the health metaverse should extend beyond virtual currency. Establishing a robust value system in the health metaverse is crucial for creating a sustainable, effective, and health-focused virtual world for healthcare.

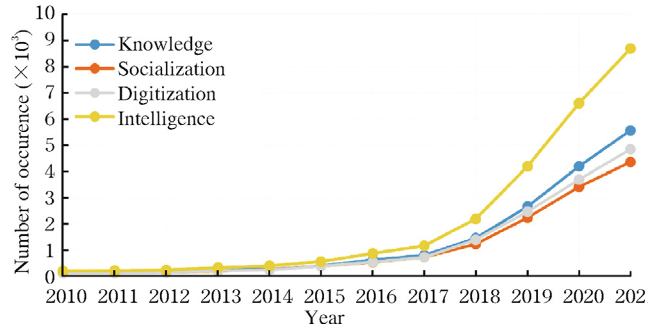

Fig. 10. Trend analysis of different perspectives.

4.4.4. Medical AI: intelligence perspective

Although the metaverse is currently in its early stages, it is highly promising for advancing and enhancing medical information technology owing to its ability to seamlessly integrate various cutting-edge technologies such as AI, VR, AR, medical IoT, Web 3.0, edge and quantum computing, as well as robotics. A critical application scenario in the health metaverse is the enhancement of clinical decision support within hospitals and the widespread deployment of distributed medical AI. Fig. 10 shows that all perspectives experienced significant growth since 2018 in terms of the number of related keyword occurrences. It highlights the fact that studies related to intelligence garnered increasing popularity, unlike studies based on other perspectives.

In the health metaverse, clinical decision support is intended to address critical areas, including disease diagnosis and treatment, ICU monitoring, and operating room surgery, as depicted in the overlay visualization (Fig. S4 in Supplementary data). XR technology has been successfully applied in more than 15,000 surgical procedures. These studies encompassed multiple stages, spanning from expert knowledge bases to machine learning, deep learning, and reinforcement learning. Meta-learning (Arroyo et al., 2009; Hospedales et al., 2021), which is one of the most advanced AI methodologies to date, is vital to the health metaverse. It catalyzes further innovation and the advancement of cutting-edge clinical decision-support systems.

Currently, the development of large-scale distributed medical AI in the metaverse is promoting innovation in clinical decision support. Patient data which feature various modalities such as user voice, actions, clinical records, and physiological signals captured by diverse devices are inherently multimodal. This abundant source of multimodal data is valuable in medical AI applications.

In the health metaverse, various virtual entities integrated into medical AI systems empower users with critical medical and health decision-making capabilities. These capabilities are based on the fusion of multimodal user data and domain knowledge (Arroyo et al., 2009). Researchers have primarily focused on single-source, single-modality AI decision-making models (Xu et al., 2019). These single-modal AI models are typically decentralized and cannot perform dynamic updates.

By contrast, the metaverse transcends its role as a mere platform for virtual user communication. Medical decision-support models undergo dynamic updates and gradually form a collaborative decision-making mechanism in the metaverse. Consequently, these models evolve into a virtual realm of self-awareness, continuous learning, and collaboration, thus providing a nurturing environment for diverse AI entities and ultimately propelling the intelligence of the health metaverse.

4.5. Applications

The concept of metaverse is not entirely novel. A conceptual model was proposed previously (Davis et al., 2009), which encompassed elements such as the metaverse, characters/avatars, technical capabilities, behaviors, and outcomes. This model serves as a valuable framework for analyzing practical issues concerning virtual teams in the metaverse. Numerous companies have investigated substantially into the research and development of metaverse-related technologies. However, a standardized architectural definition of the metaverse is yet to be established; hence, whether existing architectures can effectively satisfy the requirements for executing the metaverse is yet to be elucidated (Nevelsteen, 2018).

The metaverse is in its early stages of concept formation, with few mature applications in existence (Duan et al., 2021). The metaverse is predicted to evolve over several decades or longer, possibly among other technological advancements. The field of medical informatics can benefit from its integration with the metaverse and might transition to a practical stage earlier than the transition to a broader metaverse concept. Text analysis results obtained from relevant news sources generated numerous extracted triples, thus forming a knowledge graph for the metaverse in healthcare (refer to the online resource). This knowledge graph highlights the emerging trends in the development of the health metaverse.

Technology is critical in propelling the transition from the Internet to the metaverse. This technological shift encompasses eight fundamental domains: XR, user interaction (human–computer interaction), AI, blockchain, computer vision, IoT, robotics, edge and cloud computing, and future mobile networks (Lee, 2021). Whereas numerous papers that feature keywords such as telemedicine, VR, AR, and digital health abound, publications that specifically addresses the metaverse are scarce. Hence, a substantial gap remains in realizing the transformation toward the health metaverse.

The health metaverse can provide highly realistic virtual environments for remote online doctors during actual surgical procedures (Desselle et al., 2020). Effective navigation of complex human structures to locate lesions has been a significant challenge in conventional surgery. If surgeons can benefit from realistic simulation training or precise guidance prior to a surgical procedure, then the risks associated with actual operations can be reduced considerably. In this regard, the health metaverse offers surgeons an immersive environment in which they can enter a patient's body virtually during surgery, thus enabling them to perform high-precision operations on delicate organ structures (Penza et al., 2020). Hence, the health metaverse can potentially serve as the primary training ground for next-generation surgical robots. Through AI, these surgical robots can acquire the skills required to perform surgeries on the human body.

The health metaverse offers significant potential for enhancing patients' health management capabilities across various scenarios. VR technology can enhance the quality of life of individuals with dementia, as well as support the continuous health improvement of individuals with chronic conditions such as diabetes and hypertension. The above-mentioned technologies enable bedridden patients to virtually explore different global attractions and create diverse scenes, thereby facilitating the retrieval of old memories and improving their mood (Anderson and Molloy, 2020). The health metaverse significantly benefits patient-care improvement during surgery. It facilitates pre-and post-operative evaluations by integrating multimodal patient data into hospital metadata. This consequently results in the creation of digital patient models, thus enabling optimized surgical procedures and personalized interventions.

The health metaverse offers valuable applications, particularly in exercise training and dietary control, where its capabilities are exploited to the maximum.

Applications of the metaverse are centered around social and gaming platforms. Owing to platforms such as Roblox, which features 37 million unique daily users and is present in 180 countries, an increasing number of users seek opportunities for collaboration and connection with others. AR technology can introduce individuals to virtual coaches and innovative exercise techniques. The health metaverse congregates stakeholders such as doctors, patients, administrators, and governments, where user interactions are virtualized (Aulisio et al., 2020). Medical professionals employ the health metaverse to create content packages for healthcare service education. Healthcare stakeholders use meaningful virtual images, 3D models, MR, and spatial environments, along with their metadata, to share healthcare knowledge.

Medical educators use VR technology to train medical students. Thus, healthcare practitioners can effectively simulate real-world scenarios. Medical schools have integrated AR technology into their curricula. AR applications simulate surgical conditions, thus allowing medical students to observe real-life scenarios and practice new techniques. When coupled with information from hospital equipment, this immersive virtual experience enables students to replay the intricacies of actual surgeries as if they were the surgeon themselves (Dedeilia et al., 2020). During patient procedures, the health metaverse platform can provide medical students with domain-specific knowledge to minimize risks and errors in real-world operations.

5. Discussion

The health metaverse has become increasingly vital for healthcare service providers and stakeholders to share data that are both portable and compatible across various systems, institutions, platforms, and even different countries. The advancement and adoption of the health metaverse presents opportunities while presenting several formidable challenges.

5.1. Challenges

Based on previous experience, the healthcare sector has been slow in embracing, advocating for, and incorporating emerging information technologies (Kolodner et al., 2008). This is due to challenges associated with technological considerations (interoperability, portability, and stakeholder-specific adaptations) and human factors (proficiency, resistance, skepticism, cyber threats, regulation, and legislative) (Koohang et al., 2023).

The health metaverse must be further improved to cater effectively to the requirements of users. The COVID-19 pandemic has significantly accelerated innovative developments in digital health (Golinelli et al., 2020). However, the credibility and efficacy of healthcare platforms established warrant further investigation. Unlike existing platforms such as Mayo Clinic, Epic, and Optum, the health metaverse should be exceptionally user-friendly and possess extensive interoperability capabilities. Additionally, it should be available to various virtual entities, including individuals and organizations, particularly medical professionals and healthcare institutions. Because ordinary users do not possess sufficient clinical expertise required in the metaverse, their ability to form diagnosis and treatment standards is restricted compared with that of qualified individuals. Metaverse platforms struggle to integrate medical knowledge seamlessly into user decision-making processes.

Meanwhile, the gamification of health services can result in ethical dilemmas (Oravec, 2020). The associated consequences can be severe and may jeopardize the lives and well-being of patients. It would be unwise to entrust the creation, definition, and maintenance of health-metaverse content solely to gaming and social media companies. Platforms such as Roblox are compatible with virtual worlds, casual games, and user-generated content. Meanwhile, entertainment-focused characteristics are unsuitable for the health metaverse. Reforms and stringent oversight are necessary to ensure that the health metaverse relies on professionally curated and authoritative user-generated content. Similar to the assessment strategies used in online health communities, evaluation mechanisms should be developed in 3D space (Jarmon et al., 2009). These evaluation mechanisms should involve doctors and patients engaging in one-to-one or one-to-many interactions to evaluate their post-diagnosis experiences. This approach ensures that the health metaverse remains a reliable and trustworthy source of medical information and service.

Concerns regarding user privacy, safety, and personalization are paramount in the health metaverse. Although applications in the health metaverse can revolutionize medical practice, one must prioritize the protection of user privacy and ensure physical and psychological safety during the early stages of the metaverse (Zhang et al., 2023). The metaverse may require supervisory measures that impose ethical and moral restraints (Blobel, 2020). Additionally, the technology stack underpinning the health metaverse underscores the risks and challenges associated with maintaining a system impervious to hacking. Although the rapid promotion of the metaverse may yield substantial benefits initially, a more measured approach with comprehensive supervision and implementation will ultimately benefit users. The acquisition and commercial use of citizen data, including the use of personal information for big-data analysis, raises questions regarding the reliability and privacy of the health metaverse (Atitallah et al., 2020).

Prolonged immersion in the virtual world can expose individuals to highly realistic virtual scenarios, which typically originates from sources such as advertisements, television, gambling, and pornography (Dwivedi et al., 2023). These experiences reshape the thought processes of individuals, thus resulting in increased inclination to detach themselves from real-life circumstances. Mobile Internet technology has highlighted issues related to data rights, data security, radicalization, misinformation, and platform misuse. Excessive use of digital technology can result in various mental health problems among users, including physical symptoms, depression, paranoid ideation, and in severe cases, mental illness (Helsper and Smahel, 2020). As a significant portion of the current population relies significantly on mobile devices, such as smartphones and tablets, individuals who become deeply engrossed in the metaverse may be at a higher risk of experiencing isolation, suicidal thoughts, mental distress, and declining physical health. Pesce (2021) argues that public policies must adapt to and support technological innovations that prioritize the sustainability of the health metaverse instead of encouraging people to seek refuge in virtual worlds as a method of escaping reality.

The metaverse is being developed further by major technology companies such as Facebook and Microsoft. However, concerns arise regarding users accepting various forms of censorship and become subject to commercial interests. Zhou et al. (2018) discovered that the design of metaverse business models tends to favor platform owners and undermines competitors, which may not be conducive to the sustainable growth of the platform. Leveraging technology and the vast user base, the metaverse has rapidly expanded its platform globally, thus increasing apprehension regarding data security, sovereignty, privacy, and ethical considerations.

5.2. Future

The COVID-19 pandemic has underscored the vulnerability of the population in terms of medical management. In healthcare, profound digital transformation and disruption across various dimensions, including processes, workflows, practices, and delivery methods, are highly demanded. The advent of the health metaverse provides the foundation for such a transformation, which consolidates technologies and applications from four perspectives:

(1) Knowledge. Health metaverse should serve as a repository and platform for the dissemination and exchange of medical knowledge, thereby enabling healthcare professionals and stakeholders to seamlessly access and share updated information. Decision makers should devise strategies such that people are motivated to acquire new skills pertaining to metaverse technology as well as position themselves for the workforce transformation driven by the metaverse (Pesce, 2021; Muntaner, 2018).
(2) Socialization. The health metaverse is expected to facilitate enhanced interaction and communication among medical professionals, patients, and other relevant parties, thus fostering collaborative healthcare practices and improving patient engagement. Furthermore, it encompasses functions such as data interconnectivity, digital twins, streamlined service providers, and payment methods, which can offer more authentic consultations, personalized care, treatment, and diagnosis to patients.
(3) Digitalization. The health metaverse should promote the digitization of healthcare processes, medical records, and data; streamline administrative tasks; and improve the efficiency of healthcare delivery. Healthcare services have transitioned to digital solutions, and the COVID-19 pandemic has significantly accelerated this digital transformation (Soto Acosta, 2020). Considering pandemic-related prevention and control measures, individuals have increasingly embraced online healthcare services, which typically necessitates the provision of personal information.
(4) Intelligence. Users have become more confident in participating in remote consultations and using an array of digital services facilitated by data, personal devices, and wearables. By leveraging AI, machine learning, and data analytics, the health metaverse should empower healthcare professionals with intelligent tools and decision support systems, thereby enabling accurate diagnosis and personalized treatment plans. Thus, a foundation exists for establishing a comprehensive and healthy metaverse ecosystem.

6. Conclusions

Based on analysis of more than 34,000 academic articles and news reports, we employed text-mining methods to offer a comprehensive understanding of the integration of the metaverse into the healthcare sector. Currently, the metaverse concept has promoted the incorporation of diverse medical and health services into the metaverse ecosystem. We envision the health metaverse as a secure, efficient, and professional medical and health service ecosystem grounded in the metaverse that is characterized by knowledge, socialization, digitalization, and intelligence perspectives. Stakeholders in the healthcare sector, including physicians, patients, and government decision-makers, can benefit significantly from the health metaverse. In addition, the service ecosystem can potentially foster innovative advancements in medical education, surgery, healthcare, and online health management. The successful implementation of the health metaverse requires technological innovations and effective regulatory oversight. Meanwhile, the associated challenges encompass various dimensions, including technology, human factors, legislation, and regulations. Whereas the realization of a full-fledged metaverse application may require decades or longer, we envision that a health-service ecosystem constructed upon existing technology may emerge sooner than the adoption of the broader metaverse concept.

CRediT author statement

Pei Wu: Writing-review & editing, Writing-original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Donghua Chen:** Writing-review & editing, Visualization, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Runtong Zhang:** Supervision, Resources, Project administration, Conceptualization.

Declaration of competing interest

The authors declare that there are no conflicts of interest.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (Grant No.: 62102087), Fundamental Research Funds for the Central Universities in UIBE (Grant No.: 22PY055-62102087), and Scientific Research Laboratory of AI Technology and Applications, UIBE.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.dsm.2023.12.003.

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