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Geospatial Big Data Management and Computer Vision Algorithms, Remote Sensing and Image Recognition Technologies, and Event Modeling and Forecasting Tools in the Virtual Economy of the Metaverse

Elvira Nica[1] and Jozef Vahancik[2]

ABSTRACT. The objective of this paper is to systematically review immersive visualization and cognitive computing systems in a fully connected metaverse. The findings and analyses highlight that blockchain and geospatial mapping technologies, deep learning and predictive maintenance algorithms, and simulation modeling and automated speech recognition tools are instrumental in immersive virtual worlds. Throughout February 2023, a quantitative literature review of the Web of Science, Scopus, and ProQuest databases was performed, with search terms including "the virtual economy of the metaverse" + "geospatial big data management and computer vision algorithms," "remote sensing and image recognition technologies," and "event modeling and forecasting tools." As research published between 2022 and 2023 was inspected, only 188 articles satisfied the eligibility criteria. By taking out controversial or ambiguous findings (insufficient/irrelevant data), outcomes unsubstantiated by replication, too general material, or studies with nearly identical titles, we selected 35 mainly empirical sources. Data visualization tools: Dimensions (bibliometric mapping) and VOSviewer (layout algorithms). Reporting quality assessment tool: PRISMA. Methodological quality assessment tools include: AMSTAR, Dedoose, Distiller SR, and SRDR.

Keywords: geospatial big data management; computer vision algorithms; remote sensing and image recognition technologies; event modeling and forecasting tools; metaverse

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1. Introduction

Immersive virtual reality experiences can be achieved through Internet of Things sensing infrastructures, 3D modeling and operational modeling tools, and eye-tracking and spatial computing technologies across interconnected digital realms. The purpose of our systematic review is to examine the recently published literature on the virtual economy of the metaverse and integrate the insights it configures on geospatial big data management and computer vision algorithms, remote sensing and image recognition technologies (Andronie et al., 2021; Kliestik et al., 2020; Novak et al., 2022; Popescu et al., 2020), and event modeling and forecasting tools. By analyzing the most recent (2022–2023) and significant (Web of Science, Scopus, and ProQuest) sources, our paper has attempted to prove that interconnected sensor networks, data fusion and edge computing technologies, and deep and machine learning algorithms further 3D immersive content and digital environments. The actuality and novelty of this study are articulated by addressing interactive digital worlds and the blockchain-based metaverse, that is an emerging topic involving much interest. Our research problem is whether synthetic reality spaces develop on situational awareness and object perception algorithms, spatial computing and image recognition technologies (Andronie et al., 2023a; Lewkowich, 2022; Pop et al., 2023; Vătămănescu et al., 2022), and artificial intelligence-powered search capabilities.

In this review, prior findings have been cumulated indicating that immersive interconnected virtual worlds necessitate 3D object recognition and spatial computing technologies (Andronie et al., 2023b; Nagy et al., 2023; Popescu et al., 2017a), contextual data monitoring and deep learning-based ambient sound processing tools, and computer vision and geolocation data processing algorithms. The identified gaps advance real-time predictive and mobile location analytics (Balcerzak et al., 2022; Nica et al., 2022; Popescu et al., 2017b), spatial awareness and tracking tools, and smart sensor devices. Our main objective is to indicate that blockchain and geospatial mapping technologies, deep learning and predictive maintenance algorithms, and simulation modeling and automated speech recognition tools are instrumental in immersive virtual worlds. This systematic review contributes to the literature on blockchain-based metaverse platforms and intelligent simulation environments by clarifying that multi-machine cooperation and data visualization tools, ambient sound recognition software, and computer vision and remote sensing algorithms (Barbu et al., 2021; Nica et al., 2023; Popescu, 2018) articulate 3D immersive content and captured image data in a blockchain-based virtual world.

2. Theoretical Overview of the Main Concepts

Immersive hyper-connected virtual spaces develop on sensory data and text mining techniques, deep learning and computer vision algorithms, and digital twin and data analytics technologies. The manuscript is organized as following: theoretical overview (section 2), methodology (section 3), 3D virtual space networking and natural language processing tools, machine vision and situational awareness algorithms, and monitoring and sensing technologies in a fully connected metaverse (section 4), spatial computing and image recognition technologies, visual perception and 3D generative modeling tools, and deep learning and context awareness algorithms in the metaverse interactive environment (section 5), image processing computational and predictive modeling algorithms, multi-machine cooperation and data visualization tools, and ambient sound recognition software on blockchain-based metaverse platforms (section 6), discussion (section 7), synopsis of the main research outcomes (section 8), conclusions (section 9), limitations, implications, and further directions of research (section 10).

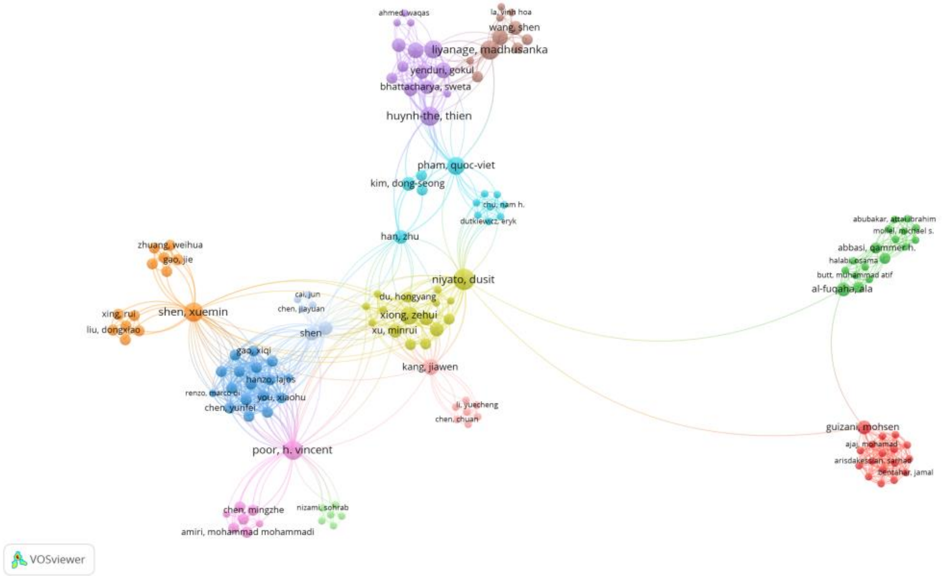
3. Methodology

Throughout February 2023, a quantitative literature review of the Web of Science, Scopus, and ProQuest databases was performed, with search terms including "the virtual economy of the metaverse" + "geospatial big data management and computer vision algorithms," "remote sensing and image recognition technologies," and "event modeling and forecasting tools." As research published between 2022 and 2023 was inspected, only 188 articles satisfied the eligibility criteria. By taking out controversial or ambiguous findings (insufficient/irrelevant data), outcomes unsubstantiated by replication, too general material, or studies with nearly identical titles, we selected 35 mainly empirical sources (Tables 1 and 2). Data visualization tools: Dimensions (bibliometric mapping) and VOSviewer (layout algorithms). Reporting quality assessment tool: PRISMA. Methodological quality assessment tools include: AMSTAR, Dedoose, Distiller SR, and SRDR (Figures 1–6).

Table 1 Topics and types of scientific products identified and selected.

Topic	**Identified**	**Selected**
the virtual economy of the metaverse + geospatial big data management and computer vision algorithms	65	12
the virtual economy of the metaverse + remote sensing and image recognition technologies	63	12
the virtual economy of the metaverse + event modeling and forecasting tools	60	11
Type of paper		
Original research	148	25
Review	24	10
Conference proceedings	11	0
Book	2	0
Editorial	3	0

Source: Processed by the authors. Some topics overlap.



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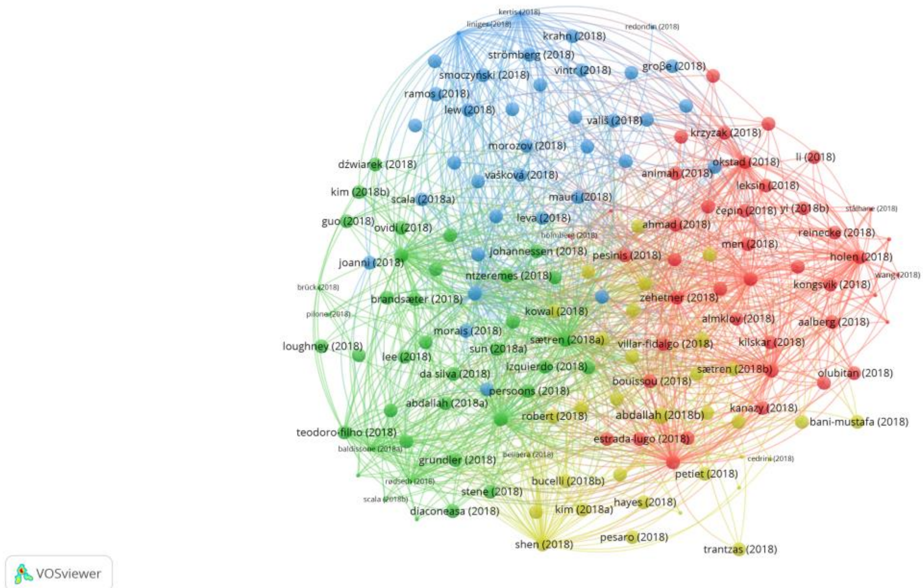

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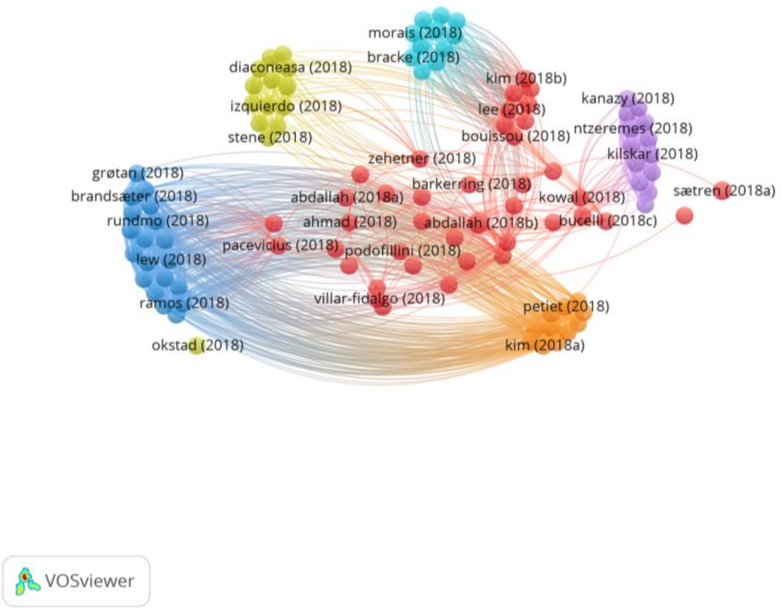

Figure 3 Bibliographic coupling

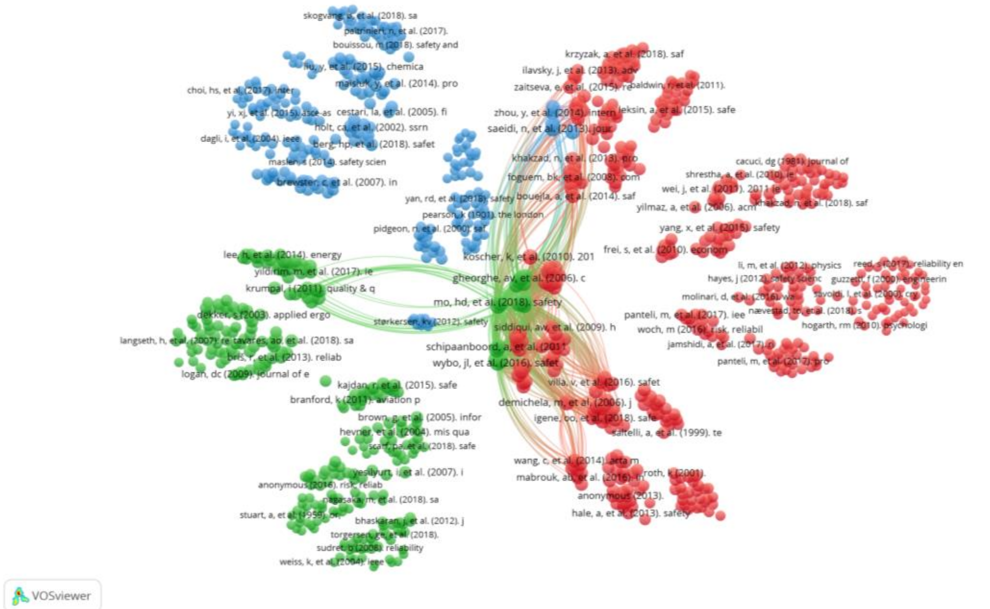

Figure 4 Co-citation

Table 2 General synopsis of evidence as regards focus topics and descriptive outcomes (research findings).

Visual perception and simulation modeling algorithms, decision support and virtual navigation tools, and immersive 3D and cloud computing technologies assist metaverse assets and services.	Barnes, 2022a; He et al., 2023; Lv et al., 2022; Xu et al., 2023a
3D virtual space networking and natural language processing tools, sensory data mining and machine learning techniques, and cognitive artificial intelligence and path planning algorithms optimize immersive visualization and cognitive computing systems in a fully connected metaverse.	Dwivedi et al., 2023; Golf-Papez et al., 2022; Huang et al., 2023; Zhang et al., 2022a
Immersive digital worlds and blockchain-based metaverse platforms integrate real-time predictive and mobile location analytics, spatial awareness and tracking tools, and smart sensor devices.	Ding et al., 2022; Han et al., 2022; Kliestik et al., 2023; Zyda, 2022
Multi-sensor data fusion and immersive technologies, deep learning artificial intelligence and virtual navigation tools, and cyber-physical cognitive and remote sensing systems are pivotal in the metaverse interactive environment.	Han et al., 2023a; Huynh-The et al., 2023; Rostami and Maier, 2022; Zarantonello and Schmitt, 2023
Immersive metaverse experiences can be attained by use of movement and behavior tracking tools, autonomous cognitive and automated speech recognition systems, and deep learning and context awareness algorithms in digital hyper-realistic worlds.	Ahn et al., 2023; Kliestik et al., 2022; Mourtzis et al., 2022; Zhang et al., 2022b
Artificial intelligence-powered prediction and immersive decentralized networking tools, behavior pattern clustering and machine vision algorithms, and deep learning-based sensing and cognitive automation technologies optimize entertaining metaverse events in extended reality environments.	Cao, 2022; Panagiotakopoulos et al., 2022; Yoo et al., 2023
Interactive digital worlds and the blockchain-based metaverse integrate geospatial mapping and contextual data monitoring tools, cognitive and behavioral algorithms, and geospatial mapping and dynamic routing technologies.	Braud et al., 2022; Han et al., 2023b; Xu et al., 2023b; Zallio and Clarkson, 2022
Blockchain-based metaverse platforms and intelligent simulation environments require cognitive computing and artificial vision systems, machine learning-based image recognition and data mining tools, and image processing computational and predictive modeling algorithms.	Bojic, 2022; Li et al., 2023; Ramadan, 2023; Zvarikova et al., 2022
Image recognition and geospatial mapping tools, biometric self-authentication devices, and computer vision and navigation systems are pivotal in the metaverse economy.	Aloqaily et al., 2022; Barnes, 2022b; Shen, 2022; Zhang et al., 2023

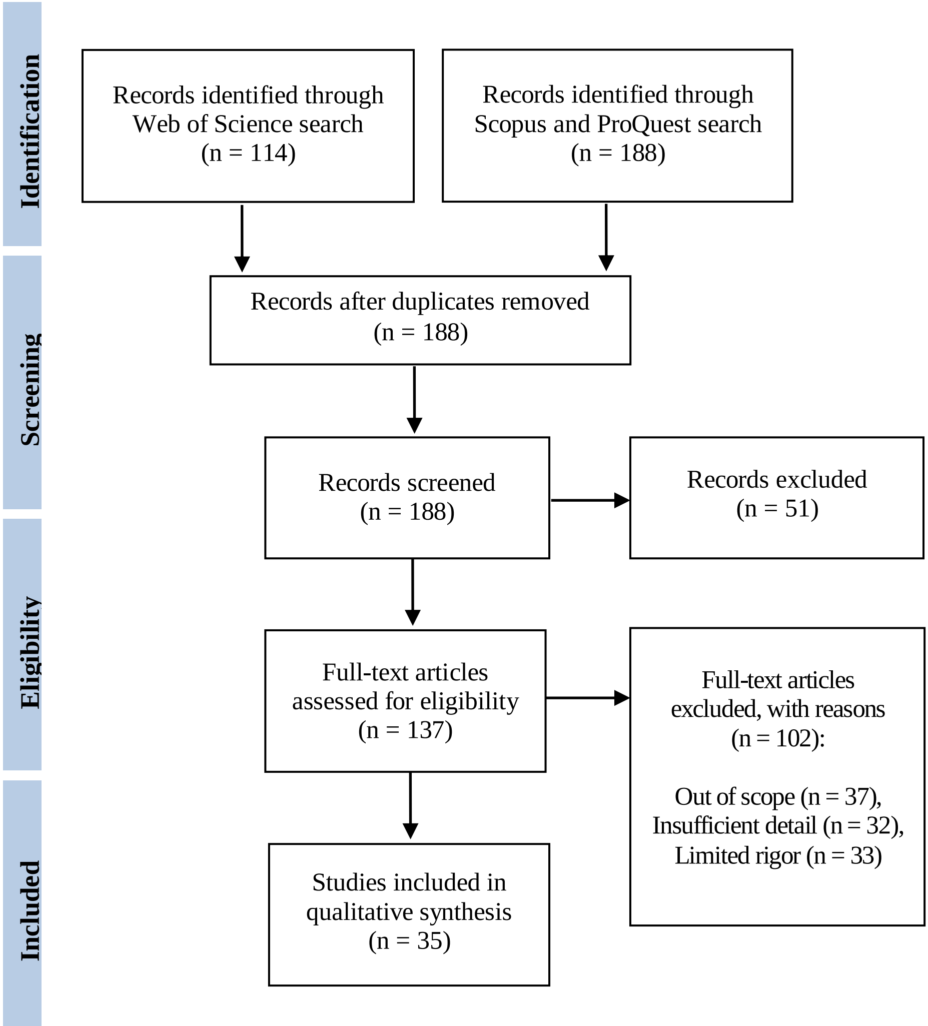

Figure 5 PRISMA flow diagram describing the search results and screening.

Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines were used that ensure the literature review is comprehensive, transparent, and replicable. The flow diagram, produced by employing a Shiny app, presents the stream of evidence-based collected and processed data through the various steps of a systematic review, designing the amount of identified, included, and removed records, and the justifications for exclusions.
To ensure compliance with PRISMA guidelines, a citation software was used, and at each stage the inclusion or exclusion of articles was tracked by use of custom spreadsheet. Justification for the removal of ineligible articles was specified during the full-text screening and final selection.

To ensure first-rate standard of evidence, a systematic search of relevant databases including peer-reviewed published journal articles was conducted using predefined search terms, covering a range of research methods and data sources. Reference lists of all relevant sources were manually reviewed for additional relevant citations.

↓

Titles of papers and abstracts were screened for suitability and selected full texts were retrieved to establish whether they satisfied the inclusion criteria. All records from each database were evaluated by using data extraction forms. Data covering research aims, participants, study design, and method of each paper were extracted.

↓

The inclusion criteria were: (i) articles included in the Web of Science, Scopus, and ProQuest databases, (ii) publication date (2022–2023), (iii) written in English, (iv) being an original empirical research or review article, and (v) particular search terms covered; (i) conference proceedings, (ii) books, and (iii) editorial materials were eliminated from the analysis.

↓

SRDR gathered, handled, and analyzed the data for the systematic review, being configured as an archive and tool harnessed in data extraction through transparent, efficient, and reliable quantitative techniques. Elaborate extraction forms can be set up, meeting the needs of research questions and study designs.

↓

Distiller SR screened and extracted the collected data.

↓

The quality of academic articles was determined and risk of bias was measured by MMAT, that tested content validity and usability of selected studies in terms of screening questions, type of design, corresponding quality criteria, and overall quality score.

↓

ROBIS assessed the risk of bias in systematic reviews.

↓

Dedoose analyzed qualitative and mixed methods research.

↓

AXIS evaluated the quality of cross-sectional studies.

↓

AMSTAR evaluated the methodological quality of systematic reviews.

Figure 6 Screening and quality assessment tools

4. 3D Virtual Space Networking and Natural Language Processing Tools, Machine Vision and Situational Awareness Algorithms, and Monitoring and Sensing Technologies in a Fully Connected Metaverse

Visual perception and simulation modeling algorithms, decision support and virtual navigation tools, and immersive 3D and cloud computing technologies (Barnes, 2022a; He et al., 2023; Lv et al., 2022; Xu et al., 2023a) assist metaverse assets and services. Cognitive enhancement and artificial intelligence technologies, spatial computing and environment mapping algorithms, and automated speech recognition and spatial data visualization tools configure immersive 3D worlds. Immersive virtual reality experiences can be achieved through Internet of Things sensing infrastructures, 3D modeling and operational modeling tools, and eye-tracking and spatial computing technologies across interconnected digital realms.

3D virtual space networking and natural language processing tools, sensory data mining and machine learning techniques, and cognitive artificial intelligence and path planning algorithms (Dwivedi et al., 2023; Golf-Papez et al., 2022; Huang et al., 2023; Zhang et al., 2022a) optimize immersive visualization and cognitive computing systems in a fully connected metaverse. Computer vision and deep learning algorithms, virtual twin modeling and ambient intelligence tools, and monitoring and sensing technologies articulate extended reality environments.

Immersive digital worlds and blockchain-based metaverse platforms (Ding et al., 2022; Han et al., 2022; Kliestik et al., 2023; Zyda, 2022) integrate real-time predictive and mobile location analytics, spatial awareness and tracking tools, and smart sensor devices. Immersive hyper-connected virtual spaces develop on sensory data and text mining techniques, deep learning and computer vision algorithms, and digital twin and data analytics technologies. (Table 3)

Table 3 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Visual perception and simulation modeling algorithms, decision support and virtual navigation tools, and immersive 3D and cloud computing technologies assist metaverse assets and services.	Barnes, 2022a; He et al., 2023; Lv et al., 2022; Xu et al., 2023a
3D virtual space networking and natural language processing tools, sensory data mining and machine learning techniques, and cognitive artificial intelligence and path planning algorithms optimize immersive visualization and cognitive computing systems in a fully connected metaverse.	Dwivedi et al., 2023; Golf-Papez et al., 2022; Huang et al., 2023; Zhang et al., 2022a
Immersive digital worlds and blockchain-based metaverse platforms integrate real-time predictive and mobile location analytics, spatial awareness and tracking tools, and smart sensor devices.	Ding et al., 2022; Han et al., 2022; Kliestik et al., 2023; Zyda, 2022

5. Spatial Computing and Image Recognition Technologies, Visual Perception and 3D Generative Modeling Tools, and Deep Learning and Context Awareness Algorithms in the Metaverse Interactive Environment

Multi-sensor data fusion and immersive technologies, deep learning artificial intelligence and virtual navigation tools, and cyber-physical cognitive and remote sensing systems (Han et al., 2023a; Huynh-The et al., 2023; Rostami and Maier, 2022; Zarantonello and Schmitt, 2023) are pivotal in the metaverse interactive environment. Interconnected sensor networks, data fusion and edge computing technologies, and deep and machine learning algorithms further 3D immersive content and digital environments.

Immersive metaverse experiences can be attained by use of movement and behavior tracking tools, autonomous cognitive and automated speech recognition systems, and deep learning and context awareness algorithms (Ahn et al., 2023; Kliestik et al., 2022; Mourtzis et al., 2022; Zhang et al., 2022b) in digital hyper-realistic worlds. Sentiment and real-time predictive analytics, modeling and forecasting tools, and spatio-temporal fusion and computer vision algorithms shape and immersive decentralized 3D digital worlds.

Artificial intelligence-powered prediction and immersive decentralized networking tools, behavior pattern clustering and machine vision algorithms, and deep learning-based sensing and cognitive automation technologies (Cao, 2022; Panagiotakopoulos et al., 2022; Yoo et al., 2023) optimize entertaining metaverse events in extended reality environments. Synthetic reality spaces develop on situational awareness and object perception algorithms, spatial computing and image recognition technologies, and artificial intelligence-powered search capabilities. (Table 4)

Table 4 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Multi-sensor data fusion and immersive technologies, deep learning artificial intelligence and virtual navigation tools, and cyber-physical cognitive and remote sensing systems are pivotal in the metaverse interactive environment.	Han et al., 2023a; Huynh-The et al., 2023; Rostami and Maier, 2022; Zarantonello and Schmitt, 2023
Immersive metaverse experiences can be attained by use of movement and behavior tracking tools, autonomous cognitive and automated speech recognition systems, and deep learning and context awareness algorithms in digital hyper-realistic worlds.	Ahn et al., 2023; Kliestik et al., 2022; Mourtzis et al., 2022; Zhang et al., 2022b
Artificial intelligence-powered prediction and immersive decentralized networking tools, behavior pattern clustering and machine vision algorithms, and deep learning-based sensing and cognitive automation technologies optimize entertaining metaverse events in extended reality environments.	Cao, 2022; Panagiotakopoulos et al., 2022; Yoo et al., 2023

6. Image Processing Computational and Predictive Modeling Algorithms, Multi-Machine Cooperation and Data Visualization Tools, and Ambient Sound Recognition Software on Blockchain-based Metaverse Platforms

Interactive digital worlds and the blockchain-based metaverse (Braud et al., 2022; Han et al., 2023b; Xu et al., 2023b; Zallio and Clarkson, 2022) integrate geospatial mapping and contextual data monitoring tools, cognitive and behavioral algorithms, and geospatial mapping and dynamic routing technologies. Multi-machine cooperation and data visualization tools, ambient sound recognition software, and computer vision and remote sensing algorithms articulate 3D immersive content and captured image data in a blockchain-based virtual world.

Blockchain-based metaverse platforms and intelligent simulation environments (Bojic, 2022; Li et al., 2023; Ramadan, 2023; Zvarikova et al., 2022) require cognitive computing and artificial vision systems, machine learning-based image recognition and data mining tools, and image processing computational and predictive modeling algorithms. Immersive interconnected virtual worlds necessitate 3D object recognition and spatial computing technologies, contextual data monitoring and deep learning-based ambient sound processing tools, and geolocation data processing algorithms.

Image recognition and geospatial mapping tools, biometric self-authentication devices, and computer vision and navigation systems (Aloqaily et al., 2022; Barnes, 2022b; Shen, 2022; Zhang et al., 2023) are pivotal in the metaverse economy. Blockchain and geospatial mapping technologies, deep learning and predictive maintenance algorithms, and simulation modeling and automated speech recognition tools are instrumental in immersive virtual worlds. (Table 5)

Table 5 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Interactive digital worlds and the blockchain-based metaverse integrate geospatial mapping and contextual data monitoring tools, cognitive and behavioral algorithms, and geospatial mapping and dynamic routing technologies.	Braud et al., 2022; Han et al., 2023b; Xu et al., 2023b; Zallio and Clarkson, 2022
Blockchain-based metaverse platforms and intelligent simulation environments require cognitive computing and artificial vision systems, machine learning-based image recognition and data mining tools, and image processing computational and predictive modeling algorithms.	Bojic, 2022; Li et al., 2023; Ramadan, 2023; Zvarikova et al., 2022
Image recognition and geospatial mapping tools, biometric self-authentication devices, and computer vision and navigation systems are pivotal in the metaverse economy.	Aloqaily et al., 2022; Barnes, 2022b; Shen, 2022; Zhang et al., 2023

7. Discussion

We integrate our systematic review throughout research indicating how cognitive enhancement and artificial intelligence technologies, spatial computing and environment mapping algorithms, and automated speech recognition and spatial data visualization tools configure immersive 3D worlds. Our research complements recent analyses clarifying how interconnected sensor networks, data fusion and edge computing technologies, and deep and machine learning algorithms further 3D immersive content and digital environments. We elucidate, by cumulative evidence, previous research demonstrating how immersive interconnected virtual worlds necessitate 3D object recognition and spatial computing technologies, contextual data monitoring and deep learning-based ambient sound processing tools, and computer vision and geolocation data processing algorithms.

8. Synopsis of the Main Research Outcomes

Computer vision and deep learning algorithms, virtual twin modeling and ambient intelligence tools, and monitoring and sensing technologies articulate extended reality environments. Immersive hyper-connected virtual spaces develop on sensory data and text mining techniques, deep learning and computer vision algorithms, and digital twin and data analytics technologies.

9. Conclusions

Relevant research has investigated whether synthetic reality spaces develop on situational awareness and object perception algorithms, spatial computing and image recognition technologies, and artificial intelligence-powered search capabilities. This systematic literature review presents the published peer-reviewed sources covering how multi-machine cooperation and data visualization tools, ambient sound recognition software, and computer vision and remote sensing algorithms articulate 3D immersive content and captured image data in a blockchain-based virtual world. The research outcomes drawn from the above analyses indicate that sentiment and real-time predictive analytics, modeling and forecasting tools, and spatio-temporal fusion and computer vision algorithms shape shared virtual environments and immersive decentralized 3D digital worlds.

10. Limitations, Implications, and Further Directions of Research

By analyzing only articles published between 2022 and 2023 in journals indexed in the Web of Science, Scopus, and ProQuest databases, relevant sources on geospatial big data management and computer vision algorithms, remote sensing and image recognition technologies, and event modeling and forecasting tools in the virtual economy of the metaverse may have been excluded. Limitations of this research comprise particular kinds of publications (original empirical research and review articles) discounting others (conference proceedings articles, books, and editorial materials). The scope of our study also does not move forward the inspection of immersive visualization and cognitive computing systems in a fully connected metaverse.

Subsequent analyses should develop on immersive digital worlds and blockchain-based metaverse platforms. Future research should thus investigate immersive metaverse experiences attained by use of movement and behavior tracking tools, autonomous cognitive and automated speech recognition systems, and deep learning and context awareness algorithms. Attention should be directed to entertaining metaverse events in extended reality environments.

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Compliance with ethical standards
This article does not contain any studies with human participants or animals performed by the authors. Extracting and inspecting publicly accessible files (scholarly sources) as evidence, before the research began no institutional ethics approval was required.

Data availability statement
All data generated or analyzed are included in the published article.

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Author contributions
All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication. The authors take full responsibility for the accuracy and the integrity of the data analysis.

Conflict of interest statement
The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Disclosure by the editors of record
The editors declare no conflict of interest in the review and publication decision regarding this article.

Transparency statement
The authors affirm that the manuscript represents an honest, accurate, and transparent account of the research being reported, that no relevant aspects of the study have been left out, and that any inconsistencies from the research as planned (and, if significant, registered) have been clarified.

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Haptic and Biometric Sensor Technologies, Spatial Data Mining and Simulation Modeling Algorithms, and Virtual Navigation and Decision Intelligence Tools across Web3-powered Metaverse Worlds

Charles Goodman*

ABSTRACT. I draw on a substantial body of theoretical and empirical research on geospatial mapping and immersive 3D technologies, distributed decision and control algorithms, and automated speech recognition and virtual navigation tools. In this research, prior findings were cumulated indicating that spatial computing and remote sensing technologies, real-time data mining and tracking tools, and spatio-temporal fusion and 3D image processing algorithms configure extended reality environments. I carried out a quantitative literature review of ProQuest, Scopus, and the Web of Science throughout December 2022, with search terms including "Web3-powered metaverse worlds" + "haptic and biometric sensor technologies," "spatial data mining and simulation modeling algorithms," and "virtual navigation and decision intelligence tools." As I analyzed research published in 2022 and 2023, only 178 papers met the eligibility criteria. By removing controversial or unclear findings (scanty/unimportant data), results unsupported by replication, undetailed content, or papers having quite similar titles, I decided on 34, chiefly empirical, sources. Data visualization tools: Dimensions (bibliometric mapping) and VOSviewer (layout algorithms). Reporting quality assessment tool: PRISMA. Methodological quality assessment tools include: AMSTAR, Distiller SR, ROBIS, and SRDR.

Keywords: haptic and biometric sensor technologies; spatial data mining and simulation modeling algorithms; virtual navigation and decision intelligence tools; metaverse

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1. Introduction

Immersive and extended reality technologies, edge artificial intelligence computing and artificial vision systems, and behavioral simulation and predictive geospatial modeling tools are pivotal in immersive 3D and blockchain-based virtual worlds. The purpose of my systematic review is to examine the recently published literature on Web3-powered metaverse worlds and integrate the insights it configures on haptic and biometric sensor technologies, spatial data mining and simulation modeling algorithms, and virtual navigation and decision intelligence tools. By analyzing the most recent (2022–2023) and significant (Web of Science, Scopus, and ProQuest) sources, my paper has attempted to prove that 3D immersive virtual reality and environment perception technologies (Andronie et al., 2023; Glogovețan et al., 2022; Nica et al., 2023), voice recognition software, and data acquisition and visual attention modeling tools (Balcerzak et al., 2022; Lăzăroiu et al., 2020; Newell, 2022) further immersive digital worlds. The actuality and novelty of this study are articulated by addressing geospatial mapping and immersive 3D technologies (Barber, 2022; Lăzăroiu et al., 2022; Popescu et al., 2017a), distributed decision and control algorithms, and automated speech recognition and virtual navigation tools, that is an emerging topic involving much interest. My research problem is whether big geospatial data and immersive visual analytics, hyper-realistic immersive 3D simulations, and sensing and computing technologies shape blockchain-based virtual worlds.

In this review, prior findings have been cumulated indicating that interoperable extended reality environments require semantic network representations, machine intelligence and 3D virtual immersive technologies (Barbu et al., 2021; Nagy and Lăzăroiu, 2022; Popescu et al., 2017b), and synthetic biometric data. The identified gaps advance voice recognition software, metaverse engagement metrics, and socially-oriented location tracking and simulation modeling tools. My main objective is to indicate that spatial computing and remote sensing technologies (Dabija et al., 2022; Nagy et al., 2023; Popescu, 2018; Watson, 2022), real-time data mining and tracking tools, and spatio-temporal fusion and 3D image processing algorithms configure extended reality environments.

2. Theoretical Overview of the Main Concepts

Immersive 3D environments require natural language processing and image data-based predictive algorithms, multisensor fusion and virtual immersive technologies, and movement and behavior tracking tools. Digital twin simulation and immersive decentralized networking tools, geospatial big data and mobile location analytics, and data sharing and distributed sensing technologies are instrumental in the digital asset-based virtual economy.

The manuscript is organized as following: theoretical overview (section 2), methodology (section 3), metaverse and immersive technologies, big data computing and socially-extended cognition systems, and spatio-temporal fusion and 3D image processing algorithms in extended reality environments (section 4), autonomous visual object detection and machine learning-based image recognition tools, multisensor fusion and virtual immersive technologies, and neuromorphic computing and conversational artificial intelligence algorithms in the metaverse interactive environment (section 5), metaverse engagement metrics, cognitive computing and haptic augmented reality systems, and socially-oriented location tracking and simulation modeling tools in photo-realistic synthetic environments (section 6), discussion (section 7), synopsis of the main research outcomes (section 8), conclusions (section 9), limitations, implications, and further directions of research (section 10).

3. Methodology

I carried out a quantitative literature review of ProQuest, Scopus, and the Web of Science throughout December 2022, with search terms including "Web3-powered metaverse worlds" + "haptic and biometric sensor technologies," "spatial data mining and simulation modeling algorithms," and "virtual navigation and decision intelligence tools." As I analyzed research published in 2022 and 2023, only 178 papers met the eligibility criteria. By removing controversial or unclear findings (scanty/unimportant data), results unsupported by replication, undetailed content, or papers having quite similar titles, I decided on 34, chiefly empirical, sources (Tables 1 and 2). Data visualization tools: Dimensions (bibliometric mapping) and VOSviewer (layout algorithms). Reporting quality assessment tool: PRISMA. Methodological quality assessment tools include: AMSTAR, Distiller SR, ROBIS, and SRDR (Figures 1–6).

Table 1 Topics and types of scientific products identified and selected.

Topic	**Identified**	**Selected**
Web3-powered metaverse worlds + haptic and biometric sensor technologies	61	12
Web3-powered metaverse worlds + spatial data mining and simulation modeling algorithms	59	11
Web3-powered metaverse worlds + virtual navigation and decision intelligence tools	58	11
Type of paper		
Original research	148	25
Review	19	9
Conference proceedings	10	0
Book	0	0
Editorial	1	0

Source: Processed by the author. Some topics overlap.

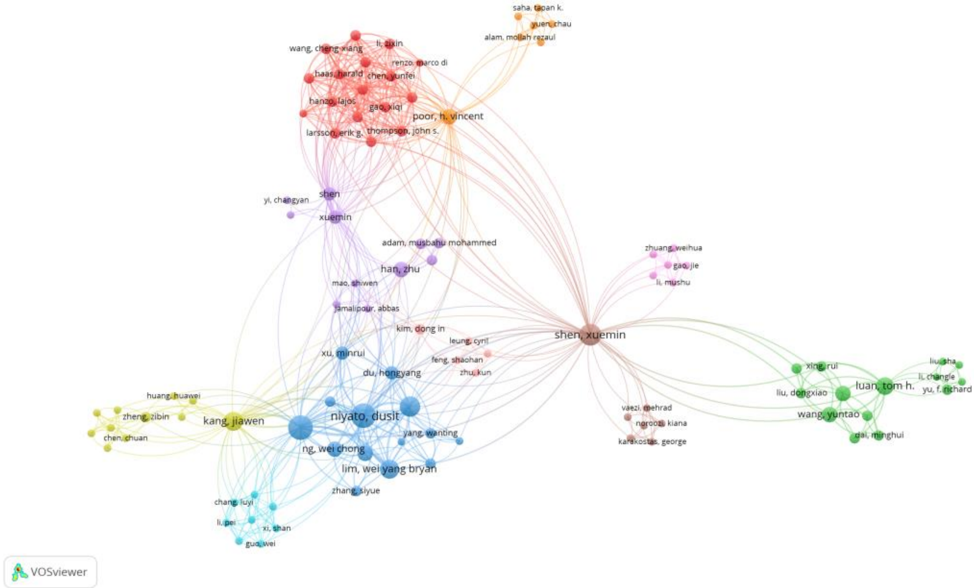

Figure 1 Co-authorship

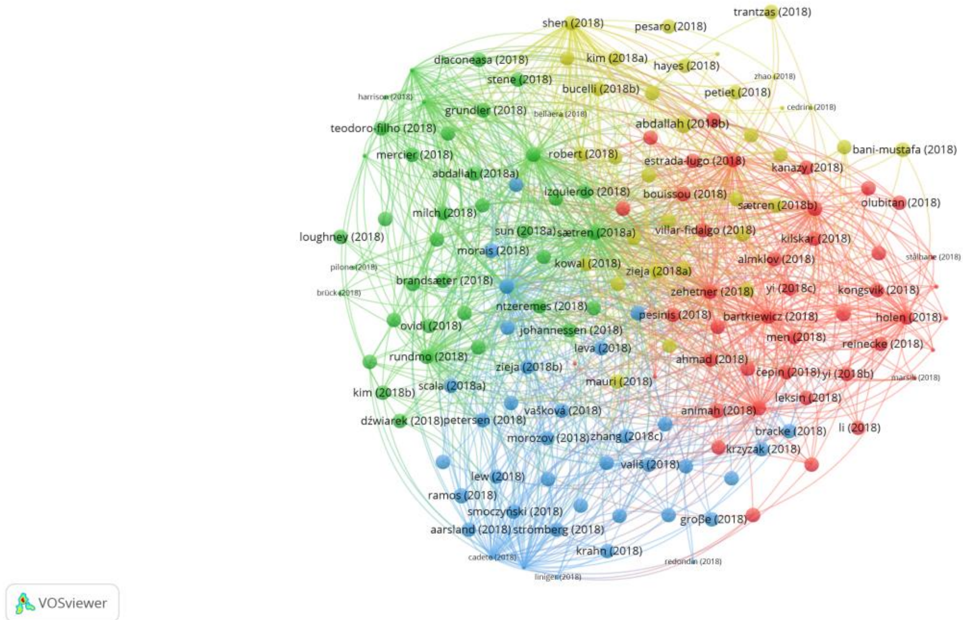

Figure 2 Citation

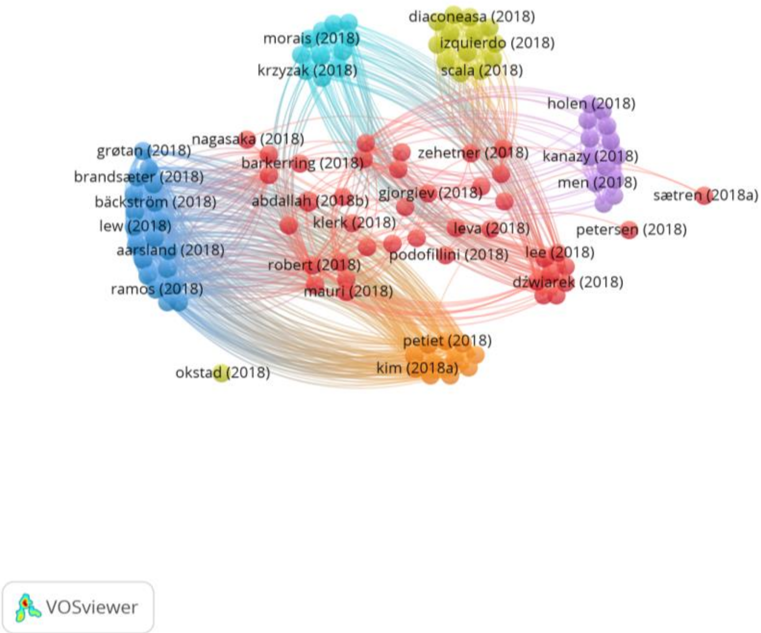

Figure 3 Bibliographic coupling

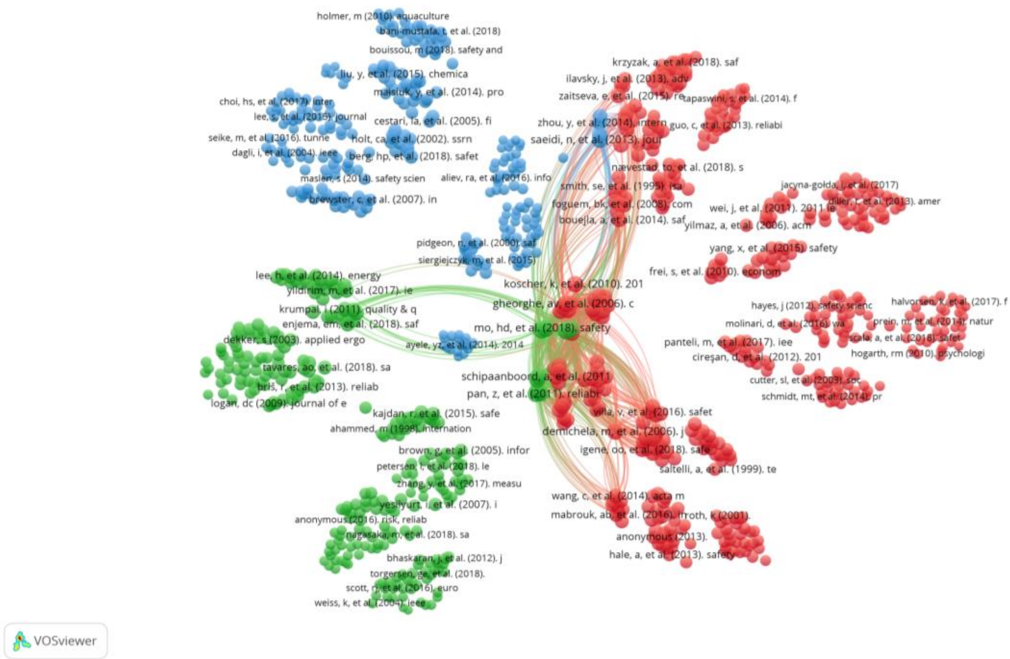

Figure 4 Co-citation

Table 2 General synopsis of evidence as regards focus topics and descriptive outcomes (research findings).

Immersive visualization and extended cognitive systems, virtual modeling and cognitive enhancement technologies, and decision-making process automation and image recognition tools articulate the virtual economy of the metaverse.	Kovacova et al., 2022a; Vidal-Tomás, 2023; Zhao et al., 2022
Synthetic user experiences can be achieved by use of virtual and augmented reality tools, metaverse and immersive technologies, and cognitive decision-making and computer vision algorithms.	Cheng et al., 2022; Panagiotakopoulos et al., 2022; Shi et al., 2023a; Zainab et al., 2022
Extended reality environments integrate virtual navigation and immersive analytics tools, big data computing and socially-extended cognition systems, and remote sensing and digital scent technologies.	Kozinets, 2023; McStay, 2023; Njoku et al., 2023; Van Huynh et al., 2022
3D metaverse experiences can be achieved through geospatial mapping and immersive 3D technologies, distributed decision and control algorithms, and automated speech recognition and virtual navigation tools.	Gordon, 2022; Kwok and Tang, 2023; Lv et al., 2022; Zhou et al., 2023
Big data computing and network virtualization systems, virtual reality-based data analytics and ambient scene detection tools, and 3D modeling and simulation technologies optimize the metaverse interactive environment.	Egliston and Carter, 2022; Rydell, 2022; Wongkitrungrueng and Suprawan, 2023
Haptic and 3D body sensory technologies, data visualization and real-time data tracking tools, and emotion detection and image recognition algorithms assist 3D holographic avatars.	Du et al., 2023; Kovacova et al., 2022b; Venugopal et al., 2023; Zabel et al., 2023
Immersive virtual experiences can be attained through voice recognition software, metaverse engagement metrics, and socially-oriented location tracking and simulation modeling tools.	Giang Barrera and Shah, 2023; Li et al., 2023; Polas et al., 2022; Xian et al., 2023
Metaverse engagement and experiences can be achieved by use of cognitive computing and haptic augmented reality systems, intelligent sensing and deep convolutional neural networks, and motion capture and digital twin technologies.	Bordegoni and Ferrise, 2023; McStay, 2022; Smart, 2022; Zhu et al., 2023
Synthetic data and virtual navigation tools, biometric and behavioral data, and spatial and sentiment analytics enable extended reality environments. Digital twin simulation and immersive decentralized networking tools, geospatial big data and mobile location analytics, and data sharing and distributed sensing technologies are instrumental in the digital asset-based virtual economy.	Braud et al., 2022; Hadi et al., 2023; Shi et al., 2023b; Wang et al., 2022

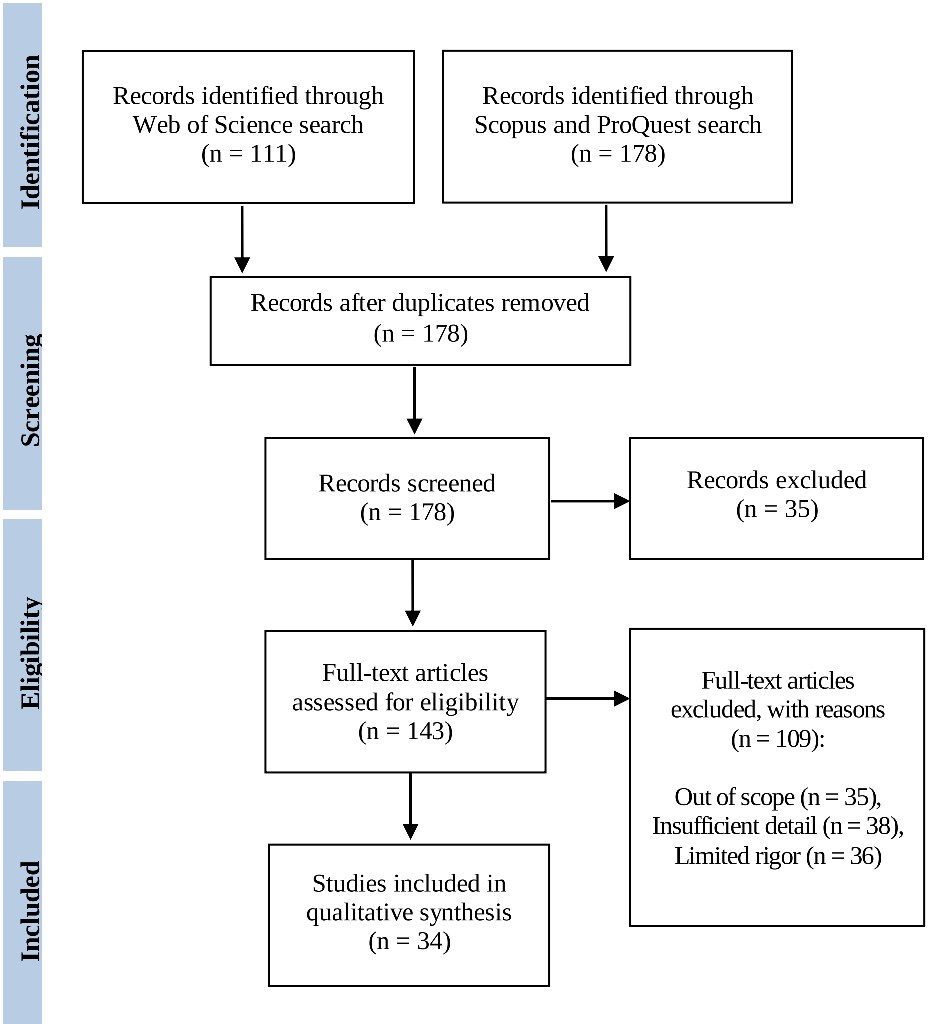

Figure 5 PRISMA flow diagram describing the search results and screening.

Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines were used that ensure the literature review is comprehensive, transparent, and replicable. The flow diagram, produced by employing a Shiny app, presents the stream of evidence-based collected and processed data through the various steps of a systematic review, designing the amount of identified, included, and removed records, and the justifications for exclusions.
To ensure compliance with PRISMA guidelines, a citation software was used, and at each stage the inclusion or exclusion of articles was tracked by use of custom spreadsheet. Justification for the removal of ineligible articles was specified during the full-text screening and final selection.

To ensure first-rate standard of evidence, a systematic search of relevant databases including peer-reviewed published journal articles was conducted using predefined search terms, covering a range of research methods and data sources. Reference lists of all relevant sources were manually reviewed for additional relevant citations.

Titles of papers and abstracts were screened for suitability and selected full texts were retrieved to establish whether they satisfied the inclusion criteria. All records from each database were evaluated by using data extraction forms. Data covering research aims, participants, study design, and method of each paper were extracted.

The inclusion criteria were: (i) articles included in the Web of Science, Scopus, and ProQuest databases, (ii) publication date (2022–2023), (iii) written in English, (iv) being an original empirical research or review article, and (v) particular search terms covered; (i) conference proceedings, (ii) books, and (iii) editorial materials were eliminated from the analysis.

Distiller SR screened and extracted the collected data.

SRDR gathered, handled, and analyzed the data for the systematic review, being configured as an archive and tool harnessed in data extraction through transparent, efficient, and reliable quantitative techniques. Elaborate extraction forms can be set up, meeting the needs of research questions and study designs.

AMSTAR evaluated the methodological quality of systematic reviews.

Dedoose analyzed qualitative and mixed methods research.

ROBIS assessed the risk of bias in systematic reviews.

AXIS evaluated the quality of cross-sectional studies.

The quality of academic articles was determined and risk of bias was measured by MMAT, that tested content validity and usability of selected studies in terms of screening questions, type of design, corresponding quality criteria, and overall quality score.

Figure 6 Screening and quality assessment tools

4. Metaverse and Immersive Technologies, Big Data Computing and Socially-Extended Cognition Systems, and Spatio-Temporal Fusion and 3D Image Processing Algorithms in Extended Reality Environments

Immersive visualization and extended cognitive systems, virtual modeling and cognitive enhancement technologies, and decision-making process automation and image recognition tools (Kovacova et al., 2022a; Vidal-Tomás, 2023; Zhao et al., 2022) articulate the virtual economy of the metaverse. 3D immersive virtual reality and environment perception technologies, voice recognition software, and data acquisition and visual attention modeling tools further immersive digital worlds.

Synthetic user experiences (Cheng et al., 2022; Panagiotakopoulos et al., 2022; Shi et al., 2023a; Zainab et al., 2022) can be achieved by use of virtual and augmented reality tools, metaverse and immersive technologies, and cognitive decision-making and computer vision algorithms. Immersive 3D virtual environments develop on spatio-temporal fusion and virtual mapping algorithms, sensorial and cognitive technologies, and digital twin simulation and data mining tools.

Extended reality environments (Kozinets, 2023; McStay, 2023; Njoku et al., 2023; Van Huynh et al., 2022) integrate virtual navigation and immersive analytics tools, big data computing and socially-extended cognition systems, and remote sensing and digital scent technologies. Spatial computing and remote sensing technologies, real-time data mining and tracking tools, and spatio-temporal fusion and 3D image processing algorithms configure extended reality environments. Immersive and extended reality technologies, edge artificial intelligence computing and artificial vision systems, and behavioral simulation and predictive geospatial modeling tools are pivotal in immersive 3D and blockchain-based virtual worlds. (Table 3)

Table 3 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Immersive visualization and extended cognitive systems, virtual modeling and cognitive enhancement technologies, and decision-making process automation and image recognition tools articulate the virtual economy of the metaverse.	Kovacova et al., 2022a; Vidal-Tomás, 2023; Zhao et al., 2022
Synthetic user experiences can be achieved by use of virtual and augmented reality tools, metaverse and immersive technologies, and cognitive decision-making and computer vision algorithms.	Cheng et al., 2022; Panagiotakopoulos et al., 2022; Shi et al., 2023a; Zainab et al., 2022
Extended reality environments integrate virtual navigation and immersive analytics tools, big data computing and socially-extended cognition systems, and remote sensing and digital scent technologies.	Kozinets, 2023; McStay, 2023; Njoku et al., 2023; Van Huynh et al., 2022

5. Autonomous Visual Object Detection and Machine Learning-based Image Recognition Tools, Multisensor Fusion and Virtual Immersive Technologies, and Neuromorphic Computing and Conversational Artificial Intelligence Algorithms in the Metaverse

3D metaverse experiences (Gordon, 2022; Kwok and Tang, 2023; Lv et al., 2022; Zhou et al., 2023) can be achieved through geospatial mapping and immersive 3D technologies, distributed decision and control algorithms, and automated speech recognition and virtual navigation tools. Hyper-realistic personalized interactive experiences can be attained by use of sensor-based object recognition and dynamic routing technologies, big geospatial data and real-time event analytics, and autonomous visual object detection and machine learning-based image recognition tools.

Big data computing and network virtualization systems, virtual reality-based data analytics and ambient scene detection tools, and 3D modeling and simulation technologies (Egliston and Carter, 2022; Rydell, 2022; Wongkitrungrueng and Suprawan, 2023) optimize the metaverse interactive environment. Immersive 3D environments require natural language processing and image data-based predictive algorithms, multisensor fusion and virtual immersive technologies, and movement and behavior tracking tools.

Haptic and 3D body sensory technologies, data visualization and real-time data tracking tools, and emotion detection and image recognition algorithms (Du et al., 2023; Kovacova et al., 2022b; Venugopal et al., 2023; Zabel et al., 2023) assist 3D holographic avatars. Hyperconnected virtual experiences can be attained through real-time 3D rendering and sentiment recognition technologies, neuromorphic computing and conversational artificial intelligence algorithms, and motion capture suits. (Table 4)

Table 4 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

3D metaverse experiences can be achieved through geospatial mapping and immersive 3D technologies, distributed decision and control algorithms, and automated speech recognition and virtual navigation tools.	Gordon, 2022; Kwok and Tang, 2023; Lv et al., 2022; Zhou et al., 2023
Big data computing and network virtualization systems, virtual reality-based data analytics and ambient scene detection tools, and 3D modeling and simulation technologies optimize the metaverse interactive environment.	Egliston and Carter, 2022; Rydell, 2022; Wongkitrungrueng and Suprawan, 2023
Haptic and 3D body sensory technologies, data visualization and real-time data tracking tools, and emotion detection and image recognition algorithms assist 3D holographic avatars.	Du et al., 2023; Kovacova et al., 2022b; Venugopal et al., 2023; Zabel et al., 2023

6. Metaverse Engagement Metrics, Cognitive Computing and Haptic Augmented Reality Systems, and Socially-oriented Location Tracking and Simulation Modeling Tools in Photorealistic Synthetic Environments

Immersive virtual experiences (Giang Barrera and Shah, 2023; Li et al., 2023; Polas et al., 2022; Xian et al., 2023) can be attained through voice recognition software, metaverse engagement metrics, and socially-oriented location tracking and simulation modeling tools. Immersive 3D virtual environments necessitate simulation and digital twin modeling tools, body-tracking data metrics, and 3D imaging and display technologies. Interoperable extended reality environments require semantic network representations, machine intelligence and 3D virtual immersive technologies, and synthetic biometric data.

Metaverse engagement and experiences (Bordegoni and Ferrise, 2023; McStay, 2022; Smart, 2022; Zhu et al., 2023) can be achieved by use of cognitive computing and haptic augmented reality systems, intelligent sensing and deep convolutional neural networks, and motion capture and digital twin technologies. Perception and planning algorithms, Internet of Things-based decision support and artificial cognitive systems, and text mining and deep generative modeling techniques are pivotal in photorealistic synthetic environments.

Synthetic data and virtual navigation tools, biometric and behavioral data, and spatial and sentiment analytics (Braud et al., 2022; Hadi et al., 2023; Shi et al., 2023b; Wang et al., 2022) enable extended reality environments. Big geospatial data and immersive visual analytics, hyper-realistic immersive 3D simulations, and sensing and computing technologies shape blockchain-based virtual worlds. Digital twin simulation and immersive decentralized networking tools, geospatial big data and mobile location analytics, and data sharing and distributed sensing technologies are instrumental in the digital asset-based virtual economy. (Table 5)

Table 5 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Immersive virtual experiences can be attained through voice recognition software, metaverse engagement metrics, and socially-oriented location tracking and simulation modeling tools.	Giang Barrera and Shah, 2023; Li et al., 2023; Polas et al., 2022; Xian et al., 2023
Metaverse engagement and experiences can be achieved by use of cognitive computing and haptic augmented reality systems, intelligent sensing and deep convolutional neural networks, and motion capture and digital twin technologies.	Bordegoni and Ferrise, 2023; McStay, 2022; Smart, 2022; Zhu et al., 2023
Synthetic data and virtual navigation tools, biometric and behavioral data, and spatial and sentiment analytics enable extended reality environments.	Braud et al., 2022; Hadi et al., 2023; Shi et al., 2023b; Wang et al., 2022

7. Discussion

I integrate my systematic review throughout research indicating how immersive 3D virtual environments necessitate simulation and digital twin modeling tools, body-tracking data metrics, and 3D imaging and display technologies. My research complements recent analyses clarifying how big geospatial data and immersive visual analytics, hyper-realistic immersive 3D simulations, and sensing and computing technologies shape blockchain-based virtual worlds. I elucidate, by cumulative evidence, previous research demonstrating how immersive 3D virtual environments develop on spatio-temporal fusion and virtual mapping algorithms, sensorial and cognitive technologies, and digital twin simulation and data mining tools.

8. Synopsis of the Main Research Outcomes

Hyperconnected virtual experiences can be attained through real-time 3D rendering and sentiment recognition technologies, neuromorphic computing and conversational artificial intelligence algorithms, and motion capture suits. Interoperable extended reality environments require semantic network representations, machine intelligence and 3D virtual immersive technologies, and synthetic biometric data.

9. Conclusions

Relevant research has investigated whether perception and planning algorithms, Internet of Things-based decision support and artificial cognitive systems, and text mining and deep generative modeling techniques are pivotal in photorealistic synthetic environments. This systematic literature review presents the published peer-reviewed sources covering how 3D immersive virtual reality and environment perception technologies, voice recognition software, and data acquisition and visual attention modeling tools further immersive digital worlds. The research outcomes drawn from the above analyses indicate that hyper-realistic personalized interactive experiences can be attained by use of sensor-based object recognition and dynamic routing technologies, big geospatial data and real-time event analytics, and autonomous visual object detection and machine learning-based image recognition tools.

10. Limitations, Implications, and Further Directions of Research

By analyzing only articles published between 2022 and 2023 in journals indexed in the Web of Science, Scopus, and ProQuest databases, relevant sources on haptic and biometric sensor technologies, spatial data mining and simulation modeling algorithms, and virtual navigation and decision intelligence tools across Web3-powered metaverse worlds may have been excluded.

Limitations of this research comprise particular kinds of publications (original empirical research and review articles) discounting others (conference proceedings articles, books, and editorial materials). The scope of my study also does not move forward the inspection of haptic and 3D body sensory technologies, data visualization and real-time data tracking tools, and emotion detection and image recognition algorithms.

Subsequent analyses should develop on immersive visualization and extended cognitive systems, virtual modeling and cognitive enhancement technologies, and decision-making process automation and image recognition tools. Future research should thus investigate synthetic data and virtual navigation tools, biometric and behavioral data, and spatial and sentiment analytics. Attention should be directed to virtual and augmented reality tools, metaverse and immersive technologies, and cognitive decision-making and computer vision algorithms.

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Compliance with ethical standards

This article does not contain any studies with human participants or animals performed by the author. Extracting and inspecting publicly accessible files (scholarly sources) as evidence, before the research began no institutional ethics approval was required.

Data availability statement

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Author contributions

The author confirms being the sole contributor of this work and approved it for publication. The author takes full responsibility for the accuracy and the integrity of the data analysis.

Conflict of interest statement

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Disclosure by the editors of record

The editors declare no conflict of interest in the review and publication decision regarding this article.

Transparency statement

The author affirms that the manuscript represents an honest, accurate, and transparent account of the research being reported, that no relevant aspects of the study have been left out, and that any inconsistencies from the research as planned (and, if significant, registered) have been clarified.

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Immersive Extended Reality and Remote Sensing Technologies, Simulation Modeling and Spatial Data Acquisition Tools, and Cooperative Decision and Control Algorithms in a Real-Time Interoperable Decentralized Metaverse

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ABSTRACT. The aim of this systematic review is to synthesize and analyze human digital twin and neuromorphic image processing systems, haptic bodysuits, and metaverse assets and services. In this research, prior findings were cumulated indicating that virtual reality-based immersive experiences can be achieved by use of multiscale spatial data processing and contextual data monitoring tools, geolocation data mining and tracking, and wearable haptic garments. We carried out a quantitative literature review of ProQuest, Scopus, and the Web of Science throughout December 2022, with search terms including "real-time interoperable decentralized metaverse" + "immersive extended reality and remote sensing technologies," "simulation modeling and spatial data acquisition tools," and "cooperative decision and control algorithms." As we analyzed research published between 2022 and 2023, only 183 papers met the eligibility criteria. By removing controversial or unclear findings (scanty/unimportant data), results unsupported by replication, undetailed content, or papers having quite similar titles, we decided on 37, chiefly empirical, sources. Data visualization tools: Dimensions (bibliometric mapping) and VOSviewer (layout algorithms). Reporting quality assessment tool: PRISMA. Methodological quality assessment tools include: AXIS, Distiller SR, ROBIS, and SRDR.

Keywords: immersive extended reality and remote sensing technologies; simulation modeling and spatial data acquisition tools; cooperative decision and control algorithms; metaverse

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1. Introduction

3D immersive environments integrate emotion detection and recognition technologies, biometrics data fusion, and socio-spatial analytics and digital twin modeling tools. The purpose of our systematic review is to examine the recently published literature on the real-time interoperable decentralized metaverse and integrate the insights it configures on immersive extended reality and remote sensing technologies, simulation modeling and spatial data acquisition tools, and cooperative decision and control algorithms. By analyzing the most recent (2022–2023) and significant (Web of Science, Scopus, and ProQuest) sources, our paper has attempted to prove that immersive multisensory virtual spaces necessitate spatial data visualization and ambient intelligence tools (Andronie et al., 2021; Kliestik et al., 2020; Pop et al., 2023), sensor path planning and situational awareness algorithms, and artificial intelligence-based image recognition and ontology-based semantic technologies. The actuality and novelty of this study are articulated by addressing human digital twin and neuromorphic image processing systems, haptic bodysuits, and metaverse assets and services, that is an emerging topic involving much interest. Our research problem is whether behavioral predictive and Internet of Things sensor data analytics, immersive geospatial data visualization and virtual modeling technologies (Andronie et al., 2023; Kovacova et al., 2022; Pop et al., 2021), and explainable artificial intelligence-based decision support and haptic object recognition systems.

In this review, prior findings have been cumulated indicating that immersive virtual experiences can be attained through machine learning-based predictive and simulation modeling algorithms (Balcerzak et al., 2022; Lăzăroiu et al., 2020; Popescu et al., 2017a), cognitive artificial intelligence and cloud computing technologies, and 3D virtual space networking and geospatial mapping tools. The identified gaps advance image processing computational and situational awareness algorithms (Blake, 2022; Nagy et al., 2023; Popescu et al., 2017b), deep learning-based sensing and data analytics technologies, and visual and spatial intelligence tools. Our main objective is to indicate that virtual reality-based immersive experiences can be achieved by use of multiscale spatial data processing and contextual data monitoring tools (Jaramillo-Aristizabal, 2022; Nica, 2017; Popescu, 2018; Vătămănescu et al., 2020), geolocation data mining and tracking, and wearable haptic garments.

2. Theoretical Overview of the Main Concepts

Immersive virtual experiences can be attained through simulation modeling and visual imagery tools, monitoring and sensing technologies, and bio-inspired computational intelligence and context awareness algorithms. The manuscript is organized as following: theoretical overview (section 2), methodology (section 3), machine learning-based predictive and simulation modeling algorithms, haptic and multisensory technologies, and spatial awareness and tracking tools in the decentralized metaverse (section 4), multiscale spatial data processing and contextual data monitoring tools, sensor fusion and affective modeling algorithms, and real-time predictive and mobile location analytics in the blockchain-based metaverse (section 5), motion capture and geospatial big data visualization systems, sensor path planning and situational awareness algorithms, and deep learning-based sensing and data analytics technologies in the interconnected metaverse (section 6), discussion (section 7), synopsis of the main research outcomes (section 8), conclusions (section 9), limitations, implications, and further directions of research (section 10).

3. Methodology

We carried out a quantitative literature review of ProQuest, Scopus, and the Web of Science throughout December 2022, with search terms including "real-time interoperable decentralized metaverse" + "immersive extended reality and remote sensing technologies," "simulation modeling and spatial data acquisition tools," and "cooperative decision and control algorithms." As we analyzed research published between 2022 and 2023, only 183 papers met the eligibility criteria. By removing controversial or unclear findings (scanty/unimportant data), results unsupported by replication, undetailed content, or papers having quite similar titles, we decided on 37, chiefly empirical, sources (Tables 1 and 2). Data visualization tools: Dimensions (bibliometric mapping) and VOSviewer (layout algorithms). Reporting quality assessment tool: PRISMA. Methodological quality assessment tools include: AXIS, Distiller SR, ROBIS, and SRDR (Figures 1–6).

Table 1 Topics and types of scientific products identified and selected.

Topic	Identified	Selected
real-time interoperable decentralized metaverse + immersive extended reality and remote sensing technologies	64	13
real-time interoperable decentralized metaverse + simulation modeling and spatial data acquisition tools	60	12
real-time interoperable decentralized metaverse + cooperative decision and control algorithms	59	12
Type of paper		
Original research	152	28
Review	21	9
Conference proceedings	9	0
Book	0	0
Editorial	1	0

Source: Processed by the authors. Some topics overlap.

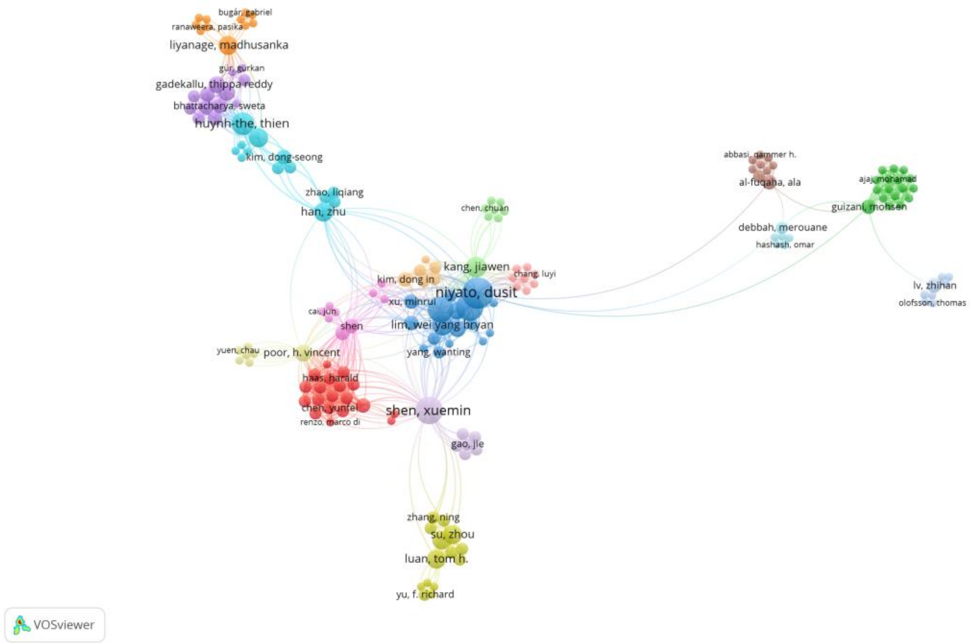

Figure 1 Co-authorship

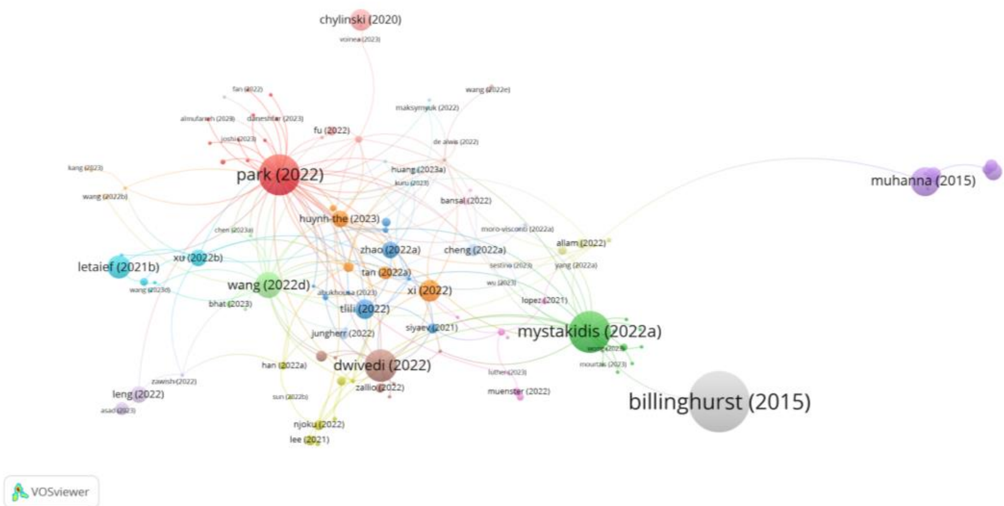

Figure 2 Citation

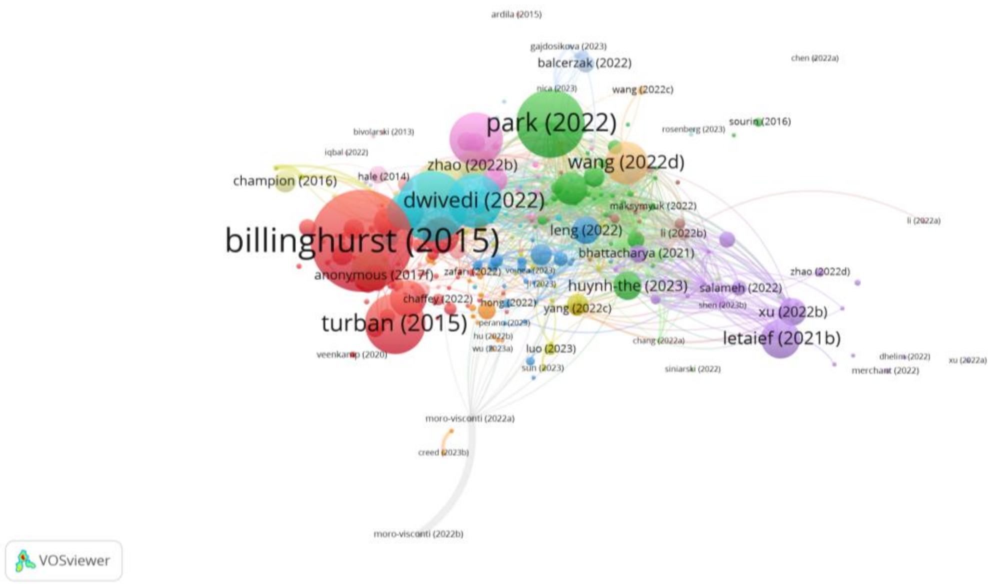

Figure 3 Bibliographic coupling

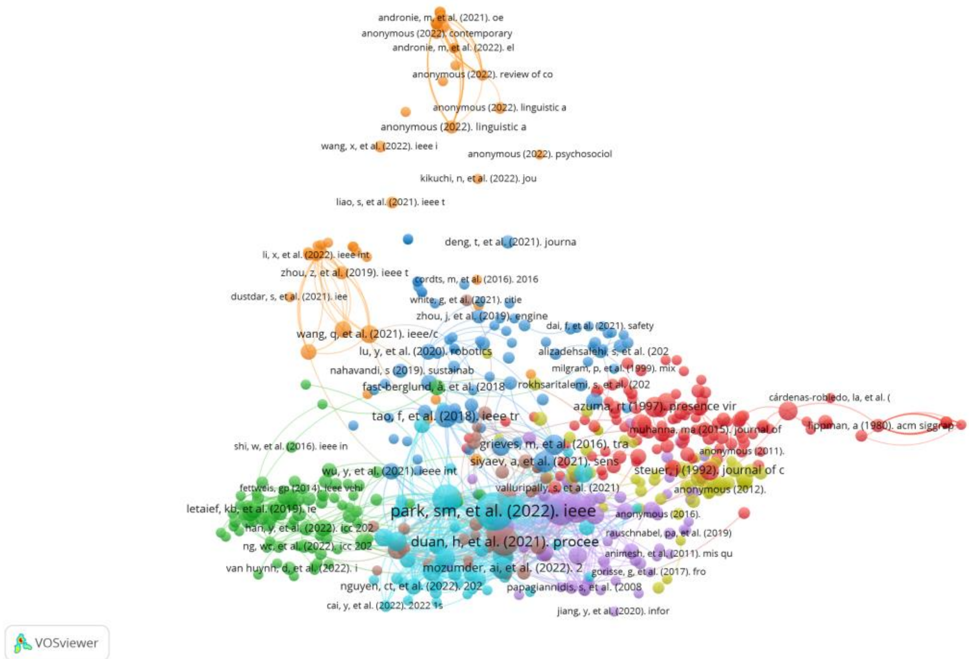

Figure 4 Co-citation

Table 2 General synopsis of evidence as regards focus topics and descriptive outcomes (research findings).

Deep learning-based generative and interconnected sensor networks, spatial awareness and tracking tools, and cognitive artificial intelligence and geolocation data processing algorithms assist the decentralized metaverse.	Daneshfar and Jamshidi, 2023; Hollensen et al., 2023; Li et al., 2023a
Haptic feedback and 3D modeling technologies, cognitive computing and visual analytics systems, and metaverse engagement metrics optimize 3D computer-generated virtual environments.	Dolata and Schwabe, 2023; McStay, 2022; Tang et al., 2023; Weking et al., 2023
User identification technology and location data, sentiment and real-time predictive analytics, and artificial intelligence-powered search capabilities configure interactive virtual and extended reality environments.	Dincelli and Yayla, 2022; Ersoy and Gürfidan, 2023; Oh et al., 2023; Zarantonello and Schmitt, 2023
Deep reinforcement learning and simulation modeling tools, real-time predictive and mobile location analytics, and virtual holographic objects further the blockchain-based metaverse and synthetic digitally-mediated environments.	Ahn et al., 2023; Cao, 2022; Hadi et al., 2023; He et al., 2023; Zheng and Yuan, 2023
Human digital twin and neuromorphic image processing systems, haptic bodysuits, and metaverse assets and services are instrumental in immersive virtual environments.	Duncan, 2022; Huynh-The et al., 2023; Nagendran et al., 2022; Venugopal et al., 2023
Deep learning-based ambient sound processing, computer vision and spatial cognition algorithms, and modeling and forecasting tools articulate intelligent connectivity infrastructures across extended reality environments.	Chen, 2022; Hawkins, 2022; Queiroz et al., 2023; Wang et al., 2022
Virtual navigation and image processing tools, eye-tracking and digital contact tracing technologies, and multi-sensory extended reality shape the interconnected metaverse and 3D virtual environments.	Du et al., 2023; Gauttier et al., 2022; Smart, 2022; Wu et al., 2023
Image processing computational and situational awareness algorithms, deep learning-based sensing and data analytics technologies, and visual and spatial intelligence tools configure 3D immersive content across the decentralized and interconnected metaverse.	Faraboschi et al., 2022; Han et al., 2023; Majerová and Pera, 2022; Park and Kim, 2023
Wireless sensor and convolutional neural networks, location-based predictive and deep learning algorithms, and affective and perceptual technologies enable decentralized 3D digital worlds.	Li et al., 2023b; Ramadan, 2023; Shen, 2022; Watson, 2022; Zhang et al., 2023

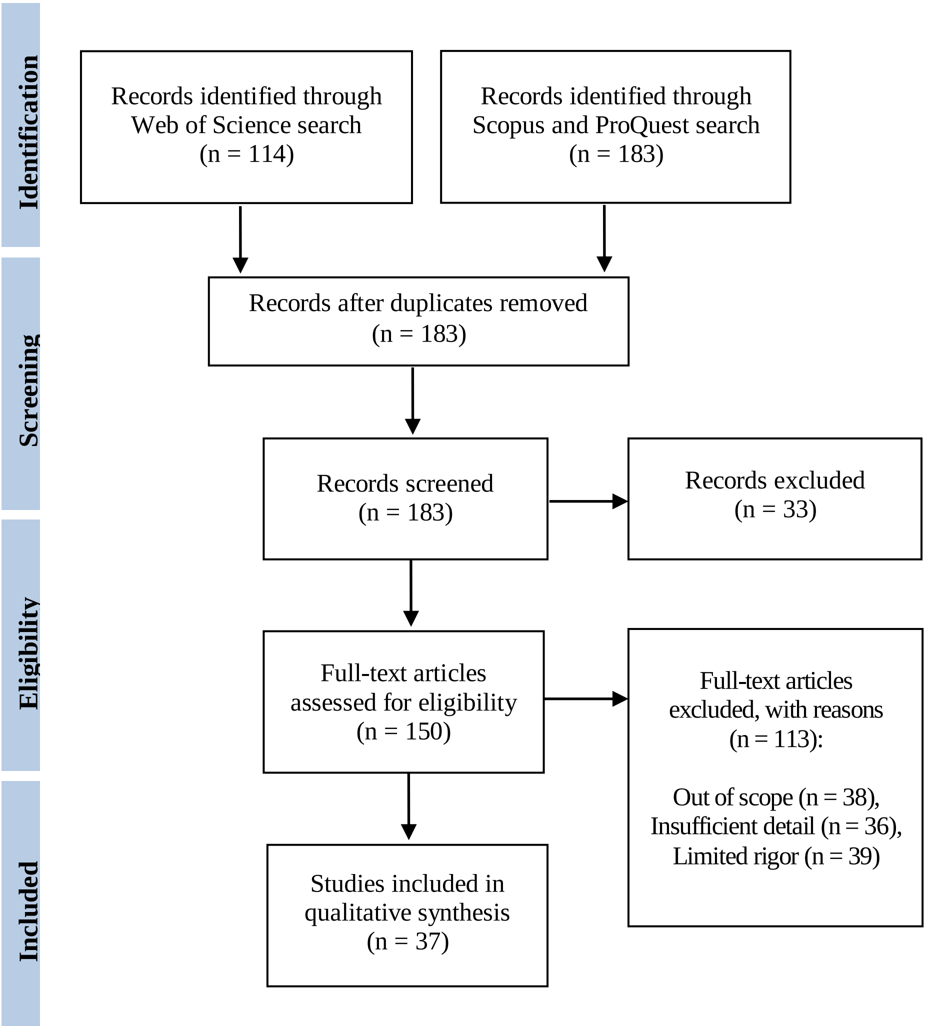

Figure 5 PRISMA flow diagram describing the search results and screening.

Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines were used that ensure the literature review is comprehensive, transparent, and replicable. The flow diagram, produced by employing a Shiny app, presents the stream of evidence-based collected and processed data through the various steps of a systematic review, designing the amount of identified, included, and removed records, and the justifications for exclusions.
To ensure compliance with PRISMA guidelines, a citation software was used, and at each stage the inclusion or exclusion of articles was tracked by use of custom spreadsheet. Justification for the removal of ineligible articles was specified during the full-text screening and final selection.

To ensure first-rate standard of evidence, a systematic search of relevant databases including peer-reviewed published journal articles was conducted using predefined search terms, covering a range of research methods and data sources. Reference lists of all relevant sources were manually reviewed for additional relevant citations.

Titles of papers and abstracts were screened for suitability and selected full texts were retrieved to establish whether they satisfied the inclusion criteria. All records from each database were evaluated by using data extraction forms. Data covering research aims, participants, study design, and method of each paper were extracted.

The inclusion criteria were: (i) articles included in the Web of Science, Scopus, and ProQuest databases, (ii) publication date (2022–2023), (iii) written in English, (iv) being an original empirical research or review article, and (v) particular search terms covered; (i) conference proceedings, (ii) books, and (iii) editorial materials were eliminated from the analysis.

SRDR gathered, handled, and analyzed the data for the systematic review, being configured as an archive and tool harnessed in data extraction through transparent, efficient, and reliable quantitative techniques. Elaborate extraction forms can be set up, meeting the needs of research questions and study designs.

Distiller SR screened and extracted the collected data.

AMSTAR evaluated the methodological quality of systematic reviews.

Dedoose analyzed qualitative and mixed methods research.

ROBIS assessed the risk of bias in systematic reviews.

AXIS evaluated the quality of cross-sectional studies.

The quality of academic articles was determined and risk of bias was measured by MMAT, that tested content validity and usability of selected studies in terms of screening questions, type of design, corresponding quality criteria, and overall quality score.

Figure 6 Screening and quality assessment tools

4. Machine Learning-based Predictive and Simulation Modeling Algorithms, Haptic and Multisensory Technologies, and Spatial Awareness and Tracking Tools in the Decentralized Metaverse

Deep learning-based generative and interconnected sensor networks, spatial awareness and tracking tools, and cognitive artificial intelligence and geolocation data processing algorithms (Daneshfar and Jamshidi, 2023; Hollensen et al., 2023; Li et al., 2023a) assist the decentralized metaverse. Immersive virtual experiences can be attained through machine learning-based predictive and simulation modeling algorithms, cognitive artificial intelligence and cloud computing technologies, and 3D virtual space networking and geospatial mapping tools.

Haptic feedback and 3D modeling technologies, cognitive computing and visual analytics systems, and metaverse engagement metrics (Dolata and Schwabe, 2023; McStay, 2022; Tang et al., 2023; Weking et al., 2023) optimize 3D computer-generated virtual environments. 3D immersive spaces and experiences can be achieved by use of haptic and multisensory technologies, computer vision and deep learning algorithms, and automated speech recognition and virtual twin modeling tools.

User identification technology and location data, sentiment and real-time predictive analytics, and artificial intelligence-powered search capabilities (Dincelli and Yayla, 2022; Ersoy and Gürfidan, 2023; Oh et al., 2023; Zarantonello and Schmitt, 2023) configure interactive virtual and extended reality environments. Immersive virtual experiences can be attained through simulation modeling and visual imagery tools, monitoring and sensing technologies, and bio-inspired computational intelligence and context awareness algorithms. (Table 3)

Table 3 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Deep learning-based generative and interconnected sensor networks, spatial awareness and tracking tools, and cognitive artificial intelligence and geolocation data processing algorithms assist the decentralized metaverse.	Daneshfar and Jamshidi, 2023; Hollensen et al., 2023; Li et al., 2023a
Haptic feedback and 3D modeling technologies, cognitive computing and visual analytics systems, and metaverse engagement metrics optimize 3D computer-generated virtual environments.	Dolata and Schwabe, 2023; McStay, 2022; Tang et al., 2023; Weking et al., 2023
User identification technology and location data, sentiment and real-time predictive analytics, and artificial intelligence-powered search capabilities configure interactive virtual and extended reality environments.	Dincelli and Yayla, 2022; Ersoy and Gürfidan, 2023; Oh et al., 2023; Zarantonello and Schmitt, 2023

5. Multiscale Spatial Data Processing and Contextual Data Monitoring Tools, Sensor Fusion and Affective Modeling Algorithms, and Real-Time Predictive and Mobile Location Analytics in the Blockchain-based Metaverse

Deep reinforcement learning and simulation modeling tools, real-time predictive and mobile location analytics, and virtual holographic objects (Ahn et al., 2023; Cao, 2022; Hadi et al., 2023; He et al., 2023; Zheng and Yuan, 2023) further the blockchain-based metaverse and synthetic digitally-mediated environments. Virtual reality-based immersive experiences can be achieved by use of multiscale spatial data processing and contextual data monitoring tools, geolocation data mining and tracking, and wearable haptic garments.

Human digital twin and neuromorphic image processing systems, haptic bodysuits, and metaverse assets and services (Duncan, 2022; Huynh-The et al., 2023; Nagendran et al., 2022; Venugopal et al., 2023) are instrumental in immersive virtual environments. Extended reality environments develop on machine learning-based object recognition and data fusion technologies, smart environment modeling and geospatial mapping tools, and sensor fusion and affective modeling algorithms.

Deep learning-based ambient sound processing, computer vision and spatial cognition algorithms, and modeling and forecasting tools (Chen, 2022; Hawkins, 2022; Queiroz et al., 2023; Wang et al., 2022) articulate intelligent connectivity infrastructures across extended reality environments. 3D immersive environments integrate emotion detection and recognition technologies, biometrics data fusion, and socio-spatial analytics and digital twin modeling tools. Blockchain token-based digital assets, virtual mapping and visual imagery tools, and wireless sensor networks shape immersive 3D worlds. (Table 4)

Table 4 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Deep reinforcement learning and simulation modeling tools, real-time predictive and mobile location analytics, and virtual holographic objects further the blockchain-based metaverse and synthetic digitally-mediated environments.	Ahn et al., 2023; Cao, 2022; Hadi et al., 2023; He et al., 2023; Zheng and Yuan, 2023
Human digital twin and neuromorphic image processing systems, haptic bodysuits, and metaverse assets and services are instrumental in immersive virtual environments.	Duncan, 2022; Huynh-The et al., 2023; Nagendran et al., 2022; Venugopal et al., 2023
Deep learning-based ambient sound processing, computer vision and spatial cognition algorithms, and modeling and forecasting tools articulate intelligent connectivity infrastructures across extended reality environments.	Chen, 2022; Hawkins, 2022; Queiroz et al., 2023; Wang et al., 2022

6. Motion Capture and Geospatial Big Data Visualization Systems, Sensor Path Planning and Situational Awareness Algorithms, and Deep Learning-based Sensing and Data Analytics Technologies in the Interconnected Metaverse

Virtual navigation and image processing tools, eye-tracking and digital contact tracing technologies, and multi-sensory extended reality (Du et al., 2023; Gauttier et al., 2022; Smart, 2022; Wu et al., 2023) shape the interconnected metaverse and 3D virtual environments. The blockchain-based virtual economy require motion capture and geospatial big data visualization systems, edge computing and affective computing technologies, and remote sensing and machine learning algorithms.

Image processing computational and situational awareness algorithms, deep learning-based sensing and data analytics technologies, and visual and spatial intelligence tools (Faraboschi et al., 2022; Han et al., 2023; Majerová and Pera, 2022; Park and Kim, 2023) configure 3D immersive content across the decentralized and interconnected metaverse. Immersive multisensory virtual spaces necessitate spatial data visualization and ambient intelligence tools, sensor path planning and situational awareness algorithms, and artificial intelligence-based image recognition and ontology-based semantic technologies.

Wireless sensor and convolutional neural networks, location-based predictive and deep learning algorithms, and affective and perceptual technologies (Li et al., 2023b; Ramadan, 2023; Shen, 2022; Watson, 2022; Zhang et al., 2023) enable decentralized 3D digital worlds. Behavioral predictive and Internet of Things sensor data analytics, immersive geospatial data visualization and virtual modeling technologies, and explainable artificial intelligence-based decision support and haptic object recognition systems. (Table 5)

Table 5 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Virtual navigation and image processing tools, eye-tracking and digital contact tracing technologies, and multi-sensory extended reality shape the interconnected metaverse and 3D virtual environments.	Du et al., 2023; Gauttier et al., 2022; Smart, 2022; Wu et al., 2023
Image processing computational and situational awareness algorithms, deep learning-based sensing and data analytics technologies, and visual and spatial intelligence tools configure 3D immersive content across the decentralized and interconnected metaverse.	Faraboschi et al., 2022; Han et al., 2023; Majerová and Pera, 2022; Park and Kim, 2023
Wireless sensor and convolutional neural networks, location-based predictive and deep learning algorithms, and affective and perceptual technologies enable decentralized 3D digital worlds.	Li et al., 2023b; Ramadan, 2023; Shen, 2022; Watson, 2022; Zhang et al., 2023

7. Discussion

We integrate our systematic review throughout research indicating how behavioral predictive and Internet of Things sensor data analytics, immersive geospatial data visualization and virtual modeling technologies, and explainable artificial intelligence-based decision support and haptic object recognition systems. Our research complements recent analyses clarifying how 3D immersive spaces and experiences can be achieved by use of haptic and multisensory technologies, computer vision and deep learning algorithms, and automated speech recognition and virtual twin modeling tools. We elucidate, by cumulative evidence, previous research demonstrating how immersive virtual experiences can be attained through machine learning-based predictive and simulation modeling algorithms, cognitive artificial intelligence and cloud computing technologies, and 3D virtual space networking and geospatial mapping tools.

8. Synopsis of the Main Research Outcomes

The blockchain-based virtual economy require motion capture and geospatial big data visualization systems, edge computing and affective computing technologies, and remote sensing and machine learning algorithms. Virtual reality-based immersive experiences can be achieved by use of multiscale spatial data processing and contextual data monitoring tools, geolocation data mining and tracking, and wearable haptic garments.

9. Conclusions

Relevant research has investigated whether extended reality environments develop on machine learning-based object recognition and data fusion technologies, smart environment modeling and geospatial mapping tools, and sensor fusion and affective modeling algorithms. This systematic literature review presents the published peer-reviewed sources covering how immersive multisensory virtual spaces necessitate spatial data visualization and ambient intelligence tools, sensor path planning and situational awareness algorithms, and artificial intelligence-based image recognition and ontology-based semantic technologies. The research outcomes drawn from the above analyses indicate that blockchain token-based digital assets, virtual mapping and visual imagery tools, and wireless sensor networks shape immersive 3D worlds.

10. Limitations, Implications, and Further Directions of Research

By analyzing only articles published between 2022 and 2023 in journals indexed in the Web of Science, Scopus, and ProQuest databases, relevant sources on immersive extended reality and remote sensing technologies, simulation modeling and spatial data acquisition tools, and cooperative decision and control algorithms in a real-time interoperable decentralized metaverse may have been excluded. Limitations of this research comprise particular kinds of publications (original empirical research and review articles) discounting others (conference proceedings articles, books, and editorial materials). The scope of our study also does not move forward the inspection of deep learning-based generative and interconnected sensor networks, spatial awareness and tracking tools, and cognitive artificial intelligence and geolocation data processing algorithms.

Subsequent analyses should develop on deep learning-based ambient sound processing, computer vision and spatial cognition algorithms, and modeling and forecasting tools. Future research should thus investigate user identification technology and location data, sentiment and real-time predictive analytics, and artificial intelligence-powered search capabilities. Attention should be directed to 3D immersive content across the decentralized and interconnected metaverse.

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Compliance with ethical standards

This article does not contain any studies with human participants or animals performed by the authors. Extracting and inspecting publicly accessible files (scholarly sources) as evidence, before the research began no institutional ethics approval was required.

Data availability statement

All data generated or analyzed are included in the published article.

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Author contributions

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication. The authors take full responsibility for the accuracy and the integrity of the data analysis.

Conflict of interest statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Disclosure by the editors of record

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Remote Big Data Management and Visual Imagery Tools, Multisensor Fusion and Dynamic Routing Technologies, and 3D Space Mapping and Object Recognition Algorithms on Blockchain-based Metaverse Platforms

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ABSTRACT. Based on an in-depth survey of the literature, the purpose of the paper is to explore metaverse assets and services, virtual personas and identities, and movement and behavior tracking tools. In this research, previous findings were cumulated showing that deep learning artificial intelligence and automated speech recognition tools, dynamic routing and multisensor fusion technologies, and cognitive and behavioral algorithms further immersive virtual worlds, and we contribute to the literature by indicating that multisensory user experiences can be attained through cognitive and behavior modeling technologies, auditory and visual immersion systems, and digital twinning and geospatial analytics tools. Throughout January 2023, a quantitative literature review of the Web of Science, Scopus, and ProQuest databases was performed, with search terms including "blockchain-based metaverse platforms" + "remote big data management and visual imagery tools," "multisensor fusion and dynamic routing technologies," and "3D space mapping and object recognition algorithms." As research published between 2022 and 2023 was inspected, only 177 articles satisfied the eligibility criteria. By taking out controversial or ambiguous findings (insufficient/irrelevant data), outcomes unsubstantiated by replication, too general material, or studies with nearly identical titles, I selected 33 mainly empirical sources. Data visualization tools: Dimensions (bibliometric mapping) and VOSviewer (layout algorithms). Reporting quality assessment tool: PRISMA. Methodological quality assessment tools include: AMSTAR, Dedoose, Distiller SR, and SRDR.

Keywords: remote big data management and visual imagery tools; multisensor fusion and dynamic routing technologies; 3D space mapping and object recognition algorithms; metaverse

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1. Introduction

3D virtual immersive environments necessitate digital twin modeling and artificial intelligence-powered prediction tools, image recognition and holographic telepresence technologies, and computer vision and motion control algorithms. The purpose of my systematic review is to examine the recently published literature on blockchain-based metaverse platforms and integrate the insights it configures on remote big data management and visual imagery tools, multisensor fusion and dynamic routing technologies, and 3D space mapping and object recognition algorithms. By analyzing the most recent (2022–2023) and significant (Web of Science, Scopus, and ProQuest) sources, my paper has attempted to prove that immersive digital worlds require text mining and analytics, cognitive computing and networked immersive virtual reality systems (Andronie et al., 2021a; Duncan, 2022; Nica et al., 2022), and deep learning-based predictive and visual tracking algorithms. The actuality and novelty of this study are articulated by addressing metaverse assets and services, virtual personas and identities, and movement and behavior tracking tools (Andronie et al., 2021b; Musova et al., 2021; Popescu et al., 2017a), that is an emerging topic involving much interest. My research problem is whether deep learning artificial intelligence and automated speech recognition tools, dynamic routing and multisensor fusion technologies, and cognitive and behavioral algorithms further immersive virtual worlds.

In this review, prior findings have been cumulated indicating that intelligent data processing and immersive decentralized networking tools, digital twin and spatial computing technologies (Andronie et al., 2021; Naepi and Naepi, 2022; Popescu et al., 2017b), and deep learning and environment mapping algorithms are instrumental in the blockchain-based virtual economy. The identified gaps advance metaverse engagement metrics, cognitive computing and immersive visualization systems (Andronie et al., 2023; Nica, 2017; Popescu, 2018), and data-driven artificial intelligence and predictive modeling algorithms. My main objective is to indicate that multisensory user experiences can be attained through cognitive and behavior modeling technologies (Dabija et al., 2018; Nica, 2018; Pelau et al., 2021; Vătămănescu et al., 2022), auditory and visual immersion systems, and digital twinning and geospatial analytics tools.

2. Theoretical Overview of the Main Concepts

Immersive virtual reality experiences can be achieved by use of multi-sensor fusion and perception systems, simulation and modeling technologies, and brain-inspired artificial intelligence and objection recognition algorithms. The manuscript is organized as following: theoretical overview (section 2), methodology (section 3), artificial vision and autonomous cognitive systems, contextual data monitoring and digital twin simulation tools, and deep learning-based sensing and immersive extended reality technologies on blockchain-based metaverse platforms (section 4), metaverse assets and services, brain-inspired artificial intelligence and objection recognition algorithms, and digital twinning and geospatial analytics tools in immersive interconnected virtual worlds (section 5), cognitive computing and networked immersive virtual reality systems, contextual intelligence and operational modeling tools, and 3D capture and sentiment recognition technologies in a fully connected and decentralized metaverse (section 6), discussion (section 7), synopsis of the main research outcomes (section 8), conclusions (section 9), limitations, implications, and further directions of research (section 10).

3. Methodology

Throughout January 2023, a quantitative literature review of the Web of Science, Scopus, and ProQuest databases was performed, with search terms including "blockchain-based metaverse platforms" + "remote big data management and visual imagery tools," "multisensor fusion and dynamic routing technologies," and "3D space mapping and object recognition algorithms." As research published between 2022 and 2023 was inspected, only 177 articles satisfied the eligibility criteria. By taking out controversial or ambiguous findings (insufficient/irrelevant data), outcomes unsubstantiated by replication, too general material, or studies with nearly identical titles, I selected 33 mainly empirical sources (Tables 1 and 2). Data visualization tools: Dimensions (bibliometric mapping) and VOSviewer (layout algorithms). Reporting quality assessment tool: PRISMA. Methodological quality assessment tools include: AMSTAR, Dedoose, Distiller SR, and SRDR (Figures 1–6).

Table 1 Topics and types of scientific products identified and selected.

Topic	**Identified**	**Selected**
blockchain-based metaverse platforms + remote big data management and visual imagery tools	60	12
blockchain-based metaverse platforms + multisensor fusion and dynamic routing technologies	59	11
blockchain-based metaverse platforms + 3D space mapping and object recognition algorithms	58	10
Type of paper		
Original research	150	25
Review	17	8
Conference proceedings	8	0
Book	0	0
Editorial	2	0

Source: Processed by the author. Some topics overlap.

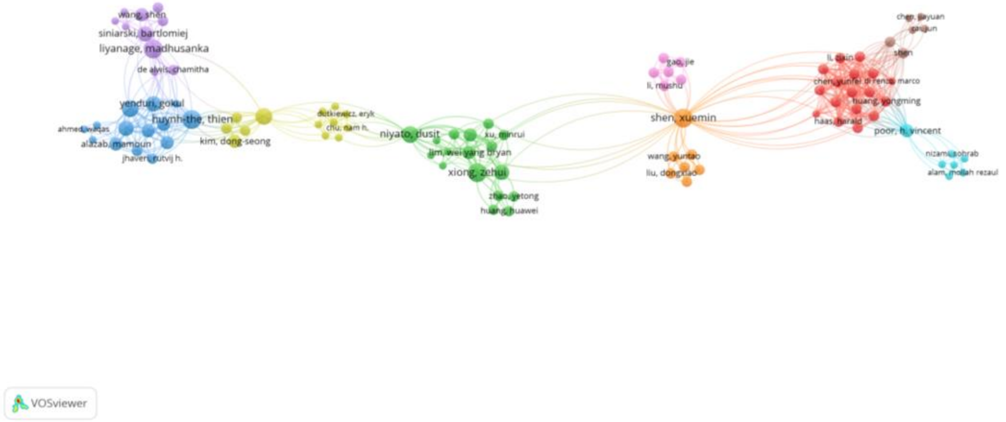

Figure 1 Co-authorship

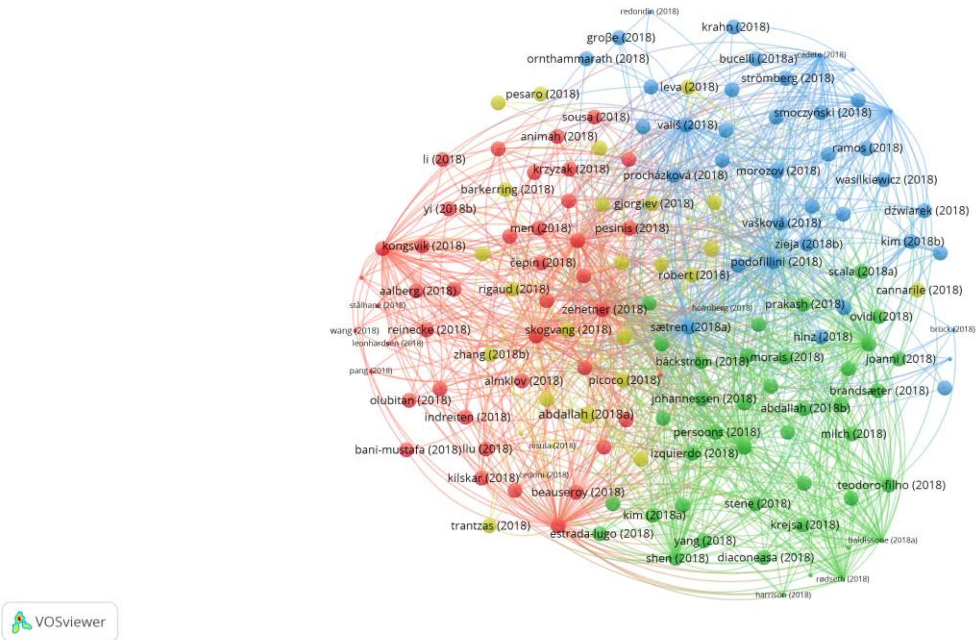

Figure 2 Citation

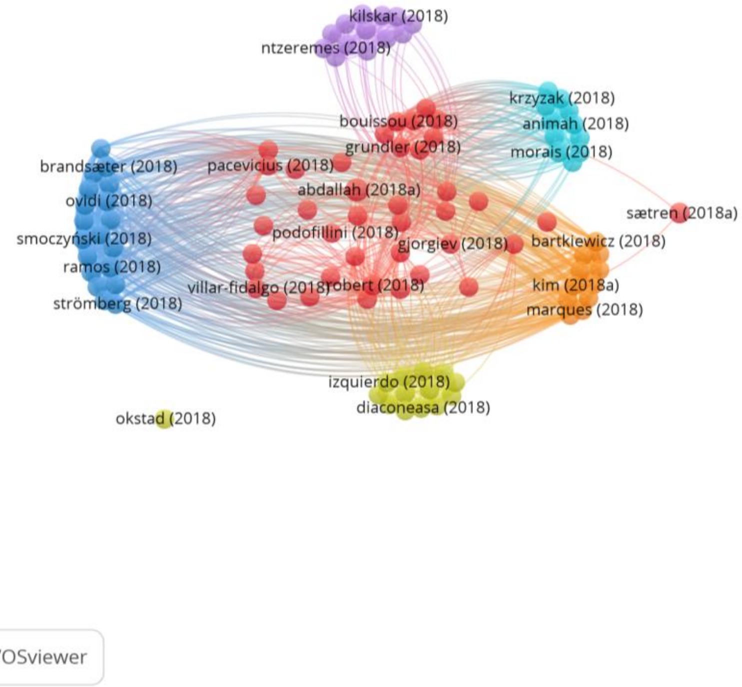

Figure 3 Bibliographic coupling

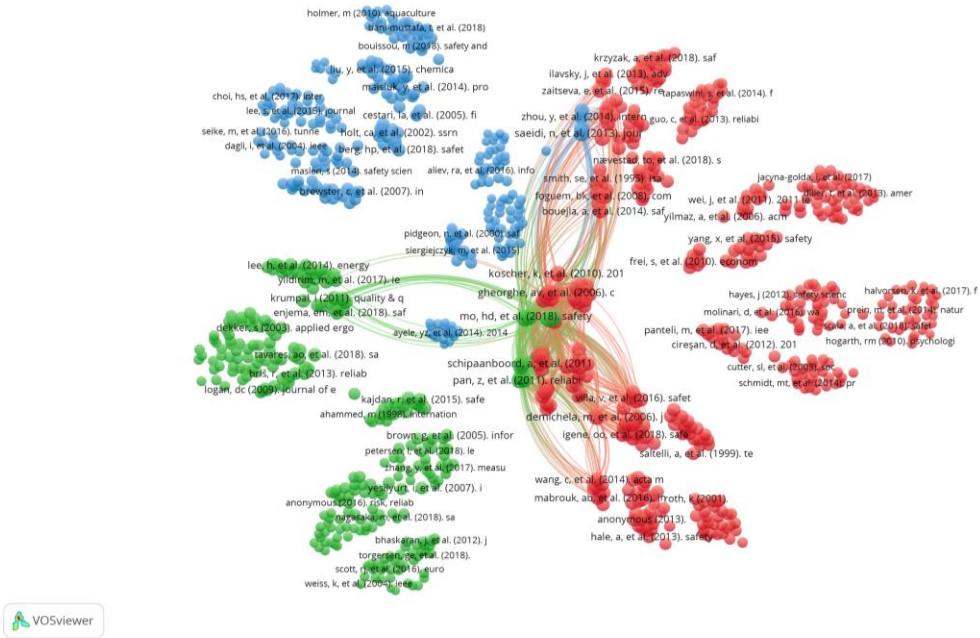

Figure 4 Co-citation

Table 2 General synopsis of evidence as regards focus topics and descriptive outcomes (research findings).

Interconnected sensor and picture-making neural networks, eye-tracking and cognitive automation technologies, and contextual data monitoring and digital twin simulation tools configure blockchain-based metaverse platforms.	Park and Kim, 2023; Rostami and Maier, 2022; Xu et al., 2023a
Immersive photorealistic virtual spaces and the metaverse economy integrate spatial and edge computing technologies, real-time visual analytics and multimodal sensing systems, and bio-sensing and actuation systems.	Dwivedi et al., 2023; Giang Barrera and Shah, 2023; Zhao et al., 2022
Eye-tracking and geospatial mapping technologies, virtual mapping and natural language processing tools, and artificial vision and autonomous cognitive systems articulate immersive interconnected virtual worlds.	Ahn et al., 2023; Han et al., 2022; Panagiotakopoulos et al., 2022; Zhou et al., 2023
Immersive metaverse experiences can be attained through behavior pattern clustering, big spatio-temporal data and user journey analytics, and photorealistic synthetic images and data.	Du et al., 2023; Han et al., 2023a; Vidal-Tomás, 2023; Xu et al., 2023b
Metaverse assets and services, virtual personas and identities, and movement and behavior tracking tools are pivotal in 3D immersive environments. 3D virtual immersive environments necessitate digital twin modeling and artificial intelligence-powered prediction tools, image recognition and holographic telepresence technologies, and computer vision and motion control algorithms.	Egliston and Carter, 2022; Han et al., 2023b; Shi et al., 2023; Zhu et al., 2023
Spatio-temporal fusion and image detection algorithms, context recognition and data visualization tools, and geospatial mapping and image-based object recognition technologies assist immersive interconnected virtual worlds.	Hamilton, 2022; Mourtzis et al., 2022; Wongkitrungrueng and Suprawan, 2023; Zhang et al., 2023
Metaverse engagement metrics, cognitive computing and immersive visualization systems, and data-driven artificial intelligence and predictive modeling algorithms shape the virtual environment of the metaverse.	Huynh-The et al., 2023; Kovacova et al., 2022; Zallio and Clarkson, 2022
A fully connected and decentralized metaverse require immersive and blockchain technologies, contextual intelligence and operational modeling tools, and real-time event analytics.	Aloqaily et al., 2022; Dolata and Schwabe, 2023; Grupac et al., 2022; Zabel et al., 2023
Dynamic routing and cognitive enhancement technologies, sensor data fusion, and movement and behavior tracking tools enable immersive 3D worlds and synthetic reality spaces.	Ding et al., 2022; Kwok and Tang, 2023; Njoku et al., 2023; Zauskova et al., 2022

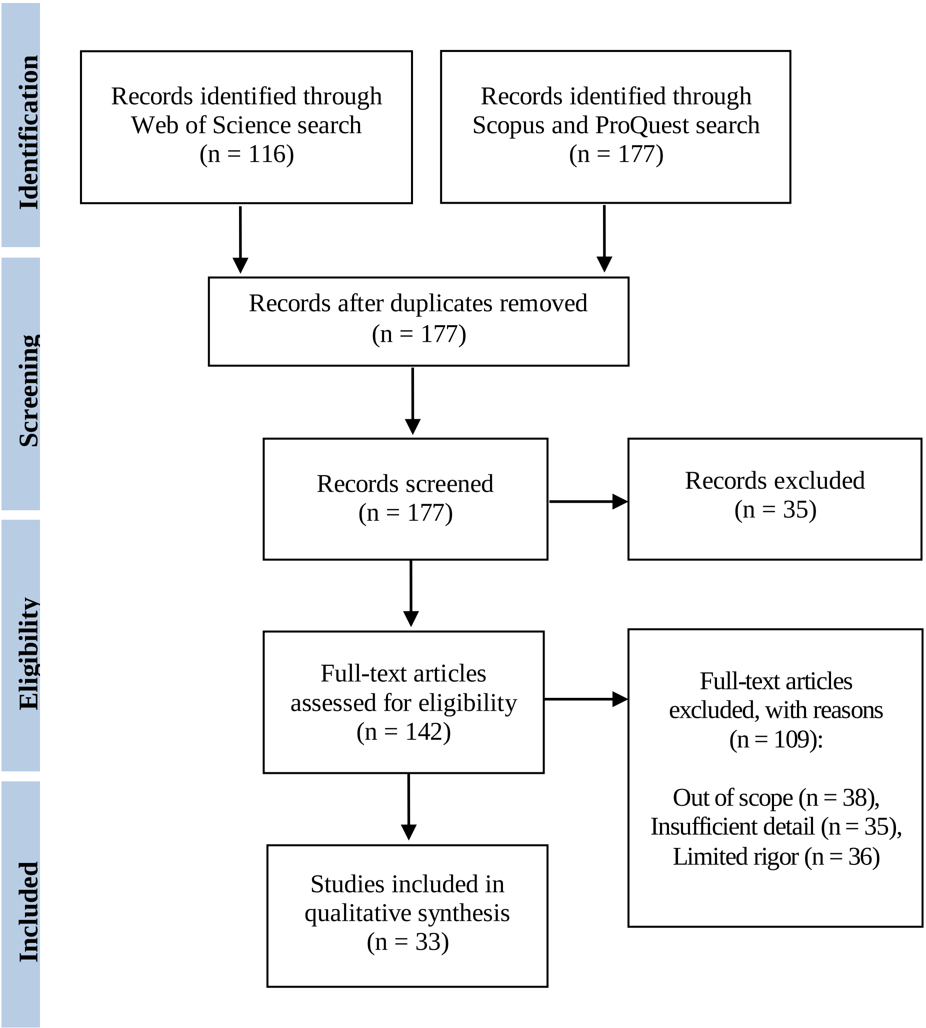

Figure 5 PRISMA flow diagram describing the search results and screening.

Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines were used that ensure the literature review is comprehensive, transparent, and replicable. The flow diagram, produced by employing a Shiny app, presents the stream of evidence-based collected and processed data through the various steps of a systematic review, designing the amount of identified, included, and removed records, and the justifications for exclusions.
To ensure compliance with PRISMA guidelines, a citation software was used, and at each stage the inclusion or exclusion of articles was tracked by use of custom spreadsheet. Justification for the removal of ineligible articles was specified during the full-text screening and final selection.

To ensure first-rate standard of evidence, a systematic search of relevant databases including peer-reviewed published journal articles was conducted using predefined search terms, covering a range of research methods and data sources. Reference lists of all relevant sources were manually reviewed for additional relevant citations.

Titles of papers and abstracts were screened for suitability and selected full texts were retrieved to establish whether they satisfied the inclusion criteria. All records from each database were evaluated by using data extraction forms. Data covering research aims, participants, study design, and method of each paper were extracted.

The inclusion criteria were: (i) articles included in the Web of Science, Scopus, and ProQuest databases, (ii) publication date (2022–2023), (iii) written in English, (iv) being an original empirical research or review article, and (v) particular search terms covered; (i) conference proceedings, (ii) books, and (iii) editorial materials were eliminated from the analysis.

Distiller SR screened and extracted the collected data.

SRDR gathered, handled, and analyzed the data for the systematic review, being configured as an archive and tool harnessed in data extraction through transparent, efficient, and reliable quantitative techniques. Elaborate extraction forms can be set up, meeting the needs of research questions and study designs.

AMSTAR evaluated the methodological quality of systematic reviews.

ROBIS assessed the risk of bias in systematic reviews.

The quality of academic articles was determined and risk of bias was measured by MMAT, that tested content validity and usability of selected studies in terms of screening questions, type of design, corresponding quality criteria, and overall quality score.

AXIS evaluated the quality of cross-sectional studies.

Dedoose analyzed qualitative and mixed methods research.

Figure 6 Screening and quality assessment tools

4. Artificial Vision and Autonomous Cognitive Systems, Contextual Data Monitoring and Digital Twin Simulation Tools, and Deep Learning-based Sensing and Immersive Extended Reality Technologies on Blockchain-based Metaverse Platforms

Interconnected sensor and picture-making neural networks, eye-tracking and cognitive automation technologies, and contextual data monitoring and digital twin simulation tools (Park and Kim, 2023; Rostami and Maier, 2022; Xu et al., 2023a) configure blockchain-based metaverse platforms. Deep learning artificial intelligence and automated speech recognition tools, dynamic routing and multisensor fusion technologies, and cognitive and behavioral algorithms further immersive virtual worlds.

Immersive photorealistic virtual spaces and the metaverse economy (Dwivedi et al., 2023; Giang Barrera and Shah, 2023; Zhao et al., 2022) integrate spatial and edge computing technologies, real-time visual analytics and multimodal sensing systems, and bio-sensing and actuation systems. Immersive virtual reality experiences can be achieved by use of biometric self-authentication devices, body-tracking data metrics, and photorealistic synthetic imagery.

Eye-tracking and geospatial mapping technologies, virtual mapping and natural language processing tools, and artificial vision and autonomous cognitive systems (Ahn et al., 2023; Han et al., 2022; Panagiotakopoulos et al., 2022; Zhou et al., 2023) articulate immersive interconnected virtual worlds. Hyper-realistic personalized interactive experiences can be attained through interactional and contextual data, deep learning-based sensing and immersive extended reality technologies, and multi-machine cooperation and image recognition tools. (Table 3)

Table 3 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Interconnected sensor and picture-making neural networks, eye-tracking and cognitive automation technologies, and contextual data monitoring and digital twin simulation tools configure blockchain-based metaverse platforms.	Park and Kim, 2023; Rostami and Maier, 2022; Xu et al., 2023a
Immersive photorealistic virtual spaces and the metaverse economy integrate spatial and edge computing technologies, real-time visual analytics and multimodal sensing systems, and bio-sensing and actuation systems.	Dwivedi et al., 2023; Giang Barrera and Shah, 2023; Zhao et al., 2022
Eye-tracking and geospatial mapping technologies, virtual mapping and natural language processing tools, and artificial vision and autonomous cognitive systems articulate immersive interconnected virtual worlds.	Ahn et al., 2023; Han et al., 2022; Panagiotakopoulos et al., 2022; Zhou et al., 2023

5. Metaverse Assets and Services, Brain-inspired Artificial Intelligence and Objection Recognition Algorithms, and Digital Twinning and Geospatial Analytics Tools in Immersive Interconnected Virtual Worlds

Immersive metaverse experiences (Du et al., 2023; Han et al., 2023a; Vidal-Tomás, 2023; Xu et al., 2023b) can be attained through behavior pattern clustering, big spatio-temporal data and user journey analytics, and photo-realistic synthetic images and data. Virtual reality-based immersive experiences can be achieved by use of synthetic biometric data, ambient intelligence and big data management tools, and machine learning-based navigation and path planning algorithms.

Metaverse assets and services, virtual personas and identities, and movement and behavior tracking tools (Egliston and Carter, 2022; Han et al., 2023b; Shi et al., 2023; Zhu et al., 2023) are pivotal in 3D immersive environments. Multisensory user experiences can be attained through cognitive and behavior modeling technologies, auditory and visual immersion systems, and digital twinning and geospatial analytics tools. 3D virtual immersive environments necessitate digital twin modeling and artificial intelligence-powered prediction tools, image recognition and holographic telepresence technologies, and computer vision and motion control algorithms.

Spatio-temporal fusion and image detection algorithms, context recognition and data visualization tools, and geospatial mapping and image-based object recognition technologies (Hamilton, 2022; Mourtzis et al., 2022; Wongkitrungrueng and Suprawan, 2023; Zhang et al., 2023) assist immersive interconnected virtual worlds. Immersive virtual reality experiences can be achieved by use of multi-sensor fusion and perception systems, simulation and modeling technologies, and brain-inspired artificial intelligence and objection recognition algorithms. Cloud-based cognitive and digital twin technologies, predictive modeling processes, and smart sensor devices configure immersive 3D virtual environments. (Table 4)

Table 4 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Immersive metaverse experiences can be attained through behavior pattern clustering, big spatio-temporal data and user journey analytics, and photorealistic synthetic images and data.	Du et al., 2023; Han et al., 2023a; Vidal-Tomás, 2023; Xu et al., 2023b
Metaverse assets and services, virtual personas and identities, and movement and behavior tracking tools are pivotal in 3D immersive environments.	Egliston and Carter, 2022; Han et al., 2023b; Shi et al., 2023; Zhu et al., 2023
Spatio-temporal fusion and image detection algorithms, context recognition and data visualization tools, and geospatial mapping and image-based object recognition technologies assist immersive interconnected virtual worlds.	Hamilton, 2022; Mourtzis et al., 2022; Wongkitrungrueng and Suprawan, 2023; Zhang et al., 2023

6. Cognitive Computing and Networked Immersive Virtual Reality Systems, Contextual Intelligence and Operational Modeling Tools, and 3D Capture and Sentiment Recognition Technologies in a Fully Connected and Decentralized Metaverse

Metaverse engagement metrics, cognitive computing and immersive visualization systems, and data-driven artificial intelligence and predictive modeling algorithms (Huynh-The et al., 2023; Kovacova et al., 2022; Zallio and Clarkson, 2022) shape the virtual environment of the metaverse. Digital twinning and geospatial artificial intelligence technologies, data visualization and hyper-realistic immersive simulation tools, and networked embedded sensing devices optimize 3D virtual environments.

A fully connected and decentralized metaverse (Aloqaily et al., 2022; Dolata and Schwabe, 2023; Grupac et al., 2022; Zabel et al., 2023) require immersive and blockchain technologies, contextual intelligence and operational modeling tools, and real-time event analytics. Ambient intelligence and extended reality environments develop on synthetic data and visual imagery tools, computer vision and predictive maintenance algorithms, and 3D capture and sentiment recognition technologies.

Dynamic routing and cognitive enhancement technologies, sensor data fusion, and movement and behavior tracking tools (Ding et al., 2022; Kwok and Tang, 2023; Njoku et al., 2023; Zauskova et al., 2022) enable immersive 3D worlds and synthetic reality spaces. Immersive digital worlds require text mining and analytics, cognitive computing and networked immersive virtual reality systems, and deep learning-based predictive and visual tracking algorithms. Intelligent data processing and immersive decentralized networking tools, digital twin and spatial computing technologies, and deep learning and environment mapping algorithms are instrumental in the blockchain-based virtual economy. (Table 5)

Table 5 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Metaverse engagement metrics, cognitive computing and immersive visualization systems, and data-driven artificial intelligence and predictive modeling algorithms shape the virtual environment of the metaverse.	Huynh-The et al., 2023; Kovacova et al., 2022; Zallio and Clarkson, 2022
A fully connected and decentralized metaverse require immersive and blockchain technologies, contextual intelligence and operational modeling tools, and real-time event analytics.	Aloqaily et al., 2022; Dolata and Schwabe, 2023; Grupac et al., 2022; Zabel et al., 2023
Dynamic routing and cognitive enhancement technologies, sensor data fusion, and movement and behavior tracking tools enable immersive 3D worlds and synthetic reality spaces.	Ding et al., 2022; Kwok and Tang, 2023; Njoku et al., 2023; Zauskova et al., 2022

7. Discussion

I integrate my systematic review throughout research indicating how immersive digital worlds require text mining and analytics, cognitive computing and networked immersive virtual reality systems, and deep learning-based predictive and visual tracking algorithms. My research complements recent analyses clarifying how immersive virtual reality experiences can be achieved by use of biometric self-authentication devices, body-tracking data metrics, and photorealistic synthetic imagery. I elucidate, by cumulative evidence, previous research demonstrating how ambient intelligence and extended reality environments develop on synthetic data and visual imagery tools, computer vision and predictive maintenance algorithms, and 3D capture and sentiment recognition technologies.

8. Synopsis of the Main Research Outcomes

Digital twinning and geospatial artificial intelligence technologies, data visualization and hyper-realistic immersive simulation tools, and networked embedded sensing devices optimize 3D virtual environments. Multisensory user experiences can be attained through cognitive and behavior modeling technologies, auditory and visual immersion systems, and digital twinning and geospatial analytics tools.

9. Conclusions

Relevant research has investigated whether hyper-realistic personalized interactive experiences can be attained through interactional and contextual data, deep learning-based sensing and immersive extended reality technologies, and multi-machine cooperation and image recognition tools. This systematic literature review presents the published peer-reviewed sources covering how 3D virtual immersive environments necessitate digital twin modeling and artificial intelligence-powered prediction tools, image recognition and holographic telepresence technologies, and computer vision and motion control algorithms. The research outcomes drawn from the above analyses indicate that virtual reality-based immersive experiences can be achieved by use of synthetic biometric data, ambient intelligence and big data management tools, and machine learning-based navigation and path planning algorithms.

10. Limitations, Implications, and Further Directions of Research

By analyzing only articles published between 2022 and 2023 in journals indexed in the Web of Science, Scopus, and ProQuest databases, relevant sources on remote big data management and visual imagery tools, multi-sensor fusion and dynamic routing technologies, and 3D space mapping and object recognition algorithms on blockchain-based metaverse platforms may have been excluded. Limitations of this research comprise particular kinds of publications (original empirical research and review articles) discounting others (conference proceedings articles, books, and editorial materials). The scope of my study also does not move forward the inspection of immersive and blockchain technologies, contextual intelligence and operational modeling tools, and real-time event analytics.

Subsequent analyses should develop on immersive photorealistic virtual spaces and the metaverse economy. Future research should thus investigate eye-tracking and geospatial mapping technologies, virtual mapping and natural language processing tools, and artificial vision and autonomous cognitive systems. Attention should be directed to interconnected sensor and picture-making neural networks, eye-tracking and cognitive automation technologies, and contextual data monitoring and digital twin simulation tools.

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Compliance with ethical standards

This article does not contain any studies with human participants or animals performed by the author. Extracting and inspecting publicly accessible files (scholarly sources) as evidence, before the research began no institutional ethics approval was required.

Data availability statement

All data generated or analyzed are included in the published article.

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Author contributions

The author confirms being the sole contributor of this work and approved it for publication. The author takes full responsibility for the accuracy and the integrity of the data analysis.

Conflict of interest statement

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Disclosure by the editors of record

The editors declare no conflict of interest in the review and publication decision regarding this article.

Transparency statement

The author affirms that the manuscript represents an honest, accurate, and transparent account of the research being reported, that no relevant aspects of the study have been left out, and that any inconsistencies from the research as planned (and, if significant, registered) have been clarified.

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Remote Sensing Data Fusion Techniques, Multimodal Behavioral Predictive and Mobile Location Analytics, and Spatial Cognition and Context Awareness Algorithms in the Metaverse Economy

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ABSTRACT. The purpose of this study is to examine big geospatial data and user journey analytics, metaverse assets and services, and cyber-physical cognitive and immersive visualization systems. We contribute to the literature on virtual modeling and immersive 3D technologies, context awareness and machine vision algorithms, and sensor and actuator devices by showing that immersive digital worlds require computer vision and cognitive decision-making algorithms, deep learning-based sensing and spatial computing technologies, and virtual navigation and data mining tools. Throughout December 2022, we performed a quantitative literature review of the Web of Science, Scopus, and ProQuest databases, with search terms including “the metaverse economy” + “remote sensing data fusion techniques,” “multimodal behavioral predictive and mobile location analytics,” and “spatial cognition and context awareness algorithms.” As we inspected research published between 2022 and 2023, only 179 articles satisfied the eligibility criteria. By removing controversial findings, outcomes unsubstantiated by replication, too imprecise material, or having similar titles, we decided upon 36, generally empirical, sources. Data visualization tools: Dimensions (bibliometric mapping) and VOSviewer (layout algorithms). Reporting quality assessment tool: PRISMA. Methodological quality assessment tools include: AXIS, Dedoose, MMAT, and SRDR.

Keywords: remote sensing data fusion techniques; multimodal behavioral predictive and mobile location analytics; spatial cognition and context awareness algorithms; metaverse

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1. Introduction

Real-time Internet of Things data, hyper-realistic immersive 3D simulations, and digital twin modeling and ambient scene detection tools shape the digital asset-based virtual economy. The purpose of our systematic review is to examine the recently published literature on the metaverse economy and integrate the insights it configures on remote sensing data fusion techniques, multimodal behavioral predictive and mobile location analytics, and spatial cognition and context awareness algorithms. By analyzing the most recent (2022–2023) and significant (Web of Science, Scopus, and ProQuest) sources, our paper has attempted to prove that visual and spatial intelligence tools, 3D modeling and simulation technologies, and Internet of Things sensing infrastructures optimize blockchain-based virtual worlds. The actuality and novelty of this study are articulated by addressing virtual modeling and immersive 3D technologies, context awareness and machine vision algorithms (Andronie et al., 2021; Glogovețan et al., 2022; Nica et al., 2023), and sensor and actuator devices, that is an emerging topic involving much interest. Our research problem is whether motion capture, computer vision, and real-time 3D rendering technologies, image generation and artificial intelligence-powered decision support tools (Krizanova et al., 2019; Lăzăroiu, 2018; Popescu et al., 2017a), and geospatial modeling and simulation devices (Andronie et al., 2023; Lewkowich, 2022; Rowland, 2022) are instrumental in immersive interconnected virtual worlds.

In this review, prior findings have been cumulated indicating that bio-inspired artificial intelligence and visual analytics systems, spatial data mining and image processing computational algorithms (Balica and Cuțitoi, 2022; Nica, 2017; Popescu et al., 2017b; Vinerean et al., 2022), and virtual navigation and simulation modeling tools configure 3D immersive environments. The identified gaps advance big geospatial data and user journey analytics, metaverse assets and services, and cyber-physical cognitive and immersive visualization systems. Our main objective is to indicate that immersive digital worlds require computer vision and cognitive decision-making algorithms, deep learning-based sensing and spatial computing technologies (Dabija et al., 2023; Nica, 2018; Popescu, 2018; Valaskova et al., 2022), and virtual navigation and data mining tools.

2. Theoretical Overview of the Main Concepts

Immersive visual analytics harnesses predictive geospatial modeling and immersive decentralized networking tools, environment perception and virtual twin technologies, and deep learning and visual object tracking algorithms. Interactive digital worlds integrate visual perception and simulation modeling tools, immersive 3D and digital twin technologies, and geolocation data mining and tracking. The manuscript is organized as following: theoretical overview (section 2), methodology (section 3), distributed autonomous control and immersive visualization systems, spatial cognition and object perception algorithms, and machine learning-based image recognition and smart environment modeling tools in the virtual economy of the metaverse (section 4), 3D object recognition and immersive metaverse technologies, visual perception and simulation modeling tools, and geolocation data mining and tracking in extended reality environments (section 5), digital twin and image-based visual computing technologies, geospatial modeling and simulation devices, and voice and gesture recognition tools on blockchain-based metaverse platforms (section 6), discussion (section 7), synopsis of the main research outcomes (section 8), conclusions (section 9), limitations, implications, and further directions of research (section 10).

3. Methodology

Throughout December 2022, we performed a quantitative literature review of the Web of Science, Scopus, and ProQuest databases, with search terms including "the metaverse economy" + "remote sensing data fusion techniques," "multimodal behavioral predictive and mobile location analytics," and "spatial cognition and context awareness algorithms." As we inspected research published between 2022 and 2023, only 179 articles satisfied the eligibility criteria. By removing controversial findings, outcomes unsubstantiated by replication, too imprecise material, or having similar titles, we decided upon 36, generally empirical, sources (Tables 1 and 2). Data visualization tools: Dimensions (bibliometric mapping) and VOSviewer (layout algorithms). Reporting quality assessment tool: PRISMA. Methodological quality assessment tools include: AXIS, Dedoose, MMAT, and SRDR (Figures 1–6).

Table 1 Topics and types of scientific products identified and selected.

Topic	**Identified**	**Selected**
the metaverse economy + remote sensing data fusion techniques	62	13
the metaverse economy + multimodal behavioral predictive and mobile location analytics	59	12
the metaverse economy + spatial cognition and context awareness algorithms	58	11
Type of paper		
Original research	147	24
Review	21	12
Conference proceedings	10	0
Book	0	0
Editorial	1	0

Source: Processed by the authors. Some topics overlap.

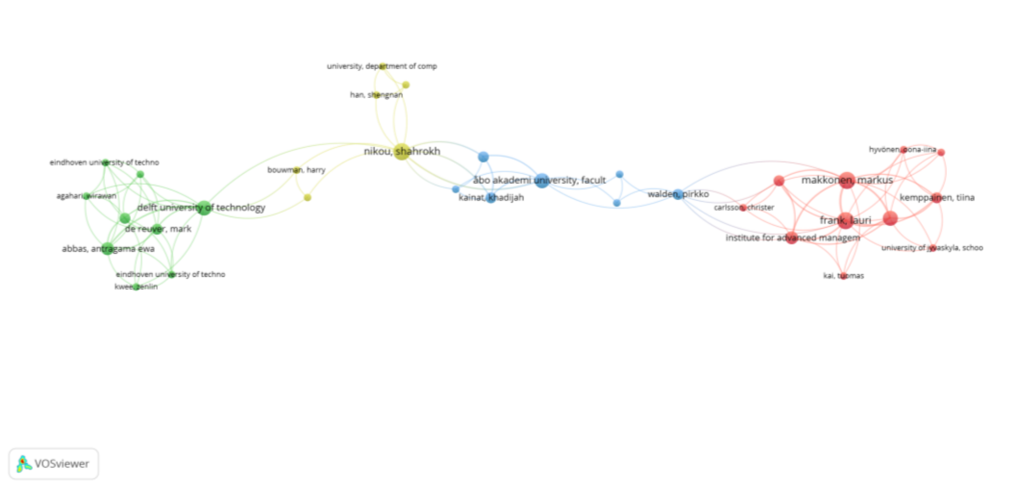

Figure 1 Co-authorship

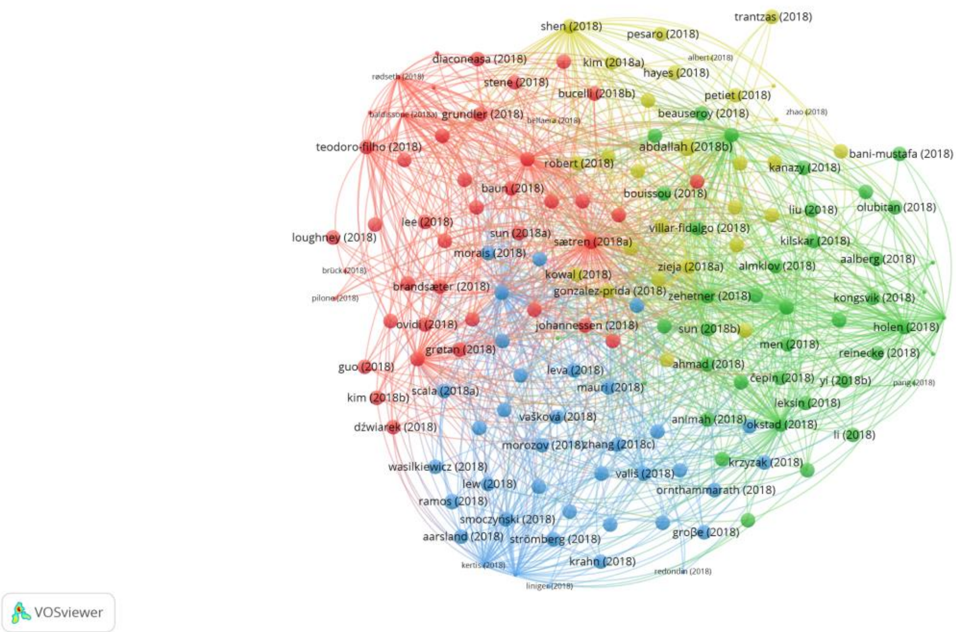

Figure 2 Citation

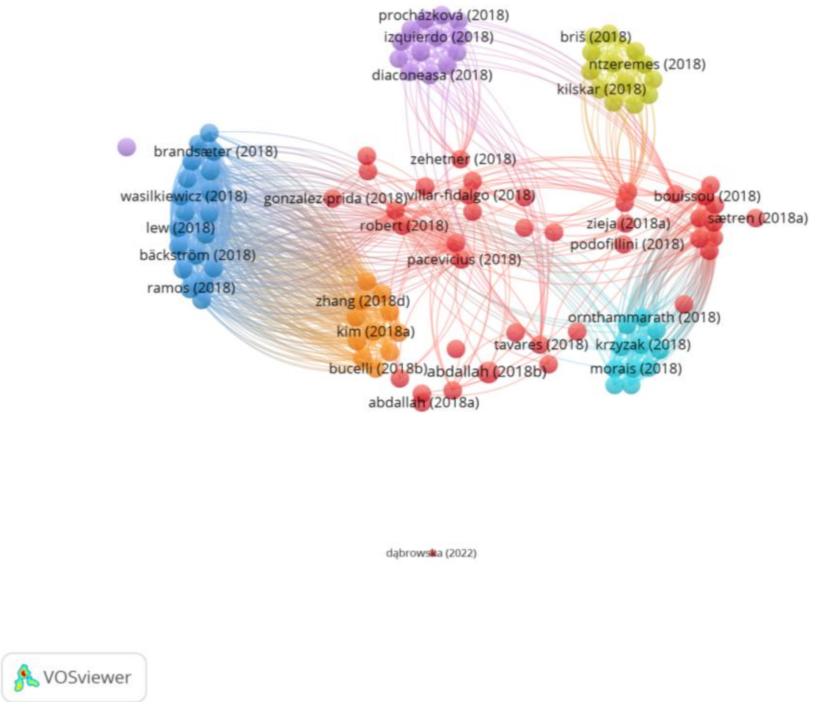

Figure 3 Bibliographic coupling

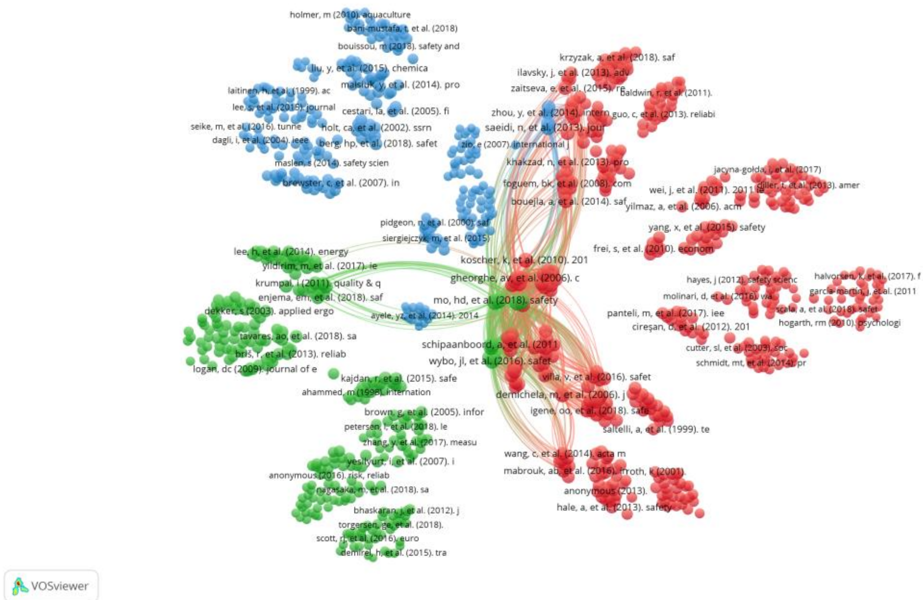

Figure 4 Co-citation

Table 2 General synopsis of evidence as regards focus topics and descriptive outcomes (research findings).

Big geospatial data and user journey analytics, metaverse assets and services, and cyber-physical cognitive and immersive visualization systems assist extended reality environments.	Adams, 2022; Hadi et al., 2023; Venugopal et al., 2023; Zhao et al., 2022
The virtual economy of the metaverse develop on Internet of Things sensing infrastructures, distributed autonomous control and immersive visualization systems, and machine learning-based image recognition and smart environment modeling tools.	Balica, 2022; Hollensen et al., 2023; Wang et al., 2022; Yoo et al., 2023
Spatial cognition and object perception algorithms, sensing and computing technologies, and text mining and analytics configure interactive virtual and extended reality environments. 3D computer vision and digital twinning technologies, decision intelligence and modelling tools, and geolocation data mining and tracking enable synthetic simulation environments.	Hennig-Thurau et al., 2022; Oh et al., 2023; Ramadan, 2023; Tang et al., 2023
Metaverse and immersive technologies, digital twin simulation and virtual navigation tools, and distributed sensor and deep convolutional neural networks further decentralized 3D digital worlds.	Cheng et al., 2022; Huynh-The et al., 2023; Zarantonello and Schmitt, 2023; Zhang et al., 2022
Big data computing and artificial neural network-based decision support systems, 3D object recognition and immersive metaverse technologies, and virtual and augmented reality tools assist mobile edge computing environments.	Golf-Papez et al., 2022; Hancock, 2022; Kozinets, 2023; Lv et al., 2022a
Decision support and deep reinforcement learning tools, cognitive enhancement and digital contact tracing technologies, and crowd navigation and visual cognitive algorithms articulate extended reality environments.	Dincelli and Yayla, 2022; Kliestik et al., 2023; McStay, 2022; Zyda, 2022
3D computational modeling and semantic sensor technologies, spatial data mapping and digital twin simulation tools, and deep learning computer vision and 3D image processing algorithms shape blockchain-based metaverse platforms.	Dawson, 2022; Meng et al., 2023; Shi et al., 2023; Van Huynh et al., 2022
3D metaverse experiences can be attained by use of 3D image and synthesis generation, voice and gesture recognition tools, and haptic and biometric sensor technologies.	Bordegoni and Ferrise, 2023; Lv et al., 2022b; Polas et al., 2022; Zabel et al., 2023
Virtual modeling and immersive 3D technologies, context awareness and machine vision algorithms, and sensor and actuator devices enable spatial virtual reality environments.	Du et al., 2023; Nagendran et al., 2022; Weking et al., 2023; Zhang et al., 2023

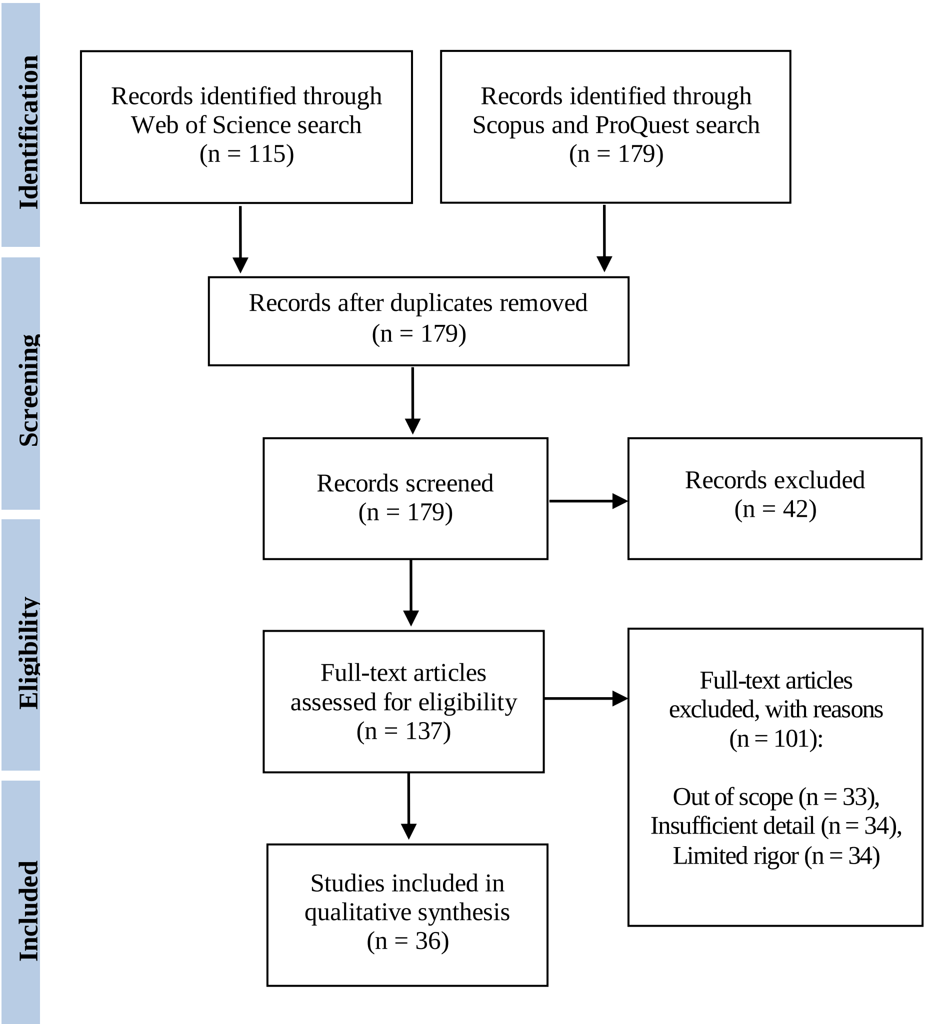

Figure 5 PRISMA flow diagram describing the search results and screening.

Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines were used that ensure the literature review is comprehensive, transparent, and replicable. The flow diagram, produced by employing a Shiny app, presents the stream of evidence-based collected and processed data through the various steps of a systematic review, designing the amount of identified, included, and removed records, and the justifications for exclusions.

To ensure compliance with PRISMA guidelines, a citation software was used, and at each stage the inclusion or exclusion of articles was tracked by use of custom spreadsheet. Justification for the removal of ineligible articles was specified during the full-text screening and final selection.

To ensure first-rate standard of evidence, a systematic search of relevant databases including peer-reviewed published journal articles was conducted using predefined search terms, covering a range of research methods and data sources. Reference lists of all relevant sources were manually reviewed for additional relevant citations.

Titles of papers and abstracts were screened for suitability and selected full texts were retrieved to establish whether they satisfied the inclusion criteria. All records from each database were evaluated by using data extraction forms. Data covering research aims, participants, study design, and method of each paper were extracted.

The inclusion criteria were: (i) articles included in the Web of Science, Scopus, and ProQuest databases, (ii) publication date (2022–2023), (iii) written in English, (iv) being an original empirical research or review article, and (v) particular search terms covered; (i) conference proceedings, (ii) books, and (iii) editorial materials were eliminated from the analysis.

SRDR gathered, handled, and analyzed the data for the systematic review, being configured as an archive and tool harnessed in data extraction through transparent, efficient, and reliable quantitative techniques. Elaborate extraction forms can be set up, meeting the needs of research questions and study designs.

Distiller SR screened and extracted the collected data.

AMSTAR evaluated the methodological quality of systematic reviews.

The quality of academic articles was determined and risk of bias was measured by MMAT, that tested content validity and usability of selected studies in terms of screening questions, type of design, corresponding quality criteria, and overall quality score.

ROBIS assessed the risk of bias in systematic reviews.

AXIS evaluated the quality of cross-sectional studies.

Dedoose analyzed qualitative and mixed methods research.

Figure 6 Screening and quality assessment tools

4. Distributed Autonomous Control and Immersive Visualization Systems, Spatial Cognition and Object Perception Algorithms, and Machine Learning-based Image Recognition and Smart Environment Modeling Tools in the Virtual Economy of the Metaverse

Big geospatial data and user journey analytics, metaverse assets and services, and cyber-physical cognitive and immersive visualization systems (Adams, 2022; Hadi et al., 2023; Venugopal et al., 2023; Zhao et al., 2022) assist extended reality environments. Data stream clustering and visual object tracking algorithms, remote sensing and cognitive enhancement technologies, and behavioral simulation and distributed intelligence tools further digital hyper-realistic worlds.

The virtual economy of the metaverse (Balica, 2022; Hollensen et al., 2023; Wang et al., 2022; Yoo et al., 2023) develop on Internet of Things sensing infrastructures, distributed autonomous control and immersive visualization systems, and machine learning-based image recognition and smart environment modeling tools. Visual and spatial intelligence tools, 3D modeling and simulation technologies, and Internet of Things sensing infrastructures optimize blockchain-based virtual worlds.

Spatial cognition and object perception algorithms, sensing and computing technologies, and text mining and analytics (Hennig-Thurau et al., 2022; Oh et al., 2023; Ramadan, 2023; Tang et al., 2023) configure interactive virtual and extended reality environments. Immersive visual analytics harnesses predictive geospatial modeling and immersive decentralized networking tools, environment perception and virtual twin technologies, and deep learning and visual object tracking algorithms. 3D computer vision and digital twinning technologies, decision intelligence and modelling tools, and geolocation data mining and tracking enable synthetic simulation environments. (Table 3)

Table 3 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Big geospatial data and user journey analytics, metaverse assets and services, and cyber-physical cognitive and immersive visualization systems assist extended reality environments.	Adams, 2022; Hadi et al., 2023; Venugopal et al., 2023; Zhao et al., 2022
The virtual economy of the metaverse develop on Internet of Things sensing infrastructures, distributed autonomous control and immersive visualization systems, and machine learning-based image recognition and smart environment modeling tools.	Balica, 2022; Hollensen et al., 2023; Wang et al., 2022; Yoo et al., 2023
Spatial cognition and object perception algorithms, sensing and computing technologies, and text mining and analytics configure interactive virtual and extended reality environments.	Hennig-Thurau et al., 2022; Oh et al., 2023; Ramadan, 2023; Tang et al., 2023

5. 3D Object Recognition and Immersive Metaverse Technologies, Visual Perception and Simulation Modeling Tools, and Geolocation Data Mining and Tracking in Extended Reality Environments

Metaverse and immersive technologies, digital twin simulation and virtual navigation tools, and distributed sensor and deep convolutional neural networks (Cheng et al., 2022; Huynh-The et al., 2023; Zarantonello and Schmitt, 2023; Zhang et al., 2022) further decentralized 3D digital worlds. Interactive digital worlds integrate visual perception and simulation modeling tools, immersive 3D and digital twin technologies, and geolocation data mining and tracking. Real-time Internet of Things data, hyper-realistic immersive 3D simulations, and digital twin modeling and ambient scene detection tools shape the digital asset-based virtual economy.

Big data computing and artificial neural network-based decision support systems, 3D object recognition and immersive metaverse technologies, and virtual and augmented reality tools (Golf-Papez et al., 2022; Hancock, 2022; Kozinets, 2023; Lv et al., 2022a) assist mobile edge computing environments. Immersive digital worlds require computer vision and cognitive decision-making algorithms, deep learning-based sensing and spatial computing technologies, and virtual navigation and data mining tools.

Decision support and deep reinforcement learning tools, cognitive enhancement and digital contact tracing technologies, and crowd navigation and visual cognitive algorithms (Dincelli and Yayla, 2022; Kliestik et al., 2023; McStay, 2022; Zyda, 2022) articulate extended reality environments. Immersive 3D and interactive digital worlds necessitate sensor-based modeling and interactive 3D geo-visualization systems, location intelligence data, and computer vision and augmented intelligence technologies. (Table 4)

Table 4 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Metaverse and immersive technologies, digital twin simulation and virtual navigation tools, and distributed sensor and deep convolutional neural networks further decentralized 3D digital worlds.	Cheng et al., 2022; Huynh-The et al., 2023; Zarantonello and Schmitt, 2023; Zhang et al., 2022
Big data computing and artificial neural network-based decision support systems, 3D object recognition and immersive metaverse technologies, and virtual and augmented reality tools assist mobile edge computing environments.	Golf-Papez et al., 2022; Hancock, 2022; Kozinets, 2023; Lv et al., 2022a
Decision support and deep reinforcement learning tools, cognitive enhancement and digital contact tracing technologies, and crowd navigation and visual cognitive algorithms articulate extended reality environments.	Dincelli and Yayla, 2022; Kliestik et al., 2023; McStay, 2022; Zyda, 2022

6. Digital Twin and Image-based Visual Computing Technologies, Geospatial Modeling and Simulation Devices, and Voice and Gesture Recognition Tools on Blockchain-based Metaverse platforms

3D computational modeling and semantic sensor technologies, spatial data mapping and digital twin simulation tools, and deep learning computer vision and 3D image processing algorithms (Dawson, 2022; Meng et al., 2023; Shi et al., 2023; Van Huynh et al., 2022) shape blockchain-based metaverse platforms. Artificial vision and sensor-based data acquisition systems, digital twin and image-based visual computing technologies, and 3D modeling and predictive algorithmic tools are pivotal in immersive virtual environments and hyper-realistic digital worlds.

3D metaverse experiences (Bordegoni and Ferrise, 2023; Lv et al., 2022b; Polas et al., 2022; Zabel et al., 2023) can be attained by use of 3D image and synthesis generation, voice and gesture recognition tools, and haptic and biometric sensor technologies. Motion capture, computer vision, and real-time 3D rendering technologies, image generation and artificial intelligence-powered decision support tools, and geospatial modeling and simulation devices are instrumental in immersive interconnected virtual worlds.

Virtual modeling and immersive 3D technologies, context awareness and machine vision algorithms, and sensor and actuator devices (Du et al., 2023; Nagendran et al., 2022; Weking et al., 2023; Zhang et al., 2023) enable spatial virtual reality environments. Bioinspired artificial intelligence and visual analytics systems, spatial data mining and image processing computational algorithms, and virtual navigation and simulation modeling tools configure 3D immersive environments. Synthetic artificial intelligence and 3D holographic virtual images, computational modeling and simulation tools, and Internet of Things digital twins optimize augmented reality-powered immersive spaces. (Table 5)

Table 5 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

3D computational modeling and semantic sensor technologies, spatial data mapping and digital twin simulation tools, and deep learning computer vision and 3D image processing algorithms shape blockchain-based metaverse platforms.	Dawson, 2022; Meng et al., 2023; Shi et al., 2023; Van Huynh et al., 2022
3D metaverse experiences can be attained by use of 3D image and synthesis generation, voice and gesture recognition tools, and haptic and biometric sensor technologies.	Bordegoni and Ferrise, 2023; Lv et al., 2022b; Polas et al., 2022; Zabel et al., 2023
Virtual modeling and immersive 3D technologies, context awareness and machine vision algorithms, and sensor and actuator devices enable spatial virtual reality environments.	Du et al., 2023; Nagendran et al., 2022; Weking et al., 2023; Zhang et al., 2023

7. Discussion

We integrate our systematic review throughout research indicating how visual and spatial intelligence tools, 3D modeling and simulation technologies, and Internet of Things sensing infrastructures optimize blockchain-based virtual worlds. Our research complements recent analyses clarifying how data stream clustering and visual object tracking algorithms, remote sensing and cognitive enhancement technologies, and behavioral simulation and distributed intelligence tools further digital hyper-realistic worlds. We elucidate, by cumulative evidence, previous research demonstrating how artificial vision and sensor-based data acquisition systems, digital twin and image-based visual computing technologies, and 3D modeling and predictive algorithmic tools are pivotal in immersive virtual environments and hyper-realistic digital worlds.

8. Synopsis of the Main Research Outcomes

Immersive digital worlds require computer vision and cognitive decision-making algorithms, deep learning-based sensing and spatial computing technologies, and virtual navigation and data mining tools. Immersive 3D and interactive digital worlds necessitate sensor-based modeling and interactive 3D geo-visualization systems, location intelligence data, and computer vision and augmented intelligence technologies.

9. Conclusions

Relevant research has investigated whether bioinspired artificial intelligence and visual analytics systems, spatial data mining and image processing computational algorithms, and virtual navigation and simulation modeling tools configure 3D immersive environments. This systematic literature review presents the published peer-reviewed sources covering how synthetic artificial intelligence and 3D holographic virtual images, computational modeling and simulation tools, and Internet of Things digital twins optimize augmented reality-powered immersive spaces. The research outcomes drawn from the above analyses indicate that 3D computer vision and digital twinning technologies, decision intelligence and modelling tools, and geolocation data mining and tracking enable synthetic simulation environments.

10. Limitations, Implications, and Further Directions of Research

By analyzing only articles published between 2022 and 2023 in journals indexed in the Web of Science, Scopus, and ProQuest databases, relevant sources on remote sensing data fusion techniques, multimodal behavioral predictive and mobile location analytics, and spatial cognition and context awareness algorithms in the metaverse economy may have been excluded. Limitations of this research comprise particular kinds of publications (original empirical research and review articles) discounting others (conference proceedings articles, books, and editorial materials). The scope of our study also does not move forward the inspection of 3D computational modeling and semantic sensor technologies, spatial data mapping and digital twin simulation tools, and deep learning computer vision and 3D image processing algorithms.

Subsequent analyses should develop on 3D image and synthesis generation, voice and gesture recognition tools, and haptic and biometric sensor technologies. Future research should thus investigate decision support and deep reinforcement learning tools, cognitive enhancement and digital contact tracing technologies, and crowd navigation and visual cognitive algorithms. Attention should be directed to metaverse and immersive technologies, digital twin simulation and virtual navigation tools, and distributed sensor and deep convolutional neural networks.

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Compliance with ethical standards
This article does not contain any studies with human participants or animals performed by the authors. Extracting and inspecting publicly accessible files (scholarly sources) as evidence, before the research began no institutional ethics approval was required.

Data availability statement
All data generated or analyzed are included in the published article.

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Extended Reality-based Metaverse Technologies, Predictive Geospatial Modeling and Simulation Tools, and Image Processing Computational and Visual Cognitive Algorithms in Immersive Multisensory Virtual Spaces

Sofia Bratu*

ABSTRACT. The objective of this paper is to systematically review extended reality-based metaverse technologies, predictive geospatial modeling and simulation tools, and image processing computational and visual cognitive algorithms. The findings and analyses highlight that virtual reality-based immersive experiences can be attained by use of wearable haptic garments, haptic and sensory technologies, and movement and behavior tracking tools. Throughout January 2023, a quantitative literature review of the Web of Science, Scopus, and ProQuest databases was performed, with search terms including "immersive multisensory virtual spaces" + "extended reality-based metaverse technologies," "predictive geospatial modeling and simulation tools," and "image processing computational and visual cognitive algorithms." As research published between 2022 and 2023 was inspected, only 172 articles satisfied the eligibility criteria. By taking out controversial or ambiguous findings (insufficient/irrelevant data), outcomes unsubstantiated by replication, too general material, or studies with nearly identical titles, I selected 33 mainly empirical sources. Data visualization tools: Dimensions (bibliometric mapping) and VOSviewer (layout algorithms). Reporting quality assessment tool: PRISMA. Methodological quality assessment tools include: AMSTAR, Dedoose, Distiller SR, and SRDR.

Keywords: extended reality-based metaverse technologies; predictive geospatial modeling and simulation tools; image processing computational and visual cognitive algorithms

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1. Introduction

Immersive virtual reality experiences can be achieved through photorealistic synthetic images and data, sensorial and cognitive technologies, and motion planning and brain-inspired artificial intelligence algorithms. The purpose of my systematic review is to examine the recently published literature on immersive multisensory virtual spaces and integrate the insights it configures on extended reality-based metaverse technologies, predictive geospatial modeling and simulation tools, and image processing computational and visual cognitive algorithms. By analyzing the most recent (2022–2023) and significant (Web of Science, Scopus, and ProQuest) sources, my paper has attempted to prove that decentralized 3D virtual spaces require visual and spatial intelligence tools, computer vision and cognitive artificial intelligence algorithms (Andronie et al., 2023; Lăzăroiu et al., 2017; Nica, 2018), and immersive and extended reality technologies. The actuality and novelty of this study are articulated by addressing immersive hyper-connected virtual spaces and the decentralized metaverse, that is an emerging topic involving much interest. My research problem is whether photorealistic 3D environments integrate virtual navigation and image recognition tools (Balcerzak et al., 2022; Lăzăroiu et al., 2022a; Nica et al., 2023), remote sensing and environment mapping algorithms, and eye-tracking and user identification technologies.

In this review, prior findings have been cumulated indicating that predictive modeling and socio-spatial analytics tools (Cegarra Navarro et al., 2023; Lăzăroiu et al., 2022b; Popescu et al., 2017a), data fusion and dynamic routing technologies, and human digital twin and network virtualization systems optimize the blockchain-based virtual economy. The identified gaps advance spatial computing and digital twinning technologies (Dabija et al., 2022; Lewkowich, 2022; Popescu et al., 2017b; Vătămănescu et al., 2020), simulation modeling and virtual reality-based data analytics tools (Kliestik et al., 2020; Morley, 2022a; Popescu, 2018; Watson, 2022), and metaverse engagement metrics. My main objective is to indicate that virtual reality-based immersive experiences can be attained by use of wearable haptic garments, haptic and sensory technologies, and movement and behavior tracking tools.

2. Theoretical Overview of the Main Concepts

Extended reality environments develop on intelligent connectivity infrastructures, 3D virtual environment mapping and digital twin modeling tools, and spatio-temporal fusion and deep learning algorithms. Hyperconnected virtual experiences can be achieved by use of ambient sound and voice recognition software, eye-tracking and affective computing technologies, and biometrics data fusion. The manuscript is organized as following: theoretical overview (section 2), methodology (section 3), digital twin simulation and data modeling tools, ambient sound and voice recognition software, and deep learning-based sensing and 3D virtual immersive technologies in the decentralized and interconnected metaverse (section 4), metaverse engagement metrics, spatial computing and digital twinning technologies, and motion planning and brain-inspired artificial intelligence algorithms in immersive multisensory virtual spaces (section 5), multimodal sensing and big data computing systems, spatio-temporal fusion and deep learning algorithms, and virtual navigation and image recognition tools in blockchain-based metaverse and immersive 3D environments (section 6), discussion (section 7), synopsis of the main research outcomes (section 8), conclusions (section 9), limitations, implications, and further directions of research (section 10).

3. Methodology

Throughout January 2023, a quantitative literature review of the Web of Science, Scopus, and ProQuest databases was performed, with search terms including "immersive multisensory virtual spaces" + "extended reality-based metaverse technologies," "predictive geospatial modeling and simulation tools," and "image processing computational and visual cognitive algorithms." As research published between 2022 and 2023 was inspected, only 172 articles satisfied the eligibility criteria. By taking out controversial or ambiguous findings (insufficient/irrelevant data), outcomes unsubstantiated by replication, too general material, or studies with nearly identical titles, I selected 33 mainly empirical sources (Tables 1 and 2). Data visualization tools: Dimensions (bibliometric mapping) and VOSviewer (layout algorithms). Reporting quality assessment tool: PRISMA. Methodological quality assessment tools include: AMSTAR, Dedoose, Distiller SR, and SRDR (Figures 1–6).

Table 1 Topics and types of scientific products identified and selected.

Topic	**Identified**	**Selected**
immersive multisensory virtual spaces + extended reality-based metaverse technologies	60	12
immersive multisensory virtual spaces + predictive geospatial modeling and simulation tools	58	11
immersive multisensory virtual spaces + image processing computational and visual cognitive algorithms	54	10
Type of paper		
Original research	142	22
Review	20	11
Conference proceedings	9	0
Book	0	0
Editorial	1	0

Source: Processed by the author. Some topics overlap.

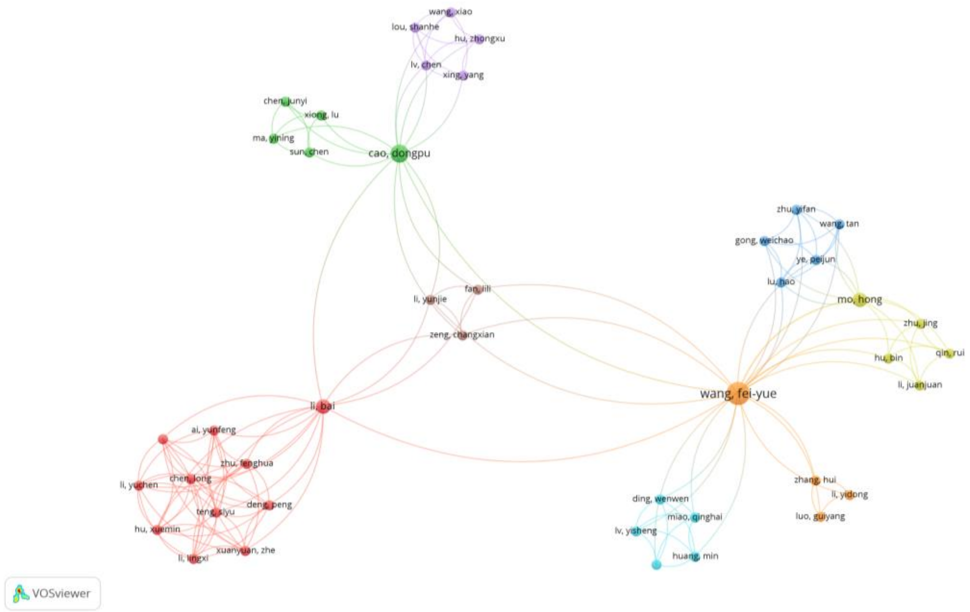

Figure 1 Co-authorship

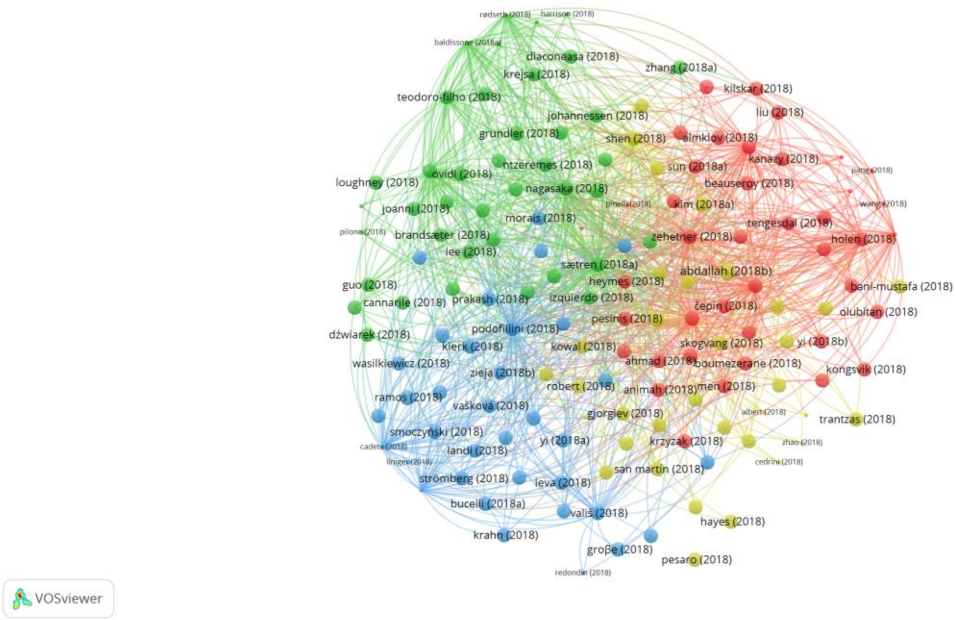

Figure 2 Citation

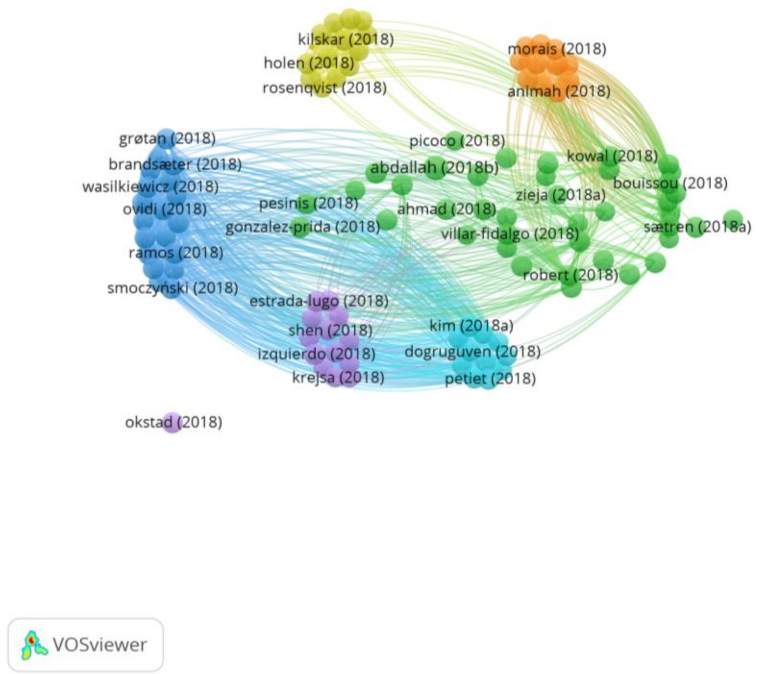

Figure 3 Bibliographic coupling

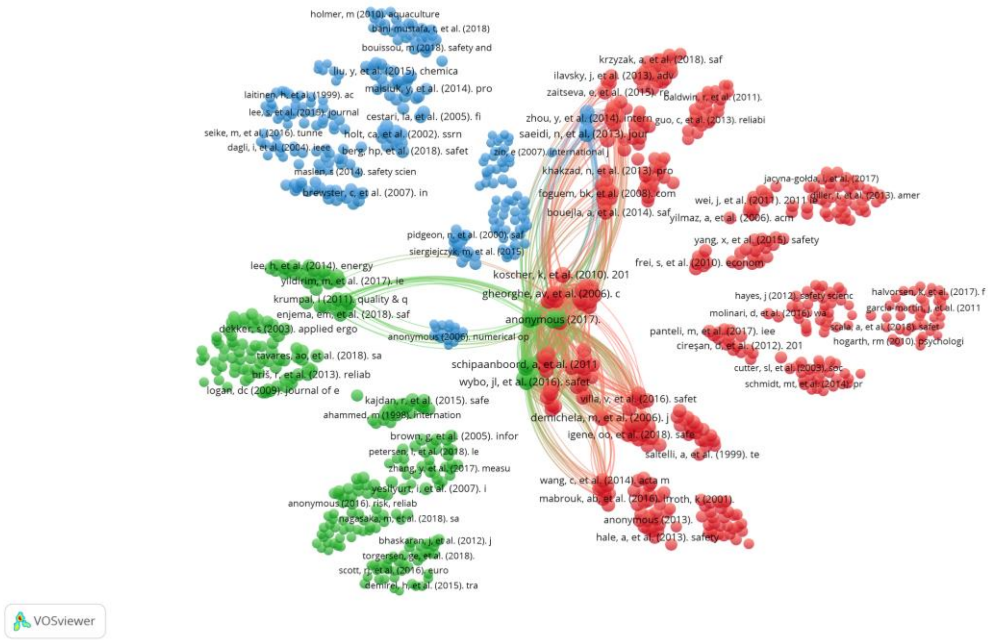

Figure 4 Co-citation

Table 2 General synopsis of evidence as regards focus topics and descriptive outcomes (research findings).

Behavioral predictive and mobile location analytics, distributed decision and control algorithms, and virtual mapping and spatial data visualization tools further the decentralized and interconnected metaverse.	Huang et al., 2023; Rostami and Maier, 2022; Xu et al., 2023a
Deep learning-based sensing and 3D virtual immersive technologies, digital twin simulation and data modeling tools, and location intelligence data assist immersive hyper-connected virtual spaces and the decentralized metaverse.	Dolata and Schwabe, 2023; Morley, 2022b; Tang et al., 2023; Xu et al., 2023b
Real-time and behavioral predictive analytics, perception and planning algorithms, and virtual navigation and geospatial mapping tools configure immersive 3D virtual environments.	Beckett, 2022; Giang Barrera and Shah, 2023; Han et al., 2022; Zhang et al., 2022
The decentralized metaverse necessitate 3D virtual environment mapping and simulation modeling tools, virtual mapping and deep learning-based image processing algorithms, and machine perception and ambient intelligence technologies.	Daneshfar and Jamshidi, 2023; Mircică, 2022; Queiroz et al., 2023; Van Huynh et al., 2022
Spatial computing and digital twinning technologies, simulation modeling and virtual reality-based data analytics tools, and metaverse engagement metrics enable extended reality environments.	Gauttier et al., 2022; Lv et al., 2022; Yoo et al., 2023)
Data stream clustering and spatio-temporal fusion algorithms, 3D modeling and automated speech recognition tools, and monitoring and sensing technologies articulate immersive multisensory virtual spaces.	Braud et al., 2022; Shen, 2022; Zallio and Clarkson, 2022
Immersive visualization and explainable artificial intelligence-based decision support systems, wearable scent and cloud-based cognitive technologies, and digital twin simulation and visual imagery tools articulate the blockchain-based metaverse and immersive 3D environments.	Bojic, 2022; Faraboschi et al., 2022; Li et al., 2023; Zarantonello and Schmitt, 2023
Multimodal sensing and big data computing systems, deep learning-based ambient sound processing, and Internet of Things digital twins optimize the interconnected metaverse and photorealistic synthetic environments.	Aloqaily et al., 2022; Chen, 2022; Panagiotakopoulos et al., 2022; Xian et al., 2023
Geospatial big data and real-time predictive analytics, conversational artificial intelligence and deep learning forecasting algorithms, and data visualization and virtual twin modeling tools assist extended reality environments.	Ahn et al., 2023; Ding et al., 2022; Popescu et al., 2022; Smart, 2022

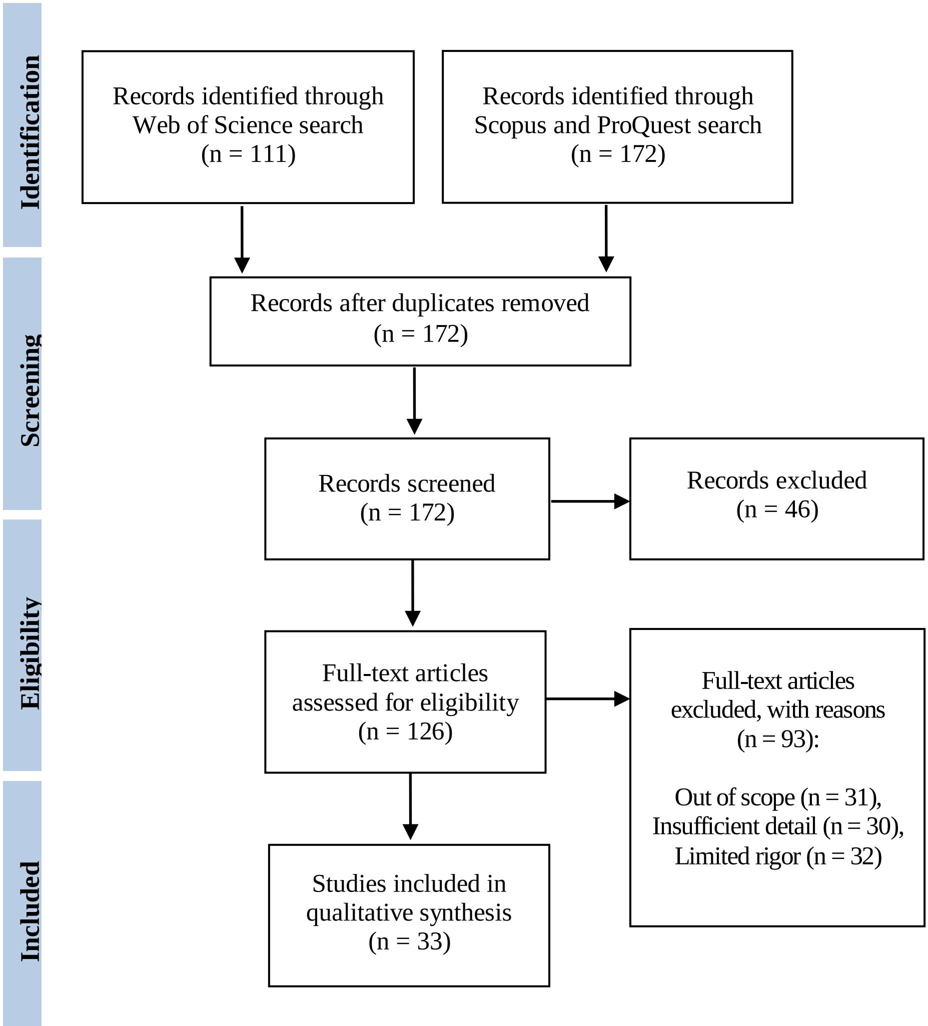

Figure 5 PRISMA flow diagram describing the search results and screening.

Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines were used that ensure the literature review is comprehensive, transparent, and replicable. The flow diagram, produced by employing a Shiny app, presents the stream of evidence-based collected and processed data through the various steps of a systematic review, designing the amount of identified, included, and removed records, and the justifications for exclusions.
To ensure compliance with PRISMA guidelines, a citation software was used, and at each stage the inclusion or exclusion of articles was tracked by use of custom spreadsheet. Justification for the removal of ineligible articles was specified during the full-text screening and final selection.

To ensure first-rate standard of evidence, a systematic search of relevant databases including peer-reviewed published journal articles was conducted using predefined search terms, covering a range of research methods and data sources. Reference lists of all relevant sources were manually reviewed for additional relevant citations.

Titles of papers and abstracts were screened for suitability and selected full texts were retrieved to establish whether they satisfied the inclusion criteria. All records from each database were evaluated by using data extraction forms. Data covering research aims, participants, study design, and method of each paper were extracted.

The inclusion criteria were: (i) articles included in the Web of Science, Scopus, and ProQuest databases, (ii) publication date (2022–2023), (iii) written in English, (iv) being an original empirical research or review article, and (v) particular search terms covered; (i) conference proceedings, (ii) books, and (iii) editorial materials were eliminated from the analysis.

SRDR gathered, handled, and analyzed the data for the systematic review, being configured as an archive and tool harnessed in data extraction through transparent, efficient, and reliable quantitative techniques. Elaborate extraction forms can be set up, meeting the needs of research questions and study designs.

Distiller SR screened and extracted the collected data.

The quality of academic articles was determined and risk of bias was measured by MMAT, that tested content validity and usability of selected studies in terms of screening questions, type of design, corresponding quality criteria, and overall quality score.

ROBIS assessed the risk of bias in systematic reviews.

Dedoose analyzed qualitative and mixed methods research.

AXIS evaluated the quality of cross-sectional studies.

AMSTAR evaluated the methodological quality of systematic reviews.

Figure 6 Screening and quality assessment tools

4. Digital Twin Simulation and Data Modeling Tools, Ambient Sound and Voice Recognition Software, and Deep Learning-based Sensing and 3D Virtual Immersive Technologies in the Decentralized and Interconnected Metaverse

Behavioral predictive and mobile location analytics, distributed decision and control algorithms, and virtual mapping and spatial data visualization tools (Huang et al., 2023; Rostami and Maier, 2022; Xu et al., 2023a) further the decentralized and interconnected metaverse. Edge computing and real-time 3D rendering technologies, data acquisition and image recognition tools, computer vision and deep learning forecasting algorithms enable 3D immersive environments. Decentralized 3D virtual spaces require visual and spatial intelligence tools, computer vision and cognitive artificial intelligence algorithms, and immersive and extended reality technologies.

Deep learning-based sensing and 3D virtual immersive technologies, digital twin simulation and data modeling tools, and location intelligence data (Dolata and Schwabe, 2023; Morley, 2022b; Tang et al., 2023; Xu et al., 2023b) assist immersive hyper-connected virtual spaces and the decentralized metaverse. Immersive virtual experiences can be attained through environment perception sensors, bio-inspired artificial vision and automated speech recognition systems, and user behavior data mining.

Real-time and behavioral predictive analytics, perception and planning algorithms, and virtual navigation and geospatial mapping tools (Beckett, 2022; Giang Barrera and Shah, 2023; Han et al., 2022; Zhang et al., 2022) configure immersive 3D virtual environments. Hyperconnected virtual experiences can be achieved by use of ambient sound and voice recognition software, eye-tracking and affective computing technologies, and biometrics data fusion. (Table 3)

Table 3 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Behavioral predictive and mobile location analytics, distributed decision and control algorithms, and virtual mapping and spatial data visualization tools further the decentralized and interconnected metaverse.	Huang et al., 2023; Rostami and Maier, 2022; Xu et al., 2023a
Deep learning-based sensing and 3D virtual immersive technologies, digital twin simulation and data modeling tools, and location intelligence data assist immersive hyper-connected virtual spaces and the decentralized metaverse.	Dolata and Schwabe, 2023; Morley, 2022b; Tang et al., 2023; Xu et al., 2023b
Real-time and behavioral predictive analytics, perception and planning algorithms, and virtual navigation and geospatial mapping tools configure immersive 3D virtual environments.	Beckett, 2022; Giang Barrera and Shah, 2023; Han et al., 2022; Zhang et al., 2022

5. Metaverse Engagement Metrics, Spatial Computing and Digital Twinning Technologies, and Motion Planning and Brain-inspired Artificial Intelligence Algorithms in Immersive Multisensory Virtual Spaces

The decentralized metaverse (Daneshfar and Jamshidi, 2023; Mircică, 2022; Queiroz et al., 2023; Van Huynh et al., 2022) necessitate 3D virtual environment mapping and simulation modeling tools, virtual mapping and deep learning-based image processing algorithms, and machine perception and ambient intelligence technologies. Virtual reality-based immersive experiences can be attained by use of wearable haptic garments, haptic and sensory technologies, and movement and behavior tracking tools.

Spatial computing and digital twinning technologies, simulation modeling and virtual reality-based data analytics tools, and metaverse engagement metrics (Gauttier et al., 2022; Lv et al., 2022; Yoo et al., 2023) enable extended reality environments. Immersive virtual reality experiences can be achieved through photorealistic synthetic images and data, sensorial and cognitive technologies, and motion planning and brain-inspired artificial intelligence algorithms. 3D object recognition and visual immersion technologies, 3D virtual space networking and virtual twin modeling tools, and location intelligence data further immersive and interoperable spaces.

Data stream clustering and spatio-temporal fusion algorithms, 3D modeling and automated speech recognition tools, and monitoring and sensing technologies (Braud et al., 2022; Shen, 2022; Zallio and Clarkson, 2022) articulate immersive multisensory virtual spaces. Modeling and forecasting tools, geospatial mapping and cloud computing technologies, and computer vision and navigation systems shape interconnected virtual worlds and 3D immersive environments. (Table 4)

Table 4 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

The decentralized metaverse necessitate 3D virtual environment mapping and simulation modeling tools, virtual mapping and deep learning-based image processing algorithms, and machine perception and ambient intelligence technologies.	Daneshfar and Jamshidi, 2023; Mircică, 2022; Queiroz et al., 2023; Van Huynh et al., 2022
Spatial computing and digital twinning technologies, simulation modeling and virtual reality-based data analytics tools, and metaverse engagement metrics enable extended reality environments.	Gauttier et al., 2022; Lv et al., 2022; Yoo et al., 2023
Data stream clustering and spatio-temporal fusion algorithms, 3D modeling and automated speech recognition tools, and monitoring and sensing technologies articulate immersive multisensory virtual spaces.	Braud et al., 2022; Shen, 2022; Zallio and Clarkson, 2022

6. Multimodal Sensing and Big Data Computing Systems, Spatio-Temporal Fusion and Deep Learning Algorithms, and Virtual Navigation and Image Recognition Tools in Blockchain-based Metaverse and Immersive 3D Environments

Immersive visualization and explainable artificial intelligence-based decision support systems, wearable scent and cloud-based cognitive technologies, and digital twin simulation and visual imagery tools (Bojic, 2022; Faraboschi et al., 2022; Li et al., 2023; Zarantonello and Schmitt, 2023) articulate the blockchain-based metaverse and immersive 3D environments. Predictive modeling and socio-spatial analytics tools, data fusion and dynamic routing technologies, and human digital twin and network virtualization systems optimize the blockchain-based virtual economy.

Multimodal sensing and big data computing systems, deep learning-based ambient sound processing, and Internet of Things digital twins (Aloqaily et al., 2022; Chen, 2022; Panagiotakopoulos et al., 2022; Xian et al., 2023) optimize the interconnected metaverse and photorealistic synthetic environments. Extended reality environments develop on intelligent connectivity infrastructures, 3D virtual environment mapping and digital twin modeling tools, and spatio-temporal fusion and deep learning algorithms.

Geospatial big data and real-time predictive analytics, conversational artificial intelligence and deep learning forecasting algorithms, and data visualization and virtual twin modeling tools (Ahn et al., 2023; Ding et al., 2022; Popescu et al., 2022; Smart, 2022) assist extended reality environments. Photorealistic 3D environments integrate virtual navigation and image recognition tools, remote sensing and environment mapping algorithms, and eye-tracking and user identification technologies. (Table 5)

Table 5 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Immersive visualization and explainable artificial intelligence-based decision support systems, wearable scent and cloud-based cognitive technologies, and digital twin simulation and visual imagery tools articulate the blockchain-based metaverse and immersive 3D environments.	Bojic, 2022; Faraboschi et al., 2022; Li et al., 2023; Zarantonello and Schmitt, 2023
Multimodal sensing and big data computing systems, deep learning-based ambient sound processing, and Internet of Things digital twins optimize the interconnected metaverse and photorealistic synthetic environments.	Aloqaily et al., 2022; Chen, 2022; Panagiotakopoulos et al., 2022; Xian et al., 2023
Geospatial big data and real-time predictive analytics, conversational artificial intelligence and deep learning forecasting algorithms, and data visualization and virtual twin modeling tools assist extended reality environments.	Ahn et al., 2023; Ding et al., 2022; Popescu et al., 2022; Smart, 2022

7. Discussion

I integrate my systematic review throughout research indicating how virtual reality-based immersive experiences can be attained by use of wearable haptic garments, haptic and sensory technologies, and movement and behavior tracking tools. My research complements recent analyses clarifying how modeling and forecasting tools, geospatial mapping and cloud computing technologies, and computer vision and navigation systems shape interconnected virtual worlds and 3D immersive environments. I elucidate, by cumulative evidence, previous research demonstrating how decentralized 3D virtual spaces require visual and spatial intelligence tools, computer vision and cognitive artificial intelligence algorithms, and immersive and extended reality technologies.

8. Synopsis of the Main Research Outcomes

3D object recognition and visual immersion technologies, 3D virtual space networking and virtual twin modeling tools, and location intelligence data further immersive and interoperable spaces. Edge computing and real-time 3D rendering technologies, data acquisition and image recognition tools, computer vision and deep learning forecasting algorithms enable 3D immersive environments.

9. Conclusions

Relevant research has investigated whether photorealistic 3D environments integrate virtual navigation and image recognition tools, remote sensing and environment mapping algorithms, and eye-tracking and user identification technologies. This systematic literature review presents the published peer-reviewed sources covering how immersive virtual experiences can be attained through environment perception sensors, bio-inspired artificial vision and automated speech recognition systems, and user behavior data mining. The research outcomes drawn from the above analyses indicate that predictive modeling and socio-spatial analytics tools, data fusion and dynamic routing technologies, and human digital twin and network virtualization systems optimize the blockchain-based virtual economy.

10. Limitations, Implications, and Further Directions of Research

By analyzing only articles published between 2022 and 2023 in journals indexed in the Web of Science, Scopus, and ProQuest databases, relevant sources on extended reality-based metaverse technologies, predictive geospatial modeling and simulation tools, and image processing computational and visual cognitive algorithms in immersive multisensory virtual spaces may have been excluded. Limitations of this research comprise particular kinds of publications (original empirical research and review articles) discounting others (conference proceedings articles, books, and editorial materials). The scope of my study also does not move forward the inspection of behavioral predictive and mobile location analytics, distributed decision and control algorithms, and virtual mapping and spatial data visualization tools.

Subsequent analyses should develop on data stream clustering and spatio-temporal fusion algorithms, 3D modeling and automated speech recognition tools, and monitoring and sensing technologies. Future research should thus investigate geospatial big data and real-time predictive analytics, conversational artificial intelligence and deep learning forecasting algorithms, and data visualization and virtual twin modeling tools. Attention should be directed to immersive visualization and explainable artificial intelligence-based decision support systems, wearable scent and cloud-based cognitive technologies, and digital twin simulation and visual imagery tools.

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Compliance with ethical standards

This article does not contain any studies with human participants or animals performed by the author. Extracting and inspecting publicly accessible files (scholarly sources) as evidence, before the research began no institutional ethics approval was required.

Data availability statement

All data generated or analyzed are included in the published article.

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Author contributions

The author confirms being the sole contributor of this work and approved it for publication. The author takes full responsibility for the accuracy and the integrity of the data analysis.

Conflict of interest statement

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Disclosure by the editors of record

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Tracking and Spatial Computing Technologies, Virtual Navigation and Ambient Scene Detection Tools, and Motion Planning and Remote Sensing Algorithms in the Metaverse

Susan Aldridge*

ABSTRACT. In this article, I cumulate previous research findings indicating that 3D digital environments integrate geospatial mapping and digital contact tracing technologies, artificial vision and immersive visualization systems, and machine learning-based recognition and sensor fusion algorithms. I contribute to the literature on artificial vision and Internet of Things-based decision support systems, metaverse and immersive technologies, and spatial computing and simulation modeling algorithms by showing that ambient intelligence and shared virtual environments require user journey and big geospatial data analytics, virtual modeling and digital twin technologies, and image recognition and visual perception algorithms. Throughout December 2022, I performed a quantitative literature review of the Web of Science, Scopus, and ProQuest databases, with search terms including "the metaverse" + "tracking and spatial computing technologies," "virtual navigation and ambient scene detection tools," and "motion planning and remote sensing algorithms." As I inspected research published between 2022 and 2023, only 167 articles satisfied the eligibility criteria. By eliminating controversial findings, outcomes unsubstantiated by replication, too imprecise material, or having similar titles, I decided upon 31, generally empirical, sources. Data visualization tools: Dimensions (bibliometric mapping) and VOSviewer (layout algorithms). Reporting quality assessment tool: PRISMA. Methodological quality assessment tools include: AXIS, Dedoose, ROBIS, and SRDR.

Keywords: tracking and spatial computing technologies; virtual navigation and ambient scene detection tools; motion planning and remote sensing algorithms; metaverse

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1. Introduction

Machine learning-based image recognition and visual attention modeling tools, immersive visualization and extended cognitive systems, and 3D image processing and machine vision algorithms are instrumental in the blockchain-based virtual economy. The purpose of my systematic review is to examine the recently published literature on the metaverse and integrate the insights it configures on tracking and spatial computing technologies, virtual navigation and ambient scene detection tools, and motion planning and remote sensing algorithms. By analyzing the most recent (2022–2023) and significant (Web of Science, Scopus, and ProQuest) sources, my paper has attempted to prove that virtual and augmented reality tools, spatial computing and ontology-based semantic technologies, and deep learning and sensor path planning algorithms optimize immersive digital worlds. The actuality and novelty of this study are articulated by addressing artificial vision and Internet of Things-based decision support systems, metaverse and immersive technologies, and spatial computing and simulation modeling algorithms (Andronie et al., 2023; Kliestik et al., 2020; Novak et al., 2022; Popescu, 2018), that is an emerging topic involving much interest. My research problem is whether 3D digital environments integrate geospatial mapping and digital contact tracing technologies, artificial vision and immersive visualization systems (Balcerzak et al., 2022; Lăzăroiu et al., 2020; Pelau et al., 2021), and machine learning-based recognition and sensor fusion algorithms.

In this review, prior findings have been cumulated indicating that blockchain-based metaverse platforms and the virtual environment of the metaverse necessitate visual imagery and data mining tools (Barbu et al., 2021; Nagy and Lăzăroiu, 2022; Pop et al., 2021), deep generative modeling and text mining techniques, and hyper-realistic immersive 3D simulations. The identified gaps advance sensor-based object recognition and data sharing technologies (Blake, 2022; Nagy et al., 2023; Popescu et al., 2017a), automated speech recognition and geospatial mapping tools, and deep learning and computer vision algorithms. My main objective is to indicate that ambient intelligence and shared virtual environments require user journey and big geospatial data analytics, virtual modeling and digital twin technologies (Jaramillo-Aristizabal, 2022; Nica et al., 2023; Popescu et al., 2017b), and image recognition and visual perception algorithms.

2. Theoretical Overview of the Main Concepts

Immersive interconnected virtual worlds necessitate spatial and sentiment analytics, deep learning-based sensing and immersive 3D technologies, and visual perception and immersive decentralized networking tools. Deep learning and predictive modeling algorithms, data acquisition and virtual navigation tools, and sensing and computing technologies further immersive photorealistic virtual spaces. The manuscript is organized as following: theoretical overview (section 2), methodology (section 3), deep learning and predictive modeling algorithms, spatial computing and ontology-based semantic technologies, and data acquisition and virtual navigation tools in the metaverse interactive environment (section 4), machine learning-based recognition and sensor fusion algorithms, socially-extended cognition and empathetic computing systems, and digital twin simulation and data visualization tools on blockchain-based metaverse platforms (section 5), metaverse and immersive technologies, 3D image processing and machine vision algorithms, and remote sensing and distributed autonomous control systems in the blockchain-based virtual economy (section 6), discussion (section 7), synopsis of the main research outcomes (section 8), conclusions (section 9), limitations, implications, and further directions of research (section 10).

3. Methodology

Throughout December 2022, I performed a quantitative literature review of the Web of Science, Scopus, and ProQuest databases, with search terms including "the metaverse" + "tracking and spatial computing technologies," "virtual navigation and ambient scene detection tools," and "motion planning and remote sensing algorithms." As I inspected research published between 2022 and 2023, only 167 articles satisfied the eligibility criteria. By eliminating controversial findings, outcomes unsubstantiated by replication, too imprecise material, or having similar titles, I decided upon 31, generally empirical, sources (Tables 1 and 2). Data visualization tools: Dimensions (bibliometric mapping) and VOSviewer (layout algorithms). Reporting quality assessment tool: PRISMA. Methodological quality assessment tools include: AXIS, Dedoose, ROBIS, and SRDR (Figures 1–6).

Table 1 Topics and types of scientific products identified and selected.

Topic	**Identified**	**Selected**
the metaverse + tracking and spatial computing technologies	58	11
the metaverse + virtual navigation and ambient scene detection tools	56	10
the metaverse + motion planning and remote sensing algorithms	53	10
Type of paper		
Original research	139	22
Review	19	9
Conference proceedings	8	0
Book	0	0
Editorial	1	0

Source: Processed by the author. Some topics overlap.

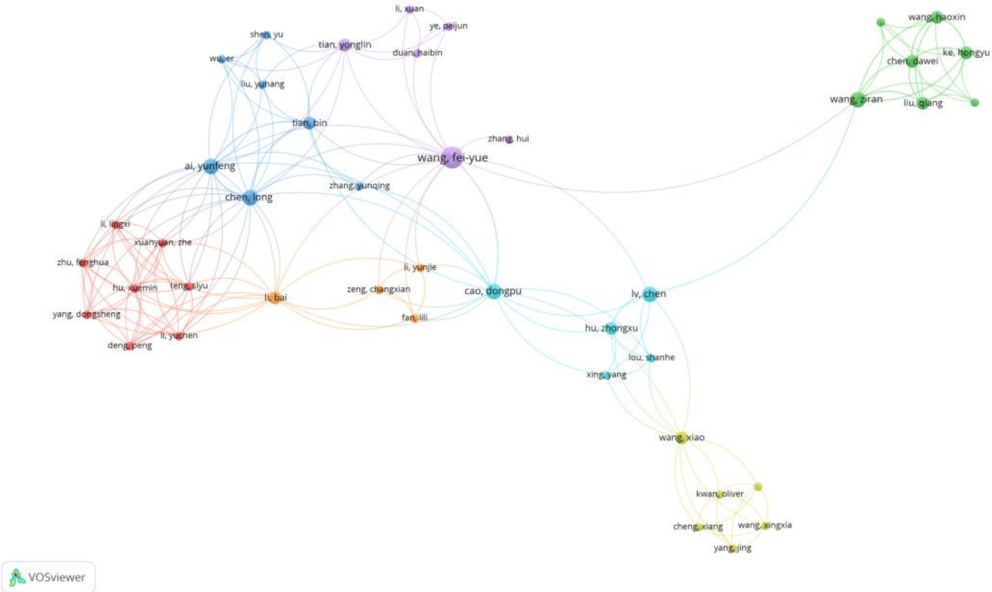

Figure 1 Co-authorship

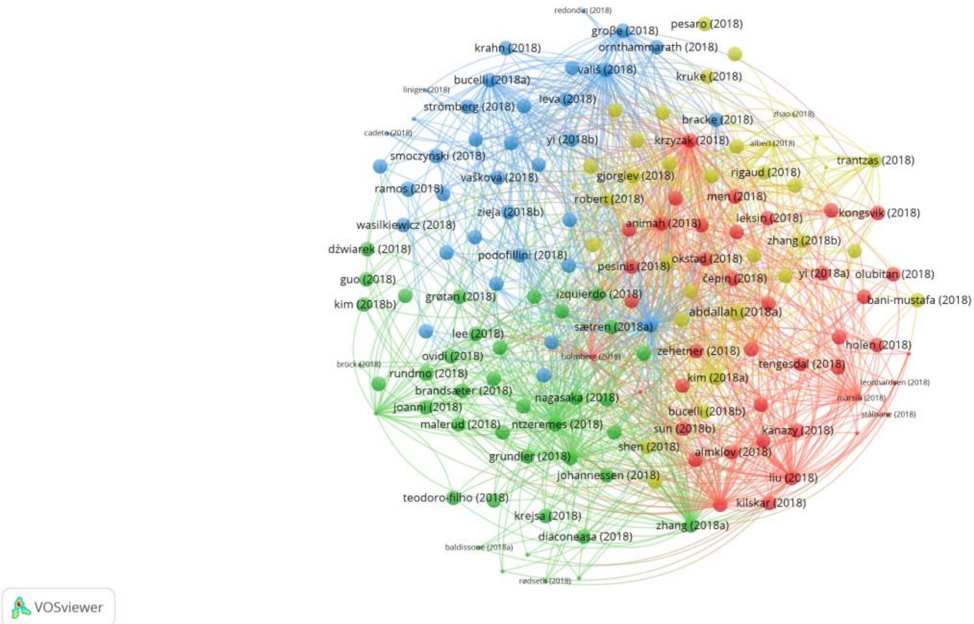

Figure 2 Citation

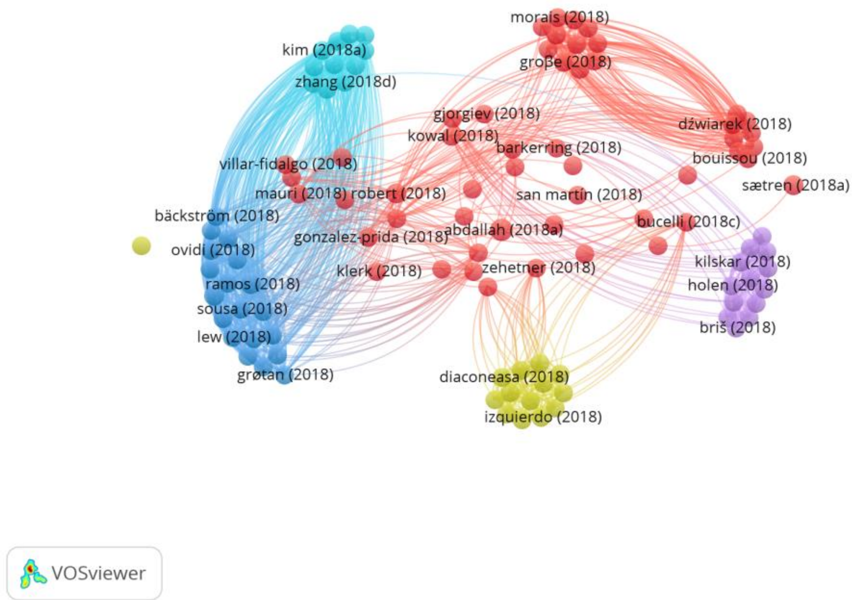

Figure 3 Bibliographic coupling

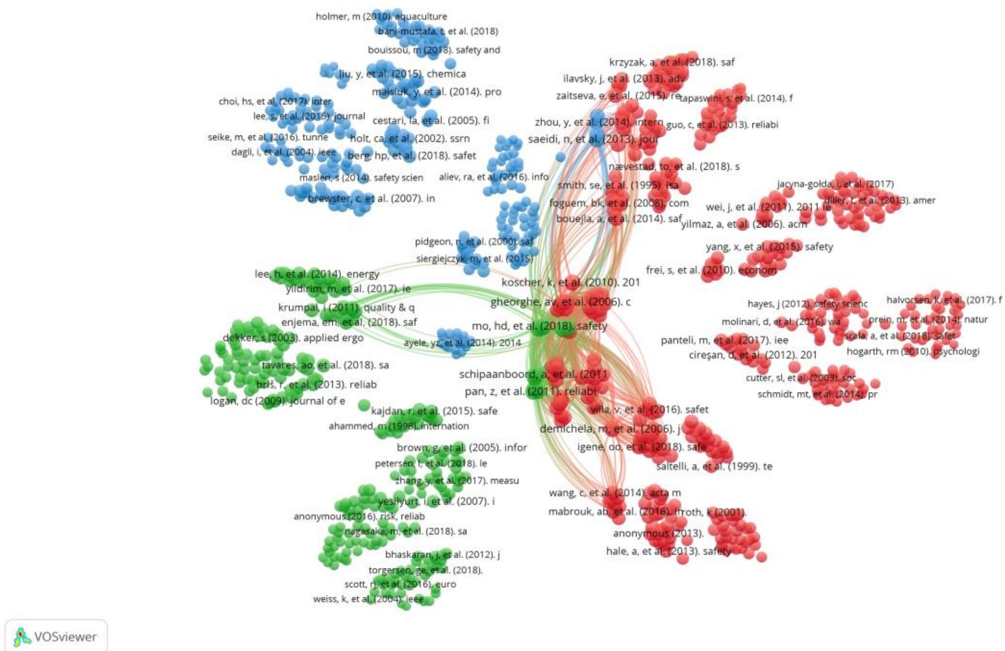

Figure 4 Co-citation

Table 2 General synopsis of evidence as regards focus topics and descriptive outcomes (research findings).

Movement and behavior tracking tools, 3D immersive virtual reality and spatial computing technologies, and computer vision and virtual simulation algorithms configure blockchain-based metaverse platforms.	Golf-Papez et al., 2022; Li et al., 2023; Ramadan, 2023; Zhou et al., 2023
Situational awareness and path planning algorithms, haptic and multisensory technologies, and deep learning-based ambient sound processing and automated speech recognition tools configure the metaverse interactive environment.	Dincelli and Yayla, 2022; Zheng and Yuan, 2023; Zvarikova et al., 2022
3D modeling and simulation technologies, spatio-temporal fusion and data-driven artificial intelligence algorithms, and simulation modeling and ambient intelligence tools articulate immersive digital worlds.	Han et al., 2023a; Machova et al., 2022; Wu et al., 2023
Modeling and forecasting tools, deep learning and 3D path planning algorithms, and digital twinning and remote sensing technologies shape blockchain-based metaverse platforms and immersive 3D worlds.	Bordegoni and Ferrise, 2023; Egliston and Carter, 2022; McStay, 2023; Zhu et al., 2023
Immersive metaverse experiences can be attained through socially-extended cognition and empathetic computing systems, user identification technology and location data, and spatial awareness and tracking tools.	Durana et al., 2022; Giang Barrera and Shah, 2023; Mourtzis et al., 2022
Sensor-based object recognition and data sharing technologies, automated speech recognition and geospatial mapping tools, and deep learning and computer vision algorithms assist interactive virtual and extended reality environments.	Cao, 2022; Han et al., 2023b; Valaskova et al., 2022; Wongkitrungrueng and Suprawan, 2023
Blockchain-based virtual worlds develop on artificial vision and Internet of Things-based decision support systems, metaverse and immersive technologies, and spatial computing and simulation modeling algorithms.	Dwivedi et al., 2023; Hennig-Thurau et al., 2022; McStay, 2022)
Extended reality environments develop on data mining and smart environment modeling tools, convolutional neural and interoperable virtual networks, and metaverse assets and services.	Huynh-The et al., 2023; Lv et al., 2022; Shi et al., 2023
Image processing and virtual navigation tools, 3D imaging and display technologies, and computer vision and image detection algorithms enable extended reality environments.	Kliestik et al., 2023; Njoku et al., 2023; Polas et al., 2022; Zhang et al., 2023

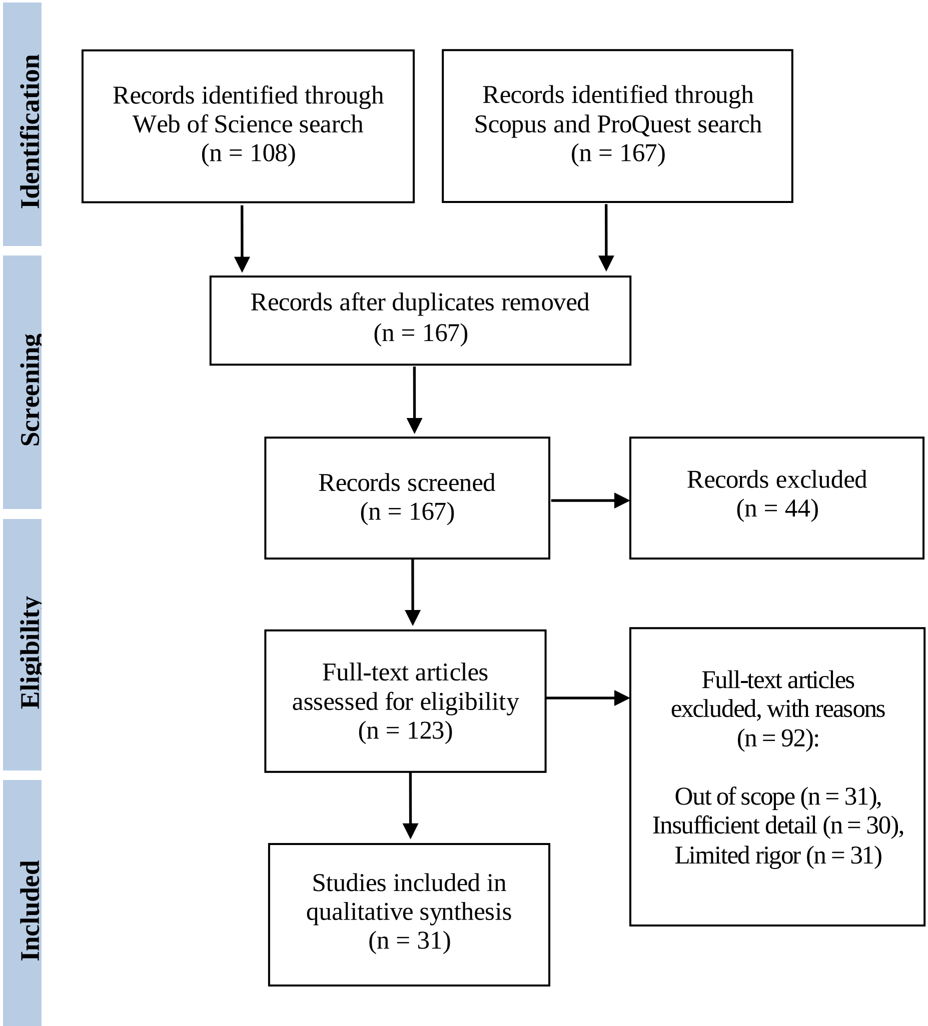

Figure 5 PRISMA flow diagram describing the search results and screening.

Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines were used that ensure the literature review is comprehensive, transparent, and replicable. The flow diagram, produced by employing a Shiny app, presents the stream of evidence-based collected and processed data through the various steps of a systematic review, designing the amount of identified, included, and removed records, and the justifications for exclusions.
To ensure compliance with PRISMA guidelines, a citation software was used, and at each stage the inclusion or exclusion of articles was tracked by use of custom spreadsheet. Justification for the removal of ineligible articles was specified during the full-text screening and final selection.

To ensure first-rate standard of evidence, a systematic search of relevant databases including peer-reviewed published journal articles was conducted using predefined search terms, covering a range of research methods and data sources. Reference lists of all relevant sources were manually reviewed for additional relevant citations.

Titles of papers and abstracts were screened for suitability and selected full texts were retrieved to establish whether they satisfied the inclusion criteria. All records from each database were evaluated by using data extraction forms. Data covering research aims, participants, study design, and method of each paper were extracted.

The inclusion criteria were: (i) articles included in the Web of Science, Scopus, and ProQuest databases, (ii) publication date (2022–2023), (iii) written in English, (iv) being an original empirical research or review article, and (v) particular search terms covered; (i) conference proceedings, (ii) books, and (iii) editorial materials were eliminated from the analysis.

SRDR gathered, handled, and analyzed the data for the systematic review, being configured as an archive and tool harnessed in data extraction through transparent, efficient, and reliable quantitative techniques. Elaborate extraction forms can be set up, meeting the needs of research questions and study designs.

Distiller SR screened and extracted the collected data.

AMSTAR evaluated the methodological quality of systematic reviews.

The quality of academic articles was determined and risk of bias was measured by MMAT, that tested content validity and usability of selected studies in terms of screening questions, type of design, corresponding quality criteria, and overall quality score.

Dedoose analyzed qualitative and mixed methods research.

AXIS evaluated the quality of cross-sectional studies.

ROBIS assessed the risk of bias in systematic reviews.

Figure 6 Screening and quality assessment tools

4. Deep Learning and Predictive Modeling Algorithms, Spatial Computing and Ontology-based Semantic Technologies, and Data Acquisition and Virtual Navigation Tools in the Metaverse Interactive Environment

Movement and behavior tracking tools, 3D immersive virtual reality and spatial computing technologies, and computer vision and virtual simulation algorithms (Golf-Papez et al., 2022; Li et al., 2023; Ramadan, 2023; Zhou et al., 2023) configure blockchain-based metaverse platforms. Deep learning and predictive modeling algorithms, data acquisition and virtual navigation tools, and sensing and computing technologies further immersive photorealistic virtual spaces.

Situational awareness and path planning algorithms, haptic and multi-sensory technologies, and deep learning-based ambient sound processing and automated speech recognition tools (Dincelli and Yayla, 2022; Zheng and Yuan, 2023; Zvarikova et al., 2022) configure the metaverse interactive environment. Virtual and augmented reality tools, spatial computing and ontology-based semantic technologies, and deep learning and sensor path planning algorithms optimize immersive digital worlds. Synthetic user experiences can be achieved by use of haptic augmented reality, cognitive and behavioral algorithms, and digital scent and sentiment recognition technologies.

3D modeling and simulation technologies, spatio-temporal fusion and data-driven artificial intelligence algorithms, and simulation modeling and ambient intelligence tools (Han et al., 2023a; Machova et al., 2022; Wu et al., 2023) articulate immersive digital worlds. Ambient intelligence and shared virtual environments require user journey and big geospatial data analytics, virtual modeling and digital twin technologies, and image recognition and visual perception algorithms. (Table 3)

Table 3 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Movement and behavior tracking tools, 3D immersive virtual reality and spatial computing technologies, and computer vision and virtual simulation algorithms configure blockchain-based metaverse platforms.	Golf-Papez et al., 2022; Li et al., 2023; Ramadan, 2023; Zhou et al., 2023
Situational awareness and path planning algorithms, haptic and multisensory technologies, and deep learning-based ambient sound processing and automated speech recognition tools configure the metaverse interactive environment.	Dincelli and Yayla, 2022; Zheng and Yuan, 2023; Zvarikova et al., 2022
3D modeling and simulation technologies, spatio-temporal fusion and data-driven artificial intelligence algorithms, and simulation modeling and ambient intelligence tools articulate immersive digital worlds.	Han et al., 2023a; Machova et al., 2022; Wu et al., 2023

5. Machine Learning-based Recognition and Sensor Fusion Algorithms, Socially-Extended Cognition and Empathetic Computing Systems, and Digital Twin Simulation and Data Visualization Tools on Blockchain-based Metaverse Platforms

Modeling and forecasting tools, deep learning and 3D path planning algorithms, and digital twinning and remote sensing technologies (Bordegoni and Ferrise, 2023; Egliston and Carter, 2022; McStay, 2023; Zhu et al., 2023) shape blockchain-based metaverse platforms and immersive 3D worlds. 3D digital environments integrate geospatial mapping and digital contact tracing technologies, artificial vision and immersive visualization systems, and machine learning-based recognition and sensor fusion algorithms.

Immersive metaverse experiences (Durana et al., 2022; Giang Barrera and Shah, 2023; Mourtzis et al., 2022) can be attained through socially-extended cognition and empathetic computing systems, user identification technology and location data, and spatial awareness and tracking tools. Immersive interconnected virtual worlds necessitate spatial and sentiment analytics, deep learning-based sensing and immersive 3D technologies, and visual perception and immersive decentralized networking tools.

Sensor-based object recognition and data sharing technologies, automated speech recognition and geospatial mapping tools, and deep learning and computer vision algorithms (Cao, 2022; Han et al., 2023b; Valaskova et al., 2022; Wongkitrungrueng and Suprawan, 2023) assist interactive virtual and extended reality environments. Decentralized data and real-time event analytics, digital twin simulation and data visualization tools, and neuromorphic computing and machine learning algorithms are pivotal in intelligent simulation environments. (Table 4)

Table 4 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Modeling and forecasting tools, deep learning and 3D path planning algorithms, and digital twinning and remote sensing technologies shape blockchain-based metaverse platforms and immersive 3D worlds.	Bordegoni and Ferrise, 2023; Egliston and Carter, 2022; McStay, 2023; Zhu et al., 2023
Immersive metaverse experiences can be attained through socially-extended cognition and empathetic computing systems, user identification technology and location data, and spatial awareness and tracking tools.	Durana et al., 2022; Giang Barrera and Shah, 2023; Mourtzis et al., 2022
Sensor-based object recognition and data sharing technologies, automated speech recognition and geospatial mapping tools, and deep learning and computer vision algorithms assist interactive virtual and extended reality environments.	Cao, 2022; Han et al., 2023b; Valaskova et al., 2022; Wongkitrungrueng and Suprawan, 2023

6. Metaverse and Immersive Technologies, 3D Image Processing and Machine Vision Algorithms, and Remote Sensing and Distributed Autonomous Control Systems in the Blockchain-based Virtual Economy

Blockchain-based virtual worlds (Dwivedi et al., 2023; Hennig-Thurau et al., 2022; McStay, 2022) develop on artificial vision and Internet of Things-based decision support systems, metaverse and immersive technologies, and spatial computing and simulation modeling algorithms. Machine learning-based image recognition and visual attention modeling tools, immersive visualization and extended cognitive systems, and 3D image processing and machine vision algorithms are instrumental in the blockchain-based virtual economy.

Extended reality environments (Huynh-The et al., 2023; Lv et al., 2022; Shi et al., 2023) develop on data mining and smart environment modeling tools, convolutional neural and interoperable virtual networks, and metaverse assets and services. Decision support and virtual navigation tools, cognitive enhancement and artificial intelligence technologies, and geolocation data mining and tracking articulate extended reality environments.

Image processing and virtual navigation tools, 3D imaging and display technologies, and computer vision and image detection algorithms (Kliestik et al., 2023; Njoku et al., 2023; Polas et al., 2022; Zhang et al., 2023) enable extended reality environments. Data mining and machine learning techniques, deep learning artificial intelligence and natural language processing tools, and remote sensing and distributed autonomous control systems assist immersive virtual environments. Blockchain-based metaverse platforms and the virtual environment of the metaverse necessitate visual imagery and data mining tools, deep generative modeling and text mining techniques, and hyper-realistic immersive 3D simulations. (Table 5)

Table 5 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Blockchain-based virtual worlds develop on artificial vision and Internet of Things-based decision support systems, metaverse and immersive technologies, and spatial computing and simulation modeling algorithms.	Dwivedi et al., 2023; Hennig-Thurau et al., 2022; McStay, 2022)
Extended reality environments develop on data mining and smart environment modeling tools, convolutional neural and interoperable virtual networks, and metaverse assets and services.	Huynh-The et al., 2023; Lv et al., 2022; Shi et al., 2023
Image processing and virtual navigation tools, 3D imaging and display technologies, and computer vision and image detection algorithms enable extended reality environments.	Kliestik et al., 2023; Njoku et al., 2023; Polas et al., 2022; Zhang et al., 2023

7. Discussion

I integrate my systematic review throughout research indicating how synthetic user experiences can be achieved by use of haptic augmented reality, cognitive and behavioral algorithms, and digital scent and sentiment recognition technologies. My research complements recent analyses clarifying how 3D digital environments integrate geospatial mapping and digital contact tracing technologies, artificial vision and immersive visualization systems, and machine learning-based recognition and sensor fusion algorithms. I elucidate, by cumulative evidence, previous research demonstrating how data mining and machine learning techniques, deep learning artificial intelligence and natural language processing tools, and remote sensing and distributed autonomous control systems assist immersive virtual environments.

8. Synopsis of the Main Research Outcomes

Blockchain-based metaverse platforms and the virtual environment of the metaverse necessitate visual imagery and data mining tools, deep generative modeling and text mining techniques, and hyper-realistic immersive 3D simulations. Decentralized data and real-time event analytics, digital twin simulation and data visualization tools, and neuromorphic computing and machine learning algorithms are pivotal in intelligent simulation environments.

9. Conclusions

Relevant research has investigated whether virtual and augmented reality tools, spatial computing and ontology-based semantic technologies, and deep learning and sensor path planning algorithms optimize immersive digital worlds. This systematic literature review presents the published peer-reviewed sources covering how ambient intelligence and shared virtual environments require user journey and big geospatial data analytics, virtual modeling and digital twin technologies, and image recognition and visual perception algorithms. The research outcomes drawn from the above analyses indicate that decision support and virtual navigation tools, cognitive enhancement and artificial intelligence technologies, and geolocation data mining and tracking articulate extended reality environments.

10. Limitations, Implications, and Further Directions of Research

By analyzing only articles published between 2022 and 2023 in journals indexed in the Web of Science, Scopus, and ProQuest databases, relevant sources on tracking and spatial computing technologies, virtual navigation and ambient scene detection tools, and motion planning and remote sensing algorithms in the metaverse may have been excluded. Limitations of this research comprise particular kinds of publications (original empirical research and review articles) discounting others (conference proceedings articles, books, and editorial materials). The scope of my study also does not move forward the inspection of movement and behavior tracking tools, 3D immersive virtual reality and spatial computing technologies, and computer vision and virtual simulation algorithms.

Subsequent analyses should develop on socially-extended cognition and empathetic computing systems, user identification technology and location data, and spatial awareness and tracking tools. Future research should thus investigate situational awareness and path planning algorithms, haptic and multisensory technologies, and deep learning-based ambient sound processing and automated speech recognition tools. Attention should be directed to image processing and virtual navigation tools, 3D imaging and display technologies, and computer vision and image detection algorithms.

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Compliance with ethical standards
This article does not contain any studies with human participants or animals performed by the author. Extracting and inspecting publicly accessible files (scholarly sources) as evidence, before the research began no institutional ethics approval was required.

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Author contributions
The author confirms being the sole contributor of this work and approved it for publication. The author takes full responsibility for the accuracy and the integrity of the data analysis.

Conflict of interest statement
The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Disclosure by the editors of record
The editors declare no conflict of interest in the review and publication decision regarding this article.

Transparency statement
The author affirms that the manuscript represents an honest, accurate, and transparent account of the research being reported, that no relevant aspects of the study have been left out, and that any inconsistencies from the research as planned (and, if significant, registered) have been clarified.

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Acoustic Environment Recognition and Visual Tracking Algorithms, Deep Learning-based Ambient Sound Processing Tools, and Geospatial Mapping and Remote Sensing Technologies in a Real-Time Interoperable Decentralized Metaverse

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ABSTRACT. The present study systematically reviews the existing research on holographic imaging and immersive 3D technologies, multi-machine cooperation and digital twin modeling tools, and computer vision and neural network-based recognition algorithms Our findings indicate that multisensory user experiences can be achieved by use of image processing computational and visual perception algorithms, digital contact tracing and cloud-based cognitive technologies, and voice and gesture recognition tools. Throughout January 2023, a quantitative literature review of the Web of Science, Scopus, and ProQuest databases was performed, with search terms including "real-time interoperable decentralized metaverse" + "acoustic environment recognition and visual tracking algorithms," "deep learning-based ambient sound processing tools," and "geospatial mapping and remote sensing technologies." As research published between 2022 and 2023 was inspected, only 171 articles satisfied the eligibility criteria. By taking out controversial or ambiguous findings (insufficient/irrelevant data), outcomes unsubstantiated by replication, too general material, or studies with nearly identical titles, we selected 34 mainly empirical sources. Data visualization tools: Dimensions (bibliometric mapping) and VOSviewer (layout algorithms). Reporting quality assessment tool: PRISMA. Methodological quality assessment tools include: AMSTAR, Dedoose, Distiller SR, and SRDR.

Keywords: acoustic environment recognition and visual tracking algorithms; deep learning-based ambient sound processing tools; geospatial mapping and remote sensing technologies; metaverse

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1. Introduction

Dynamic routing and multisensor fusion technologies, spatial awareness and data mining tools, and bio-sensing and actuation systems shape synthetic digitally-mediated environments. The purpose of our systematic review is to examine the recently published literature on the real-time interoperable decentralized metaverse and integrate the insights it configures on acoustic environment recognition and visual tracking algorithms, deep learning-based ambient sound processing tools, and geospatial mapping and remote sensing technologies. By analyzing the most recent (2022–2023) and significant (Web of Science, Scopus, and ProQuest) sources, our paper has attempted to prove that multisensory user experiences can be achieved by use of image processing computational and visual perception algorithms (Andronie et al., 2021; Dabija et al., 2023; Perkins, 2022), digital contact tracing and cloud-based cognitive technologies, and voice and gesture recognition tools. The actuality and novelty of this study are articulated by addressing holographic imaging and immersive 3D technologies, multi-machine cooperation and digital twin modeling tools (Andronie et al., 2023a; Kliestik et al., 2020; Pop et al., 2023), and computer vision and neural network-based recognition algorithms, that is an emerging topic involving much interest. Our research problem is whether 3D virtual environments develop on eye-tracking and autonomous cognitive systems, image-based object recognition and digital twin technologies (Andronie et al., 2023b; Lăzăroiu et al., 2020; Popescu et al., 2017a; Rowland, 2022), and contextual data monitoring and digital twinning tools.

In this review, prior findings have been cumulated indicating that immersive virtual reality experiences can be achieved through spatio-temporal fusion and natural language processing algorithms, sensorial and cognitive technologies (Balcerzak et al., 2022; Lewkowich, 2022; Popescu et al., 2017b), and computational intelligence and simulation modeling tools. The identified gaps advance context awareness and machine learning-based image recognition tools (Dabija et al., 2018; Nica, 2017; Popescu, 2018), object recognition and affective modeling algorithms, and deep learning-based sensing and cognitive automation technologies. Our main objective is to indicate that immersive virtual experiences can be achieved through spatial cognition and deep learning artificial intelligence algorithms, monitoring and sensing technologies, and autonomous visual object detection and intelligent data processing tools.

2. Theoretical Overview of the Main Concepts

Immersive virtual experiences can be attained by use of virtual navigation and digital twin simulation tools, spatio-temporal fusion and deep learning computer vision algorithms, and emotion detection and recognition technologies. The manuscript is organized as following: theoretical overview (section

2), methodology (section 3), holographic imaging and immersive 3D technologies, big geospatial data and deep learning-based sentiment analytics, and computational intelligence and simulation modeling tools in the virtual economy of the metaverse (section 4), geolocation data processing and predictive modeling algorithms, context awareness and machine learning-based image recognition tools, and digital contact tracing and cloud-based cognitive technologies in a fully connected metaverse (section 5), digital twin simulation and autonomous visual object detection tools, cognitive computing and machine learning-based decision support systems, and big spatio-temporal data and real-time predictive analytics in the virtual environment of the metaverse (section 6), discussion (section 7), synopsis of the main research outcomes (section 8), conclusions (section 9), limitations, implications, and further directions of research (section 10).

3. Methodology

Throughout January 2023, a quantitative literature review of the Web of Science, Scopus, and ProQuest databases was performed, with search terms including "real-time interoperable decentralized metaverse" + "acoustic environment recognition and visual tracking algorithms," "deep learning-based ambient sound processing tools," and "geospatial mapping and remote sensing technologies." As research published between 2022 and 2023 was inspected, only 171 articles satisfied the eligibility criteria. By taking out controversial or ambiguous findings (insufficient/irrelevant data), outcomes unsubstantiated by replication, too general material, or studies with nearly identical titles, we selected 34 mainly empirical sources (Tables 1 and 2). Data visualization tools: Dimensions (bibliometric mapping) and VOSviewer (layout algorithms). Reporting quality assessment tool: PRISMA. Methodological quality assessment tools include: AMSTAR, Dedoose, Distiller SR, and SRDR (Figures 1–6).

Table 1 Topics and types of scientific products identified and selected.

Topic	**Identified**	**Selected**
real-time interoperable decentralized metaverse + acoustic environment recognition and visual tracking algorithms	58	12
real-time interoperable decentralized metaverse + deep learning-based ambient sound processing tools	57	11
real-time interoperable decentralized metaverse + geospatial mapping and remote sensing technologies	56	11
Type of paper		
Original research	141	24
Review	21	10
Conference proceedings	8	0
Book	0	0
Editorial	1	0

Source: Processed by the authors. Some topics overlap.

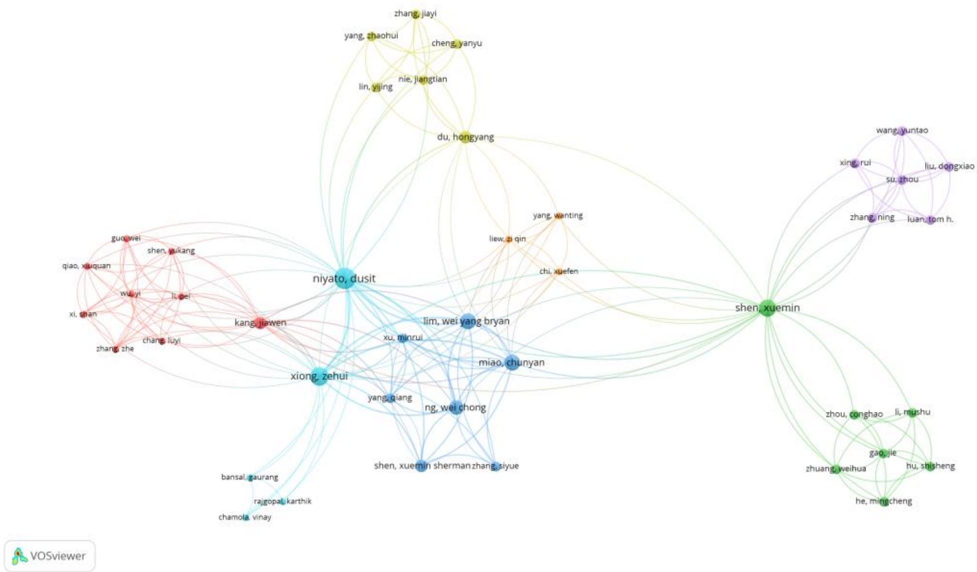

Figure 1 Co-authorship

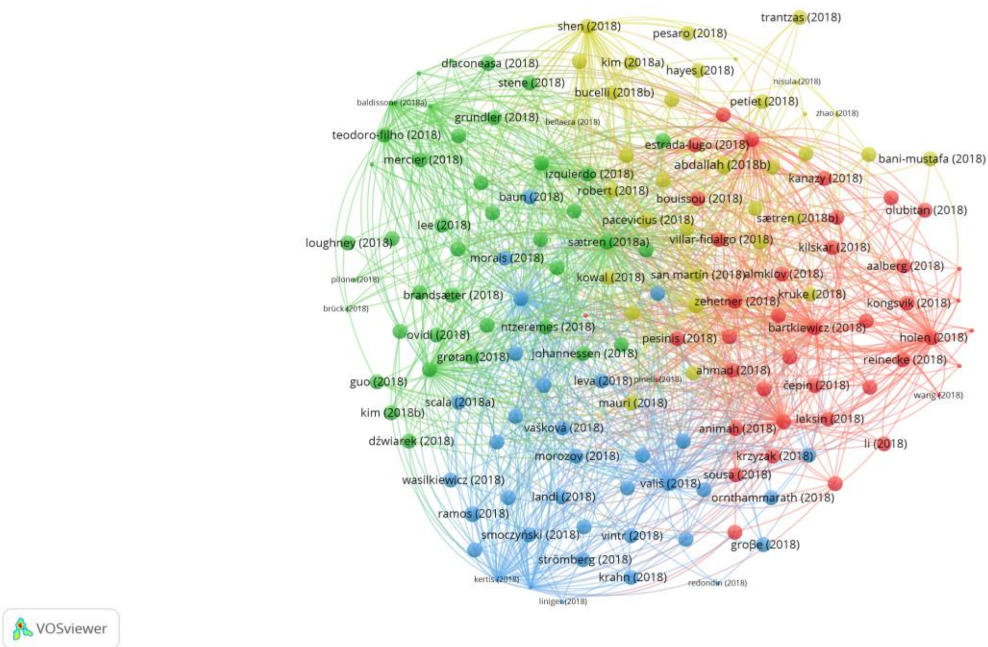

Figure 2 Citation

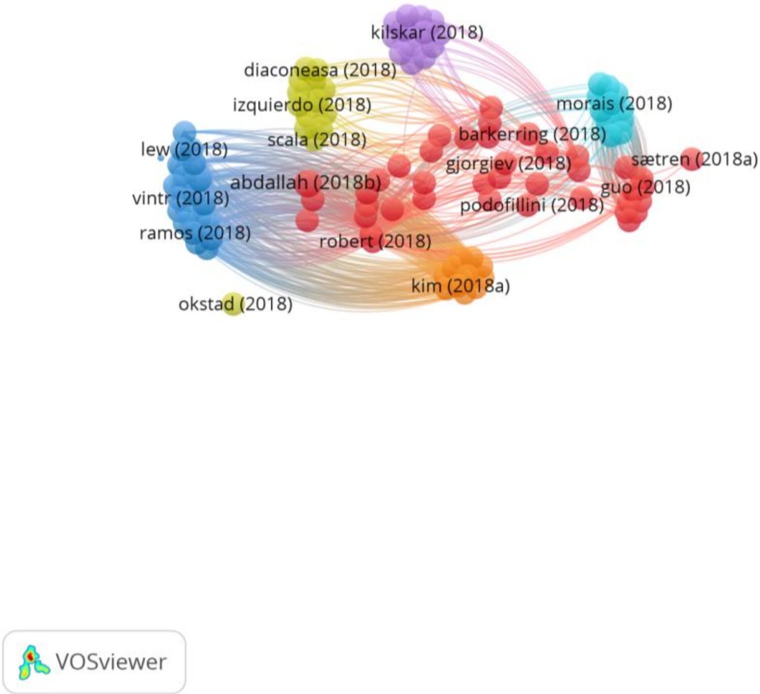

Figure 3 Bibliographic coupling

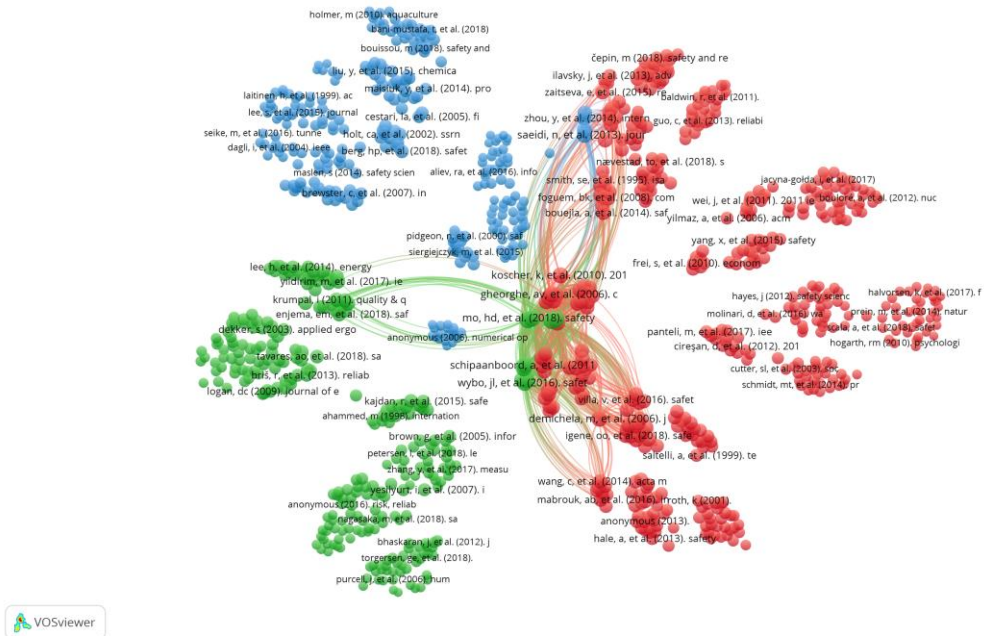

Figure 4 Co-citation

Table 2 General synopsis of evidence as regards focus topics and descriptive outcomes (research findings).

Interconnected sensor networks, cloud computing machines, and 3D modeling and deep reinforcement learning tools configure the virtual economy of the metaverse.	Faraboschi et al., 2022; Kwok and Tang, 2023; Zhao et al., 2022
3D metaverse experiences can be attained through holographic imaging and immersive 3D technologies, multi-machine cooperation and digital twin modeling tools, and computer vision and neural network-based recognition algorithms.	Du et al., 2023a; Hollensen et al., 2023; Queiroz et al., 2023; Zainab et al., 2022
Big geospatial data and deep learning-based sentiment analytics, cognitive artificial intelligence and computer vision algorithms, and virtual mapping and and visual imagery tools assist extended reality environments.	Cheng et al., 2022; Ersoy and Gürfidan, 2023; Oh et al., 2023; Yoo et al., 2023
3D generative modeling and deep learning artificial intelligence tools, real-time predictive and machine learning-based sentiment analytics, and image processing computational and spatio-temporal fusion algorithms articulate a fully connected metaverse.	Carey, 2022; Daneshfar and Jamshidi, 2023; Egliston and Carter, 2022; Vidal-Tomás, 2023
3D metaverse experiences can be attained by use of context awareness and machine learning-based image recognition tools, object recognition and affective modeling algorithms, and deep learning-based sensing and cognitive automation technologies.	Du et al., 2023b; Geambazi et al., 2022; Hadi et al., 2023; Xian et al., 2023
Virtual navigation and automated speech recognition tools, text mining and analytics, and bio-inspired computational intelligence and spatial data mining algorithms enable shared virtual environments.	Bojic, 2022; Huang et al., 2023; Shi et al., 2023; Zyda, 2022
Immersive metaverse experiences can be attained through digital twin simulation and autonomous visual object detection tools, spatial cognition and virtual mapping algorithms, and haptic and sensory technologies.	Kovacova et al., 2022; Meng et al., 2023; Zabel et al., 2023
Virtual immersive and haptic feedback technologies, contextual data monitoring and natural language processing tools, and big data computing and visual analytics systems optimize the metaverse.	Chen, 2022; Kozinets, 2023; Li et al., 2023; Xu et al., 2023
Big spatio-temporal data and real-time predictive analytics, brain-inspired artificial intelligence and machine learning-based navigation algorithms, and immersive analytics and decision-making process automation tools further extended reality environments.	Crowell, 2022; Park and Kim, 2023; Smart, 2022; Wu et al., 2023

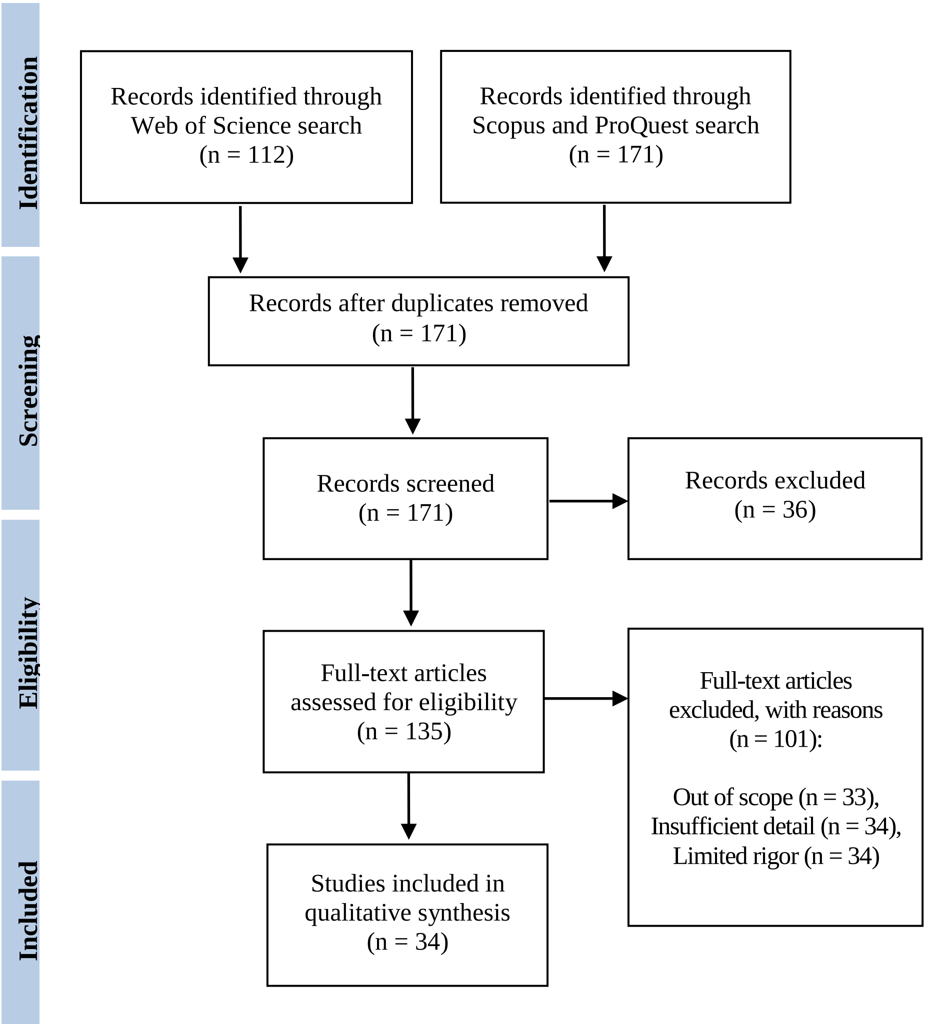

Figure 5 PRISMA flow diagram describing the search results and screening.

Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines were used that ensure the literature review is comprehensive, transparent, and replicable. The flow diagram, produced by employing a Shiny app, presents the stream of evidence-based collected and processed data through the various steps of a systematic review, designing the amount of identified, included, and removed records, and the justifications for exclusions.

To ensure compliance with PRISMA guidelines, a citation software was used, and at each stage the inclusion or exclusion of articles was tracked by use of custom spreadsheet. Justification for the removal of ineligible articles was specified during the full-text screening and final selection.

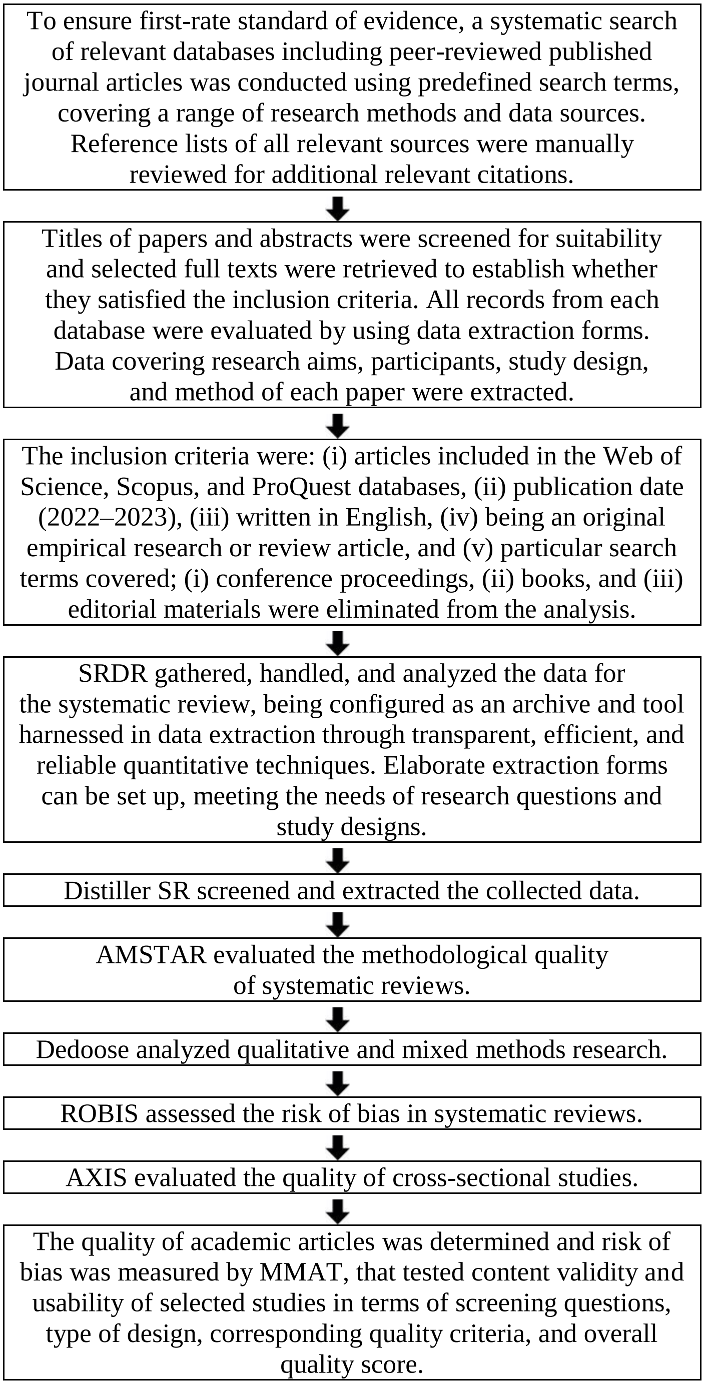

Figure 6 Screening and quality assessment tools

4. Holographic Imaging and Immersive 3D Technologies, Big Geospatial Data and Deep Learning-based Sentiment Analytics, and Computational Intelligence and Simulation Modeling Tools in the Virtual Economy of the Metaverse

Interconnected sensor networks, cloud computing machines, and 3D modeling and deep reinforcement learning tools (Faraboschi et al., 2022; Kwok and Tang, 2023; Zhao et al., 2022) configure the virtual economy of the metaverse. Immersive virtual reality experiences can be achieved through spatio-temporal fusion and natural language processing algorithms, sensorial and cognitive technologies, and computational intelligence and simulation modeling tools.

3D metaverse experiences (Du et al., 2023a; Hollensen et al., 2023; Queiroz et al., 2023; Zainab et al., 2022) can be attained through holographic imaging and immersive 3D technologies, multi-machine cooperation and digital twin modeling tools, and computer vision and neural network-based recognition algorithms. Immersive virtual experiences can be achieved through spatial cognition and deep learning artificial intelligence algorithms, monitoring and sensing technologies, and autonomous visual object detection and intelligent data processing tools.

Big geospatial data and deep learning-based sentiment analytics, cognitive artificial intelligence and computer vision algorithms, and virtual mapping and and visual imagery tools (Cheng et al., 2022; Ersoy and Gürfidan, 2023; Oh et al., 2023; Yoo et al., 2023) assist extended reality environments. Immersive virtual experiences can be attained by use of virtual navigation and digital twin simulation tools, spatio-temporal fusion and deep learning computer vision algorithms, and emotion detection and recognition technologies. (Table 3)

Table 3 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Interconnected sensor networks, cloud computing machines, and 3D modeling and deep reinforcement learning tools configure the virtual economy of the metaverse.	Faraboschi et al., 2022; Kwok and Tang, 2023; Zhao et al., 2022
3D metaverse experiences can be attained through holographic imaging and immersive 3D technologies, multi-machine cooperation and digital twin modeling tools, and computer vision and neural network-based recognition algorithms.	Du et al., 2023a; Hollensen et al., 2023; Queiroz et al., 2023; Zainab et al., 2022
Big geospatial data and deep learning-based sentiment analytics, cognitive artificial intelligence and computer vision algorithms, and virtual mapping and and visual imagery tools assist extended reality environments.	Cheng et al., 2022; Ersoy and Gürfidan, 2023; Oh et al., 2023; Yoo et al., 2023

5. Geolocation Data Processing and Predictive Modeling Algorithms, Context Awareness and Machine Learning-based Image Recognition Tools, and Digital Contact Tracing and Cloud-based Cognitive Technologies in a Fully Connected Metaverse

3D generative modeling and deep learning artificial intelligence tools, real-time predictive and machine learning-based sentiment analytics, and image processing computational and spatio-temporal fusion algorithms (Carey, 2022; Daneshfar and Jamshidi, 2023; Egliston and Carter, 2022; Vidal-Tomás, 2023) articulate a fully connected metaverse. Virtual reality-based immersive experiences can be achieved by use of behavior modeling and motion capture technologies, geolocation data processing and predictive modeling algorithms, and context modeling and ambient scene detection tools.

3D metaverse experiences (Du et al., 2023b; Geambazi et al., 2022; Hadi et al., 2023; Xian et al., 2023) can be attained by use of context awareness and machine learning-based image recognition tools, object recognition and affective modeling algorithms, and deep learning-based sensing and cognitive automation technologies. Multisensory user experiences can be achieved by use of image processing computational and visual perception algorithms, digital contact tracing and cloud-based cognitive technologies, and voice and gesture recognition tools.

Virtual navigation and automated speech recognition tools, text mining and analytics, and bio-inspired computational intelligence and spatial data mining algorithms (Bojic, 2022; Huang et al., 2023; Shi et al., 2023; Zyda, 2022) enable shared virtual environments. Dynamic routing and multisensor fusion technologies, spatial awareness and data mining tools, and bio-sensing and actuation systems shape synthetic digitally-mediated environments. (Table 4)

Table 4 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

3D generative modeling and deep learning artificial intelligence tools, real-time predictive and machine learning-based sentiment analytics, and image processing computational and spatio-temporal fusion algorithms articulate a fully connected metaverse.	Carey, 2022; Daneshfar and Jamshidi, 2023; Egliston and Carter, 2022; Vidal-Tomás, 2023
3D metaverse experiences can be attained by use of context awareness and machine learning-based image recognition tools, object recognition and affective modeling algorithms, and deep learning-based sensing and cognitive automation technologies.	Du et al., 2023b; Geambazi et al., 2022; Hadi et al., 2023; Xian et al., 2023
Virtual navigation and automated speech recognition tools, text mining and analytics, and bio-inspired computational intelligence and spatial data mining algorithms enable shared virtual environments.	Bojic, 2022; Huang et al., 2023; Shi et al., 2023; Zyda, 2022

6. Digital Twin Simulation and Autonomous Visual Object Detection Tools, Cognitive Computing and Machine Learning-based Decision Support Systems, and Big Spatio-Temporal Data and Real-Time Predictive Analytics in the Virtual Environment of the Metaverse

Immersive metaverse experiences (Kovacova et al., 2022; Meng et al., 2023; Zabel et al., 2023) can be attained through digital twin simulation and autonomous visual object detection tools, spatial cognition and virtual mapping algorithms, and haptic and sensory technologies. 3D virtual environments develop on eye-tracking and autonomous cognitive systems, image-based object recognition and digital twin technologies, and contextual data monitoring and digital twinning tools.

Virtual immersive and haptic feedback technologies, contextual data monitoring and natural language processing tools, and big data computing and visual analytics systems (Chen, 2022; Kozinets, 2023; Li et al., 2023; Xu et al., 2023) optimize the virtual environment of the metaverse. Photo-realistic synthetic environments integrate geospatial mapping and digital contact tracing technologies, cognitive computing and machine learning-based decision support systems, and artificial intelligence-powered prediction and data modeling tools.

Big spatio-temporal data and real-time predictive analytics, brain-inspired artificial intelligence and machine learning-based navigation algorithms, and immersive analytics and decision-making process automation tools (Crowell, 2022; Park and Kim, 2023; Smart, 2022; Wu et al., 2023) further extended reality environments. Immersive 3D virtual environments require visual and spatial intelligence tools, cognitive and behavioral technologies, and Internet of Things-based sensing and edge artificial intelligence computing systems. (Table 5)

Table 5 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Immersive metaverse experiences can be attained through digital twin simulation and autonomous visual object detection tools, spatial cognition and virtual mapping algorithms, and haptic and sensory technologies.	Kovacova et al., 2022; Meng et al., 2023; Zabel et al., 2023
Virtual immersive and haptic feedback technologies, contextual data monitoring and natural language processing tools, and big data computing and visual analytics systems optimize the metaverse.	Chen, 2022; Kozinets, 2023; Li et al., 2023; Xu et al., 2023
Big spatio-temporal data and real-time predictive analytics, brain-inspired artificial intelligence and machine learning-based navigation algorithms, and immersive analytics and decision-making process automation tools further extended reality environments.	Crowell, 2022; Park and Kim, 2023; Smart, 2022; Wu et al., 2023

7. Discussion

We integrate our systematic review throughout research indicating how 3D virtual environments develop on eye-tracking and autonomous cognitive systems, image-based object recognition and digital twin technologies, and contextual data monitoring and digital twinning tools. Our research complements recent analyses clarifying how photorealistic synthetic environments integrate geospatial mapping and digital contact tracing technologies, cognitive computing and machine learning-based decision support systems, and artificial intelligence-powered prediction and data modeling tools. We elucidate, by cumulative evidence, previous research demonstrating how immersive virtual reality experiences can be achieved through spatio-temporal fusion and natural language processing algorithms, sensorial and cognitive technologies, and computational intelligence and simulation modeling tools.

8. Synopsis of the Main Research Outcomes

Immersive virtual experiences can be achieved through spatial cognition and deep learning artificial intelligence algorithms, monitoring and sensing technologies, and autonomous visual object detection and intelligent data processing tools. Multisensory user experiences can be achieved by use of image processing computational and visual perception algorithms, digital contact tracing and cloud-based cognitive technologies, and voice and gesture recognition tools.

9. Conclusions

Relevant research has investigated whether virtual reality-based immersive experiences can be achieved by use of behavior modeling and motion capture technologies, geolocation data processing and predictive modeling algorithms, and context modeling and ambient scene detection tools. This systematic literature review presents the published peer-reviewed sources covering how dynamic routing and multisensor fusion technologies, spatial awareness and data mining tools, and bio-sensing and actuation systems shape synthetic digitally-mediated environments. The research outcomes drawn from the above analyses indicate that immersive 3D virtual environments require visual and spatial intelligence tools, cognitive and behavioral technologies, and Internet of Things-based sensing and edge artificial intelligence computing systems.

10. Limitations, Implications, and Further Directions of Research

By analyzing only articles published between 2022 and 2023 in journals indexed in the Web of Science, Scopus, and ProQuest databases, relevant sources on acoustic environment recognition and visual tracking algorithms, deep learning-based ambient sound processing tools, and geospatial mapping and remote sensing technologies in a real-time interoperable decentralized metaverse may have been excluded. Limitations of this research comprise particular kinds of publications (original empirical research and review articles) discounting others (conference proceedings articles, books, and editorial materials). The scope of our study also does not move forward the inspection of 3D generative modeling and deep learning artificial intelligence tools, real-time predictive and machine learning-based sentiment analytics, and image processing computational and spatio-temporal fusion algorithms.

Subsequent analyses should develop on virtual navigation and automated speech recognition tools, text mining and analytics, and bio-inspired computational intelligence and spatial data mining algorithms. Future research should thus investigate big spatio-temporal data and real-time predictive analytics, brain-inspired artificial intelligence and machine learning-based navigation algorithms, and immersive analytics and decision-making process automation tools. Attention should be directed to digital twin simulation and autonomous visual object detection tools, spatial cognition and virtual mapping algorithms, and haptic and sensory technologies.

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Compliance with ethical standards
This article does not contain any studies with human participants or animals performed by the authors. Extracting and inspecting publicly accessible files (scholarly sources) as evidence, before the research began no institutional ethics approval was required.

Data availability statement
All data generated or analyzed are included in the published article.

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Author contributions
All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication. The authors take full responsibility for the accuracy and the integrity of the data analysis.

Conflict of interest statement
The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Disclosure by the editors of record
The editors declare no conflict of interest in the review and publication decision regarding this article.

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Predictive Modeling and Visual Perception Algorithms, Ambient Sound Recognition and Processing Tools, and Deep Neural Network and Vision Sensing Technologies in the Decentralized and Interconnected Metaverse

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ABSTRACT. This paper provides a systematic literature review of studies investigating deep learning-based ambient sound processing and real-time data tracking tools, metaverse and immersive technologies, and image detection and computer vision algorithms. The analysis highlights that virtual navigation and automated speech recognition tools, machine learning and computer vision algorithms, and digital twinning and multisensor fusion technologies shape extended reality environments and interactive digital worlds. Throughout December 2022, I performed a quantitative literature review of the Web of Science, Scopus, and ProQuest databases, with search terms including "the decentralized and interconnected metaverse" + "predictive modeling and visual perception algorithms," "ambient sound recognition and processing tools," and "deep neural network and vision sensing technologies." As I inspected research published between 2022 and 2023, only 168 articles satisfied the eligibility criteria. By eliminating controversial findings, outcomes unsubstantiated by replication, too imprecise material, or having similar titles, I decided upon 36, generally empirical, sources. Data visualization tools: Dimensions (bibliometric mapping) and VOSviewer (layout algorithms). Reporting quality assessment tool: PRISMA. Methodological quality assessment tools include: AMSTAR, Distiller SR, MMAT, and ROBIS.

Keywords: predictive modeling and visual perception algorithms; ambient sound recognition and processing tools; deep neural network and vision sensing technologies; metaverse

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1. Introduction

Immersive 3D environments integrate movement and behavior tracking tools, geospatial artificial intelligence and cognitive modeling technologies, and 3D image processing and computer vision algorithms. The purpose of my systematic review is to examine the recently published literature on the decentralized and interconnected metaverse and integrate the insights it configures on predictive modeling and visual perception algorithms, ambient sound recognition and processing tools, and deep neural network and vision sensing technologies. By analyzing the most recent (2022–2023) and significant (Web of Science, Scopus, and ProQuest) sources, my paper has attempted to prove that artificial intelligence-based image recognition and digital twin technologies, visual and spatial intelligence tools, and predictive maintenance and computer vision algorithms (Andronie et al., 2021a; Lewkowich, 2022; Popescu et al., 2017a; Watson, 2022) are instrumental in 3D interactive digital spaces and blockchain-based virtual worlds. The actuality and novelty of this study are articulated by addressing deep learning-based ambient sound processing and real-time data tracking tools, metaverse and immersive technologies, and image detection and computer vision algorithms (Andronie et al., 2021b; Musova et al., 2021; Popescu et al., 2017b), that is an emerging topic involving much interest. My research problem is whether virtual navigation and automated speech recognition tools, machine learning and computer vision algorithms (Cegarra Navarro et al., 2023; Nica, 2017; Popescu, 2018), and digital twinning and multisensor fusion technologies shape extended reality environments and interactive digital worlds..

In this review, prior findings have been cumulated indicating that deep learning-based sensing and geospatial mapping technologies, movement and behavior tracking tools, and computer vision and immersive visualization systems (Glogovețan et al., 2022; Nica, 2018; Valaskova et al., 2022) assist extended reality environments. The identified gaps advance decision-making process automation and geospatial mapping tools (Kliestik et al., 2020; Pera, 2022; Vătămănescu et al., 2022), 3D modeling and simulation technologies, and deep learning-based predictive and image recognition algorithms. My main objective is to indicate that simulation modeling and image recognition tools, deep learning-based sentiment and behavioral predictive analytics, and dynamic routing and spatial computing technologies configure immersive virtual environments.

2. Theoretical Overview of the Main Concepts

3D capture and spatial computing technologies, artificial neural network-based decision support and immersive visualization systems, and data visualization and socio-spatial analytics tools further extended reality environments. The manuscript is organized as following: theoretical overview (section 2), methodology (section 3), deep learning-based sensing and geospatial mapping technologies, immersive decentralized networking and digital twin simulation tools, and motion control and emotion detection algorithms in the metaverse interactive environment (section 4), deep learning-based ambient sound processing and real-time data tracking tools, geospatial artificial intelligence and cognitive modeling technologies, and machine vision and situational awareness algorithms in the blockchain-based metaverse (section 5), deep learning-based predictive and image recognition algorithms, geospatial mapping and environment perception technologies, and data acquisition and 3D generative modeling tools in Web3-powered metaverse worlds (section 6), discussion (section 7), synopsis of the main research outcomes (section 8), conclusions (section 9), limitations, implications, and further directions of research (section 10).

3. Methodology

Throughout December 2022, I performed a quantitative literature review of the Web of Science, Scopus, and ProQuest databases, with search terms including "the decentralized and interconnected metaverse" + "predictive modeling and visual perception algorithms," "ambient sound recognition and processing tools," and "deep neural network and vision sensing technologies." As I inspected research published between 2022 and 2023, only 168 articles satisfied the eligibility criteria. By eliminating controversial findings, outcomes unsubstantiated by replication, too imprecise material, or having similar titles, I decided upon 36, generally empirical, sources (Tables 1 and 2). Data visualization tools: Dimensions (bibliometric mapping) and VOSviewer (layout algorithms). Reporting quality assessment tool: PRISMA. Methodological quality assessment tools include: AMSTAR, Distiller SR, MMAT, and ROBIS (Figures 1–6).

Table 1 Topics and types of scientific products identified and selected.

Topic	**Identified**	**Selected**
the decentralized and interconnected metaverse + predictive modeling and visual perception algorithms	58	13
the decentralized and interconnected metaverse + ambient sound recognition and processing tools	56	12
the decentralized and interconnected metaverse + deep neural network and vision sensing technologies	54	11
Type of paper		
Original research	139	28
Review	19	8
Conference proceedings	9	0
Book	0	0
Editorial	1	0

Source: Processed by the author. Some topics overlap.

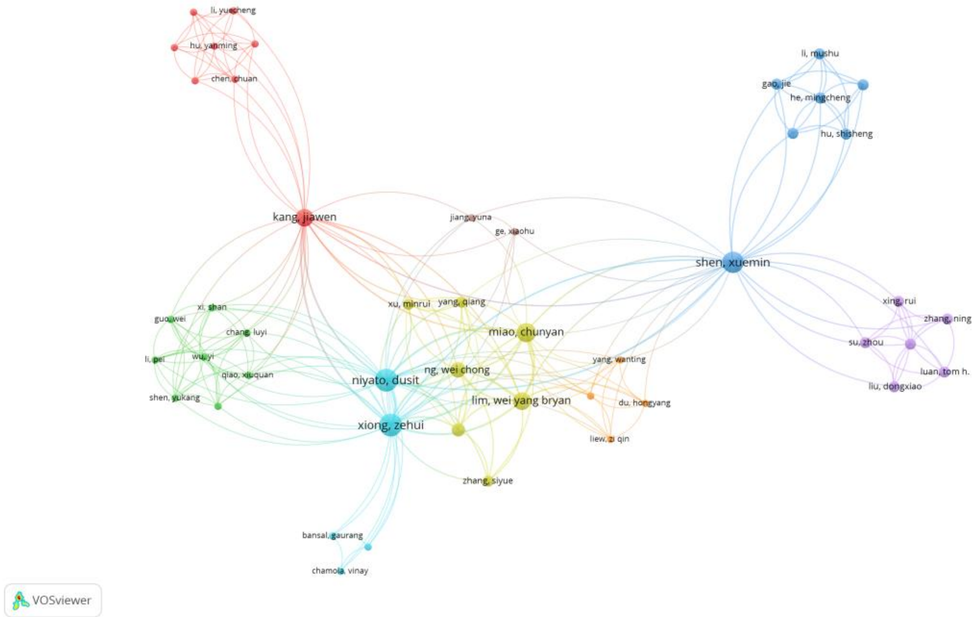

Figure 1 Co-authorship

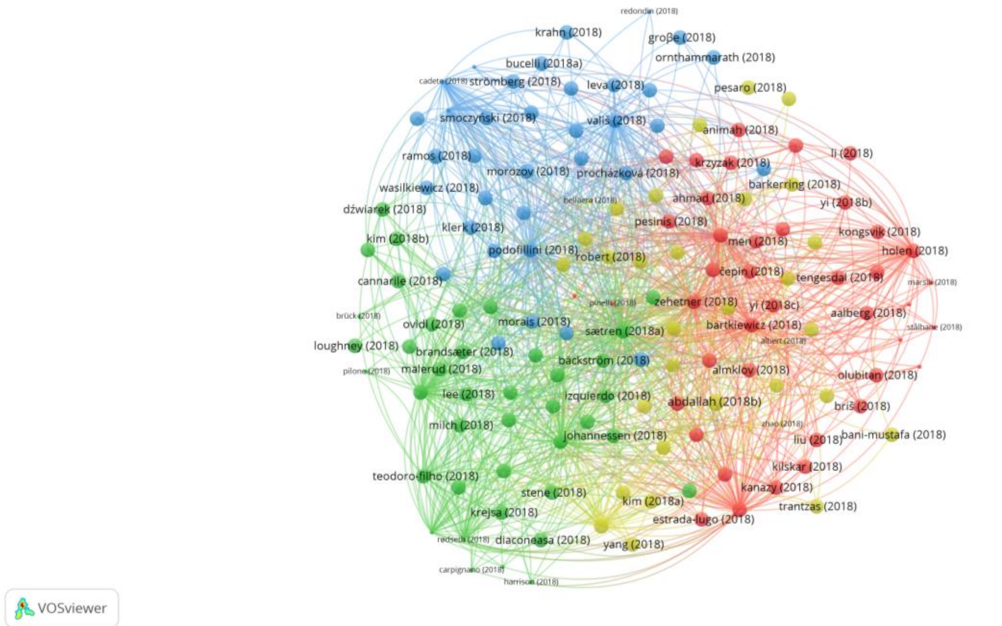

Figure 2 Citation

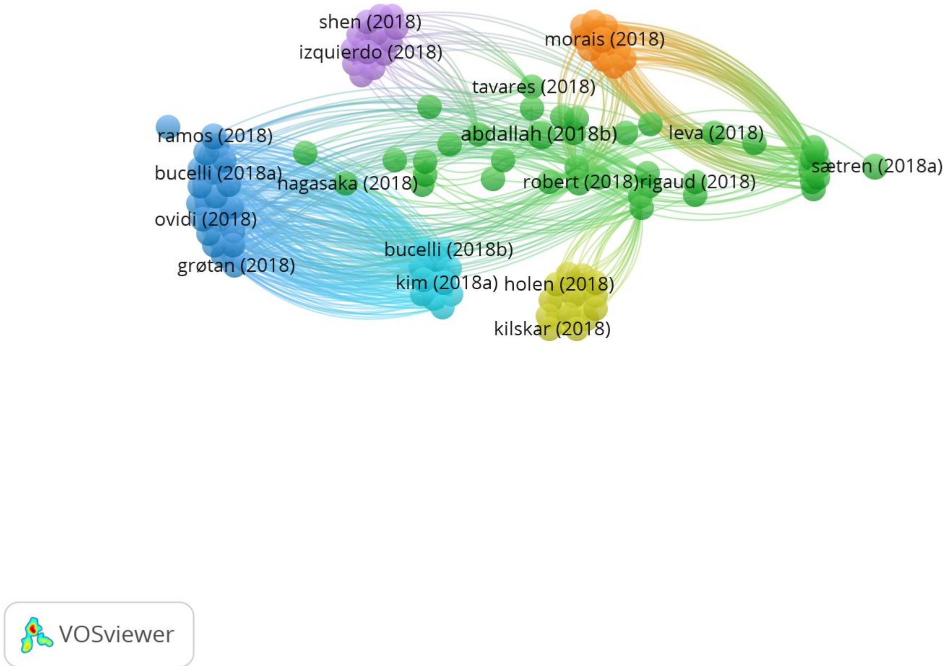

Figure 3 Bibliographic coupling

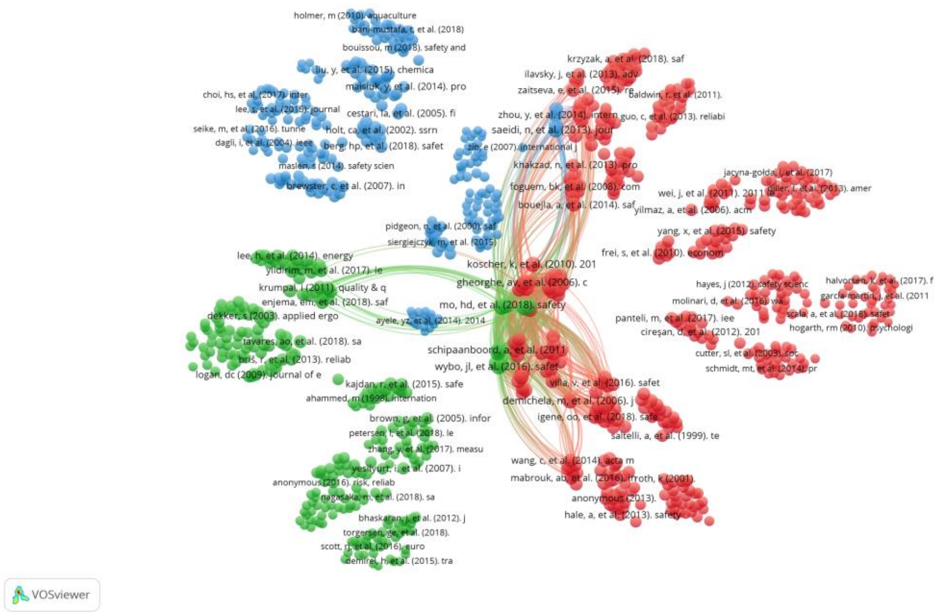

Figure 4 Co-citation

Table 2 General synopsis of evidence as regards focus topics and descriptive outcomes (research findings).

Context recognition and ambient scene detection tools, sensing and computing technologies, and immersive visualization and navigation systems articulate the metaverse interactive environment.	Braud et al., 2022; Dolata and Schwabe, 2023; Han et al., 2022; McStay, 2023
Immersive decentralized networking and digital twin simulation tools, blockchain and cloud computing technologies, and distributed decision and control algorithms are pivotal in the interconnected metaverse.	Dincelli and Yayla, 2022; Gauttier et al., 2022; Han et al., 2023a; Perkins, 2022
Hyper-realistic personalized interactive experiences can be attained through holographic telepresence and cognitive enhancement technologies, visual perceptive and multimodal sensing systems, and motion control and emotion detection algorithms.	Han et al., 2023b; He et al., 2023; Li et al., 2023a; Zhang et al., 2022
Immersive and extended reality technologies, artificial vision and remote sensing systems, and digital twin simulation and smart environment modeling tools enable the blockchain-based metaverse.	Dwivedi et al., 2023; Lv et al., 2022; Polas et al., 2022; Zheng and Yuan, 2023
Deep learning-based ambient sound processing and real-time data tracking tools, metaverse and immersive technologies, and image detection and computer vision algorithms assist synthetic digitally-mediated environments.	Ersoy and Gürfidan, 2023; Grupac and Lăzăroiu, 2022; Nica et al., 2022; Zallio and Clarkson, 2022
3D immersive spaces and experiences can be achieved by use of conversational artificial intelligence and situational awareness algorithms, neuromorphic image processing and haptic object recognition systems, and affective and perceptual technologies.	Hennig-Thurau et al., 2022; McStay, 2022; Newell, 2022; Zhang et al., 2023a
Blockchain-based metaverse platforms necessitate decision-making process automation and geospatial mapping tools, 3D modeling and simulation technologies, and deep learning-based predictive and image recognition algorithms.	Aloqaily et al., 2022; Shen, 2022; Venugopal et al., 2023; Zhang et al., 2023b
Decision support and data visualization tools, immersive extended reality technologies, and image data-based predictive and visual object tracking algorithms enable Web3-powered metaverse worlds and 3D virtual environments.	Ding et al., 2022; Panagiotakopoulos et al., 2022; Weking et al., 2023; Zhu et al., 2023
Geospatial mapping and environment perception technologies, big data computing and autonomous cognitive systems, and data acquisition and 3D generative modeling tools configure extended reality environments.	Bordegoni and Ferrise, 2023; Li et al., 2023b; Rostami and Maier, 2022; Wang et al., 2022

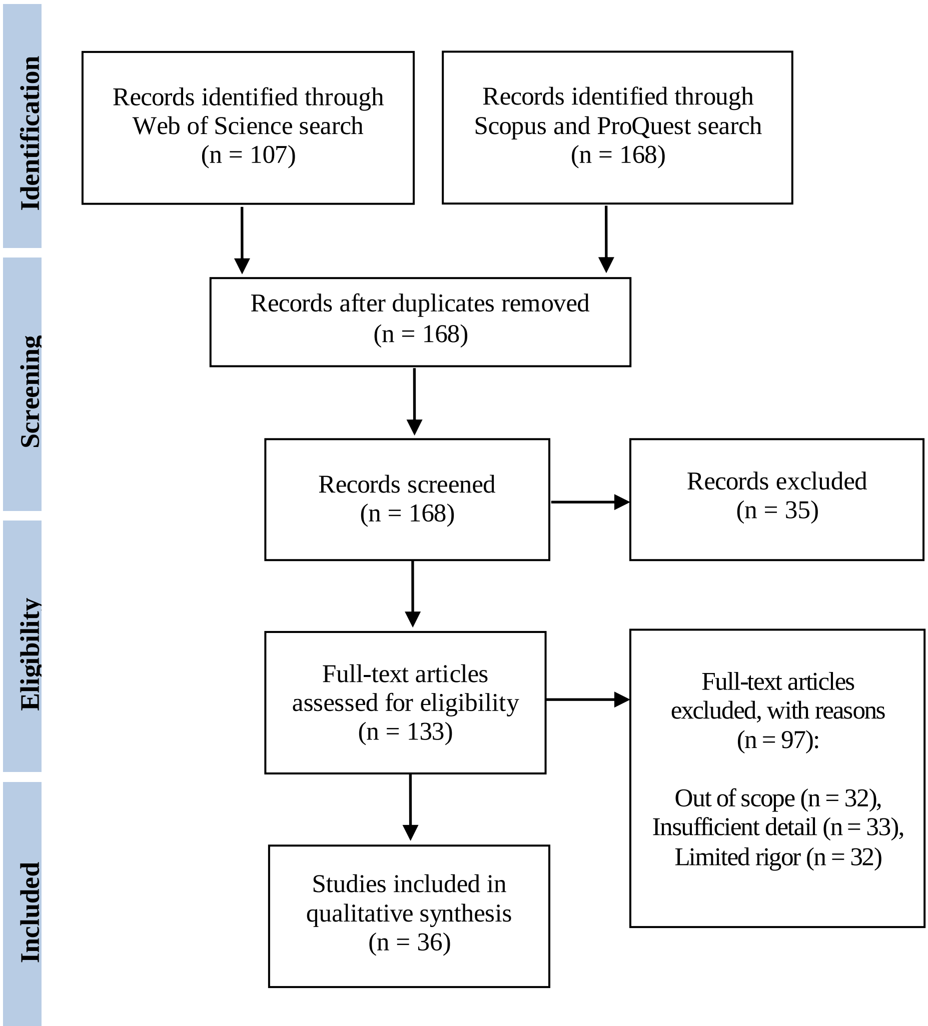

Figure 5 PRISMA flow diagram describing the search results and screening.

Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines were used that ensure the literature review is comprehensive, transparent, and replicable. The flow diagram, produced by employing a Shiny app, presents the stream of evidence-based collected and processed data through the various steps of a systematic review, designing the amount of identified, included, and removed records, and the justifications for exclusions.
To ensure compliance with PRISMA guidelines, a citation software was used, and at each stage the inclusion or exclusion of articles was tracked by use of custom spreadsheet. Justification for the removal of ineligible articles was specified during the full-text screening and final selection.

To ensure first-rate standard of evidence, a systematic search of relevant databases including peer-reviewed published journal articles was conducted using predefined search terms, covering a range of research methods and data sources. Reference lists of all relevant sources were manually reviewed for additional relevant citations.

Titles of papers and abstracts were screened for suitability and selected full texts were retrieved to establish whether they satisfied the inclusion criteria. All records from each database were evaluated by using data extraction forms. Data covering research aims, participants, study design, and method of each paper were extracted.

The inclusion criteria were: (i) articles included in the Web of Science, Scopus, and ProQuest databases, (ii) publication date (2022–2023), (iii) written in English, (iv) being an original empirical research or review article, and (v) particular search terms covered; (i) conference proceedings, (ii) books, and (iii) editorial materials were eliminated from the analysis.

SRDR gathered, handled, and analyzed the data for the systematic review, being configured as an archive and tool harnessed in data extraction through transparent, efficient, and reliable quantitative techniques. Elaborate extraction forms can be set up, meeting the needs of research questions and study designs.

Distiller SR screened and extracted the collected data.

AMSTAR evaluated the methodological quality of systematic reviews.

The quality of academic articles was determined and risk of bias was measured by MMAT, that tested content validity and usability of selected studies in terms of screening questions, type of design, corresponding quality criteria, and overall quality score.

Dedoose analyzed qualitative and mixed methods research.

AXIS evaluated the quality of cross-sectional studies.

ROBIS assessed the risk of bias in systematic reviews.

Figure 6 Screening and quality assessment tools

4. Deep Learning-based Sensing and Geospatial Mapping Technologies, Immersive Decentralized Networking and Digital Twin Simulation Tools, and Motion Control and Emotion Detection Algorithms in the Metaverse Interactive Environment

Context recognition and ambient scene detection tools, sensing and computing technologies, and immersive visualization and navigation systems (Braud et al., 2022; Dolata and Schwabe, 2023; Han et al., 2022; McStay, 2023) articulate the metaverse interactive environment. Deep learning-based sensing and geospatial mapping technologies, movement and behavior tracking tools, and computer vision and immersive visualization systems assist extended reality environments. Immersive virtual environments integrate sensory data mining techniques, haptic bodysuits, real-time sensor data, and image acquisition devices.

Immersive decentralized networking and digital twin simulation tools, blockchain and cloud computing technologies, and distributed decision and control algorithms (Dincelli and Yayla, 2022; Gauttier et al., 2022; Han et al., 2023a; Perkins, 2022) are pivotal in the interconnected metaverse. 3D capture and spatial computing technologies, artificial neural network-based decision support and immersive visualization systems, and data visualization and socio-spatial analytics tools further extended reality environments.

Hyper-realistic personalized interactive experiences (Han et al., 2023b; He et al., 2023; Li et al., 2023a; Zhang et al., 2022) can be attained through holographic telepresence and cognitive enhancement technologies, visual perceptive and multimodal sensing systems, and motion control and emotion detection algorithms. Virtual navigation and automated speech recognition tools, machine learning and computer vision algorithms, and digital twinning and multisensor fusion technologies shape extended reality environments and interactive digital worlds. (Table 3)

Table 3 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Context recognition and ambient scene detection tools, sensing and computing technologies, and immersive visualization and navigation systems articulate the metaverse interactive environment.	Braud et al., 2022; Dolata and Schwabe, 2023; Han et al., 2022; McStay, 2023
Immersive decentralized networking and digital twin simulation tools, blockchain and cloud computing technologies, and distributed decision and control algorithms are pivotal in the interconnected metaverse.	Dincelli and Yayla, 2022; Gauttier et al., 2022; Han et al., 2023a; Perkins, 2022
Hyper-realistic personalized interactive experiences can be attained through holographic telepresence and cognitive enhancement technologies, visual perceptive and multimodal sensing systems, and motion control and emotion detection algorithms.	Han et al., 2023b; He et al., 2023; Li et al., 2023a; Zhang et al., 2022

5. Deep Learning-based Ambient Sound Processing and Real-Time Data Tracking Tools, Geospatial Artificial Intelligence and Cognitive Modeling Technologies, and Machine Vision and Situational Awareness Algorithms in the Blockchain-based Metaverse

Immersive and extended reality technologies, artificial vision and remote sensing systems, and digital twin simulation and smart environment modeling tools (Dwivedi et al., 2023; Lv et al., 2022; Polas et al., 2022; Zheng and Yuan, 2023) enable the blockchain-based metaverse. 3D modeling and natural language processing tools, data fusion and cognitive artificial intelligence technologies, and machine vision and situational awareness algorithms optimize interactive virtual and extended reality environments.

Deep learning-based ambient sound processing and real-time data tracking tools, metaverse and immersive technologies, and image detection and computer vision algorithms (Ersoy and Gürfidan, 2023; Grupac and Lăzăroiu, 2022; Nica et al., 2022; Zallio and Clarkson, 2022) assist synthetic digitally-mediated environments. Interactive digital worlds develop on monitoring and sensing technologies, digital twin modeling and virtual navigation tools, and automated speech recognition and artificial vision systems.

3D immersive spaces and experiences (Hennig-Thurau et al., 2022; McStay, 2022; Newell, 2022; Zhang et al., 2023a) can be achieved by use of conversational artificial intelligence and situational awareness algorithms, neuromorphic image processing and haptic object recognition systems, and affective and perceptual technologies. Immersive 3D environments integrate movement and behavior tracking tools, geospatial artificial intelligence and cognitive modeling technologies, and 3D image processing and computer vision algorithms. (Table 4)

Table 4 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Immersive and extended reality technologies, artificial vision and remote sensing systems, and digital twin simulation and smart environment modeling tools enable the blockchain-based metaverse.	Dwivedi et al., 2023; Lv et al., 2022; Polas et al., 2022; Zheng and Yuan, 2023
Deep learning-based ambient sound processing and real-time data tracking tools, metaverse and immersive technologies, and image detection and computer vision algorithms assist synthetic digitally-mediated environments.	Ersoy and Gürfidan, 2023; Grupac and Lăzăroiu, 2022; Nica et al., 2022; Zallio and Clarkson, 2022
3D immersive spaces and experiences can be achieved by use of conversational artificial intelligence and situational awareness algorithms, neuromorphic image processing and haptic object recognition systems, and affective and perceptual technologies.	Hennig-Thurau et al., 2022; McStay, 2022; Newell, 2022; Zhang et al., 2023a

6. Deep Learning-based Predictive and Image Recognition Algorithms, Geospatial Mapping and Environment Perception Technologies, and Data Acquisition and 3D Generative Modeling Tools in Web3-powered Metaverse Worlds

Blockchain-based metaverse platforms (Aloqaily et al., 2022; Shen, 2022; Venugopal et al., 2023; Zhang et al., 2023b) necessitate decision-making process automation and geospatial mapping tools, 3D modeling and simulation technologies, and deep learning-based predictive and image recognition algorithms. Extended reality environments require 3D object recognition and virtual twin technologies, deep learning and path planning algorithms, and virtual navigation and real-time data tracking tools.

Decision support and data visualization tools, immersive extended reality technologies, and image data-based predictive and visual object tracking algorithms (Ding et al., 2022; Panagiotakopoulos et al., 2022; Weking et al., 2023; Zhu et al., 2023) enable Web3-powered metaverse worlds and 3D virtual environments. Artificial intelligence-based image recognition and digital twin technologies, visual and spatial intelligence tools, and predictive maintenance and computer vision algorithms are instrumental in 3D interactive digital spaces and blockchain-based virtual worlds.

Geospatial mapping and environment perception technologies, big data computing and autonomous cognitive systems, and data acquisition and 3D generative modeling tools (Bordegoni and Ferrise, 2023; Li et al., 2023b; Rostami and Maier, 2022; Wang et al., 2022) configure extended reality environments. Simulation modeling and image recognition tools, deep learning-based sentiment and behavioral predictive analytics, and dynamic routing and spatial computing technologies configure immersive virtual environments. (Table 5)

Table 5 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Blockchain-based metaverse platforms necessitate decision-making process automation and geospatial mapping tools, 3D modeling and simulation technologies, and deep learning-based predictive and image recognition algorithms.	Aloqaily et al., 2022; Shen, 2022; Venugopal et al., 2023; Zhang et al., 2023b
Decision support and data visualization tools, immersive extended reality technologies, and image data-based predictive and visual object tracking algorithms enable Web3-powered metaverse worlds and 3D virtual environments.	Ding et al., 2022; Panagiotakopoulos et al., 2022; Weking et al., 2023; Zhu et al., 2023
Geospatial mapping and environment perception technologies, big data computing and autonomous cognitive systems, and data acquisition and 3D generative modeling tools configure extended reality environments.	Bordegoni and Ferrise, 2023; Li et al., 2023b; Rostami and Maier, 2022; Wang et al., 2022

7. Discussion

I integrate my systematic review throughout research indicating how virtual navigation and automated speech recognition tools, machine learning and computer vision algorithms, and digital twinning and multisensor fusion technologies shape extended reality environments and interactive digital worlds. My research complements recent analyses clarifying how 3D modeling and natural language processing tools, data fusion and cognitive artificial intelligence technologies, and machine vision and situational awareness algorithms optimize interactive virtual and extended reality environments. I elucidate, by cumulative evidence, previous research demonstrating how deep learning-based sensing and geospatial mapping technologies, movement and behavior tracking tools, and computer vision and immersive visualization systems assist extended reality environments.

8. Synopsis of the Main Research Outcomes

Interactive digital worlds develop on monitoring and sensing technologies, digital twin modeling and virtual navigation tools, and automated speech recognition and artificial vision systems. Simulation modeling and image recognition tools, deep learning-based sentiment and behavioral predictive analytics, and dynamic routing and spatial computing technologies configure immersive virtual environments.

9. Conclusions

Relevant research has investigated whether extended reality environments require 3D object recognition and virtual twin technologies, deep learning and path planning algorithms, and virtual navigation and real-time data tracking tools. This systematic literature review presents the published peer-reviewed sources covering how artificial intelligence-based image recognition and digital twin technologies, visual and spatial intelligence tools, and predictive maintenance and computer vision algorithms are instrumental in 3D interactive digital spaces and blockchain-based virtual worlds. The research outcomes drawn from the above analyses indicate that immersive virtual environments integrate sensory data mining techniques, haptic bodysuits, real-time sensor data, and image acquisition devices.

10. Limitations, Implications, and Further Directions of Research

By analyzing only articles published between 2022 and 2023 in journals indexed in the Web of Science, Scopus, and ProQuest databases, relevant sources on predictive modeling and visual perception algorithms, ambient sound recognition and processing tools, and deep neural network and vision sensing technologies in the decentralized and interconnected metaverse may have been excluded. Limitations of this research comprise particular kinds of publications (original empirical research and review articles) discounting others (conference proceedings articles, books, and editorial materials). The scope of my study also does not move forward the inspection of context recognition and ambient scene detection tools, sensing and computing technologies, and immersive visualization and navigation systems.

Subsequent analyses should develop on immersive decentralized networking and digital twin simulation tools, blockchain and cloud computing technologies, and distributed decision and control algorithms. Future research should thus investigate decision support and data visualization tools, immersive extended reality technologies, and image data-based predictive and visual object tracking algorithms. Attention should be directed to immersive and extended reality technologies, artificial vision and remote sensing systems, and digital twin simulation and smart environment modeling tools.

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Compliance with ethical standards
This article does not contain any studies with human participants or animals performed by the author. Extracting and inspecting publicly accessible files (scholarly sources) as evidence, before the research began no institutional ethics approval was required.

Data availability statement
All data generated or analyzed are included in the published article.

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Author contributions
The author confirms being the sole contributor of this work and approved it for publication. The author takes full responsibility for the accuracy and the integrity of the data analysis.

Conflict of interest statement
The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Disclosure by the editors of record
The editors declare no conflict of interest in the review and publication decision regarding this article.

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Movement and Behavior Tracking Tools, Spatial Computing and Visual Perception Algorithms, and Deep Learning-based Sensing and Digital Twin Technologies in the Virtual Economy of the Metaverse

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ABSTRACT. This article reviews and advances existing literature concerning affective and perceptual technologies, metaverse engagement metrics, and intelligent connectivity infrastructures. We contribute to the literature by indicating that immersive 3D worlds develop on Internet of Things-based decision support and distributed autonomous control systems, physics-based modeling and simulation tools, and spatial computing and environment mapping algorithms. Throughout January 2023, a quantitative literature review of the Web of Science, Scopus, and ProQuest databases was performed, with search terms including "the virtual economy of the metaverse" + "movement and behavior tracking tools," "spatial computing and visual perception algorithms," and "deep learning-based sensing and digital twin technologies." As research published between 2022 and 2023 was inspected, only 173 articles satisfied the eligibility criteria. By taking out controversial or ambiguous findings (insufficient/irrelevant data), outcomes unsubstantiated by replication, too general material, or studies with nearly identical titles, we selected 33 mainly empirical sources. Data visualization tools: Dimensions (bibliometric mapping) and VOSviewer (layout algorithms). Reporting quality assessment tool: PRISMA. Methodological quality assessment tools include: AXIS, MMAT, ROBIS, and SRDR.

Keywords: movement and behavior tracking tools, spatial computing and visual perception algorithms, and deep learning-based sensing and digital twin technologies; metaverse

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1. Introduction

Deep learning-based spatial analytics, eye-tracking and digital contact tracing technologies, and deep learning artificial intelligence and image recognition tools further immersive interconnected virtual worlds. The purpose of our systematic review is to examine the recently published literature on the virtual economy of the metaverse and integrate the insights it configures on movement and behavior tracking tools, spatial computing and visual perception algorithms, and deep learning-based sensing and digital twin technologies. By analyzing the most recent (2022–2023) and significant (Web of Science, Scopus, and ProQuest) sources, our paper has attempted to prove that immersive 3D worlds develop on Internet of Things-based decision support and distributed autonomous control systems (Andronie et al., 2023; Lăzăroiu, 2018; Popescu et al., 2017), physics-based modeling and simulation tools, and spatial computing and environment mapping algorithms. The actuality and novelty of this study are articulated by addressing affective and perceptual technologies, metaverse engagement metrics, and intelligent connectivity infrastructures, that is an emerging topic involving much interest. Our research problem is whether mobile geofencing and digital contact tracing technologies, multiscale spatial data processing and operational modeling tools (Andronie et al., 2021; Krizanova et al., 2019; Popescu et al., 2017), and text mining and analytics assist digitally-networked mediated spaces.

In this review, prior findings have been cumulated indicating that multisensor fusion and real-time visual analytics systems (Barber, 2022; Nica, 2017; Popescu, 2018; Vătămănescu et al., 2020), machine vision and location-based predictive algorithms, and virtual and augmented reality tools optimize immersive digital worlds. The identified gaps advance machine learning-based image recognition and context awareness tools (Barbu et al., 2021; Nica, 2018; Rowland, 2022; Vinerean et al., 2022), biometric authentication and immersive visualization systems, and virtual simulation and cognitive decision-making algorithms. Our main objective is to indicate that geospatial mapping and digital twin simulation tools (Barnes, 2022; Nica et al., 2023; Valaskova et al., 2022), sensorial and cognitive technologies, and deep learning-based ambient sound processing are instrumental in extended reality environments.

2. Theoretical Overview of the Main Concepts

Machine learning-based predictive and virtual mapping algorithms, artificial intelligence-powered prediction and autonomous visual object detection tools, and cloud-based cognitive and immersive 3D technologies are pivotal in immersive decentralized 3D digital worlds. Spatial computing and digital twinning technologies, virtual twin modeling and data mining tools, and big geospatial data and user journey analytics enable immersive 3D virtual environments. The manuscript is organized as following: theoretical overview (section 2), methodology (section 3), immersive visualization and cyber-physical cognitive systems, spatial computing and data analytics technologies, and natural language processing and virtual navigation tools in the metaverse economy (section 4), digital twinning and intelligent data processing tools, machine learning-based predictive and virtual mapping algorithms, and biometric authentication and immersive visualization systems in the metaverse interactive environment (section 5), deep learning-based sensing and immersive technologies, multiscale spatial data processing and operational modeling tools, and cognitive artificial intelligence and computer vision algorithms in the virtual economy of the metaverse (section 6), discussion (section 7), synopsis of the main research outcomes (section 8), conclusions (section 9), limitations, implications, and further directions of research (section 10).

3. Methodology

Throughout January 2023, a quantitative literature review of the Web of Science, Scopus, and ProQuest databases was performed, with search terms including “the virtual economy of the metaverse” + “movement and behavior tracking tools,” “spatial computing and visual perception algorithms,” and “deep learning-based sensing and digital twin technologies.” As research published between 2022 and 2023 was inspected, only 173 articles satisfied the eligibility criteria. By taking out controversial or ambiguous findings (insufficient/irrelevant data), outcomes unsubstantiated by replication, too general material, or studies with nearly identical titles, we selected 33 mainly empirical sources (Tables 1 and 2). Data visualization tools: Dimensions (bibliometric mapping) and VOSviewer (layout algorithms). Reporting quality assessment tool: PRISMA. Methodological quality assessment tools include: AXIS, MMAT, ROBIS, and SRDR (Figures 1–6).

Table 1 Topics and types of scientific products identified and selected.

Topic	**Identified**	**Selected**
the virtual economy of the metaverse + movement and behavior tracking tools	60	12
the virtual economy of the metaverse + spatial computing and visual perception algorithms	58	11
the virtual economy of the metaverse + deep learning-based sensing and digital twin technologies	55	10
Type of paper		
Original research	143	24
Review	21	9
Conference proceedings	8	0
Book	0	0
Editorial	1	0

Source: Processed by the authors. Some topics overlap.

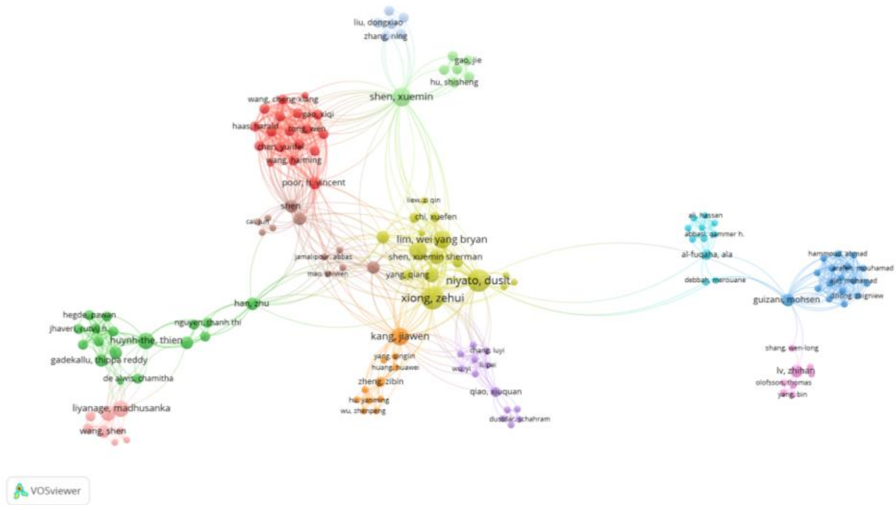

Figure 1 Co-authorship

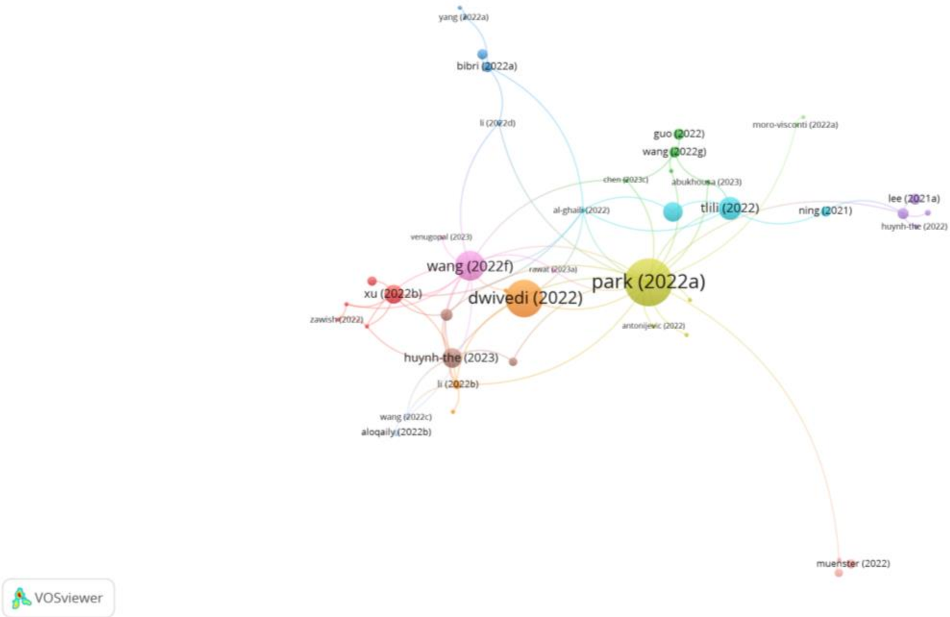

Figure 2 Citation

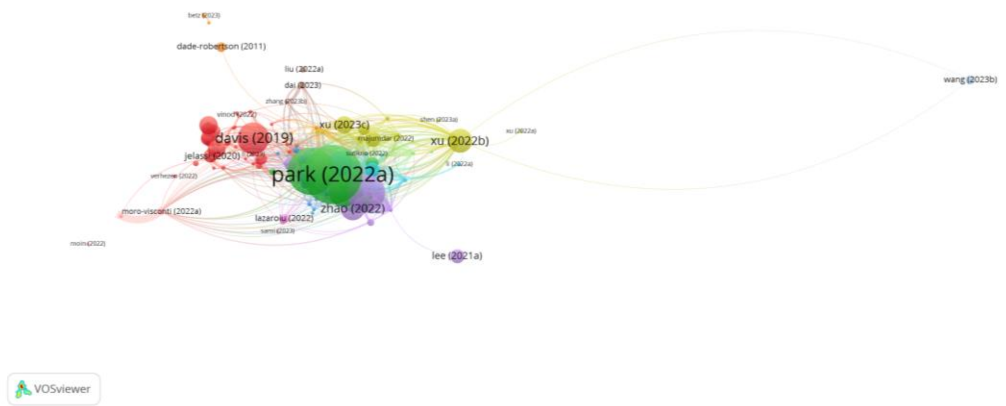

Figure 3 Bibliographic coupling

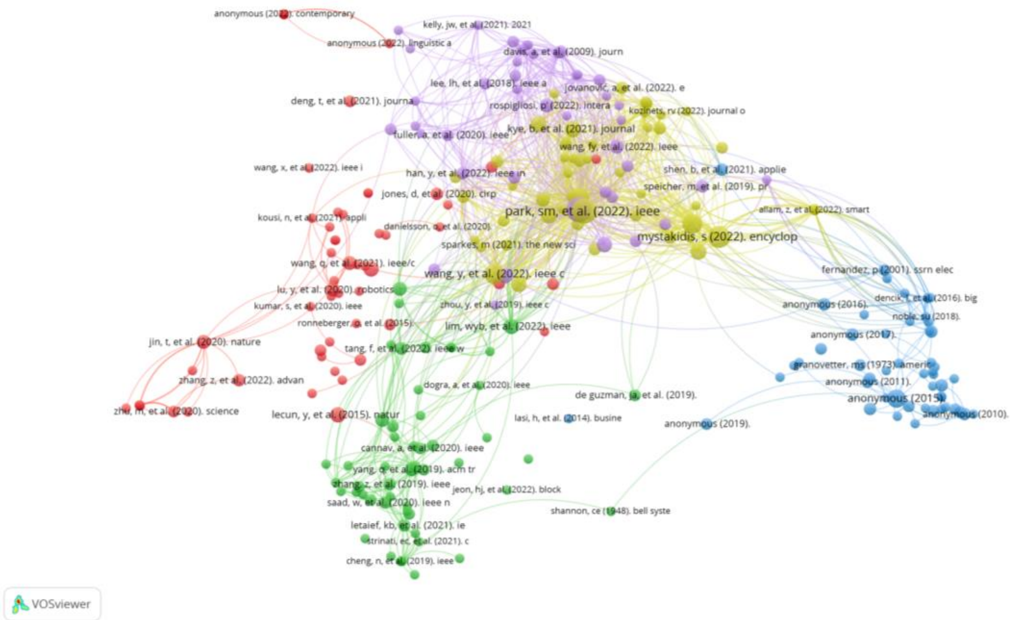

Figure 4 Co-citation

Table 2 General synopsis of evidence as regards focus topics and descriptive outcomes (research findings).

Immersive metaverse experiences can be attained through deep learning and spatial cognition algorithms, immersive visualization and cyber-physical cognitive systems, and movement and behavior tracking tools.	Chen, 2022; Duncan, 2022; Xu et al., 2023; Zarantonello and Schmitt, 2023
Spatial computing and data analytics technologies, natural language processing and virtual navigation tools, and machine learning-based sentiment analytics articulate 3D virtual environments in the metaverse economy.	Gauttier et al., 2022; Hollensen et al., 2023; Kliestik et al., 2023; Park and Kim, 2023
Immersive virtual reality experiences can be achieved by use of auditory and visual immersion systems, context awareness and spatio-temporal fusion algorithms, and movement and behavior tracking tools.	Cuțitoi, 2022; Giang Barrera and Shah, 2023; Tang et al., 2023
Autonomous cognitive and networked immersive virtual reality systems, modeling and forecasting tools, and computer vision and spatio-temporal fusion algorithms shape blockchain-based metaverse platforms and 3D virtual immersive environments.	Cheng et al., 2022; Ersoy and Gürfidan, 2023; Hancock, 2022; Zhang et al., 2023
The metaverse interactive environment and immersive digital worlds develop on digital twinning and intelligent data processing tools, cloud and edge computing technologies, and picture-making neural and interoperable virtual networks.	Du et al., 2023; Golf-Papez et al., 2022; Huynh-The et al., 2023a; Zhou et al., 2023
Immersive virtual experiences can be attained by use of machine learning-based image recognition and context awareness tools, biometric authentication and immersive visualization systems, and virtual simulation and cognitive decision-making algorithms.	Jenkins, 2022; Van Huynh et al., 2022; Weking et al., 2023; Zainab et al., 2022
The virtual economy of the metaverse necessitate deep reinforcement learning and predictive modeling tools, eye-tracking and 3D object recognition technologies, and hyper-realistic immersive 3D simulations.	Kwok and Tang, 2023; Lv et al., 2022a; Zhang et al., 2022
The digital asset-based virtual economy and extended reality environments integrate affective and perceptual technologies, metaverse engagement metrics, and intelligent connectivity infrastructures.	Faraboschi et al., 2022; Mourtzis et al., 2022; Wongkitrungrueng and Suprawan, 2023
Hyperconnected virtual experiences can be achieved through cognitive artificial intelligence and computer vision algorithms, spatial awareness and tracking tools, and empathetic computing and immersive visualization systems.	Huynh-The et al., 2023b; Nagendran et al., 2022; Lv et al., 2022b; Wu et al., 2023

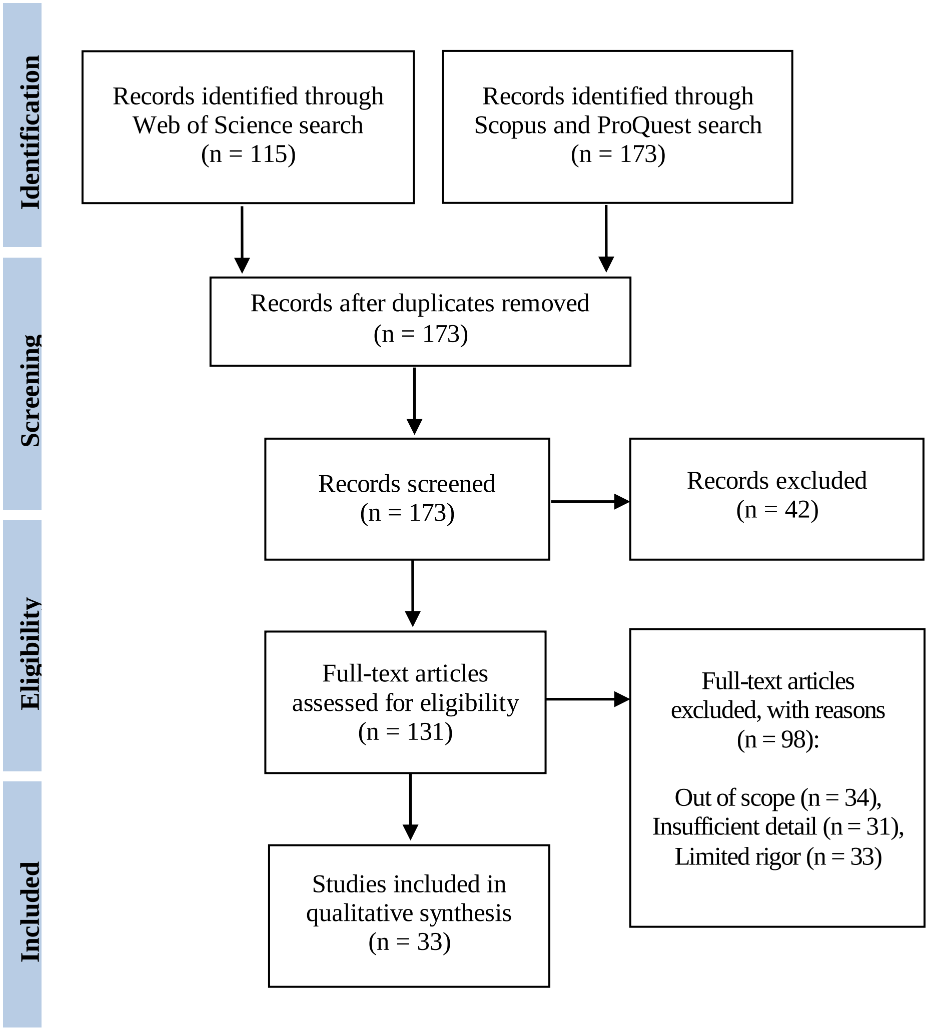

Figure 5 PRISMA flow diagram describing the search results and screening.

Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines were used that ensure the literature review is comprehensive, transparent, and replicable. The flow diagram, produced by employing a Shiny app, presents the stream of evidence-based collected and processed data through the various steps of a systematic review, designing the amount of identified, included, and removed records, and the justifications for exclusions.
To ensure compliance with PRISMA guidelines, a citation software was used, and at each stage the inclusion or exclusion of articles was tracked by use of custom spreadsheet. Justification for the removal of ineligible articles was specified during the full-text screening and final selection.

To ensure first-rate standard of evidence, a systematic search of relevant databases including peer-reviewed published journal articles was conducted using predefined search terms, covering a range of research methods and data sources. Reference lists of all relevant sources were manually reviewed for additional relevant citations.

↓

Titles of papers and abstracts were screened for suitability and selected full texts were retrieved to establish whether they satisfied the inclusion criteria. All records from each database were evaluated by using data extraction forms. Data covering research aims, participants, study design, and method of each paper were extracted.

↓

The inclusion criteria were: (i) articles included in the Web of Science, Scopus, and ProQuest databases, (ii) publication date (2022–2023), (iii) written in English, (iv) being an original empirical research or review article, and (v) particular search terms covered; (i) conference proceedings, (ii) books, and (iii) editorial materials were eliminated from the analysis.

↓

SRDR gathered, handled, and analyzed the data for the systematic review, being configured as an archive and tool harnessed in data extraction through transparent, efficient, and reliable quantitative techniques. Elaborate extraction forms can be set up, meeting the needs of research questions and study designs.

↓

Distiller SR screened and extracted the collected data.

↓

AMSTAR evaluated the methodological quality of systematic reviews.

↓

The quality of academic articles was determined and risk of bias was measured by MMAT, that tested content validity and usability of selected studies in terms of screening questions, type of design, corresponding quality criteria, and overall quality score.

↓

Dedoose analyzed qualitative and mixed methods research.

↓

AXIS evaluated the quality of cross-sectional studies.

↓

ROBIS assessed the risk of bias in systematic reviews.

Figure 6 Screening and quality assessment tools

4. Immersive Visualization and Cyber-Physical Cognitive Systems, Spatial Computing and Data Analytics Technologies, and Natural Language Processing and Virtual Navigation Tools in the Metaverse Economy

Immersive metaverse experiences (Chen, 2022; Duncan, 2022; Xu et al., 2023; Zarantonello and Schmitt, 2023) can be attained through deep learning and spatial cognition algorithms, immersive visualization and cyber-physical cognitive systems, and movement and behavior tracking tools. Multi-sensor fusion and real-time visual analytics systems, machine vision and location-based predictive algorithms, and virtual and augmented reality tools optimize immersive digital worlds.

Spatial computing and data analytics technologies, natural language processing and virtual navigation tools, and machine learning-based sentiment analytics (Gauttier et al., 2022; Hollensen et al., 2023; Kliestik et al., 2023; Park and Kim, 2023) articulate 3D virtual environments in the metaverse economy. Immersive 3D worlds develop on Internet of Things-based decision support and distributed autonomous control systems, physics-based modeling and simulation tools, and spatial computing and environment mapping algorithms.

Immersive virtual reality experiences (Cuțitoi, 2022; Giang Barrera and Shah, 2023; Tang et al., 2023) can be achieved by use of auditory and visual immersion systems, context awareness and spatio-temporal fusion algorithms, and movement and behavior tracking tools. Extended reality environments integrate edge artificial intelligence computing and network virtualization systems, multi-machine cooperation and socio-spatial analytics tools, and deep learning and visual cognitive algorithms. (Table 3)

Table 3 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Immersive metaverse experiences can be attained through deep learning and spatial cognition algorithms, immersive visualization and cyber-physical cognitive systems, and movement and behavior tracking tools.	Chen, 2022; Duncan, 2022; Xu et al., 2023; Zarantonello and Schmitt, 2023
Spatial computing and data analytics technologies, natural language processing and virtual navigation tools, and machine learning-based sentiment analytics articulate 3D virtual environments in the metaverse economy.	Gauttier et al., 2022; Hollensen et al., 2023; Kliestik et al., 2023; Park and Kim, 2023
Immersive virtual reality experiences can be achieved by use of auditory and visual immersion systems, context awareness and spatio-temporal fusion algorithms, and movement and behavior tracking tools.	Cuțitoi, 2022; Giang Barrera and Shah, 2023; Tang et al., 2023

5. Digital Twinning and Intelligent Data Processing Tools, Machine Learning-based Predictive and Virtual Mapping Algorithms, and Biometric Authentication and Immersive Visualization Systems in the Metaverse Interactive Environment

Autonomous cognitive and networked immersive virtual reality systems, modeling and forecasting tools, and computer vision and spatio-temporal fusion algorithms (Cheng et al., 2022; Ersoy and Gürfidan, 2023; Hancock, 2022; Zhang et al., 2023) shape blockchain-based metaverse platforms and 3D virtual immersive environments. Shared virtual environments require deep learning and visual perception algorithms, machine learning-based image recognition and big data management tools, and sensing and computing technologies.

The metaverse interactive environment and immersive digital worlds (Du et al., 2023; Golf-Papez et al., 2022; Huynh-The et al., 2023a; Zhou et al., 2023) develop on digital twinning and intelligent data processing tools, cloud and edge computing technologies, and picture-making neural and interoperable virtual networks. Machine learning-based predictive and virtual mapping algorithms, artificial intelligence-powered prediction and autonomous visual object detection tools, and cloud-based cognitive and immersive 3D technologies are pivotal in immersive decentralized 3D digital worlds.

Immersive virtual experiences (Jenkins, 2022; Van Huynh et al., 2022; Weking et al., 2023; Zainab et al., 2022) can be attained by use of machine learning-based image recognition and context awareness tools, biometric authentication and immersive visualization systems, and virtual simulation and cognitive decision-making algorithms. Geospatial mapping and digital twin simulation tools, sensorial and cognitive technologies, and deep learning-based ambient sound processing are instrumental in extended reality environments. (Table 4)

Table 4 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Autonomous cognitive and networked immersive virtual reality systems, modeling and forecasting tools, and computer vision and spatio-temporal fusion algorithms shape blockchain-based metaverse platforms and 3D virtual immersive environments.	Cheng et al., 2022; Ersoy and Gürfidan, 2023; Hancock, 2022; Zhang et al., 2023
The metaverse interactive environment and immersive digital worlds develop on digital twinning and intelligent data processing tools, cloud and edge computing technologies, and picture-making neural and interoperable virtual networks.	Du et al., 2023; Golf-Papez et al., 2022; Huynh-The et al., 2023a; Zhou et al., 2023
Immersive virtual experiences can be attained by use of machine learning-based image recognition and context awareness tools, biometric authentication and immersive visualization systems, and virtual simulation and cognitive decision-making algorithms.	Jenkins, 2022; Van Huynh et al., 2022; Weking et al., 2023; Zainab et al., 2022

6. Deep Learning-based Sensing and Immersive Technologies, Multiscale Spatial Data Processing and Operational Modeling Tools, and Cognitive Artificial Intelligence and Computer Vision Algorithms in the Virtual Economy of the Metaverse

The virtual economy of the metaverse (Kwok and Tang, 2023; Lv et al., 2022a; Zhang et al., 2022) necessitate deep reinforcement learning and predictive modeling tools, eye-tracking and 3D object recognition technologies, and hyper-realistic immersive 3D simulations. Deep learning-based sensing and immersive technologies, automated speech recognition and 3D modeling tools, and text mining and analytics configure blockchain-based virtual worlds.

The digital asset-based virtual economy and extended reality environments (Faraboschi et al., 2022; Mourtzis et al., 2022; Wongkitrungrueng and Suprawan, 2023) integrate affective and perceptual technologies, metaverse engagement metrics, and intelligent connectivity infrastructures. Mobile geofencing and digital contact tracing technologies, multiscale spatial data processing and operational modeling tools, and text mining and analytics assist digitally-networked mediated spaces. Deep learning-based spatial analytics, eye-tracking and digital contact tracing technologies, and deep learning artificial intelligence and image recognition tools further immersive interconnected virtual worlds.

Hyperconnected virtual experiences (Huynh-The et al., 2023b; Nagendran et al., 2022; Lv et al., 2022b; Wu et al., 2023) can be achieved through cognitive artificial intelligence and computer vision algorithms, spatial awareness and tracking tools, and empathetic computing and immersive visualization systems. Spatial computing and digital twinning technologies, virtual twin modeling and data mining tools, and big geospatial data and user journey analytics enable immersive 3D virtual environments. (Table 5)

Table 5 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

The virtual economy of the metaverse necessitate deep reinforcement learning and predictive modeling tools, eye-tracking and 3D object recognition technologies, and hyper-realistic immersive 3D simulations.	Kwok and Tang, 2023; Lv et al., 2022a; Zhang et al., 2022
The digital asset-based virtual economy and extended reality environments integrate affective and perceptual technologies, metaverse engagement metrics, and intelligent connectivity infrastructures.	Faraboschi et al., 2022; Mourtzis et al., 2022; Wongkitrungrueng and Suprawan, 2023
Hyperconnected virtual experiences can be achieved through cognitive artificial intelligence and computer vision algorithms, spatial awareness and tracking tools, and empathetic computing and immersive visualization systems.	Huynh-The et al., 2023b; Nagendran et al., 2022; Lv et al., 2022b; Wu et al., 2023

7. Discussion

We integrate our systematic review throughout research indicating how immersive 3D worlds develop on Internet of Things-based decision support and distributed autonomous control systems, physics-based modeling and simulation tools, and spatial computing and environment mapping algorithms. Our research complements recent analyses clarifying how extended reality environments integrate edge artificial intelligence computing and network virtualization systems, multi-machine cooperation and socio-spatial analytics tools, and deep learning and visual cognitive algorithms. We elucidate, by cumulative evidence, previous research demonstrating how multi-sensor fusion and real-time visual analytics systems, machine vision and location-based predictive algorithms, and virtual and augmented reality tools optimize immersive digital worlds.

8. Synopsis of the Main Research Outcomes

Deep learning-based sensing and immersive technologies, automated speech recognition and 3D modeling tools, and text mining and analytics configure blockchain-based virtual worlds. Deep learning-based spatial analytics, eye-tracking and digital contact tracing technologies, and deep learning artificial intelligence and image recognition tools further immersive interconnected virtual worlds.

9. Conclusions

Relevant research has investigated whether mobile geofencing and digital contact tracing technologies, multiscale spatial data processing and operational modeling tools, and text mining and analytics assist digitally-networked mediated spaces. This systematic literature review presents the published peer-reviewed sources covering how shared virtual environments require deep learning and visual perception algorithms, machine learning-based image recognition and big data management tools, and sensing and computing technologies. The research outcomes drawn from the above analyses indicate that geospatial mapping and digital twin simulation tools, sensorial and cognitive technologies, and deep learning-based ambient sound processing are instrumental in extended reality environments.

10. Limitations, Implications, and Further Directions of Research

By analyzing only articles published between 2022 and 2023 in journals indexed in the Web of Science, Scopus, and ProQuest databases, relevant sources on movement and behavior tracking tools, spatial computing and visual perception algorithms, and deep learning-based sensing and digital twin technologies in the virtual economy of the metaverse may have been excluded. Limitations of this research comprise particular kinds of publications (original empirical research and review articles) discounting others (conference proceedings articles, books, and editorial materials). The scope of our study also does not move forward the inspection of deep learning and spatial cognition algorithms, immersive visualization and cyber-physical cognitive systems, and movement and behavior tracking tools.

Subsequent analyses should develop on digital twinning and intelligent data processing tools, cloud and edge computing technologies, and picture-making neural and interoperable virtual networks. Future research should thus investigate deep reinforcement learning and predictive modeling tools, eye-tracking and 3D object recognition technologies, and hyper-realistic immersive 3D simulations. Attention should be directed to cognitive artificial intelligence and computer vision algorithms, spatial awareness and tracking tools, and empathetic computing and immersive visualization systems.

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Compliance with ethical standards

This article does not contain any studies with human participants or animals performed by the authors. Extracting and inspecting publicly accessible files (scholarly sources) as evidence, before the research began no institutional ethics approval was required.

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Author contributions

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication. The authors take full responsibility for the accuracy and the integrity of the data analysis.

Conflict of interest statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Disclosure by the editors of record

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Digital Twin and Metaverse Technologies, Cognitive Mapping and Navigation Tools, and Image Processing Computational and Object Tracking Algorithms in Immersive 3D Virtual Reality Environments

Kathleen Porter*

ABSTRACT. Despite the relevance of biometric authentication and immersive visualization systems, spatial data mapping and simulation modeling tools, user identification technology and location data, and image recognition and visual perception algorithms, only limited research has been conducted on this topic. In this article, I cumulate previous research findings indicating that voice recognition software, virtual modeling technologies, data mining techniques, and multi-sensory extended reality shape immersive 3D worlds. I contribute to the literature on the metaverse interactive environment by showing that computer vision and spatio-temporal fusion algorithms, haptic and multisensory technologies, and cognitive computing and visual perceptive systems shape 3D interactive digital spaces. Throughout December 2022, I performed a quantitative literature review of the Web of Science, Scopus, and ProQuest databases, with search terms including "immersive 3D virtual reality environments" + "digital twin and metaverse technologies," "cognitive mapping and navigation tools," and "processing computational and object tracking algorithms." As I inspected research published between 2022 and 2023, only 174 articles satisfied the eligibility criteria. By eliminating controversial findings, outcomes unsubstantiated by replication, too imprecise material, or having similar titles, I decided upon 33, generally empirical, sources. Data visualization tools: Dimensions (bibliometric mapping) and VOSviewer (layout algorithms). Reporting quality assessment tool: PRISMA. Methodological quality assessment tools include: AXIS, Dedoose, Distiller SR, and MMAT.

Keywords: digital twin and metaverse technologies; cognitive mapping and navigation tools; image processing computational and object tracking algorithms

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1. Introduction

Sensor fusion and objection recognition algorithms, 3D imaging and display technologies, and geospatial analytics and image processing tools are pivotal in interactive virtual and extended reality environments. The purpose of my systematic review is to examine the recently published literature on immersive 3D virtual reality environments and integrate the insights it configures on digital twin and metaverse technologies, cognitive mapping and navigation tools, and image processing computational and object tracking algorithms. By analyzing the most recent (2022–2023) and significant (Web of Science, Scopus, and ProQuest) sources, my paper has attempted to prove that voice recognition software, virtual modeling technologies, data mining techniques, and multi-sensory extended reality shape immersive 3D worlds. The actuality and novelty of this study are articulated by addressing Internet of Things-based decision support and cognitive computing systems (Andronie et al., 2021; Lăzăroiu et al., 2022a; Nica et al., 2023), data visualization and digital twin simulation tools, and machine learning-based navigation and 3D path planning algorithms, that is an emerging topic involving much interest. My research problem is whether bio-sensing and actuation systems, data modeling and automated speech recognition tools, and cognitive decision-making and image processing computational algorithms (Balcerzak et al., 2022; Lăzăroiu et al., 2022b; Pelau et al., 2021) further synthetic reality spaces.

In this review, prior findings have been cumulated indicating that extended reality environments necessitate simulation and modeling technologies, sensor data fusion, real-time data tracking and geospatial intelligence tools (Dabija et al., 2022; Lewkowich, 2022; Pop et al., 2018), and cognitive and behavioral algorithms. The identified gaps advance use of data visualization and deep reinforcement learning tools, environment mapping and conversational artificial intelligence algorithms, and cognitive enhancement and image recognition technologies. My main objective is to indicate that computer vision and spatio-temporal fusion algorithms (Kliestik et al., 2020; Nica, 2018; Popescu et al., 2017a), haptic and multisensory technologies, and cognitive computing and visual perceptive systems (Lăzăroiu et al., 2017; Nica et al., 2022; Popescu et al., 2017b; Valaskova et al., 2022a) shape 3D interactive digital spaces.

2. Theoretical Overview of the Main Concepts

Digital twin simulation and virtual navigation tools, bio-inspired computational intelligence and emotion detection algorithms, and immersive and extended reality technologies are instrumental in 3D digital environments. Interconnected virtual worlds integrate deep learning and edge intelligence algorithms, affective computing and digital scent technologies, and decision-making process automation and data visualization tools. The manuscript is organized as following: theoretical overview (section 2), methodology (section 3), cognitive decision-making and image processing computational algorithms, machine learning-based object recognition and spatial computing technologies, and bio-sensing and actuation systems in the metaverse interactive environment (section 4), geospatial mapping and cognitive automation technologies, socially-oriented location tracking and contextual data monitoring tools, and sensor path planning and situational awareness algorithms in the decentralized metaverse (section 5), bio-inspired computational intelligence and emotion detection algorithms, Internet of Things-based decision support and cognitive computing systems, and geospatial analytics and image processing tools in the virtual environment of the metaverse (section 6), discussion (section 7), synopsis of the main research outcomes (section 8), conclusions (section 9), limitations, implications, and further directions of research (section 10).

3. Methodology

Throughout December 2022, I performed a quantitative literature review of the Web of Science, Scopus, and ProQuest databases, with search terms including "immersive 3D virtual reality environments" + "digital twin and metaverse technologies," "cognitive mapping and navigation tools," and "processing computational and object tracking algorithms." As I inspected research published between 2022 and 2023, only 174 articles satisfied the eligibility criteria. By eliminating controversial findings, outcomes unsubstantiated by replication, too imprecise material, or having similar titles, I decided upon 33, generally empirical, sources (Tables 1 and 2). Data visualization tools: Dimensions (bibliometric mapping) and VOSviewer (layout algorithms). Reporting quality assessment tool: PRISMA. Methodological quality assessment tools include: AXIS, Dedoose, Distiller SR, and MMAT (Figures 1–6).

Table 1 Topics and types of scientific products identified and selected.

Topic	**Identified**	**Selected**
immersive 3D virtual reality environments + digital twin and metaverse technologies	60	12
immersive 3D virtual reality environments + cognitive mapping and navigation tools	58	11
immersive 3D virtual reality environments + image processing computational and object tracking algorithms	56	10
Type of paper		
Original research	145	22
Review	21	11
Conference proceedings	7	0
Book	0	0
Editorial	1	0

Source: Processed by the author. Some topics overlap.

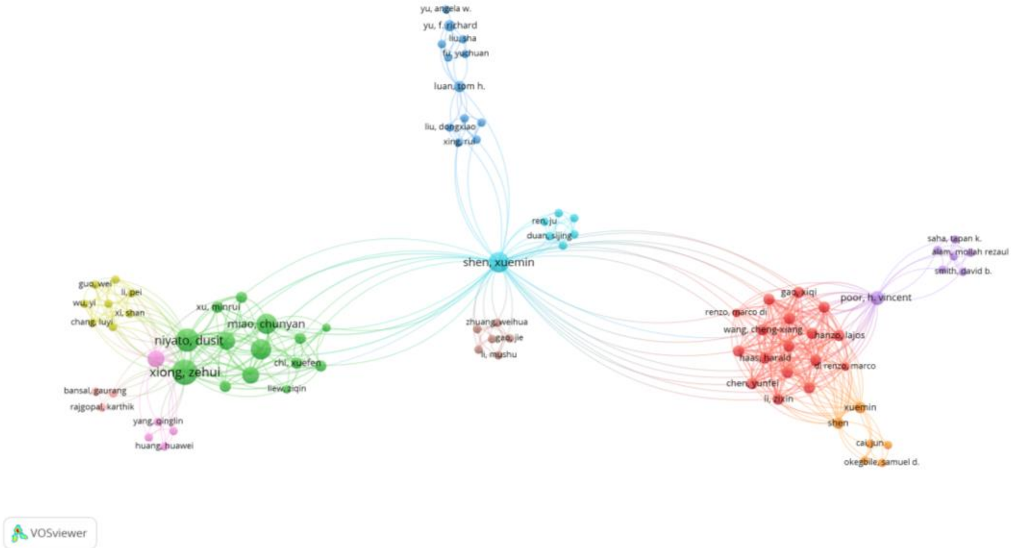

Figure 1 Co-authorship

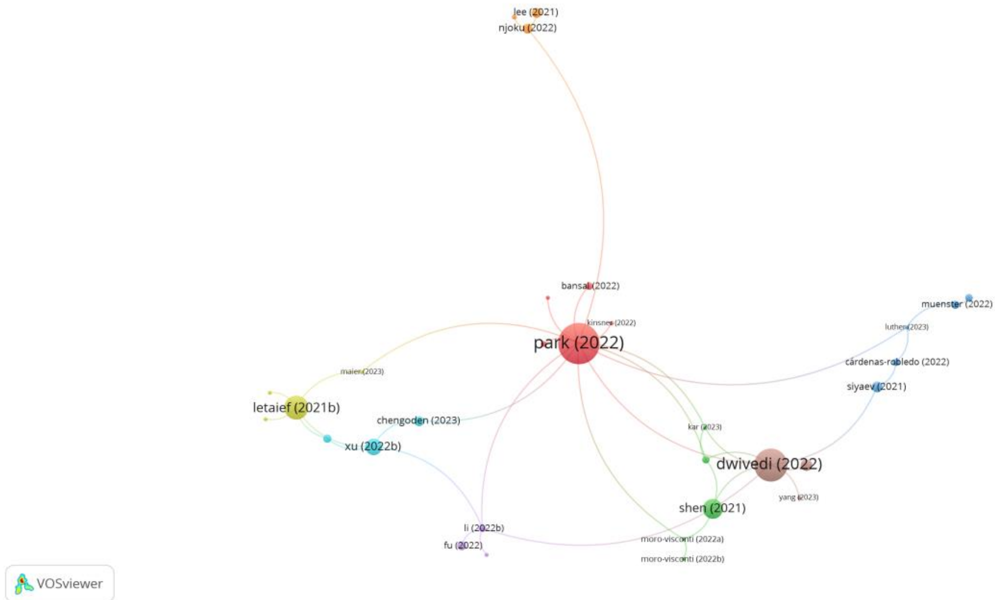

Figure 2 Citation

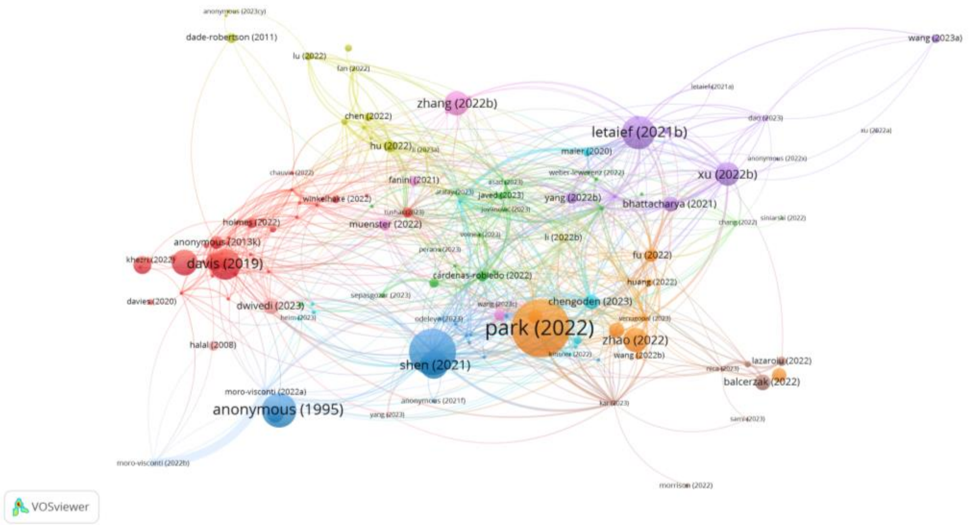

Figure 3 Bibliographic coupling

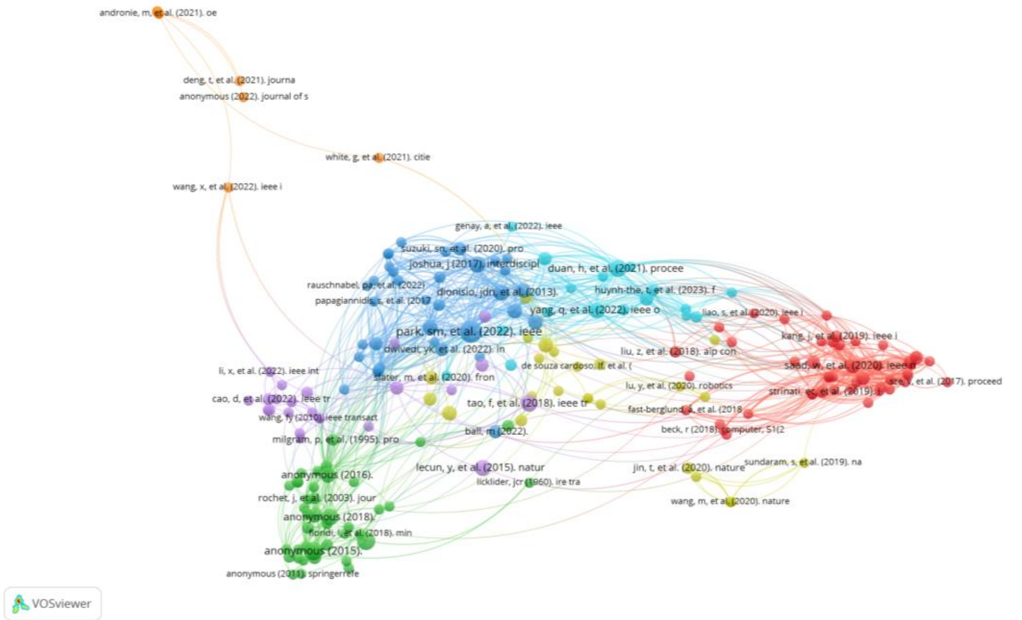

Figure 4 Co-citation

Table 2 General synopsis of evidence as regards focus topics and descriptive outcomes (research findings).

Metaverse engagement and experiences can be achieved by use of data visualization and deep reinforcement learning tools, environment mapping and conversational artificial intelligence algorithms, and cognitive enhancement and image recognition technologies.	Cao, 2022; Panagiotakopoulos et al., 2022; Vidal-Tomás, 2023
The metaverse interactive environment requires deep learning-based sensing and cognitive artificial intelligence technologies, virtual navigation and real-time data tracking tools, and spatial computing and predictive maintenance algorithms.	Dincelli and Yayla, 2022; Kozinets, 2023; Zhang et al., 2022
Immersive virtual experiences can be attained through monitoring and sensing technologies, image recognition and synthetic data tools, and machine vision and spatial cognition algorithms.	Bratu and Sabău, 2022; Corpodean et al., 2022; Ding et al., 2022; Xian et al., 2023
Biometric authentication and immersive visualization systems, spatial data mapping and simulation modeling tools, user identification technology and location data, and image recognition and visual perception algorithms configure the metaverse economy.	Du et al., 2023; Hadi et al., 2023; Queiroz et al., 2023; Zarantonello and Schmitt, 2023
Eye-tracking and visual immersion technologies, sensor path planning and situational awareness algorithms, and spatial awareness and data acquisition tools articulate the decentralized metaverse.	He et al., 2023; Huang et al., 2023; Lv et al., 2022; Shen, 2022
Socially-oriented location tracking and contextual data monitoring tools, 3D modeling technologies, simulation modeling and deep learning algorithms, and big data computing and artificial vision systems articulate ambient intelligence environments.	Daneshfar and Jamshidi, 2023; Meng et al., 2023; Njoku et al., 2023; Xu et al., 2023
Perception and planning algorithms, digital twin modeling and machine learning-based image recognition tools, and computer vision and navigation systems enable the virtual environment of the metaverse.	Rostami and Maier, 2022; Yoo et al., 2023; Zheng and Yuan, 2023
Synthetic data and ambient intelligence tools, metaverse engagement metrics, and sensor-based object recognition and tactile sensing technologies further real-time immersive 3D worlds.	Huynh-The et al., 2023; Smart, 2022; Valaskova et al., 2022b; Zyda, 2022
Internet of Things-based decision support and cognitive computing systems, data visualization and digital twin simulation tools, and machine learning-based navigation and 3D path planning algorithms assist augmented reality-powered immersive spaces.	Braud et al., 2022; Ramadan, 2023; Valaskova et al., 2022c; Zhang et al., 2023

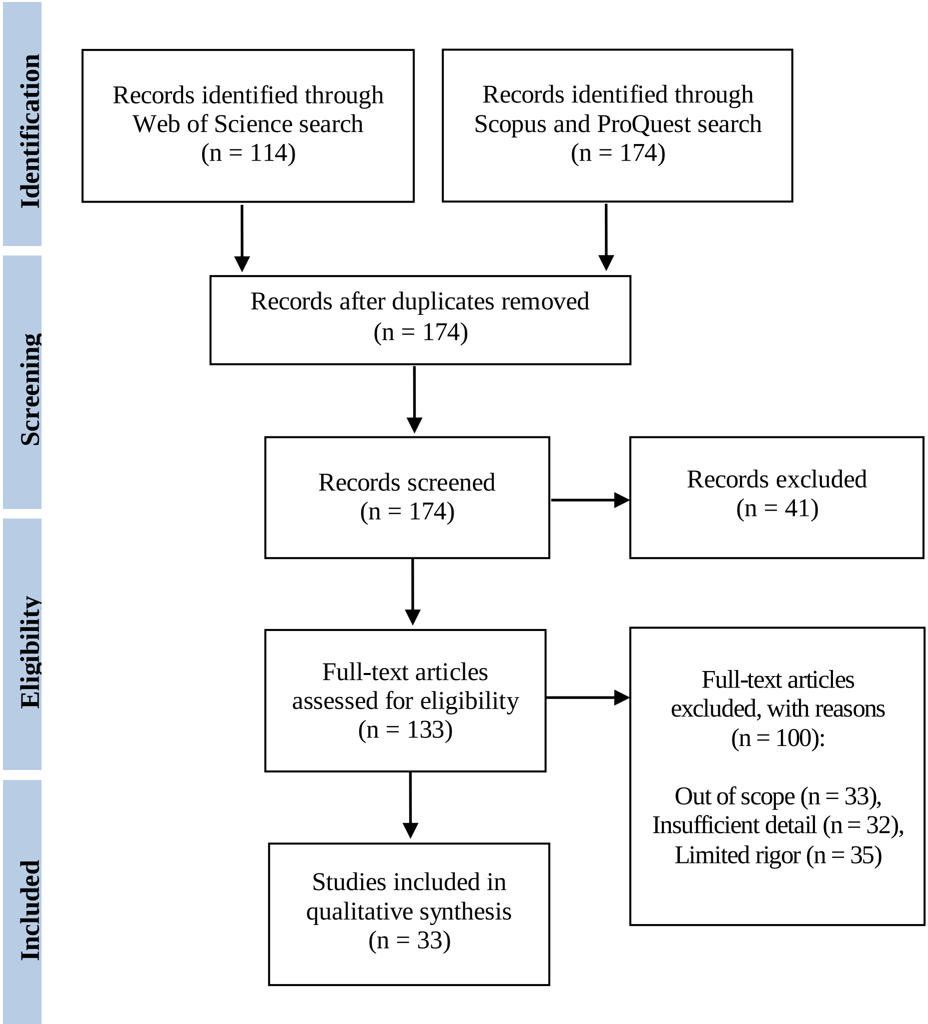

Figure 5 PRISMA flow diagram describing the search results and screening.

Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines were used that ensure the literature review is comprehensive, transparent, and replicable. The flow diagram, produced by employing a Shiny app, presents the stream of evidence-based collected and processed data through the various steps of a systematic review, designing the amount of identified, included, and removed records, and the justifications for exclusions.
To ensure compliance with PRISMA guidelines, a citation software was used, and at each stage the inclusion or exclusion of articles was tracked by use of custom spreadsheet. Justification for the removal of ineligible articles was specified during the full-text screening and final selection.

To ensure first-rate standard of evidence, a systematic search of relevant databases including peer-reviewed published journal articles was conducted using predefined search terms, covering a range of research methods and data sources. Reference lists of all relevant sources were manually reviewed for additional relevant citations.

↓

Titles of papers and abstracts were screened for suitability and selected full texts were retrieved to establish whether they satisfied the inclusion criteria. All records from each database were evaluated by using data extraction forms. Data covering research aims, participants, study design, and method of each paper were extracted.

↓

The inclusion criteria were: (i) articles included in the Web of Science, Scopus, and ProQuest databases, (ii) publication date (2022–2023), (iii) written in English, (iv) being an original empirical research or review article, and (v) particular search terms covered; (i) conference proceedings, (ii) books, and (iii) editorial materials were eliminated from the analysis.

↓

Distiller SR screened and extracted the collected data.

↓

SRDR gathered, handled, and analyzed the data for the systematic review, being configured as an archive and tool harnessed in data extraction through transparent, efficient, and reliable quantitative techniques. Elaborate extraction forms can be set up, meeting the needs of research questions and study designs.

↓

AMSTAR evaluated the methodological quality of systematic reviews.

↓

AXIS evaluated the quality of cross-sectional studies.

↓

The quality of academic articles was determined and risk of bias was measured by MMAT, that tested content validity and usability of selected studies in terms of screening questions, type of design, corresponding quality criteria, and overall quality score.

↓

ROBIS assessed the risk of bias in systematic reviews.

↓

Dedoose analyzed qualitative and mixed methods research.

Figure 6 Screening and quality assessment tools

4. Cognitive Decision-Making and Image Processing Computational Algorithms, Machine Learning-based Object Recognition and Spatial Computing Technologies, and Bio-Sensing and Actuation Systems in the Metaverse Interactive Environment

Metaverse engagement and experiences (Cao, 2022; Panagiotakopoulos et al., 2022; Vidal-Tomás, 2023) can be achieved by use of data visualization and deep reinforcement learning tools, environment mapping and conversational artificial intelligence algorithms, and cognitive enhancement and image recognition technologies. Bio-sensing and actuation systems, data modeling and automated speech recognition tools, and cognitive decision-making and image processing computational algorithms further synthetic reality spaces.

The metaverse interactive environment (Dincelli and Yayla, 2022; Kozinets, 2023; Zhang et al., 2022) requires deep learning-based sensing and cognitive artificial intelligence technologies, virtual navigation and real-time data tracking tools, and spatial computing and predictive maintenance algorithms. Computer vision and spatio-temporal fusion algorithms, haptic and multisensory technologies, and cognitive computing and visual perceptive systems shape 3D interactive digital spaces.

Immersive virtual experiences (Bratu and Sabău, 2022; Corpodean et al., 2022; Ding et al., 2022; Xian et al., 2023) can be attained through monitoring and sensing technologies, image recognition and synthetic data tools, and machine vision and spatial cognition algorithms. Multi-sensor fusion and perception systems, computer vision and data-driven artificial intelligence algorithms, and machine learning-based object recognition and spatial computing technologies optimize the blockchain-based virtual economy. (Table 3)

Table 3 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Metaverse engagement and experiences can be achieved by use of data visualization and deep reinforcement learning tools, environment mapping and conversational artificial intelligence algorithms, and cognitive enhancement and image recognition technologies.	Cao, 2022; Panagiotakopoulos et al., 2022; Vidal-Tomás, 2023
The metaverse interactive environment requires deep learning-based sensing and cognitive artificial intelligence technologies, virtual navigation and real-time data tracking tools, and spatial computing and predictive maintenance algorithms.	Dincelli and Yayla, 2022; Kozinets, 2023; Zhang et al., 2022
Immersive virtual experiences can be attained through monitoring and sensing technologies, image recognition and synthetic data tools, and machine vision and spatial cognition algorithms.	Bratu and Sabău, 2022; Corpodean et al., 2022; Ding et al., 2022; Xian et al., 2023

5. Geospatial Mapping and Cognitive Automation Technologies, Socially-oriented Location Tracking and Contextual Data Monitoring Tools, and Sensor Path Planning and Situational Awareness Algorithms in the Decentralized Metaverse

Biometric authentication and immersive visualization systems, spatial data mapping and simulation modeling tools, user identification technology and location data, and image recognition and visual perception algorithms (Du et al., 2023; Hadi et al., 2023; Queiroz et al., 2023; Zarantonello and Schmitt, 2023) configure the metaverse economy. Extended reality environments develop on brain-inspired artificial intelligence and sensor fusion algorithms, geospatial mapping and cognitive automation technologies, and human digital twin and geospatial big data visualization systems.

Eye-tracking and visual immersion technologies, sensor path planning and situational awareness algorithms, and spatial awareness and data acquisition tools (He et al., 2023; Huang et al., 2023; Lv et al., 2022; Shen, 2022) articulate the decentralized metaverse. Interconnected virtual worlds integrate deep learning and edge intelligence algorithms, affective computing and digital scent technologies, and decision-making process automation and data visualization tools.

Socially-oriented location tracking and contextual data monitoring tools, 3D modeling technologies, simulation modeling and deep learning algorithms, and big data computing and artificial vision systems (Daneshfar and Jamshidi, 2023; Meng et al., 2023; Njoku et al., 2023; Xu et al., 2023) articulate ambient intelligence environments. Extended reality environments necessitate simulation and modeling technologies, sensor data fusion, real-time data tracking and geospatial intelligence tools, and cognitive and behavioral algorithms. (Table 4)

Table 4 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Biometric authentication and immersive visualization systems, spatial data mapping and simulation modeling tools, user identification technology and location data, and image recognition and visual perception algorithms configure the metaverse economy.	Du et al., 2023; Hadi et al., 2023; Queiroz et al., 2023; Zarantonello and Schmitt, 2023
Eye-tracking and visual immersion technologies, sensor path planning and situational awareness algorithms, and spatial awareness and data acquisition tools articulate the decentralized metaverse.	He et al., 2023; Huang et al., 2023; Lv et al., 2022; Shen, 2022
Socially-oriented location tracking and contextual data monitoring tools, 3D modeling technologies, simulation modeling and deep learning algorithms, and big data computing and artificial vision systems articulate ambient intelligence environments.	Daneshfar and Jamshidi, 2023; Meng et al., 2023; Njoku et al., 2023; Xu et al., 2023

6. Bio-inspired Computational Intelligence and Emotion Detection Algorithms, Internet of Things-based Decision Support and Cognitive Computing Systems, and Geospatial Analytics and Image Processing Tools in the Virtual Environment of the Metaverse

Perception and planning algorithms, digital twin modeling and machine learning-based image recognition tools, and computer vision and navigation systems (Rostami and Maier, 2022; Yoo et al., 2023; Zheng and Yuan, 2023) enable the virtual environment of the metaverse. Sensor fusion and objection recognition algorithms, 3D imaging and display technologies, and geospatial analytics and image processing tools are pivotal in interactive virtual and extended reality environments. Voice recognition software, virtual modeling technologies, data mining techniques, and multi-sensory extended reality shape immersive 3D worlds.

Synthetic data and ambient intelligence tools, metaverse engagement metrics, and sensor-based object recognition and tactile sensing technologies (Huynh-The et al., 2023; Smart, 2022; Valaskova et al., 2022a; Zyda, 2022) further real-time immersive 3D worlds. Digital twin simulation and virtual navigation tools, bio-inspired computational intelligence and emotion detection algorithms, and immersive and extended reality technologies are instrumental in 3D digital environments.

Internet of Things-based decision support and cognitive computing systems, data visualization and digital twin simulation tools, and machine learning-based navigation and 3D path planning algorithms (Braud et al., 2022; Ramadan, 2023; Valaskova et al., 2022b; Zhang et al., 2023) assist augmented reality-powered immersive spaces. Haptic and sensory technologies, movement and behavior tracking tools, and machine learning-based recognition and image detection algorithms configure 3D computer-generated virtual environments. (Table 5)

Table 5 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Perception and planning algorithms, digital twin modeling and machine learning-based image recognition tools, and computer vision and navigation systems enable the virtual environment of the metaverse.	Rostami and Maier, 2022; Yoo et al., 2023; Zheng and Yuan, 2023
Synthetic data and ambient intelligence tools, metaverse engagement metrics, and sensor-based object recognition and tactile sensing technologies further real-time immersive 3D worlds.	Huynh-The et al., 2023; Smart, 2022; Valaskova et al., 2022b; Zyda, 2022
Internet of Things-based decision support and cognitive computing systems, data visualization and digital twin simulation tools, and machine learning-based navigation and 3D path planning algorithms assist augmented reality-powered immersive spaces.	Braud et al., 2022; Ramadan, 2023; Valaskova et al., 2022c; Zhang et al., 2023

7. Discussion

I integrate my systematic review throughout research indicating how computer vision and spatio-temporal fusion algorithms, haptic and multisensory technologies, and cognitive computing and visual perceptive systems shape 3D interactive digital spaces. My research complements recent analyses clarifying how multi-sensor fusion and perception systems, computer vision and data-driven artificial intelligence algorithms, and machine learning-based object recognition and spatial computing technologies optimize the blockchain-based virtual economy. I elucidate, by cumulative evidence, previous research demonstrating how bio-sensing and actuation systems, data modeling and automated speech recognition tools, and cognitive decision-making and image processing computational algorithms further synthetic reality spaces.

8. Synopsis of the Main Research Outcomes

Extended reality environments develop on brain-inspired artificial intelligence and sensor fusion algorithms, geospatial mapping and cognitive automation technologies, and human digital twin and geospatial big data visualization systems. Extended reality environments necessitate simulation and modeling technologies, sensor data fusion, real-time data tracking and geospatial intelligence tools, and cognitive and behavioral algorithms.

9. Conclusions

Relevant research has investigated whether voice recognition software, virtual modeling technologies, data mining techniques, and multi-sensory extended reality shape immersive 3D worlds. This systematic literature review presents the published peer-reviewed sources covering how haptic and sensory technologies, movement and behavior tracking tools, and machine learning-based recognition and image detection algorithms configure 3D computer-generated virtual environments. The research outcomes drawn from the above analyses indicate that sensor fusion and objection recognition algorithms, 3D imaging and display technologies, and geospatial analytics and image processing tools are pivotal in interactive virtual and extended reality environments.

10. Limitations, Implications, and Further Directions of Research

By analyzing only articles published between 2022 and 2023 in journals indexed in the Web of Science, Scopus, and ProQuest databases, relevant sources on digital twin and metaverse technologies, cognitive mapping and navigation tools, and image processing computational and object tracking algorithms in immersive 3D virtual reality environments may have been excluded. Limitations of this research comprise particular kinds of publications (original empirical research and review articles) discounting others (conference proceedings articles, books, and editorial materials). The scope of my study also does not move forward the inspection of biometric authentication and immersive visualization systems, spatial data mapping and simulation modeling tools, user identification technology and location data, and image recognition and visual perception algorithms.

Subsequent analyses should develop on perception and planning algorithms, digital twin modeling and machine learning-based image recognition tools, and computer vision and navigation systems. Future research should thus investigate synthetic data and ambient intelligence tools, metaverse engagement metrics, and sensor-based object recognition and tactile sensing technologies. Attention should be directed to deep learning-based sensing and cognitive artificial intelligence technologies, virtual navigation and real-time data tracking tools, and spatial computing and predictive maintenance algorithms.

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Compliance with ethical standards
This article does not contain any studies with human participants or animals performed by the author. Extracting and inspecting publicly accessible files (scholarly sources) as evidence, before the research began no institutional ethics approval was required.

Data availability statement
All data generated or analyzed are included in the published article.

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Author contributions
The author confirms being the sole contributor of this work and approved it for publication. The author takes full responsibility for the accuracy and the integrity of the data analysis.

Conflict of interest statement
The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Disclosure by the editors of record
The editors declare no conflict of interest in the review and publication decision regarding this article.

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Immersive Engagement and Geospatial Mapping Technologies, Deep Learning and Neural Network Algorithms, and Visual Perception and Data Mining Tools in Metaverse Interactive and Extended Reality Environments

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ABSTRACT. The purpose of this study is to examine object recognition and geolocation data processing algorithms, visual and spatial intelligence tools, and metaverse and immersive technologies. In this article, we cumulate previous research findings indicating that visual imagery and deep learning-based ambient sound processing tools, cloud computing and 3D immersive virtual reality technologies, and predictive modeling and machine vision algorithms assist immersive photorealistic virtual spaces. Throughout January 2023, we performed a quantitative literature review of the Web of Science, Scopus, and ProQuest databases, with search terms including "metaverse interactive and extended reality environments" + "immersive engagement and geospatial mapping technologies," "deep learning and neural network algorithms," and "visual perception and data mining tools." As we inspected research published between 2022 and 2023, only 166 articles satisfied the eligibility criteria. By removing controversial findings, outcomes unsubstantiated by replication, too imprecise material, or having similar titles, we decided upon 31, generally empirical, sources. Data visualization tools: Dimensions (bibliometric mapping) and VOSviewer (layout algorithms). Reporting quality assessment tool: PRISMA. Methodological quality assessment tools include: AXIS, Dedoose, MMAT, and SRDR.

Keywords: immersive engagement and geospatial mapping technologies; deep learning and neural network algorithms; visual perception and data mining tools; metaverse

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1. Introduction

3D modeling and virtual navigation tools, haptic and biometric sensor technologies, and visual tracking and natural language processing algorithms enable ambient intelligence and 3D immersive environments. The purpose of our systematic review is to examine the recently published literature on metaverse interactive and extended reality environments and integrate the insights it configures on immersive engagement and geospatial mapping technologies, deep learning and neural network algorithms, and visual perception and data mining tools. By analyzing the most recent (2022–2023) and significant (Web of Science, Scopus, and ProQuest) sources, our paper has attempted to prove that visual imagery and deep learning-based ambient sound processing tools, cloud computing and 3D immersive virtual reality technologies (Andronie et al., 2023; Lăzăroiu et al., 2020; Pop et al., 2021), and predictive modeling and machine vision algorithms assist immersive photorealistic virtual spaces. The actuality and novelty of this study are articulated by addressing object recognition and geolocation data processing algorithms (Balcerzak et al., 2022; Lăzăroiu et al., 2022; Popescu et al., 2017a), visual and spatial intelligence tools, and metaverse and immersive technologies, that is an emerging topic involving much interest. Our research problem is whether virtual twin modeling and intelligent data processing tools, emotion detection and recognition technologies, and deep learning-based predictive and virtual mapping algorithms (Dabija et al., 2023; Nagy and Lăzăroiu, 2022; Popescu et al., 2017b) shape immersive 3D virtual environments.

In this review, prior findings have been cumulated indicating that synthetic user experiences can be achieved by use of haptic object recognition and cognitive computing systems, neuromorphic sensing and computing technologies, and natural language processing and simulation modeling tools. The identified gaps advance virtual navigation and digital twin simulation tools, remote sensing and 3D object recognition technologies (Gordon, 2022; Nagy et al., 2023; Popescu, 2018; Vătămănescu et al., 2022), and deep learning artificial intelligence and visual cognitive algorithms. Our main objective is to indicate that entertaining metaverse events, virtual modeling and environment perception technologies (Jaramillo-Aristizabal, 2022; Nica et al., 2023; Popescu et al., 2022), and sensor data fusion configure 3D immersive environments.

2. Theoretical Overview of the Main Concepts

Multisensor fusion and mobile geofencing technologies, path planning and computer vision algorithms, and data mining and deep generative modeling techniques shape the metaverse interactive environment and synthetic reality spaces. The manuscript is organized as following: theoretical overview (section 2), methodology (section 3), haptic object recognition and cognitive computing systems, 3D virtual space networking and geospatial mapping tools, and distributed decision and control algorithms on blockchain-based metaverse platforms (section 4), metaverse and immersive technologies, spatial data visualization and contextual awareness tools, and object recognition and geolocation data processing algorithms in ambient intelligence environments (section 5), deep learning artificial intelligence and visual cognitive algorithms, multisensor fusion and mobile geofencing technologies, and decentralized data and user journey analytics in blockchain-based metaverse platforms and immersive 3D virtual environments (section 6), discussion (section 7), synopsis of the main research outcomes (section 8), conclusions (section 9), limitations, implications, and further directions of research (section 10).

3. Methodology

Throughout January 2023, we performed a quantitative literature review of the Web of Science, Scopus, and ProQuest databases, with search terms including "metaverse interactive and extended reality environments" + "immersive engagement and geospatial mapping technologies," "deep learning and neural network algorithms," and "visual perception and data mining tools." As we inspected research published between 2022 and 2023, only 166 articles satisfied the eligibility criteria. By removing controversial findings, outcomes unsubstantiated by replication, too imprecise material, or having similar titles, we decided upon 31, generally empirical, sources (Tables 1 and 2). Data visualization tools: Dimensions (bibliometric mapping) and VOSviewer (layout algorithms). Reporting quality assessment tool: PRISMA. Methodological quality assessment tools include: AXIS, Dedoose, MMAT, and SRDR (Figures 1–6).

Table 1 Topics and types of scientific products identified and selected.

Topic	**Identified**	**Selected**
metaverse interactive and extended reality environments + immersive engagement and geospatial mapping technologies	57	11
metaverse interactive and extended reality environments + deep learning and neural network algorithms	55	10
metaverse interactive and extended reality environments + visual perception and data mining tools	54	10
Type of paper		
Original research	140	23
Review	18	8
Conference proceedings	7	0
Book	0	0
Editorial	1	0

Source: Processed by the authors. Some topics overlap.

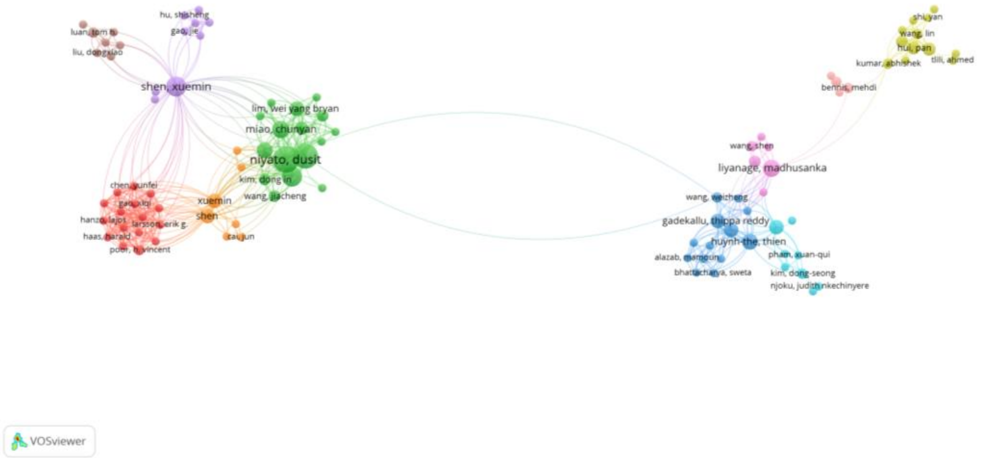

Figure 1 Co-authorship

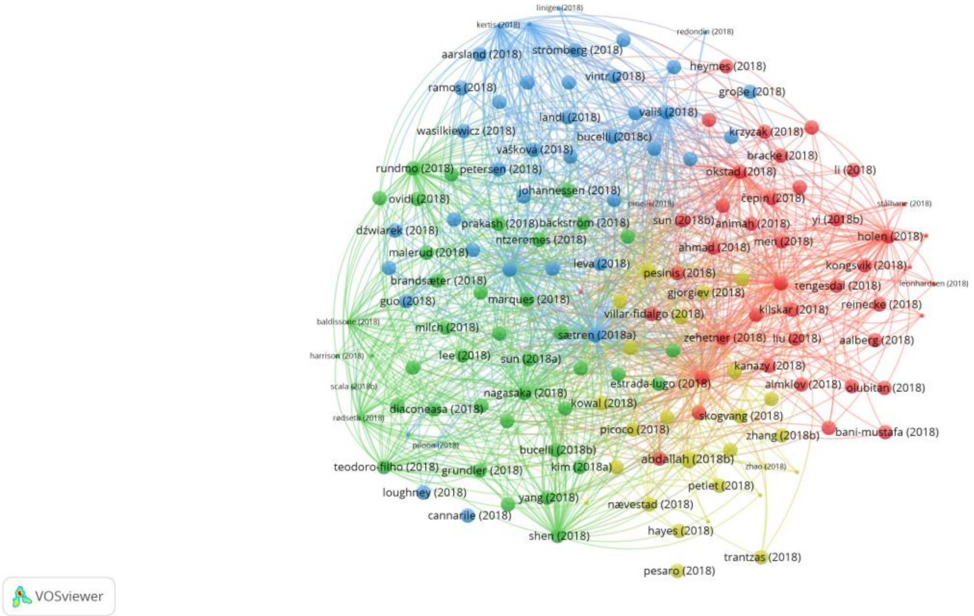

Figure 2 Citation

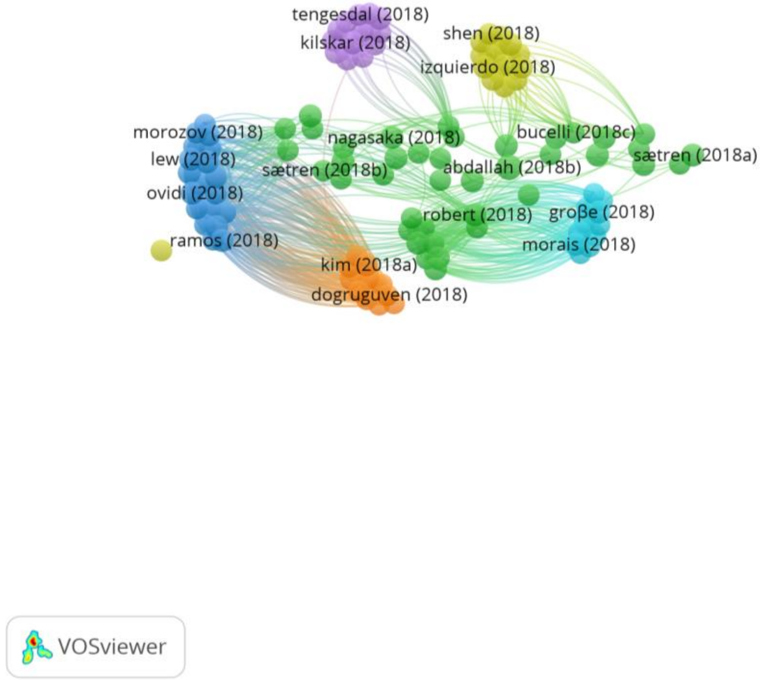

Figure 3 Bibliographic coupling

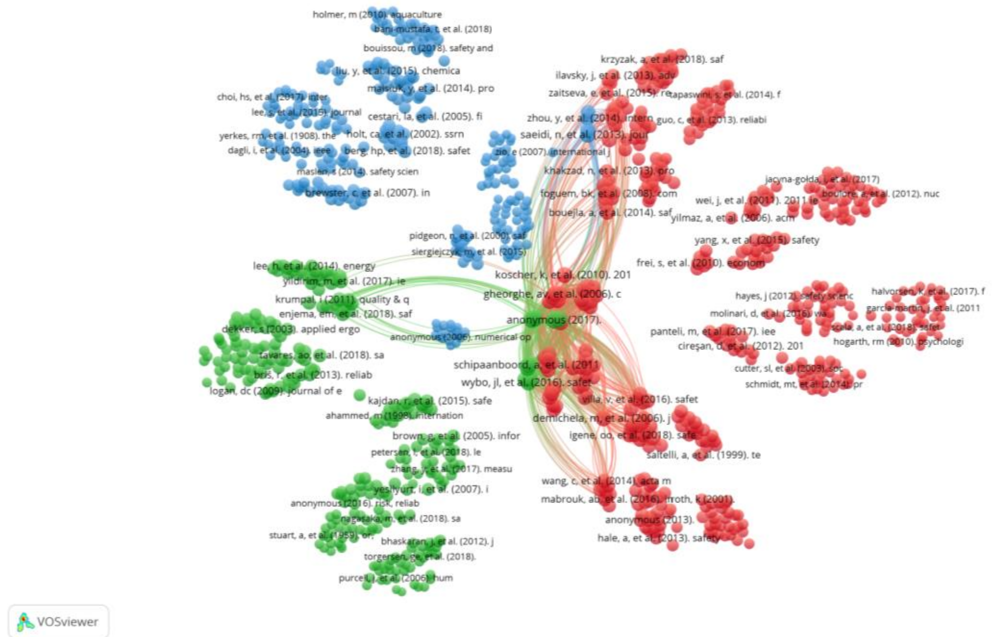

Figure 4 Co-citation

Table 2 General synopsis of evidence as regards focus topics and descriptive outcomes (research findings).

Immersive metaverse experiences can be attained through artificial vision and automated speech recognition systems, wireless sensor networks, eye-tracking and immersive technologies, and image processing and digital twin modeling tools.	Li et al., 2023a; Wongkitrungrueng and Suprawan, 2023; Xu et al., 2023
Distributed decision and control algorithms, automated speech recognition and deep learning artificial intelligence tools, and immersive 3D and edge computing technologies configure blockchain-based metaverse platforms and interactive digital worlds.	Hollensen et al., 2023; Nagendran et al., 2022; Weking et al., 2023
Hyper-realistic personalized interactive experiences can be achieved by use of cyber-physical cognitive and immersive visualization systems, simulation modeling and machine learning-based image recognition tools, and virtual twin and spatial computing technologies.	Faraboschi et al., 2022; Kliestik et al., 2022; Tang et al., 2023; Venugopal et al., 2023
3D metaverse experiences can be attained through extended cognitive and big data computing systems, digital twinning and haptic feedback technologies, and intelligent data processing and context awareness tools.	Golf-Papez et al., 2022; Polas et al., 2022; Zhou et al., 2023
Object recognition and geolocation data processing algorithms, visual and spatial intelligence tools, and metaverse and immersive technologies further immersive digital worlds.	Han et al., 2022; Rowland and Newell, 2022; Zabel et al., 2023
Immersive virtual experiences can be achieved by use of socially-extended cognition and real-time visual analytics systems, 3D modeling and immersive extended reality technologies, and digital twin simulation and computational intelligence tools.	Du et al., 2023; Li et al., 2023b; Queiroz et al., 2023; Valaskova et al., 2022
3D metaverse experiences can be attained through cognitive artificial intelligence and geospatial mapping technologies, autonomous visual object detection and virtual mapping tools, and spatio-temporal fusion and computer vision algorithms.	McStay, 2023; Oh et al., 2023; Shi et al., 2023; Zallio and Clarkson, 2022
Virtual navigation and digital twin simulation tools, remote sensing and 3D object recognition technologies, and deep learning artificial intelligence and visual cognitive algorithms optimize blockchain-based metaverse platforms and immersive 3D virtual environments.	Aloqaily et al., 2022; Hennig-Thurau et al., 2022; Zhu et al., 2023
Immersive virtual experiences can be attained through remote sensing and artificial cognitive systems, immersive geospatial data visualization and dynamic routing technologies, and virtual navigation and decision support tools.	Bojic, 2022; Kliestik et al., 2023; Morley, 2022; Zainab et al., 2022

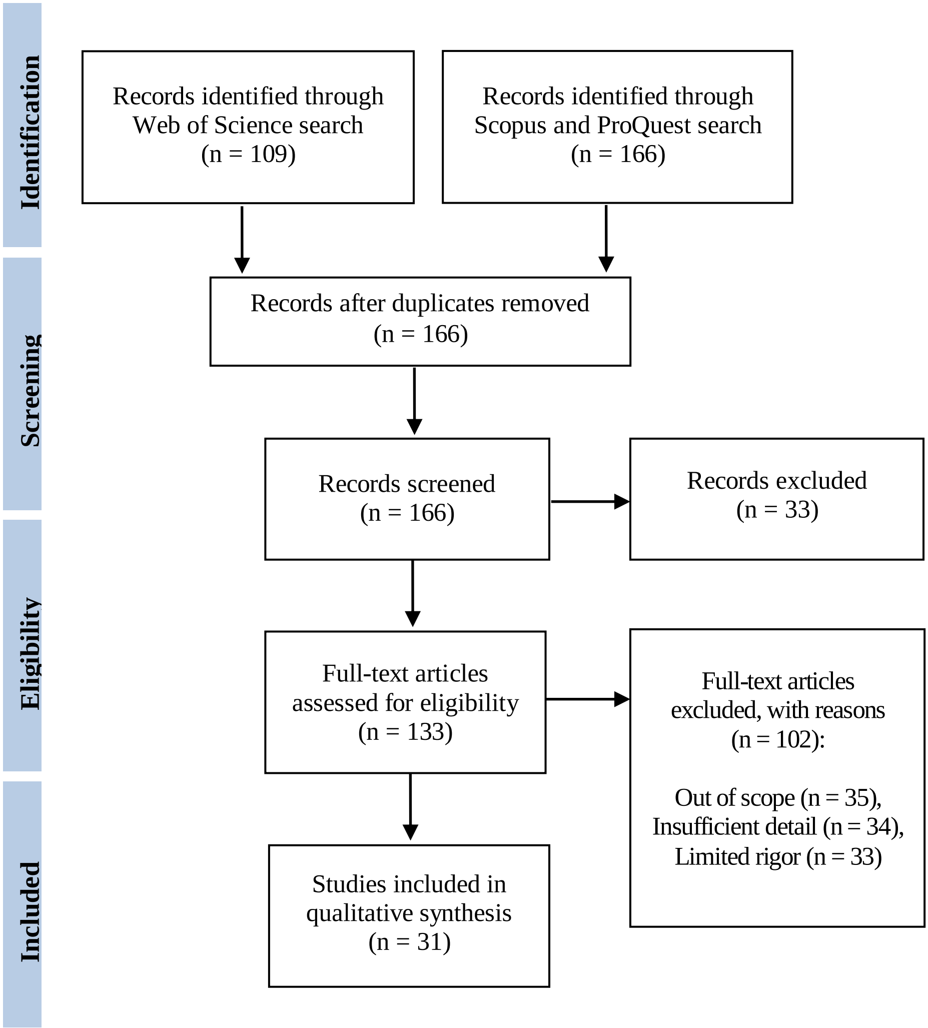

Figure 5 PRISMA flow diagram describing the search results and screening.

Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines were used that ensure the literature review is comprehensive, transparent, and replicable. The flow diagram, produced by employing a Shiny app, presents the stream of evidence-based collected and processed data through the various steps of a systematic review, designing the amount of identified, included, and removed records, and the justifications for exclusions.
To ensure compliance with PRISMA guidelines, a citation software was used, and at each stage the inclusion or exclusion of articles was tracked by use of custom spreadsheet. Justification for the removal of ineligible articles was specified during the full-text screening and final selection.

To ensure first-rate standard of evidence, a systematic search of relevant databases including peer-reviewed published journal articles was conducted using predefined search terms, covering a range of research methods and data sources. Reference lists of all relevant sources were manually reviewed for additional relevant citations.

Titles of papers and abstracts were screened for suitability and selected full texts were retrieved to establish whether they satisfied the inclusion criteria. All records from each database were evaluated by using data extraction forms. Data covering research aims, participants, study design, and method of each paper were extracted.

The inclusion criteria were: (i) articles included in the Web of Science, Scopus, and ProQuest databases, (ii) publication date (2022–2023), (iii) written in English, (iv) being an original empirical research or review article, and (v) particular search terms covered; (i) conference proceedings, (ii) books, and (iii) editorial materials were eliminated from the analysis.

Distiller SR screened and extracted the collected data.

SRDR gathered, handled, and analyzed the data for the systematic review, being configured as an archive and tool harnessed in data extraction through transparent, efficient, and reliable quantitative techniques. Elaborate extraction forms can be set up, meeting the needs of research questions and study designs.

AMSTAR evaluated the methodological quality of systematic reviews.

Dedoose analyzed qualitative and mixed methods research.

ROBIS assessed the risk of bias in systematic reviews.

AXIS evaluated the quality of cross-sectional studies.

The quality of academic articles was determined and risk of bias was measured by MMAT, that tested content validity and usability of selected studies in terms of screening questions, type of design, corresponding quality criteria, and overall quality score.

Figure 6 Screening and quality assessment tools

4. Haptic Object Recognition and Cognitive Computing Systems, 3D Virtual Space Networking and Geospatial Mapping Tools, and Distributed Decision and Control Algorithms on Blockchain-based Metaverse Platforms

Immersive metaverse experiences (Li et al., 2023a; Wongkitrungrueng and Suprawan, 2023; Xu et al., 2023) can be attained through artificial vision and automated speech recognition systems, wireless sensor networks, eye-tracking and immersive technologies, and image processing and digital twin modeling tools. Synthetic user experiences can be achieved by use of haptic object recognition and cognitive computing systems, neuromorphic sensing and computing technologies, and natural language processing and simulation modeling tools.

Distributed decision and control algorithms, automated speech recognition and deep learning artificial intelligence tools, and immersive 3D and edge computing technologies (Hollensen et al., 2023; Nagendran et al., 2022; Weking et al., 2023) configure blockchain-based metaverse platforms and interactive digital worlds. 3D immersive spaces and experiences can be attained through automated perception and visual analytics systems, data sharing and deep learning-based sensing technologies, and virtual navigation and data mining tools.

Hyper-realistic personalized interactive experiences (Faraboschi et al., 2022; Kliestik et al., 2022; Tang et al., 2023; Venugopal et al., 2023) can be achieved by use of cyber-physical cognitive and immersive visualization systems, simulation modeling and machine learning-based image recognition tools, and virtual twin and spatial computing technologies. Virtual reality-based immersive experiences can be achieved by use of neuromorphic image processing and empathetic computing systems, data fusion and digital twin technologies, and 3D virtual space networking and geospatial mapping tools. (Table 3)

Table 3 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Immersive metaverse experiences can be attained through artificial vision and automated speech recognition systems, wireless sensor networks, eye-tracking and immersive technologies, and image processing and digital twin modeling tools.	Li et al., 2023a; Wongkitrungrueng and Suprawan, 2023; Xu et al., 2023
Distributed decision and control algorithms, automated speech recognition and deep learning artificial intelligence tools, and immersive 3D and edge computing technologies configure blockchain-based metaverse platforms and interactive digital worlds.	Hollensen et al., 2023; Nagendran et al., 2022; Weking et al., 2023
Hyper-realistic personalized interactive experiences can be achieved by use of cyber-physical cognitive and immersive visualization systems, simulation modeling and machine learning-based image recognition tools, and virtual twin and spatial computing technologies.	Faraboschi et al., 2022; Kliestik et al., 2022; Tang et al., 2023; Venugopal et al., 2023

5. Metaverse and Immersive Technologies, Spatial Data Visualization and Contextual Awareness Tools, and Object Recognition and Geolocation Data Processing Algorithms in Ambient Intelligence Environments

3D metaverse experiences (Golf-Papez et al., 2022; Polas et al., 2022; Zhou et al., 2023) can be attained through extended cognitive and big data computing systems, digital twinning and haptic feedback technologies, and intelligent data processing and context awareness tools. Spatial data visualization and contextual awareness tools, sentiment recognition and digital twin technologies, and cognitive artificial intelligence and deep learning algorithms articulate blockchain-based virtual worlds and immersive and interoperable spaces.

Object recognition and geolocation data processing algorithms, visual and spatial intelligence tools, and metaverse and immersive technologies (Han et al., 2022; Rowland and Newell, 2022; Zabel et al., 2023) further immersive digital worlds. Visual imagery and deep learning-based ambient sound processing tools, cloud computing and 3D immersive virtual reality technologies, and predictive modeling and machine vision algorithms assist immersive photorealistic virtual spaces.

Immersive virtual experiences (Du et al., 2023; Li et al., 2023b; Queiroz et al., 2023; Valaskova et al., 2022) can be achieved by use of socially-extended cognition and real-time visual analytics systems, 3D modeling and immersive extended reality technologies, and digital twin simulation and computational intelligence tools. 3D modeling and virtual navigation tools, haptic and biometric sensor technologies, and visual tracking and natural language processing algorithms enable ambient intelligence and 3D immersive environments. Entertaining metaverse events, virtual modeling and environment perception technologies, and sensor data fusion configure 3D immersive environments. (Table 4)

Table 4 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

3D metaverse experiences can be attained through extended cognitive and big data computing systems, digital twinning and haptic feedback technologies, and intelligent data processing and context awareness tools.	Golf-Papez et al., 2022; Polas et al., 2022; Zhou et al., 2023
Object recognition and geolocation data processing algorithms, visual and spatial intelligence tools, and metaverse and immersive technologies further immersive digital worlds.	Han et al., 2022; Rowland and Newell, 2022; Zabel et al., 2023
Immersive virtual experiences can be achieved by use of socially-extended cognition and real-time visual analytics systems, 3D modeling and immersive extended reality technologies, and digital twin simulation and computational intelligence tools.	Du et al., 2023; Li et al., 2023b; Queiroz et al., 2023; Valaskova et al., 2022

6. Deep Learning Artificial Intelligence and Visual Cognitive Algorithms, Multisensor Fusion and Mobile Geofencing Technologies, and Decentralized Data and User Journey Analytics in Blockchain-based Metaverse Platforms and Immersive 3D Virtual Environments

3D metaverse experiences (McStay, 2023; Oh et al., 2023; Shi et al., 2023; Zallio and Clarkson, 2022) can be attained through cognitive artificial intelligence and geospatial mapping technologies, autonomous visual object detection and virtual mapping tools, and spatio-temporal fusion and computer vision algorithms. Virtual twin modeling and intelligent data processing tools, emotion detection and recognition technologies, and deep learning-based predictive and virtual mapping algorithms shape immersive 3D virtual environments.

Virtual navigation and digital twin simulation tools, remote sensing and 3D object recognition technologies, and deep learning artificial intelligence and visual cognitive algorithms (Aloqaily et al., 2022; Hennig-Thurau et al., 2022; Zhu et al., 2023) optimize blockchain-based metaverse platforms and immersive 3D virtual environments. Multisensor fusion and mobile geofencing technologies, path planning and computer vision algorithms, and data mining and deep generative modeling techniques shape the metaverse interactive environment and synthetic reality spaces.

Immersive virtual experiences (Bojic, 2022; Kliestik et al., 2023; Morley, 2022; Zainab et al., 2022) can be attained through remote sensing and artificial cognitive systems, immersive geospatial data visualization and dynamic routing technologies, and virtual navigation and decision support tools. Visual imagery and data modeling tools, computer vision and spatial data mining algorithms, and decentralized data and user journey analytics optimize the interconnected metaverse and immersive virtual environments. (Table 5)

Table 5 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

3D metaverse experiences can be attained through cognitive artificial intelligence and geospatial mapping technologies, autonomous visual object detection and virtual mapping tools, and spatio-temporal fusion and computer vision algorithms.	McStay, 2023; Oh et al., 2023; Shi et al., 2023; Zallio and Clarkson, 2022
Virtual navigation and digital twin simulation tools, remote sensing and 3D object recognition technologies, and deep learning artificial intelligence and visual cognitive algorithms optimize blockchain-based metaverse platforms and immersive 3D virtual environments.	Aloqaily et al., 2022; Hennig-Thurau et al., 2022; Zhu et al., 2023
Immersive virtual experiences can be attained through remote sensing and artificial cognitive systems, immersive geospatial data visualization and dynamic routing technologies, and virtual navigation and decision support tools.	Bojic, 2022; Kliestik et al., 2023; Morley, 2022; Zainab et al., 2022

7. Discussion

We integrate our systematic review throughout research indicating how visual imagery and data modeling tools, computer vision and spatial data mining algorithms, and decentralized data and user journey analytics optimize the interconnected metaverse and immersive virtual environments. Our research complements recent analyses clarifying how 3D immersive spaces and experiences can be attained through automated perception and visual analytics systems, data sharing and deep learning-based sensing technologies, and virtual navigation and data mining tools. We elucidate, by cumulative evidence, previous research demonstrating how entertaining metaverse events, virtual modeling and environment perception technologies, and sensor data fusion configure 3D immersive environments.

8. Synopsis of the Main Research Outcomes

Spatial data visualization and contextual awareness tools, sentiment recognition and digital twin technologies, and cognitive artificial intelligence and deep learning algorithms articulate blockchain-based virtual worlds and immersive and interoperable spaces. Synthetic user experiences can be achieved by use of haptic object recognition and cognitive computing systems, neuromorphic sensing and computing technologies, and natural language processing and simulation modeling tools.

9. Conclusions

Relevant research has investigated whether visual imagery and deep learning-based ambient sound processing tools, cloud computing and 3D immersive virtual reality technologies, and predictive modeling and machine vision algorithms assist immersive photorealistic virtual spaces. This systematic literature review presents the published peer-reviewed sources covering how virtual twin modeling and intelligent data processing tools, emotion detection and recognition technologies, and deep learning-based predictive and virtual mapping algorithms shape immersive 3D virtual environments. The research outcomes drawn from the above analyses indicate that virtual reality-based immersive experiences can be achieved by use of neuromorphic image processing and empathetic computing systems, data fusion and digital twin technologies, and 3D virtual space networking and geospatial mapping tools.

10. Limitations, Implications, and Further Directions of Research

By analyzing only articles published between 2022 and 2023 in journals indexed in the Web of Science, Scopus, and ProQuest databases, relevant sources on immersive engagement and geospatial mapping technologies, deep learning and neural network algorithms, and visual perception and data mining tools in metaverse interactive and extended reality environments may have been excluded. Limitations of this research comprise particular kinds of publications (original empirical research and review articles) discounting others (conference proceedings articles, books, and editorial materials). The scope of our study also does not move forward the inspection of remote sensing and artificial cognitive systems, immersive geospatial data visualization and dynamic routing technologies, and virtual navigation and decision support tools.

Subsequent analyses should develop on distributed decision and control algorithms, automated speech recognition and deep learning artificial intelligence tools, and immersive 3D and edge computing technologies. Future research should thus investigate cyber-physical cognitive and immersive visualization systems, simulation modeling and machine learning-based image recognition tools, and virtual twin and spatial computing technologies. Attention should be directed to extended cognitive and big data computing systems, digital twinning and haptic feedback technologies, and intelligent data processing and context awareness tools.

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Compliance with ethical standards

This article does not contain any studies with human participants or animals performed by the authors. Extracting and inspecting publicly accessible files (scholarly sources) as evidence, before the research began no institutional ethics approval was required.

Data availability statement

All data generated or analyzed are included in the published article.

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Author contributions

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication. The authors take full responsibility for the accuracy and the integrity of the data analysis.

Conflict of interest statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Visual Perception and Environment Mapping Algorithms, Spatial Computing and Immersive 3D Technologies, and Movement and Behavior Tracking Tools in the Metaverse

Elizabeth Blackburn*

ABSTRACT. In this article, I cumulate previous research findings indicating that computer vision and deep learning algorithms, digital twinning and remote sensing technologies, and machine learning-based image recognition and decision support tools optimize immersive hyper-connected virtual spaces. I contribute to the literature on metaverse assets and services, data visualization and virtual navigation tools, and artificial intelligence-powered search capabilities by showing that movement and behavior tracking tools, data sharing and image-based object recognition technologies, and real-time visual analytics and immersive visualization systems are instrumental in extended reality environments. Throughout December 2022, I performed a quantitative literature review of the Web of Science, Scopus, and ProQuest databases, with search terms including "the metaverse" + "visual perception and environment mapping algorithms," "spatial computing and immersive 3D technologies," and "movement and behavior tracking tools." As I inspected research published between 2022 and 2023, only 176 articles satisfied the eligibility criteria. By eliminating controversial findings, outcomes unsubstantiated by replication, too imprecise material, or having similar titles, I decided upon 35, generally empirical, sources. Data visualization tools: Dimensions (bibliometric mapping) and VOSviewer (layout algorithms). Reporting quality assessment tool: PRISMA. Methodological quality assessment tools include: AXIS, Dedoose, ROBIS, and SRDR.

Keywords: visual perception and environment mapping algorithms; spatial computing and immersive 3D technologies; movement and behavior tracking tools; metaverse

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1. Introduction

Deep learning-based ambient sound processing and big data management tools, immersive visualization systems, and picture-making neural networks configure extended reality environments. The purpose of my systematic review is to examine the recently published literature on the metaverse and integrate the insights it configures on visual perception and environment mapping algorithms, spatial computing and immersive 3D technologies, and movement and behavior tracking tools. By analyzing the most recent (2022–2023) and significant (Web of Science, Scopus, and ProQuest) sources, my paper has attempted to prove that extended reality environments require geospatial analytics and image processing tools, blockchain token-based digital assets, and auditory and visual immersion systems. The actuality and novelty of this study are articulated by addressing metaverse assets and services, data visualization and virtual navigation tools (Andronie et al., 2021; Dabija et al., 2018; Nica, 2017; Vinerean et al., 2022), and artificial intelligence-powered search capabilities, that is an emerging topic involving much interest. My research problem is whether computer vision and deep learning algorithms, digital twinning and remote sensing technologies, and machine learning-based image recognition and decision support tools (Andronie et al., 2023; Gasparin and Schinckus, 2022; Poliak et al., 2022) optimize immersive hyper-connected virtual spaces.

In this review, prior findings have been cumulated indicating that simulation modeling and natural language processing tools (Balcerzak et al., 2022; Kliestik et al., 2020; Popescu et al., 2017a), biometrics data fusion, and environment perception sensors are pivotal in decentralized 3D digital and immersive interconnected virtual worlds. The identified gaps advance autonomous visual object detection and simulation modeling tools (Barbu et al., 2021; Lăzăroiu et al., 2020; Popescu et al., 2017b), behavioral predictive and decentralized data analytics, and geospatial mapping and cognitive neuro-engineering technologies. My main objective is to indicate that movement and behavior tracking tools, data sharing and image-based object recognition technologies (Blake, 2022; Nagy and Lăzăroiu, 2022; Popescu, 2018), and real-time visual analytics and immersive visualization systems are instrumental in extended reality environments.

2. Theoretical Overview of the Main Concepts

Image processing and ambient scene detection tools, data mining techniques, and eye-tracking technologies assist augmented reality-powered immersive spaces and extended reality environments. User identification technology and location data, cloud computing machines, and machine vision and situational awareness algorithms enable immersive digital worlds. The manuscript is organized as following: theoretical overview (section 2), methodology (section 3), Internet of Things-based decision support and bio-inspired artificial vision systems, virtual simulation and predictive modeling algorithms, and digital twinning and remote sensing technologies on blockchain-based metaverse platforms (section 4), machine vision and situational awareness algorithms, deep learning-based ambient sound processing and big data management tools, and geospatial mapping and cognitive neuro-engineering technologies In the virtual environment of the metaverse (section 5), visual perception and 3D generative modeling tools, geospatial mapping and spatial computing technologies, and bio-sensing and actuation systems in the metaverse interactive environment (section 6), discussion (section 7), synopsis of the main research outcomes (section 8), conclusions (section 9), limitations, implications, and further directions of research (section 10).

3. Methodology

Throughout December 2022, I performed a quantitative literature review of the Web of Science, Scopus, and ProQuest databases, with search terms including "the metaverse" + "visual perception and environment mapping algorithms," "spatial computing and immersive 3D technologies," and "movement and behavior tracking tools." As I inspected research published between 2022 and 2023, only 176 articles satisfied the eligibility criteria. By eliminating controversial findings, outcomes unsubstantiated by replication, too imprecise material, or having similar titles, I decided upon 35, generally empirical, sources (Tables 1 and 2). Data visualization tools: Dimensions (bibliometric mapping) and VOSviewer (layout algorithms). Reporting quality assessment tool: PRISMA. Methodological quality assessment tools include: AXIS, Dedoose, ROBIS, and SRDR (Figures 1–6).

Table 1 Topics and types of scientific products identified and selected.

Topic	**Identified**	**Selected**
the metaverse + visual perception and environment mapping algorithms	61	12
the metaverse + spatial computing and immersive 3D technologies	58	12
the metaverse + movement and behavior tracking tools	57	11
Type of paper		
Original research	146	24
Review	20	11
Conference proceedings	9	0
Book	0	0
Editorial	1	0

Source: Processed by the author. Some topics overlap.

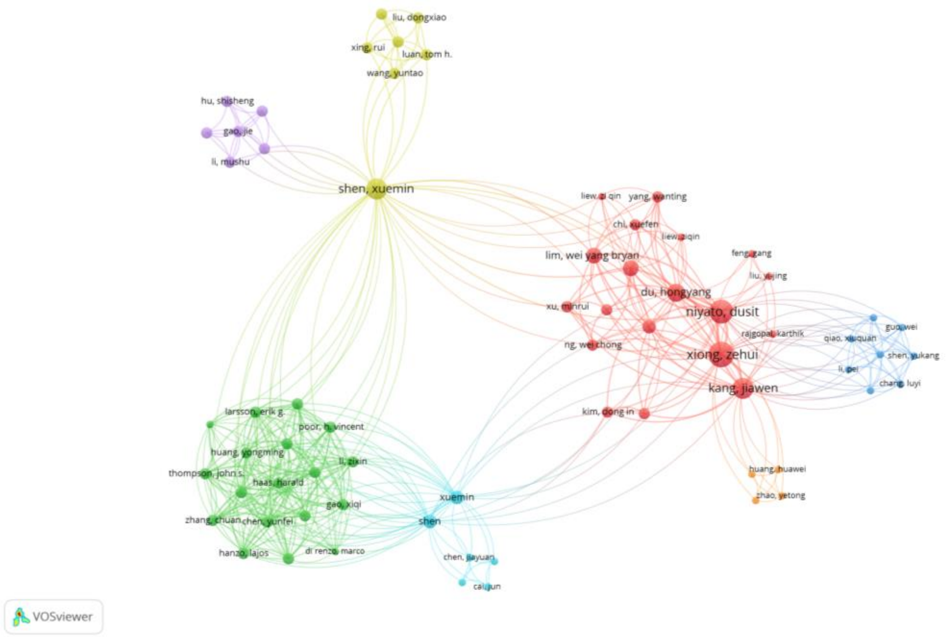

Figure 1 Co-authorship

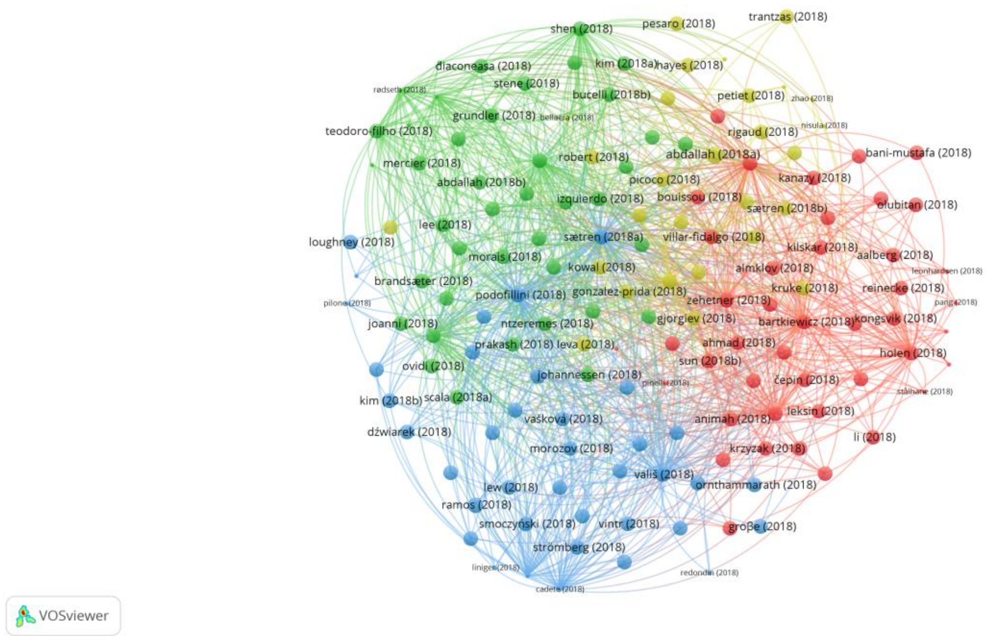

Figure 2 Citation

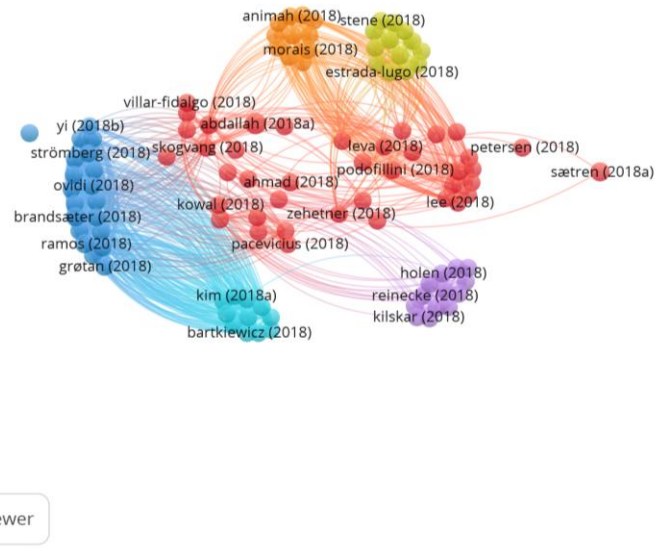

Figure 3 Bibliographic coupling

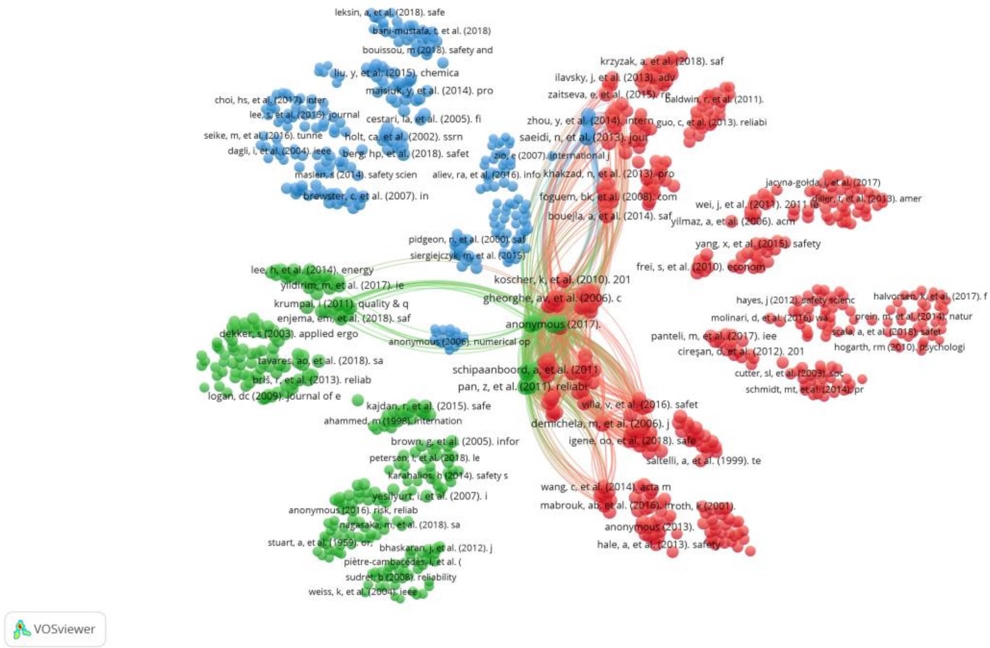

Figure 4 Co-citation

Table 2 General synopsis of evidence as regards focus topics and descriptive outcomes (research findings).

Ambient sound recognition software, digital twin simulation and predictive modeling tools, and spatial data mining and object recognition algorithms assist blockchain-based metaverse platforms.	Braud et al., 2022; Hadi et al., 2023; Ramadan, 2023; Zhao et al., 2022
Visual immersion and tactile sensing technologies, edge intelligence and visual cognitive algorithms, and cognitive computing and Internet of Things-based sensing systems configure spatial virtual reality environments and Web3-powered metaverse worlds.	Cheng et al., 2022; Huynh-The et al., 2023a; Shi et al., 2023; Zhang et al., 2022a
Internet of Things-based decision support and bio-inspired artificial vision systems, machine perception and digital twin technologies, and mobile sensors and actuators are pivotal in extended reality environments.	Ersoy and Gürfidan, 2023; Golf-Papez et al., 2022; Yoo et al., 2023; Zabel et al., 2023
Deep learning and data processing algorithms, automated perception and remote sensing systems, and digital twin simulation and distributed intelligence tools shape the virtual environment of the metaverse.	Giang Barrera and Shah, 2023; Han et al., 2023; Zhang et al., 2022b
Immersive interconnected virtual worlds integrate metaverse assets and services, data visualization and virtual navigation tools, and artificial intelligence-powered search capabilities.	Dwivedi et al., 2023; Hopkins, 2022; Mourtzis et al., 2022; Xian et al., 2023
Autonomous visual object detection and simulation modeling tools, behavioral predictive and decentralized data analytics, and geospatial mapping and cognitive neuro-engineering technologies articulate immersive 3D worlds.	Cao, 2022; Dolata and Schwabe, 2023; He et al., 2023; Newell, 2022
The metaverse interactive environment and immersive digital worlds integrate geospatial mapping and spatial computing technologies, virtual machine interoperability, and 3D generative modeling and image processing tools.	Gauttier et al., 2022; Kwok and Tang, 2023; Meng et al., 2023; Zhang et al., 2023
Immersive digital worlds and extended reality environments require biometric self-authentication devices, metaverse engagement metrics, and behavior pattern clustering.	Bordegoni and Ferrise, 2023; Chen, 2022; Oláh and Nica, 2022; Zheng and Yuan, 2023
Digital twin simulation and 3D modeling tools, computer vision and navigation systems, and multisensor fusion and deep learning-based sensing technologies enable immersive virtual environments and 3D interactive digital spaces.	Huynh-The et al., 2023b; Mișa et al., 2022; Polas et al., 2022; Wang et al., 2022

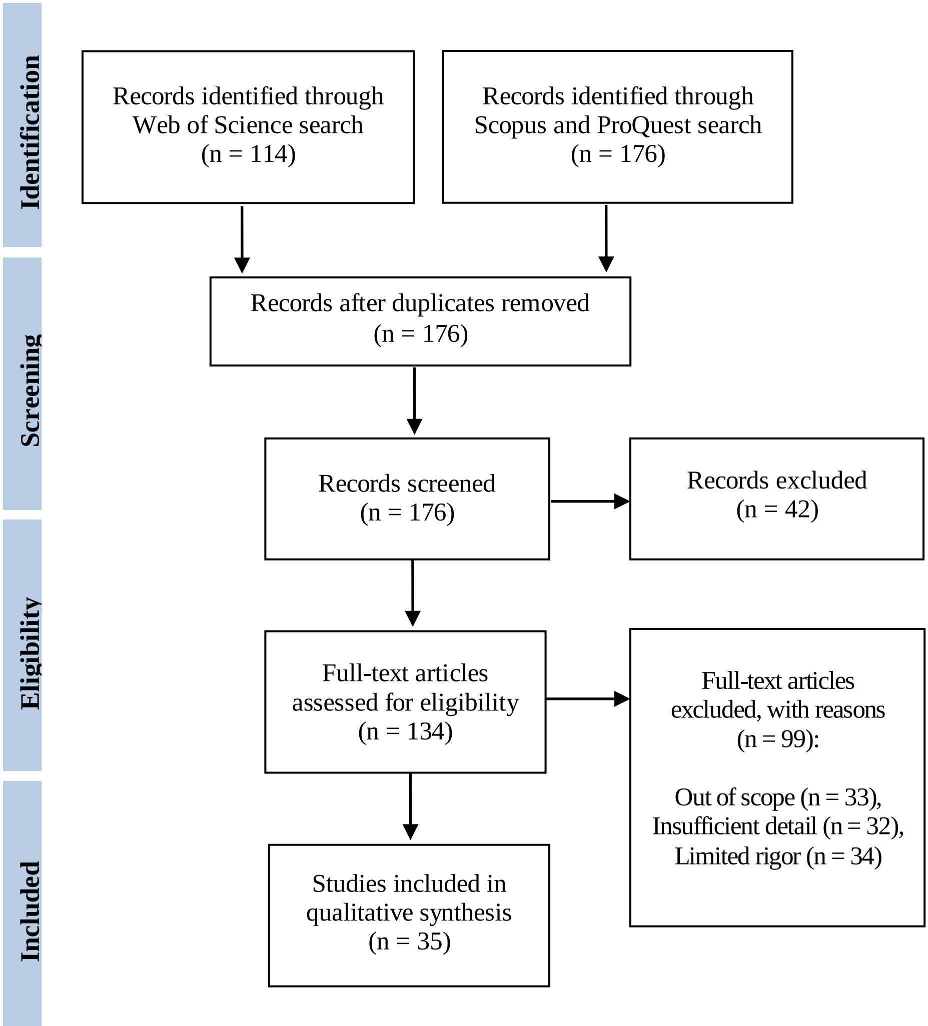

Figure 5 PRISMA flow diagram describing the search results and screening.

Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines were used that ensure the literature review is comprehensive, transparent, and replicable. The flow diagram, produced by employing a Shiny app, presents the stream of evidence-based collected and processed data through the various steps of a systematic review, designing the amount of identified, included, and removed records, and the justifications for exclusions.
To ensure compliance with PRISMA guidelines, a citation software was used, and at each stage the inclusion or exclusion of articles was tracked by use of custom spreadsheet. Justification for the removal of ineligible articles was specified during the full-text screening and final selection.

To ensure first-rate standard of evidence, a systematic search of relevant databases including peer-reviewed published journal articles was conducted using predefined search terms, covering a range of research methods and data sources. Reference lists of all relevant sources were manually reviewed for additional relevant citations.

Titles of papers and abstracts were screened for suitability and selected full texts were retrieved to establish whether they satisfied the inclusion criteria. All records from each database were evaluated by using data extraction forms. Data covering research aims, participants, study design, and method of each paper were extracted.

The inclusion criteria were: (i) articles included in the Web of Science, Scopus, and ProQuest databases, (ii) publication date (2022–2023), (iii) written in English, (iv) being an original empirical research or review article, and (v) particular search terms covered; (i) conference proceedings, (ii) books, and (iii) editorial materials were eliminated from the analysis.

Distiller SR screened and extracted the collected data.

SRDR gathered, handled, and analyzed the data for the systematic review, being configured as an archive and tool harnessed in data extraction through transparent, efficient, and reliable quantitative techniques. Elaborate extraction forms can be set up, meeting the needs of research questions and study designs.

AMSTAR evaluated the methodological quality of systematic reviews.

AXIS evaluated the quality of cross-sectional studies.

The quality of academic articles was determined and risk of bias was measured by MMAT, that tested content validity and usability of selected studies in terms of screening questions, type of design, corresponding quality criteria, and overall quality score.

ROBIS assessed the risk of bias in systematic reviews.

Dedoose analyzed qualitative and mixed methods research.

Figure 6 Screening and quality assessment tools

4. Internet of Things-based Decision Support and Bio-inspired Artificial Vision Systems, Virtual Simulation and Predictive Modeling Algorithms, and Digital Twinning and Remote Sensing Technologies on Blockchain-based Metaverse Platforms

Ambient sound recognition software, digital twin simulation and predictive modeling tools, and spatial data mining and object recognition algorithms (Braud et al., 2022; Hadi et al., 2023; Ramadan, 2023; Zhao et al., 2022) assist blockchain-based metaverse platforms. User behavior data mining, 3D modeling and digital twin technologies, and machine learning-based recognition and deep learning artificial intelligence algorithms further interconnected digital spaces.

Visual immersion and tactile sensing technologies, edge intelligence and visual cognitive algorithms, and cognitive computing and Internet of Things-based sensing systems (Cheng et al., 2022; Huynh-The et al., 2023a; Shi et al., 2023; Zhang et al., 2022a) configure spatial virtual reality environments and Web3-powered metaverse worlds. Computer vision and deep learning algorithms, digital twinning and remote sensing technologies, and machine learning-based image recognition and decision support tools optimize immersive hyper-connected virtual spaces.

Internet of Things-based decision support and bio-inspired artificial vision systems, machine perception and digital twin technologies, and mobile sensors and actuators (Ersoy and Gürfidan, 2023; Golf-Papez et al., 2022; Yoo et al., 2023; Zabel et al., 2023) are pivotal in extended reality environments. Immersive decentralized 3D digital worlds develop on machine learning-based image recognition and spatial awareness tools, implantable intra-body sensors, and virtual simulation and predictive modeling algorithms. (Table 3)

Table 3 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Ambient sound recognition software, digital twin simulation and predictive modeling tools, and spatial data mining and object recognition algorithms assist blockchain-based metaverse platforms.	Braud et al., 2022; Hadi et al., 2023; Ramadan, 2023; Zhao et al., 2022
Visual immersion and tactile sensing technologies, edge intelligence and visual cognitive algorithms, and cognitive computing and Internet of Things-based sensing systems configure spatial virtual reality environments and Web3-powered metaverse worlds.	Cheng et al., 2022; Huynh-The et al., 2023a; Shi et al., 2023; Zhang et al., 2022a
Internet of Things-based decision support and bio-inspired artificial vision systems, machine perception and digital twin technologies, and mobile sensors and actuators are pivotal in extended reality environments.	Ersoy and Gürfidan, 2023; Golf-Papez et al., 2022; Yoo et al., 2023; Zabel et al., 2023

5. Machine Vision and Situational Awareness Algorithms, Deep Learning-based Ambient Sound Processing and Big Data Management Tools, and Geospatial Mapping and Cognitive Neuro-Engineering Technologies in the Virtual Environment of the Metaverse

Deep learning and data processing algorithms, automated perception and remote sensing systems, and digital twin simulation and distributed intelligence tools (Giang Barrera and Shah, 2023; Han et al., 2023; Zhang et al., 2022b) shape the virtual environment of the metaverse. User identification technology and location data, cloud computing machines, and machine vision and situational awareness algorithms enable immersive digital worlds.

Immersive interconnected virtual worlds (Dwivedi et al., 2023; Hopkins, 2022; Mourtzis et al., 2022; Xian et al., 2023) integrate metaverse assets and services, data visualization and virtual navigation tools, and artificial intelligence-powered search capabilities. Deep learning-based ambient sound processing and big data management tools, immersive visualization systems, and picture-making neural networks configure extended reality environments. Interconnected virtual worlds require 3D virtual space networking and geospatial analytics tools, deep learning-based ambient sound processing, and real-time Internet of Things data.

Autonomous visual object detection and simulation modeling tools, behavioral predictive and decentralized data analytics, and geospatial mapping and cognitive neuro-engineering technologies (Cao, 2022; Dolata and Schwabe, 2023; He et al., 2023; Newell, 2022) articulate immersive 3D worlds. Movement and behavior tracking tools, data sharing and image-based object recognition technologies, and real-time visual analytics and immersive visualization systems are instrumental in extended reality environments. (Table 4)

Table 4 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Deep learning and data processing algorithms, automated perception and remote sensing systems, and digital twin simulation and distributed intelligence tools shape the virtual environment of the metaverse.	Giang Barrera and Shah, 2023; Han et al., 2023; Zhang et al., 2022b
Immersive interconnected virtual worlds integrate metaverse assets and services, data visualization and virtual navigation tools, and artificial intelligence-powered search capabilities.	Dwivedi et al., 2023; Hopkins, 2022; Mourtzis et al., 2022; Xian et al., 2023
Autonomous visual object detection and simulation modeling tools, behavioral predictive and decentralized data analytics, and geospatial mapping and cognitive neuro-engineering technologies articulate immersive 3D worlds.	Cao, 2022; Dolata and Schwabe, 2023; He et al., 2023; Newell, 2022

6. Visual Perception and 3D Generative Modeling Tools, Geospatial Mapping and Spatial Computing Technologies, and Bio-Sensing and Actuation Systems in the Metaverse Interactive Environment

The metaverse interactive environment and immersive digital worlds (Gauttier et al., 2022; Kwok and Tang, 2023; Meng et al., 2023; Zhang et al., 2023) integrate geospatial mapping and spatial computing technologies, virtual machine interoperability, and 3D generative modeling and image processing tools. Interconnected virtual worlds necessitate visual perception and 3D generative modeling tools, bio-sensing and actuation systems, and behavioral predictive analytics.

Immersive digital worlds and extended reality environments (Bordegoni and Ferrise, 2023; Chen, 2022; Oláh and Nica, 2022; Zheng and Yuan, 2023) require biometric self-authentication devices, metaverse engagement metrics, and behavior pattern clustering. Extended reality environments require geospatial analytics and image processing tools, blockchain token-based digital assets, and auditory and visual immersion systems. Simulation modeling and natural language processing tools, biometrics data fusion, and environment perception sensors are pivotal in decentralized 3D digital and immersive interconnected virtual worlds.

Digital twin simulation and 3D modeling tools, computer vision and navigation systems, and multisensor fusion and deep learning-based sensing technologies (Huynh-The et al., 2023b; Mișa et al., 2022; Polas et al., 2022; Wang et al., 2022) enable immersive virtual environments and 3D interactive digital spaces. Image processing and ambient scene detection tools, data mining techniques, and eye-tracking technologies assist augmented reality-powered immersive spaces and extended reality environments. (Table 5)

Table 5 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

The metaverse interactive environment and immersive digital worlds integrate geospatial mapping and spatial computing technologies, virtual machine interoperability, and 3D generative modeling and image processing tools.	Gauttier et al., 2022; Kwok and Tang, 2023; Meng et al., 2023; Zhang et al., 2023
Immersive digital worlds and extended reality environments require biometric self-authentication devices, metaverse engagement metrics, and behavior pattern clustering.	Bordegoni and Ferrise, 2023; Chen, 2022; Oláh and Nica, 2022; Zheng and Yuan, 2023
Digital twin simulation and 3D modeling tools, computer vision and navigation systems, and multisensor fusion and deep learning-based sensing technologies enable immersive virtual environments and 3D interactive digital spaces.	Huynh-The et al., 2023b; Mișa et al., 2022; Polas et al., 2022; Wang et al., 2022

7. Discussion

I integrate my systematic review throughout research indicating how interconnected virtual worlds necessitate visual perception and 3D generative modeling tools, bio-sensing and actuation systems, and behavioral predictive analytics. My research complements recent analyses clarifying how user behavior data mining, 3D modeling and digital twin technologies, and machine learning-based recognition and deep learning artificial intelligence algorithms further interconnected digital spaces. I elucidate, by cumulative evidence, previous research demonstrating how movement and behavior tracking tools, data sharing and image-based object recognition technologies, and real-time visual analytics and immersive visualization systems are instrumental in extended reality environments.

8. Synopsis of the Main Research Outcomes

Immersive decentralized 3D digital worlds develop on machine learning-based image recognition and spatial awareness tools, implantable intra-body sensors, and virtual simulation and predictive modeling algorithms. Computer vision and deep learning algorithms, digital twinning and remote sensing technologies, and machine learning-based image recognition and decision support tools optimize immersive hyper-connected virtual spaces.

9. Conclusions

Relevant research has investigated whether extended reality environments require geospatial analytics and image processing tools, blockchain token-based digital assets, and auditory and visual immersion systems. This systematic literature review presents the published peer-reviewed sources covering how simulation modeling and natural language processing tools, biometrics data fusion, and environment perception sensors are pivotal in decentralized 3D digital and immersive interconnected virtual worlds. The research outcomes drawn from the above analyses indicate that interconnected virtual worlds require 3D virtual space networking and geospatial analytics tools, deep learning-based ambient sound processing, and real-time Internet of Things data.

10. Limitations, Implications, and Further Directions of Research

By analyzing only articles published between 2022 and 2023 in journals indexed in the Web of Science, Scopus, and ProQuest databases, relevant sources on visual perception and environment mapping algorithms, spatial computing and immersive 3D technologies, and movement and behavior tracking tools in the metaverse may have been excluded. Limitations of this research comprise particular kinds of publications (original empirical research and review articles) discounting others (conference proceedings articles, books, and editorial materials). The scope of my study also does not move forward the inspection of geospatial mapping and spatial computing technologies, virtual machine interoperability, and 3D generative modeling and image processing tools.

Subsequent analyses should develop on visual immersion and tactile sensing technologies, edge intelligence and visual cognitive algorithms, and cognitive computing and Internet of Things-based sensing systems. Future research should thus investigate Internet of Things-based decision support and bio-inspired artificial vision systems, machine perception and digital twin technologies, and mobile sensors and actuators. Attention should be directed to digital twin simulation and 3D modeling tools, computer vision and navigation systems, and multisensor fusion and deep learning-based sensing technologies.

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Compliance with ethical standards
This article does not contain any studies with human participants or animals performed by the author. Extracting and inspecting publicly accessible files (scholarly sources) as evidence, before the research began no institutional ethics approval was required.

Data availability statement
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Author contributions
The author confirms being the sole contributor of this work and approved it for publication. The author takes full responsibility for the accuracy and the integrity of the data analysis.

Conflict of interest statement
The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Disclosure by the editors of record
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Transparency statement
The author affirms that the manuscript represents an honest, accurate, and transparent account of the research being reported, that no relevant aspects of the study have been left out, and that any inconsistencies from the research as planned (and, if significant, registered) have been clarified.

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Interactive 3D Geo-Visualization Systems, Deep Learning-based Image Classification Algorithms, and Virtual Navigation and Simulation Modeling Tools across Web3-powered Metaverse Worlds

Karen Griffin*

ABSTRACT. Based on an in-depth survey of the literature, the purpose of the paper is to explore The virtual environment of the metaverse and the digital asset-based virtual economy. In this research, previous findings were cumulated showing that Photo-realistic simulation environments necessitate sensor and actuator devices, haptic object recognition and multi-sensor fusion systems, and cognitive modeling and digital twin technologies, and I contribute to the literature by indicating that immersive virtual experiences can be achieved through autonomous cognitive and biometric authentication systems, movement and behavior tracking tools, and emotion detection and situational awareness algorithms. Throughout January 2023, a quantitative literature review of the Web of Science, Scopus, and ProQuest databases was performed, with search terms including "Web3-powered metaverse worlds" + "interactive 3D geo-visualization systems," "deep learning-based image classification algorithms," and "virtual navigation and simulation modeling tools." As research published between 2022 and 2023 was inspected, only 169 articles satisfied the eligibility criteria. By taking out controversial or ambiguous findings (insufficient/irrelevant data), outcomes unsubstantiated by replication, too general material, or studies with nearly identical titles, I selected 35 mainly empirical sources. Data visualization tools: Dimensions (bibliometric mapping) and VOSviewer (layout algorithms). Reporting quality assessment tool: PRISMA. Methodological quality assessment tools include: AMSTAR, Dedoose, Distiller SR, and SRDR.

Keywords: interactive 3D geo-visualization systems, deep learning-based image classification algorithms, and virtual navigation and simulation modeling tools; metaverse

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1. Introduction

Generative artificial intelligence and immersive visualization systems, predictive maintenance and geolocation data processing algorithms, and spatial computing and data sharing technologies articulate photorealistic 3D environments. The purpose of my systematic review is to examine the recently published literature on Web3-powered metaverse worlds and integrate the insights it configures on interactive 3D geo-visualization systems, deep learning-based image classification algorithms, and virtual navigation and simulation modeling tools. By analyzing the most recent (2022–2023) and significant (Web of Science, Scopus, and ProQuest) sources, my paper has attempted to prove that photo-realistic simulation environments necessitate sensor and actuator devices, haptic object recognition and multi-sensor fusion systems, and cognitive modeling and digital twin technologies. The actuality and novelty of this study are articulated by addressing the virtual environment of the metaverse and the digital asset-based virtual economy, that is an emerging topic involving much interest. My research problem is whether signal processing and predictive geospatial modeling tools, ambient sound recognition software, and virtual navigation tools are instrumental in immersive 3D worlds.

In this review, prior findings have been cumulated indicating that 3D immersive spaces and experiences can be attained by use of movement and behavior tracking tools (Andronie et al., 2021a; Glogovețan et al., 2022; Pop et al., 2023), affective and perceptual technologies (Dabija et al., 2022; Nica, 2017; Popescu, 2018; Valaskova et al., 2022), and context awareness and cognitive decision-making algorithms. The identified gaps advance situational awareness and object perception algorithms (Andronie et al., 2021b; Kliestik et al., 2022; Popescu et al., 2017a), text and data mining techniques, and big geospatial data and real-time event analytics. My main objective is to indicate that immersive virtual experiences can be achieved through autonomous cognitive and biometric authentication systems (Andronie et al., 2021c; Musova et al., 2021; Popescu et al., 2017b), movement and behavior tracking tools (Gasparin and Schinckus, 2022; Nica, 2018; Popescu et al., 2022), and emotion detection and situational awareness algorithms.

2. Theoretical Overview of the Main Concepts

Digital twin simulation and virtual navigation tools, spatial computing and object tracking algorithms, and cognitive and behavioral technologies further extended reality environments. Geolocation data mining and tracking, predictive maintenance and image detection algorithms, and image recognition and spatial computing technologies optimize the digital asset-based virtual economy. Context recognition and immersive decentralized networking tools, intelligent connectivity infrastructures, and synthetic biometric data enable immersive 3D virtual environments. The manuscript is organized as following: theoretical overview (section 2), methodology (section 3), situational awareness and object perception algorithms, image recognition and spatial computing technologies, and geolocation data mining and tracking on blockchain-based metaverse platforms (section 4), predictive maintenance and geolocation data processing algorithms, spatial computing and data sharing technologies, and immersive visualization and empathetic computing systems in metaverse interactive and photo-realistic simulation environments (section 5), metaverse assets and services, real-time visual analytics and artificial cognitive systems, and deep learning-based sensing and digital twinning technologies in immersive 3D virtual environments (section 6), discussion (section 7), synopsis of the main research outcomes (section 8), conclusions (section 9), limitations, implications, and further directions of research (section 10).

3. Methodology

Throughout January 2023, a quantitative literature review of the Web of Science, Scopus, and ProQuest databases was performed, with search terms including "Web3-powered metaverse worlds" + "interactive 3D geo-visualization systems," "deep learning-based image classification algorithms," and "virtual navigation and simulation modeling tools." As research published between 2022 and 2023 was inspected, only 169 articles satisfied the eligibility criteria. By taking out controversial or ambiguous findings (insufficient/irrelevant data), outcomes unsubstantiated by replication, too general material, or studies with nearly identical titles, I selected 35 mainly empirical sources (Tables 1 and 2). Data visualization tools: Dimensions (bibliometric mapping) and VOSviewer (layout algorithms). Reporting quality assessment tool: PRISMA. Methodological quality assessment tools include: AMSTAR, Dedoose, Distiller SR, and SRDR (Figures 1–6).

Table 1 Topics and types of scientific products identified and selected.

Topic	**Identified**	**Selected**
Web3-powered metaverse worlds + interactive 3D geo-visualization systems	59	12
Web3-powered metaverse worlds + deep learning-based image classification algorithms	56	12
Web3-powered metaverse worlds + virtual navigation and simulation modeling tools	54	11
Type of paper		
Original research	142	28
Review	18	7
Conference proceedings	8	0
Book	0	0
Editorial	1	0

Source: Processed by the author. Some topics overlap.

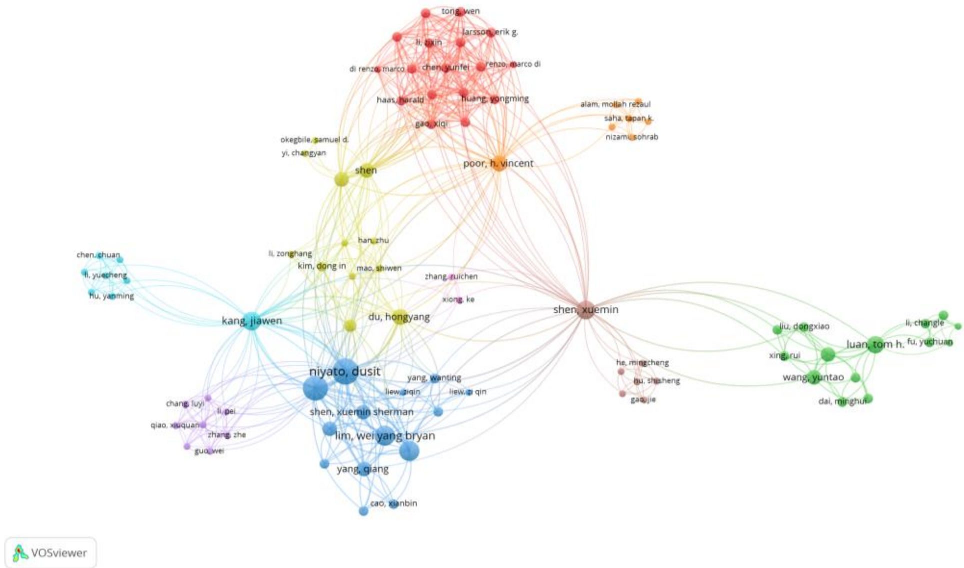

Figure 1 Co-authorship

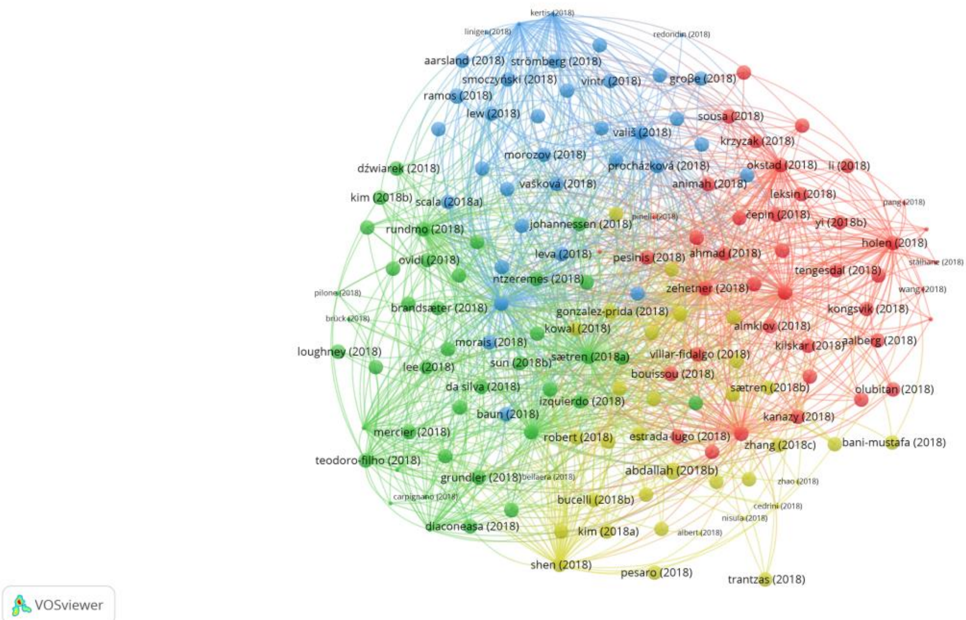

Figure 2 Citation

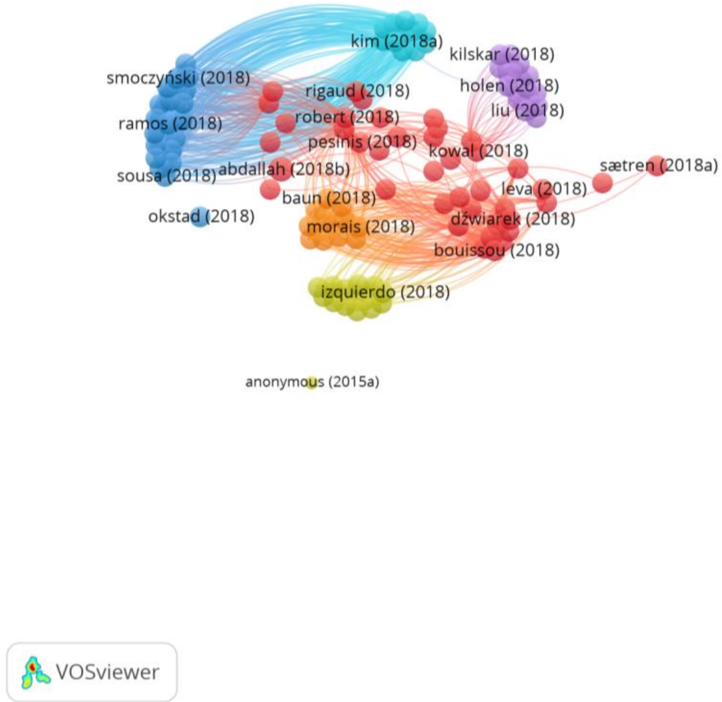

Figure 3 Bibliographic coupling

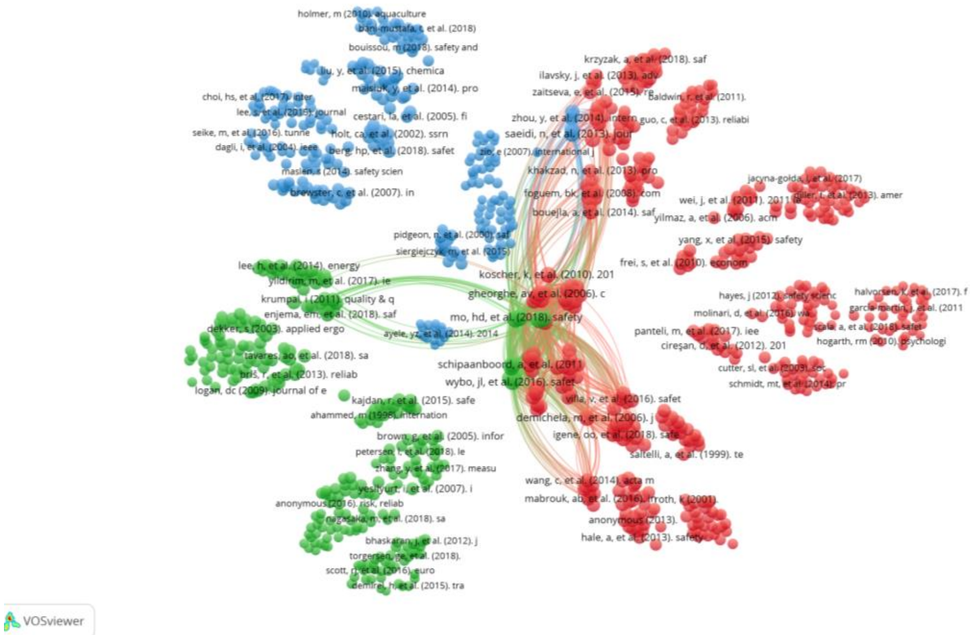

Figure 4 Co-citation

Table 2 General synopsis of evidence as regards focus topics and descriptive outcomes (research findings).

Synthetic data and digital twin modeling tools, semantic network representations, and voice recognition software are pivotal in interoperable extended reality environments across the metaverse economy.	Egliston and Carter, 2022; Han et al., 2023a; Kozinets, 2023; Zainab et al., 2022
Blockchain-based metaverse platforms and immersive digital worlds develop on situational awareness and object perception algorithms, text and data mining techniques, and big geospatial data and real-time event analytics.	Park and Kim, 2023; Tang et al., 2023; Vidal-Tomás, 2023; Zhang et al., 2023a
Simulation modeling, intelligent data processing, contextual awareness, and visual imagery tools enable immersive interconnected virtual and decentralized 3D digital worlds.	Balica et al., 2022; Du et al., 2023; Han et al., 2022; Oh et al., 2023
Interactional and contextual data, 3D holographic avatars, and virtual twin technology are instrumental in metaverse interactive and photo-realistic simulation environments.	Han et al., 2023b; Njoku et al., 2023; Perkins, 2022; Zhang et al., 2023b
The virtual environment of the metaverse and the digital asset-based virtual economy necessitate data mining techniques, intelligent connectivity infrastructures, real-time predictive and big spatio-temporal data analytics, and cloud computing machines.	Daneshfar and Jamshidi, 2023; He et al., 2023; Queiroz et al., 2023; Zallio and Clarkson, 2022
Environment perception sensors, immersive visualization and empathetic computing systems, and spatio-temporal modeling and mapping tools are instrumental in digitally-networked mediated spaces.	Hennig-Thurau et al., 2022; Vochozka et al., 2022; Wongkitrungrueng and Suprawan, 2023
The blockchain-based metaverse develop on virtual immersive and real-time 3D rendering technologies, environment perception sensors, behavioral simulation and data mining tools, and artificial intelligence-powered search capabilities.	Bojic, 2022; McStay, 2023; Rostami and Maier, 2022; Wu et al., 2023
Deep learning-based ambient sound processing, metaverse assets and services, text mining and analytics, and implantable intra-body sensors are instrumental in immersive 3D worlds and across digitally-networked mediated spaces.	Ding et al., 2022; Nagendran et al., 2022; Shi et al., 2023; Zyda, 2022
Sensor fusion and 3D path planning algorithms, distributed autonomous control and artificial vision systems, and deep learning-based sensing and digital twinning technologies shape interactive digital worlds.	Carey, 2022; Kwok and Tang, 2023; Lv et al., 2022; Smart, 2022

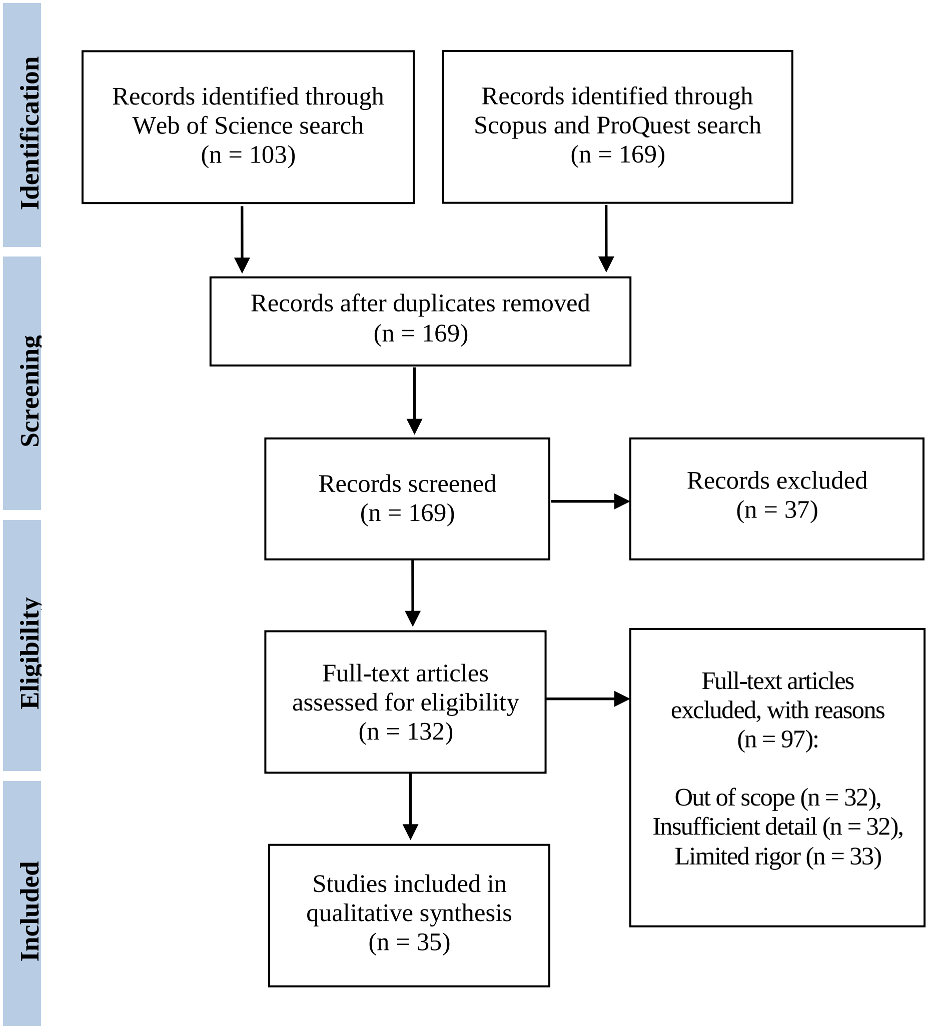

Figure 5 PRISMA flow diagram describing the search results and screening.

Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines were used that ensure the literature review is comprehensive, transparent, and replicable. The flow diagram, produced by employing a Shiny app, presents the stream of evidence-based collected and processed data through the various steps of a systematic review, designing the amount of identified, included, and removed records, and the justifications for exclusions.

To ensure compliance with PRISMA guidelines, a citation software was used, and at each stage the inclusion or exclusion of articles was tracked by use of custom spreadsheet. Justification for the removal of ineligible articles was specified during the full-text screening and final selection.

To ensure first-rate standard of evidence, a systematic search of relevant databases including peer-reviewed published journal articles was conducted using predefined search terms, covering a range of research methods and data sources. Reference lists of all relevant sources were manually reviewed for additional relevant citations.

Titles of papers and abstracts were screened for suitability and selected full texts were retrieved to establish whether they satisfied the inclusion criteria. All records from each database were evaluated by using data extraction forms. Data covering research aims, participants, study design, and method of each paper were extracted.

The inclusion criteria were: (i) articles included in the Web of Science, Scopus, and ProQuest databases, (ii) publication date (2022–2023), (iii) written in English, (iv) being an original empirical research or review article, and (v) particular search terms covered; (i) conference proceedings, (ii) books, and (iii) editorial materials were eliminated from the analysis.

Distiller SR screened and extracted the collected data.

SRDR gathered, handled, and analyzed the data for the systematic review, being configured as an archive and tool harnessed in data extraction through transparent, efficient, and reliable quantitative techniques. Elaborate extraction forms can be set up, meeting the needs of research questions and study designs.

AMSTAR evaluated the methodological quality of systematic reviews.

ROBIS assessed the risk of bias in systematic reviews.

The quality of academic articles was determined and risk of bias was measured by MMAT, that tested content validity and usability of selected studies in terms of screening questions, type of design, corresponding quality criteria, and overall quality score.

AXIS evaluated the quality of cross-sectional studies.

Dedoose analyzed qualitative and mixed methods research.

Figure 6 Screening and quality assessment tools

4. Situational Awareness and Object Perception Algorithms, Image Recognition and Spatial Computing Technologies, and Geolocation Data Mining and Tracking on Blockchain-based Metaverse Platforms

Synthetic data and digital twin modeling tools, semantic network representations, and voice recognition software (Egliston and Carter, 2022; Han et al., 2023a; Kozinets, 2023; Zainab et al., 2022) are pivotal in interoperable extended reality environments across the metaverse economy. Geolocation data mining and tracking, predictive maintenance and image detection algorithms, and image recognition and spatial computing technologies optimize the digital asset-based virtual economy.

Blockchain-based metaverse platforms and immersive digital worlds (Park and Kim, 2023; Tang et al., 2023; Vidal-Tomás, 2023; Zhang et al., 2023a) develop on situational awareness and object perception algorithms, text and data mining techniques, and big geospatial data and real-time event analytics. Decentralized 3D virtual spaces develop on geospatial intelligence and digital twin simulation tools, 3D object recognition and performance capture technologies, and visual object tracking and motion planning algorithms.

Simulation modeling, intelligent data processing, contextual awareness, and visual imagery tools (Balica et al., 2022; Du et al., 2023; Han et al., 2022; Oh et al., 2023) enable immersive interconnected virtual and decentralized 3D digital worlds. Photo-realistic simulation environments necessitate sensor and actuator devices, haptic object recognition and multi-sensor fusion systems, and cognitive modeling and digital twin technologies. Signal processing and predictive geospatial modeling tools, ambient sound recognition software, and virtual navigation tools are instrumental in immersive 3D worlds. (Table 3)

Table 3 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Synthetic data and digital twin modeling tools, semantic network representations, and voice recognition software are pivotal in interoperable extended reality environments across the metaverse economy.	Egliston and Carter, 2022; Han et al., 2023a; Kozinets, 2023; Zainab et al., 2022
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Simulation modeling, intelligent data processing, contextual awareness, and visual imagery tools enable immersive interconnected virtual and decentralized 3D digital worlds.	Balica et al., 2022; Du et al., 2023; Han et al., 2022; Oh et al., 2023

5. Predictive Maintenance and Geolocation Data Processing Algorithms, Spatial Computing and Data Sharing Technologies, and Immersive Visualization and Empathetic Computing Systems in Metaverse Interactive and Photo-Realistic Simulation Environments

Interactional and contextual data, 3D holographic avatars, and virtual twin technology (Han et al., 2023b; Njoku et al., 2023; Perkins, 2022; Zhang et al., 2023b) are instrumental in metaverse interactive and photo-realistic simulation environments. Generative artificial intelligence and immersive visualization systems, predictive maintenance and geolocation data processing algorithms, and spatial computing and data sharing technologies articulate photorealistic 3D environments. Digital twin simulation and virtual navigation tools, spatial computing and object tracking algorithms, and cognitive and behavioral technologies further extended reality environments.

The virtual environment of the metaverse and the digital asset-based virtual economy (Daneshfar and Jamshidi, 2023; He et al., 2023; Queiroz et al., 2023; Zallio and Clarkson, 2022) necessitate data mining techniques, intelligent connectivity infrastructures, real-time predictive and big spatio-temporal data analytics, and cloud computing machines. Immersive virtual experiences can be achieved through autonomous cognitive and biometric authentication systems, movement and behavior tracking tools, and emotion detection and situational awareness algorithms.

Environment perception sensors, immersive visualization and empathetic computing systems, and spatio-temporal modeling and mapping tools (Hennig-Thurau et al., 2022; Vochozka et al., 2022; Wongkitrungrueng and Suprawan, 2023) are instrumental in digitally-networked mediated spaces. 3D immersive spaces and experiences can be attained by use of movement and behavior tracking tools, affective and perceptual technologies, and context awareness and cognitive decision-making algorithms. (Table 4)

Table 4 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Interactional and contextual data, 3D holographic avatars, and virtual twin technology are instrumental in metaverse interactive and photo-realistic simulation environments.	Han et al., 2023b; Njoku et al., 2023; Perkins, 2022; Zhang et al., 2023b
The virtual environment of the metaverse and the digital asset-based virtual economy necessitate data mining techniques, intelligent connectivity infrastructures, real-time predictive and big spatio-temporal data analytics, and cloud computing machines.	Daneshfar and Jamshidi, 2023; He et al., 2023; Queiroz et al., 2023; Zallio and Clarkson, 2022
Environment perception sensors, immersive visualization and empathetic computing systems, and spatio-temporal modeling and mapping tools are instrumental in digitally-networked mediated spaces.	Hennig-Thurau et al., 2022; Vochozka et al., 2022; Wongkitrungrueng and Suprawan, 2023

6. Metaverse Assets and Services, Real-Time Visual Analytics and Artificial Cognitive Systems, and Deep Learning-based Sensing and Digital Twinning Technologies in Immersive 3D Virtual Environments

The blockchain-based metaverse (Bojic, 2022; McStay, 2023; Rostami and Maier, 2022; Wu et al., 2023) develop on virtual immersive and real-time 3D rendering technologies, environment perception sensors, behavioral simulation and data mining tools, and artificial intelligence-powered search capabilities. Context recognition and immersive decentralized networking tools, intelligent connectivity infrastructures, and synthetic biometric data enable immersive 3D virtual environments. Contextual awareness and spatial data visualization tools, immersive 3D and cognitive enhancement technologies, and biometric and behavioral data optimize extended reality environments and immersive virtual worlds.

Deep learning-based ambient sound processing, metaverse assets and services, text mining and analytics, and implantable intra-body sensors (Ding et al., 2022; Nagendran et al., 2022; Shi et al., 2023; Zyda, 2022) are instrumental in immersive 3D worlds and across digitally-networked mediated spaces. Spatio-temporal modeling and mapping tools, real-time visual analytics and artificial cognitive systems, and eye-tracking and immersive technologies further interactive digital worlds.

Sensor fusion and 3D path planning algorithms, distributed autonomous control and artificial vision systems, and deep learning-based sensing and digital twinning technologies (Carey, 2022; Kwok and Tang, 2023; Lv et al., 2022; Smart, 2022) shape interactive digital worlds. Data visualization and socially-oriented location tracking tools, deep learning-based generative and wireless sensor networks, and sensor data fusion shape blockchain-based virtual and digital hyper-realistic worlds. (Table 5)

Table 5 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

The blockchain-based metaverse develop on virtual immersive and real-time 3D rendering technologies, environment perception sensors, behavioral simulation and data mining tools, and artificial intelligence-powered search capabilities.	Bojic, 2022; McStay, 2023; Rostami and Maier, 2022; Wu et al., 2023
Deep learning-based ambient sound processing, metaverse assets and services, text mining and analytics, and implantable intra-body sensors are instrumental in immersive 3D worlds and across digitally-networked mediated spaces.	Ding et al., 2022; Nagendran et al., 2022; Shi et al., 2023; Zyda, 2022
Sensor fusion and 3D path planning algorithms, distributed autonomous control and artificial vision systems, and deep learning-based sensing and digital twinning technologies shape interactive digital worlds.	Carey, 2022; Kwok and Tang, 2023; Lv et al., 2022; Smart, 2022

7. Discussion

I integrate my systematic review throughout research indicating how 3D immersive spaces and experiences can be attained by use of movement and behavior tracking tools, affective and perceptual technologies, and context awareness and cognitive decision-making algorithms. My research complements recent analyses clarifying how contextual awareness and spatial data visualization tools, immersive 3D and cognitive enhancement technologies, and biometric and behavioral data optimize extended reality environments and immersive virtual worlds. I elucidate, by cumulative evidence, previous research demonstrating how decentralized 3D virtual spaces develop on geospatial intelligence and digital twin simulation tools, 3D object recognition and performance capture technologies, and visual object tracking and motion planning algorithms.

8. Synopsis of the Main Research Outcomes

Data visualization and socially-oriented location tracking tools, deep learning-based generative and wireless sensor networks, and sensor data fusion shape blockchain-based virtual and digital hyper-realistic worlds. Signal processing and predictive geospatial modeling tools, ambient sound recognition software, and virtual navigation tools are instrumental in immersive 3D worlds.

9. Conclusions

Relevant research has investigated whether spatio-temporal modeling and mapping tools, real-time visual analytics and artificial cognitive systems, and eye-tracking and immersive technologies further interactive digital worlds. This systematic literature review presents the published peer-reviewed sources covering how photo-realistic simulation environments necessitate sensor and actuator devices, haptic object recognition and multi-sensor fusion systems, and cognitive modeling and digital twin technologies. The research outcomes drawn from the above analyses indicate that immersive virtual experiences can be achieved through autonomous cognitive and biometric authentication systems, movement and behavior tracking tools, and emotion detection and situational awareness algorithms.

10. Limitations, Implications, and Further Directions of Research

By analyzing only articles published between 2022 and 2023 in journals indexed in the Web of Science, Scopus, and ProQuest databases, relevant sources on interactive 3D geo-visualization systems, deep learning-based image classification algorithms, and virtual navigation and simulation modeling tools across Web3-powered metaverse worlds may have been excluded. Limitations of this research comprise particular kinds of publications (original empirical research and review articles) discounting others (conference proceedings articles, books, and editorial materials). The scope of my study also does not move forward the inspection of blockchain-based metaverse platforms and immersive digital worlds.

Subsequent analyses should develop on synthetic data and digital twin modeling tools, semantic network representations, and voice recognition software. Future research should thus investigate environment perception sensors, immersive visualization and empathetic computing systems, and spatio-temporal modeling and mapping tools. Attention should be directed to immersive interconnected virtual and decentralized 3D digital worlds.

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Compliance with ethical standards

This article does not contain any studies with human participants or animals performed by the author. Extracting and inspecting publicly accessible files (scholarly sources) as evidence, before the research began no institutional ethics approval was required.

Data availability statement

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Author contributions

The author confirms being the sole contributor of this work and approved it for publication. The author takes full responsibility for the accuracy and the integrity of the data analysis.

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The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Disclosure by the editors of record

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Transparency statement

The author affirms that the manuscript represents an honest, accurate, and transparent account of the research being reported, that no relevant aspects of the study have been left out, and that any inconsistencies from the research as planned (and, if significant, registered) have been clarified.

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Deep Learning-Based Object Detection and Holographic Virtual Imaging Technologies, Mobile Biometric and Sentiment Data, and Digital Twin Simulation and Modeling Tools in the Metaverse Economy

Katarina Frajtova Michalikova[1], Roman Ondrejka[2], and Evelyn Johnson[3]

ABSTRACT. The objective of this paper is to systematically review immersive decentralized networking and virtual navigation tools, photorealistic synthetic images and data, and metaverse assets and services. The findings and analyses highlight that cognitive computing and multimodal sensing systems, environment mapping and predictive modeling algorithms, and digital twin and tactile sensing technologies articulate extended reality environments. Throughout December 2022, a quantitative literature review of the Web of Science, Scopus, and ProQuest databases was performed, with search terms including "the metaverse economy" + "deep learning-based object detection and holographic virtual imaging technologies," "mobile biometric and sentiment data," and "digital twin simulation and modeling tools." As research published between 2022 and 2023 was inspected, only 168 articles satisfied the eligibility criteria. By taking out controversial or ambiguous findings (insufficient/ irrelevant data), outcomes unsubstantiated by replication, too general material, or studies with nearly identical titles, we selected 32 mainly empirical sources. Data visualization tools: Dimensions (bibliometric mapping) and VOSviewer (layout algorithms). Reporting quality assessment tool: PRISMA. Methodological quality assessment tools include: AMSTAR, Dedoose, Distiller SR, and SRDR.

Keywords: deep learning-based object detection and holographic virtual imaging technologies; mobile biometric and sentiment data; digital twin simulation and modeling tools; metaverse

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1. Introduction

Big geospatial and Internet of Things sensor data analytics, virtual twin and cognitive enhancement technologies, and operational modeling and spatial data visualization tools assist interconnected digital realms. The purpose of our systematic review is to examine the recently published literature on the metaverse economy and integrate the insights it configures on deep learning-based object detection and holographic virtual imaging technologies, mobile biometric and sentiment data, and digital twin simulation and modeling tools. By analyzing the most recent (2022–2023) and significant (Web of Science, Scopus, and ProQuest) sources, our paper has attempted to prove that immersive holographic virtual experiences can be achieved by use of cognitive enhancement and modeling technologies, biometric-based user recognition and hyper-real avatars, and photorealistic synthetic imagery. The actuality and novelty of this study are articulated by addressing immersive decentralized networking and virtual navigation tools (Andronie et al., 2021a; Krizanova et al., 2019; Nica et al., 2023; Popescu et al., 2022), photorealistic synthetic images and data, and metaverse assets and services, that is an emerging topic involving much interest. Our research problem is whether visual imagery and ambient intelligence tools, data fusion and digital twin technologies, and real-time sensor and captured image data shape interconnected digital spaces.

In this review, prior findings have been cumulated indicating that cognitive computing and multimodal sensing systems, environment mapping and predictive modeling algorithms (Andronie et al., 2021b; Lăzăroiu et al., 2017; Pop et al., 2021), and digital twin and tactile sensing technologies articulate extended reality environments. The identified gaps advance big data management and simulation modeling tools (Andronie et al., 2023; Naepi and Naepi, 2022; Popescu et al., 2017a), computer vision and remote sensing algorithms, and geospatial mapping and machine learning-based object recognition technologies. Our main objective is to indicate that immersive visual and mobile location analytics (Gasparin and Schinckus, 2022; Nica, 2017; Popescu et al., 2017b; Vătămănescu et al., 2020), edge computing and cognitive enhancement technologies, and virtual navigation and image processing tools (Kliestik et al., 2022; Nica, 2018; Popescu, 2018; Vătămănescu et al., 2022) enable augmented reality-powered immersive spaces.

2. Theoretical Overview of the Main Concepts

Digital twin and simulation technologies, cognitive computing and Internet of Things-based sensing systems, and machine learning-based image recognition and autonomous visual object detection tools configure realistic appearances of animated 3D reconstructions of individuals, objects, and spaces. The manuscript is organized as following: theoretical overview (section 2), methodology (section 3), machine learning-based image recognition and autonomous visual object detection tools, human digital twin and geospatial big data visualization systems, and location intelligence and synthetic biometric data in a fully connected metaverse (section 4), digital twin simulation and visual imagery tools, spatial computing and 3D modeling technologies, and haptic object recognition and automated perception systems in the virtual environment of the metaverse (section 5), cognitive computing and multimodal sensing systems, operational modeling and spatial data visualization tools, and geospatial mapping and machine learning-based object recognition technologies in the decentralized metaverse (section 6), discussion (section 7), synopsis of the main research outcomes (section 8), conclusions (section 9), limitations, implications, and further directions of research (section 10).

3. Methodology

Throughout December 2022, a quantitative literature review of the Web of Science, Scopus, and ProQuest databases was performed, with search terms including "the metaverse economy" + "deep learning-based object detection and holographic virtual imaging technologies," "mobile biometric and sentiment data," and "digital twin simulation and modeling tools." As research published between 2022 and 2023 was inspected, only 168 articles satisfied the eligibility criteria. By taking out controversial or ambiguous findings (insufficient/irrelevant data), outcomes unsubstantiated by replication, too general material, or studies with nearly identical titles, we selected 32 mainly empirical sources (Tables 1 and 2). Data visualization tools: Dimensions (bibliometric mapping) and VOSviewer (layout algorithms). Reporting quality assessment tool: PRISMA. Methodological quality assessment tools include: AMSTAR, Dedoose, Distiller SR, and SRDR (Figures 1–6).

Table 1 Topics and types of scientific products identified and selected.

Topic	**Identified**	**Selected**
the metaverse economy + deep learning-based object detection and holographic virtual imaging technologies	58	12
the metaverse economy + mobile biometric and sentiment data	56	10
the metaverse economy + digital twin simulation and modeling tools	54	10
Type of paper		
Original research	138	23
Review	20	9
Conference proceedings	9	0
Book	0	0
Editorial	1	0

Source: Processed by the authors. Some topics overlap.

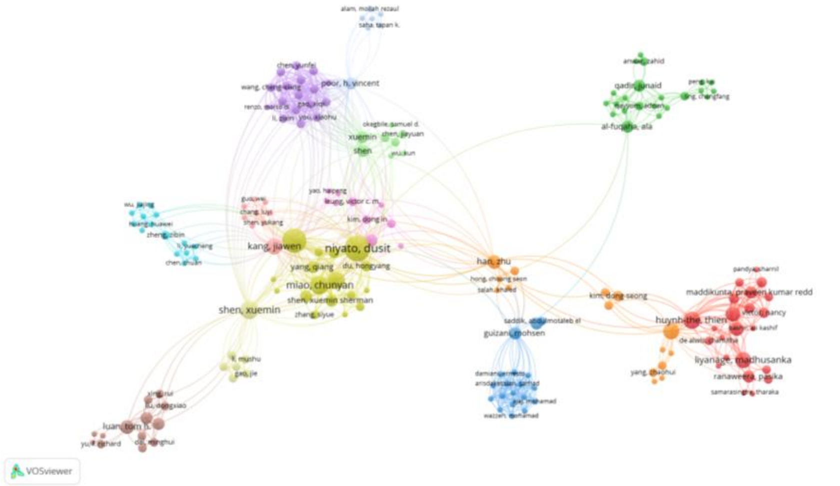

Figure 1 Co-authorship

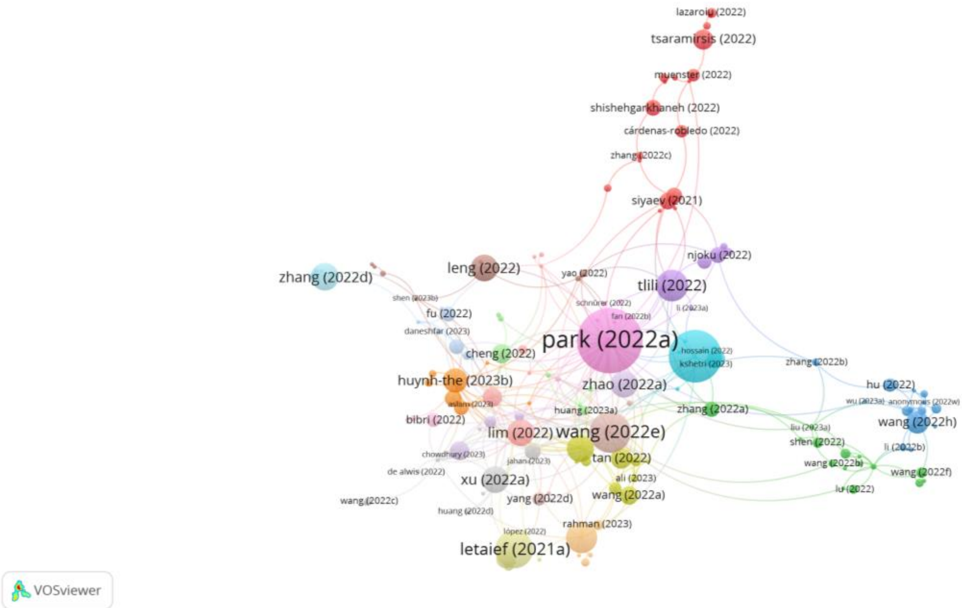

Figure 2 Citation

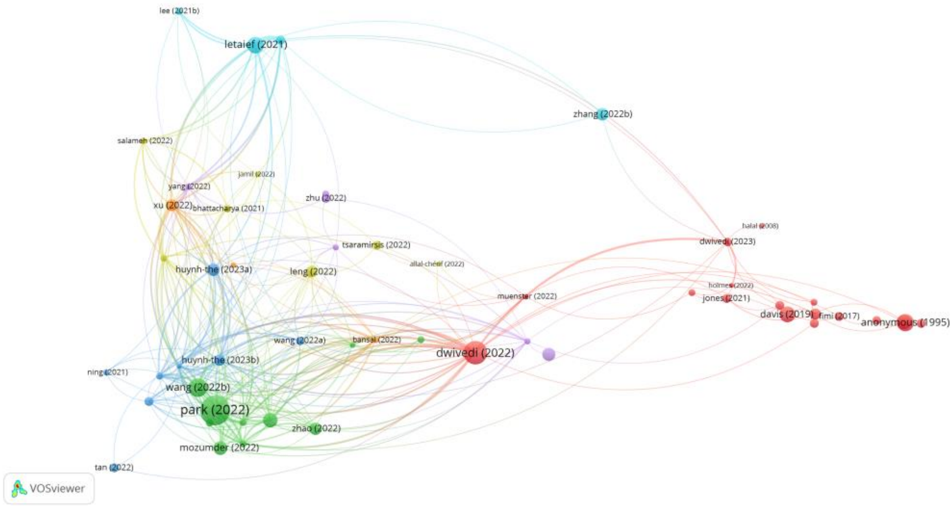

Figure 3 Bibliographic coupling

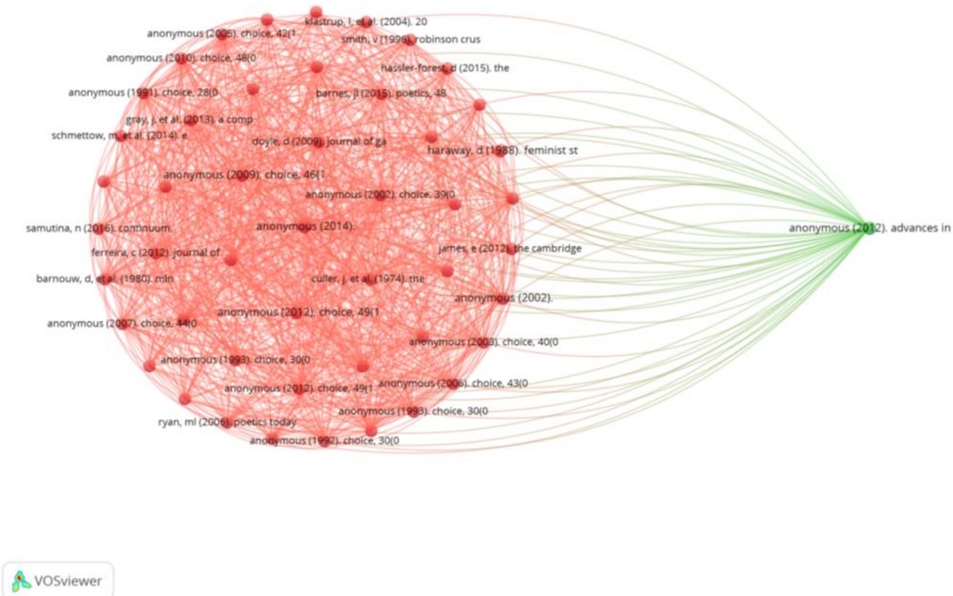

Figure 4 Co-citation

Table 2 General synopsis of evidence as regards focus topics and descriptive outcomes (research findings).

Digital twinning and multisensor fusion technologies, synthetic biometric data, blockchain token-based digital assets, and text mining techniques configure a fully connected metaverse.	Ahn et al., 2023; Hancock, 2022; Shen, 2022; Zhao et al., 2022
Sensory data mining and machine learning techniques, 3D virtual immersive technology, and location intelligence and synthetic biometric data optimize synthetic simulation environments and the decentralized metaverse.	Hollensen et al., 2023; Meng et al., 2023; Zhang et al., 2022a
Ambient intelligence and data mining tools, interconnected sensor and intelligent sensing networks, and 3D immersive content optimize extended reality environments.	Cheng et al., 2022; Dwivedi et al., 2023; Zvarikova et al., 2022
Synthetic data and ambient intelligence tools, virtual immersive and digital twin technologies, and artificial intelligence-powered search capabilities further immersive 3D worlds and the virtual environment of the metaverse.	Dincelli and Yayla, 2022; Gauttier et al., 2022; Zhou et al., 2023
The blockchain-based virtual economy and immersive 3D worlds develop on immersive decentralized networking and virtual navigation tools, photorealistic synthetic images and data, and metaverse assets and services.	Dolata and Schwabe, 2023; Morley, 2022; Van Huynh et al., 2022
Multi-machine cooperation and digital twin simulation tools, routing and clustering algorithms, and image recognition and deep learning-based sensing technologies are pivotal in immersive virtual environments.	Lv et al., 2022; Njoku et al., 2023; Xian et al., 2023; Zainab et al., 2022
The decentralized metaverse necessitate contextual intelligence and digital twin simulation tools, user identification technology and location data, and interconnected sensor and deep convolutional neural networks.	Cao, 2022; Hudson, 2022; Kozinets, 2023; Zhu et al., 2023
Photorealistic synthetic and immersive 3D virtual environments require interconnected sensor networks, behavior pattern clustering, and metaverse engagement metrics.	Du et al., 2023; Huang et al., 2023; Kliestik et al., 2023; Zhang et al., 2022b
Big data management and simulation modeling tools, computer vision and remote sensing algorithms, and geospatial mapping and machine learning-based object recognition technologies are instrumental in extended reality environments.	Aloqaily et al., 2022; McStay, 2022; Xu et al., 2023; Zheng and Yuan, 2023

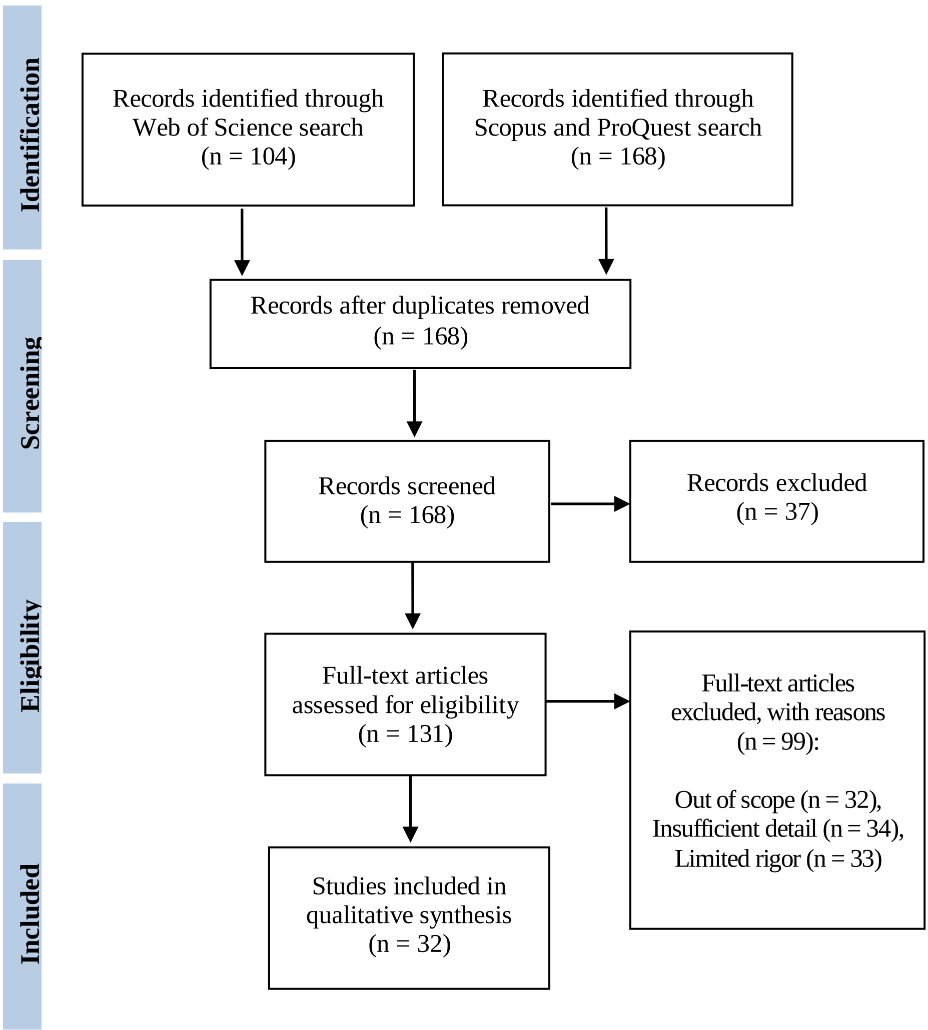

Figure 5 PRISMA flow diagram describing the search results and screening.

Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines were used that ensure the literature review is comprehensive, transparent, and replicable. The flow diagram, produced by employing a Shiny app, presents the stream of evidence-based collected and processed data through the various steps of a systematic review, designing the amount of identified, included, and removed records, and the justifications for exclusions.
To ensure compliance with PRISMA guidelines, a citation software was used, and at each stage the inclusion or exclusion of articles was tracked by use of custom spreadsheet. Justification for the removal of ineligible articles was specified during the full-text screening and final selection.

To ensure first-rate standard of evidence, a systematic search of relevant databases including peer-reviewed published journal articles was conducted using predefined search terms, covering a range of research methods and data sources. Reference lists of all relevant sources were manually reviewed for additional relevant citations.

Titles of papers and abstracts were screened for suitability and selected full texts were retrieved to establish whether they satisfied the inclusion criteria. All records from each database were evaluated by using data extraction forms. Data covering research aims, participants, study design, and method of each paper were extracted.

The inclusion criteria were: (i) articles included in the Web of Science, Scopus, and ProQuest databases, (ii) publication date (2022–2023), (iii) written in English, (iv) being an original empirical research or review article, and (v) particular search terms covered; (i) conference proceedings, (ii) books, and (iii) editorial materials were eliminated from the analysis.

SRDR gathered, handled, and analyzed the data for the systematic review, being configured as an archive and tool harnessed in data extraction through transparent, efficient, and reliable quantitative techniques. Elaborate extraction forms can be set up, meeting the needs of research questions and study designs.

Distiller SR screened and extracted the collected data.

AMSTAR evaluated the methodological quality of systematic reviews.

Dedoose analyzed qualitative and mixed methods research.

ROBIS assessed the risk of bias in systematic reviews.

AXIS evaluated the quality of cross-sectional studies.

The quality of academic articles was determined and risk of bias was measured by MMAT, that tested content validity and usability of selected studies in terms of screening questions, type of design, corresponding quality criteria, and overall quality score.

Figure 6 Screening and quality assessment tools

4. Machine Learning-based Image Recognition and Autonomous Visual Object Detection Tools, Human Digital Twin and Geospatial Big Data Visualization Systems, and Location Intelligence and Synthetic Biometric Data in a Fully Connected Metaverse

Digital twinning and multisensor fusion technologies, synthetic biometric data, blockchain token-based digital assets, and text mining techniques (Ahn et al., 2023; Hancock, 2022; Shen, 2022; Zhao et al., 2022) configure a fully connected metaverse. Immersive holographic virtual experiences can be achieved by use of cognitive enhancement and modeling technologies, biometric-based user recognition and hyper-real avatars, and photorealistic synthetic imagery.

Sensory data mining and machine learning techniques, 3D virtual immersive technology, and location intelligence and synthetic biometric data (Hollensen et al., 2023; Meng et al., 2023; Zhang et al., 2022a) optimize synthetic simulation environments and the decentralized metaverse. Digital twin and simulation technologies, cognitive computing and Internet of Things-based sensing systems, and machine learning-based image recognition and autonomous visual object detection tools configure realistic appearances of animated 3D reconstructions of individuals, objects, and spaces.

Ambient intelligence and data mining tools, interconnected sensor and intelligent sensing networks, and 3D immersive content (Cheng et al., 2022; Dwivedi et al., 2023; Zvarikova et al., 2022) optimize extended reality environments. Digital hyper-realistic worlds necessitate human digital twin and geospatial big data visualization systems, eye-tracking and distributed sensing technologies, and virtual twin modeling and real-time data tracking tools. Visual imagery and ambient intelligence tools, data fusion and digital twin technologies, and real-time sensor and captured image data shape interconnected digital spaces. (Table 3)

Table 3 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Digital twinning and multisensor fusion technologies, synthetic biometric data, blockchain token-based digital assets, and text mining techniques configure a fully connected metaverse.	Ahn et al., 2023; Hancock, 2022; Shen, 2022; Zhao et al., 2022
Sensory data mining and machine learning techniques, 3D virtual immersive technology, and location intelligence and synthetic biometric data optimize synthetic simulation environments and the decentralized metaverse.	Hollensen et al., 2023; Meng et al., 2023; Zhang et al., 2022a
Ambient intelligence and data mining tools, interconnected sensor and intelligent sensing networks, and 3D immersive content optimize extended reality environments.	Cheng et al., 2022; Dwivedi et al., 2023; Zvarikova et al., 2022

5. Digital Twin Simulation and Visual Imagery Tools, Spatial Computing and 3D Modeling Technologies, and Haptic Object Recognition and Automated Perception Systems in the Virtual Environment of the Metaverse

Synthetic data and ambient intelligence tools, virtual immersive and digital twin technologies, and artificial intelligence-powered search capabilities (Dincelli and Yayla, 2022; Gauttier et al., 2022; Zhou et al., 2023) further immersive 3D worlds and the virtual environment of the metaverse. Digital twinning and data sharing technologies, digital twin simulation and visual imagery tools, and motion capture and cognitive computing systems are pivotal in a blockchain-based virtual world.

The blockchain-based virtual economy and immersive 3D worlds (Dolata and Schwabe, 2023; Morley, 2022; Van Huynh et al., 2022) develop on immersive decentralized networking and virtual navigation tools, photorealistic synthetic images and data, and metaverse assets and services. Spatial computing and 3D modeling technologies, haptic object recognition and automated perception systems, and geospatial mapping and big data management tools are instrumental in immersive decentralized 3D digital worlds.

Multi-machine cooperation and digital twin simulation tools, routing and clustering algorithms, and image recognition and deep learning-based sensing technologies (Lv et al., 2022; Njoku et al., 2023; Xian et al., 2023; Zainab et al., 2022) are pivotal in immersive virtual environments. Automated speech recognition and immersive visualization systems, geospatial mapping and immersive 3D technologies, and computer vision and remote sensing algorithms configure extended reality environments. (Table 4)

Table 4 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Synthetic data and ambient intelligence tools, virtual immersive and digital twin technologies, and artificial intelligence-powered search capabilities further immersive 3D worlds and the virtual environment of the metaverse.	Dincelli and Yayla, 2022; Gauttier et al., 2022; Zhou et al., 2023
The blockchain-based virtual economy and immersive 3D worlds develop on immersive decentralized networking and virtual navigation tools, photorealistic synthetic images and data, and metaverse assets and services.	Dolata and Schwabe, 2023; Morley, 2022; Van Huynh et al., 2022
Multi-machine cooperation and digital twin simulation tools, routing and clustering algorithms, and image recognition and deep learning-based sensing technologies are pivotal in immersive virtual environments.	Lv et al., 2022; Njoku et al., 2023; Xian et al., 2023; Zainab et al., 2022

6. Cognitive Computing and Multimodal Sensing Systems, Operational Modeling and Spatial Data Visualization Tools, and Geospatial Mapping and Machine Learning-based Object Recognition Technologies in the Decentralized Metaverse

The decentralized metaverse (Cao, 2022; Hudson, 2022; Kozinets, 2023; Zhu et al., 2023) necessitate contextual intelligence and digital twin simulation tools, user identification technology and location data, and interconnected sensor and deep convolutional neural networks. Cognitive computing and multimodal sensing systems, environment mapping and predictive modeling algorithms, and digital twin and tactile sensing technologies articulate extended reality environments.

Photorealistic synthetic and immersive 3D virtual environments (Du et al., 2023; Huang et al., 2023; Kliestik et al., 2023; Zhang et al., 2022b) require interconnected sensor networks, behavior pattern clustering, and metaverse engagement metrics. Big geospatial and Internet of Things sensor data analytics, virtual twin and cognitive enhancement technologies, and operational modeling and spatial data visualization tools assist interconnected digital realms. Hyper-realistic immersive 3D simulations, environment perception sensors, and real-time sensor data assist photorealistic synthetic and mobile edge computing environments.

Big data management and simulation modeling tools, computer vision and remote sensing algorithms, and geospatial mapping and machine learning-based object recognition technologies (Aloqaily et al., 2022; McStay, 2022; Xu et al., 2023; Zheng and Yuan, 2023) are instrumental in extended reality environments. Immersive visual and mobile location analytics, edge computing and cognitive enhancement technologies, and virtual navigation and image processing tools enable augmented reality-powered immersive spaces. (Table 5)

Table 5 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

The decentralized metaverse necessitate contextual intelligence and digital twin simulation tools, user identification technology and location data, and interconnected sensor and deep convolutional neural networks.	Cao, 2022; Hudson, 2022; Kozinets, 2023; Zhu et al., 2023
Photorealistic synthetic and immersive 3D virtual environments require interconnected sensor networks, behavior pattern clustering, and metaverse engagement metrics.	Du et al., 2023; Huang et al., 2023; Kliestik et al., 2023; Zhang et al., 2022b
Big data management and simulation modeling tools, computer vision and remote sensing algorithms, and geospatial mapping and machine learning-based object recognition technologies are instrumental in extended reality environments.	Aloqaily et al., 2022; McStay, 2022; Xu et al., 2023; Zheng and Yuan, 2023

7. Discussion

We integrate our systematic review throughout research indicating how hyper-realistic immersive 3D simulations, environment perception sensors, and real-time sensor data assist photorealistic synthetic and mobile edge computing environments. Our research complements recent analyses clarifying how digital twinning and data sharing technologies, digital twin simulation and visual imagery tools, and motion capture and cognitive computing systems are pivotal in a blockchain-based virtual world. We elucidate, by cumulative evidence, previous research demonstrating how big geospatial and Internet of Things sensor data analytics, virtual twin and cognitive enhancement technologies, and operational modeling and spatial data visualization tools assist interconnected digital realms.

8. Synopsis of the Main Research Outcomes

Automated speech recognition and immersive visualization systems, geo-spatial mapping and immersive 3D technologies, and computer vision and remote sensing algorithms configure extended reality environments. Immersive holographic virtual experiences can be achieved by use of cognitive enhancement and modeling technologies, biometric-based user recognition and hyper-real avatars, and photorealistic synthetic imagery.

9. Conclusions

Relevant research has investigated whether immersive visual and mobile location analytics, edge computing and cognitive enhancement technologies, and virtual navigation and image processing tools enable augmented reality-powered immersive spaces. This systematic literature review presents the published peer-reviewed sources covering how digital hyper-realistic worlds necessitate human digital twin and geospatial big data visualization systems, eye-tracking and distributed sensing technologies, and virtual twin modeling and real-time data tracking tools. The research outcomes drawn from the above analyses indicate that spatial computing and 3D modeling technologies, haptic object recognition and automated perception systems, and geospatial mapping and big data management tools are instrumental in immersive decentralized 3D digital worlds.

10. Limitations, Implications, and Further Directions of Research

By analyzing only articles published between 2022 and 2023 in journals indexed in the Web of Science, Scopus, and ProQuest databases, relevant sources on deep learning-based object detection and holographic virtual imaging technologies, mobile biometric and sentiment data, and digital twin simulation and modeling tools in the metaverse economy may have been excluded. Limitations of this research comprise particular kinds of publications (original empirical research and review articles) discounting others (conference proceedings articles, books, and editorial materials). The scope of our study also does not move forward the inspection of sensory data mining and machine learning techniques, 3D virtual immersive technology, and location intelligence and synthetic biometric data.

Subsequent analyses should develop on contextual intelligence and digital twin simulation tools, user identification technology and location data, and interconnected sensor and deep convolutional neural networks. Future research should thus investigate multi-machine cooperation and digital twin simulation tools, routing and clustering algorithms, and image recognition and deep learning-based sensing technologies. Attention should be directed to photorealistic synthetic and immersive 3D virtual environments.

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Compliance with ethical standards

This article does not contain any studies with human participants or animals performed by the authors. Extracting and inspecting publicly accessible files (scholarly sources) as evidence, before the research began no institutional ethics approval was required.

Data availability statement

All data generated or analyzed are included in the published article.

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Author contributions

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication. The authors take full responsibility for the accuracy and the integrity of the data analysis.

Conflict of interest statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Disclosure by the editors of record

The editors declare no conflict of interest in the review and publication decision regarding this article.

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Digital Twin and Metaverse Technologies, Geospatial Simulation and Sensor Fusion Tools, and Object Perception and Motion Control Algorithms in Immersive Hyper-Connected Virtual Spaces

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ABSTRACT. I draw on a substantial body of theoretical and empirical research on sensory data mining techniques, metaverse assets and services, and virtual twin and holographic imaging technology. With increasing evidence of immersive metaverse and remote sensing technologies, spatial computing devices, and blockchain token-based digital assets, there is an essential demand for comprehending whether 3D modeling and simulation technologies, data mining and virtual navigation tools, and photorealistic synthetic imagery shape extended reality environments. In this research, prior findings were cumulated indicating that the blockchain-based virtual economy integrates remote sensing and ontology-based semantic technologies, visual analytics systems, geolocation data mining and tracking, and 3D holographic avatars. I carried out a quantitative literature review of ProQuest, Scopus, and the Web of Science throughout January 2023, with search terms including "immersive hyper-connected virtual spaces" + "digital twin and metaverse technologies," "geospatial simulation and sensor fusion tools," and "object perception and motion control algorithms." As I analyzed research published in 2022 and 2023, only 178 papers met the eligibility criteria. By removing controversial or unclear findings (scanty/unimportant data), results unsupported by replication, undetailed content, or papers having quite similar titles, I decided on 32, chiefly empirical, sources. Data visualization tools: Dimensions (bibliometric mapping) and VOSviewer (layout algorithms). Reporting quality assessment tool: PRISMA. Methodological quality assessment tools include: AMSTAR, Distiller SR, ROBIS, and SRDR.

Keywords: digital twin and metaverse technologies; geospatial simulation and sensor fusion tools; object perception and motion control algorithms

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1. Introduction

Extended reality environments require image recognition and immersive 3D technologies, interconnected sensor networks, biometric and behavioral data, and voice recognition software. The purpose of my systematic review is to examine the recently published literature on immersive hyper-connected virtual spaces and integrate the insights it configures on digital twin and metaverse technologies, geospatial simulation and sensor fusion tools, and object perception and motion control algorithms. By analyzing the most recent (2022–2023) and significant (Web of Science, Scopus, and ProQuest) sources, my paper has attempted to prove that data mining and simulation modeling tools, multisensor fusion and spatial computing technologies, and user journey and real-time predictive analytics articulate immersive hyper-connected virtual spaces. The actuality and novelty of this study are articulated by addressing immersive metaverse and remote sensing technologies, spatial computing devices, and blockchain token-based digital assets, that is an emerging topic involving much interest. My research problem is whether the blockchain-based virtual economy integrates remote sensing and ontology-based semantic technologies, visual analytics systems (Andronie et al., 2021; Kliestik et al., 2020; Nica, 2018; Popescu, 2018), geolocation data mining and tracking (Balcerzak et al., 2022; Kliestik et al., 2022; Nica et al., 2022), and 3D holographic avatars.

In this review, prior findings have been cumulated indicating that immersive 3D environments necessitate cognitive neuro-engineering and spatial computing technologies (Cegarra Navarro et al., 2023; Lăzăroiu et al., 2017; Nica et al., 2023), intelligent sensing and convolutional neural networks, voice recognition software, and haptic bodysuits. The identified gaps advance sensory data mining techniques (Dabija et al., 2018; Lăzăroiu, 2018; Popescu et al., 2017a), metaverse assets and services, and virtual twin and holographic imaging technology. My main objective is to indicate that 3D modeling and simulation technologies (Jaramillo-Aristizabal, 2022; Lăzăroiu et al., 2022; Popescu et al., 2017b; Vinerean et al., 2022), data mining and virtual navigation tools, and photorealistic synthetic imagery shape extended reality environments.

2. Theoretical Overview of the Main Concepts

Real-time event analytics, blockchain token-based digital assets, and 3D immersive virtual reality and haptic feedback technologies enable immersive and interoperable spaces. Digital twin and cognitive enhancement technologies, 3D immersive content, visual perception and operational modeling tools, and interactional and contextual data optimize extended reality environments. Performance capture and 3D virtual immersive technologies, machine learning algorithms, multi-sensory extended reality, and cloud computing machines are pivotal in immersive digital worlds. The manuscript is organized as following: theoretical overview (section 2), methodology (section 3), multisensor fusion and spatial computing technologies, contextual data monitoring and 3D generative modeling tools, and machine learning-based sentiment and immersive visual analytics in the virtual economy of the metaverse (section 4), metaverse engagement metrics, 3D modeling and simulation technologies, and data mining and virtual navigation tools in digitally-networked mediated spaces (section 5), intelligent sensing and convolutional neural networks, metaverse assets and services, and cognitive neuro-engineering and spatial computing technologies in immersive digital worlds (section 6), discussion (section 7), synopsis of the main research outcomes (section 8), conclusions (section 9), limitations, implications, and further directions of research (section 10).

3. Methodology

I carried out a quantitative literature review of ProQuest, Scopus, and the Web of Science throughout January 2023, with search terms including "immersive hyper-connected virtual spaces" + "digital twin and metaverse technologies," "geospatial simulation and sensor fusion tools," and "object perception and motion control algorithms." As I analyzed research published in 2022 and 2023, only 178 papers met the eligibility criteria. By removing controversial or unclear findings (scanty/unimportant data), results unsupported by replication, undetailed content, or papers having quite similar titles, I decided on 32, chiefly empirical, sources (Tables 1 and 2). Data visualization tools: Dimensions (bibliometric mapping) and VOSviewer (layout algorithms). Reporting quality assessment tool: PRISMA. Methodological quality assessment tools include: AMSTAR, Distiller SR, ROBIS, and SRDR (Figures 1–6).

Table 1 Topics and types of scientific products identified and selected.

Topic	**Identified**	**Selected**
immersive hyper-connected virtual spaces + digital twin and metaverse technologies	61	12
immersive hyper-connected virtual spaces + geospatial simulation and sensor fusion tools	60	10
immersive hyper-connected virtual spaces + object perception and motion control algorithms	57	10
Type of paper		
Original research	146	21
Review	19	11
Conference proceedings	11	0
Book	0	0
Editorial	2	0

Source: Processed by the author. Some topics overlap.

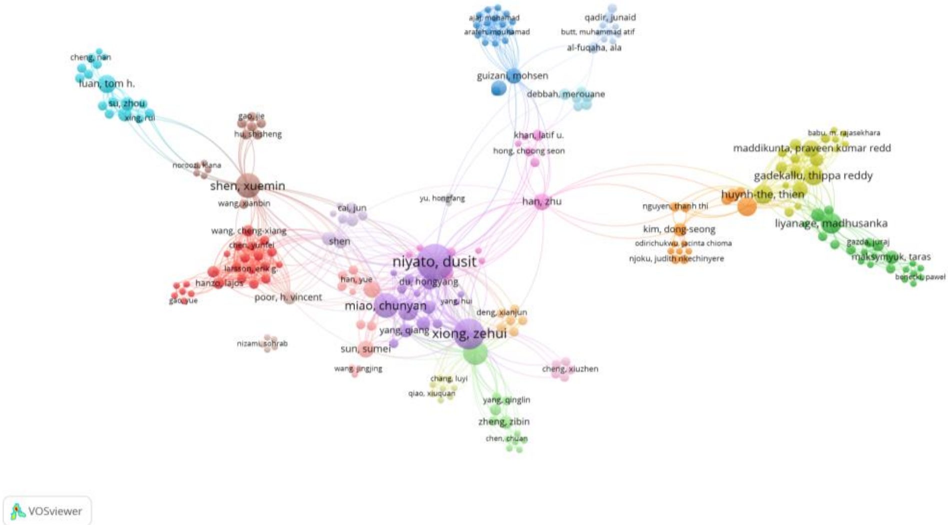

Figure 1 Co-authorship

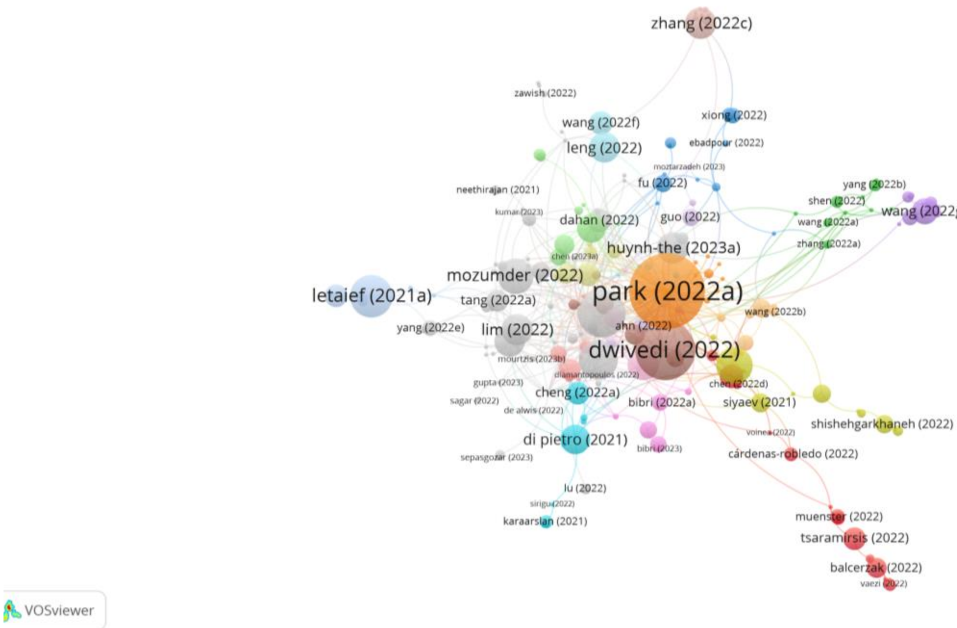

Figure 2 Citation

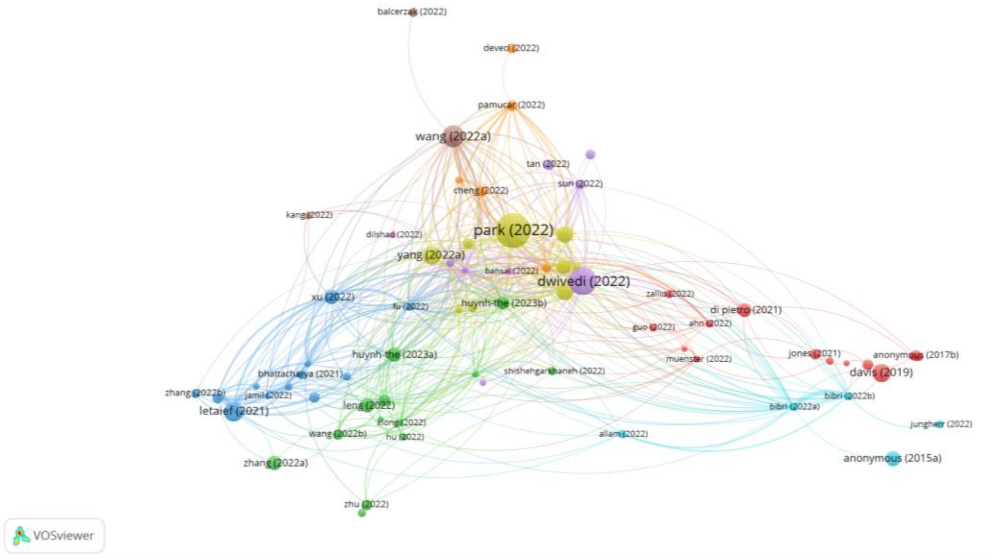

Figure 3 Bibliographic coupling

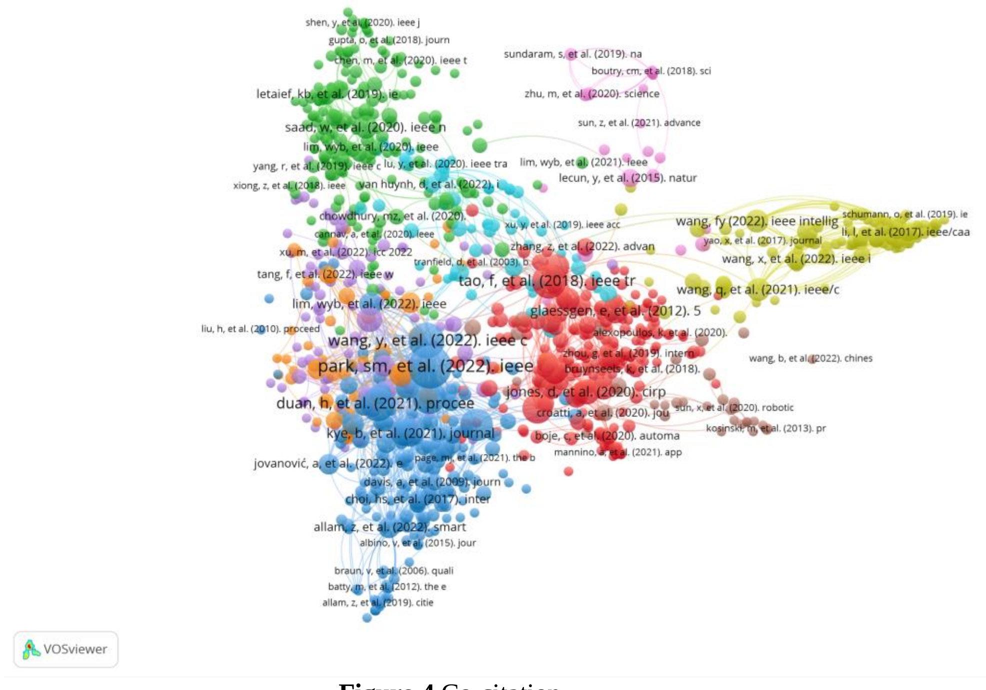

Figure 4 Co-citation

Table 2 General synopsis of evidence as regards focus topics and descriptive outcomes (research findings).

Deep learning-based generative and interconnected sensor networks, 3D immersive content, and virtual holographic objects configure photo-realistic simulation environments and the virtual economy of the metaverse.	Ahn et al., 2023; Li et al., 2023; McStay, 2023; Xu et al., 2023
Decentralized 3D digital worlds and extended reality environments integrate immersive metaverse and remote sensing technologies, spatial computing devices, and blockchain token-based digital assets.	Egliston and Carter, 2022; Park and Kim, 2023; Zhang et al., 2022
Environment perception and implantable intra-body sensors, computer vision and data processing algorithms, and 3D modeling and image recognition technologies further synthetic reality spaces and immersive digital worlds.	Ersoy and Gürfidan, 2023; Huynh-The et al., 2023a; Mourtzis et al., 2022
Interconnected virtual worlds and synthetic digitally-mediated environments develop on virtual twin and wearable scent technologies, 3D dynamic scene modeling and real-time data tracking tools, and metaverse engagement metrics.	Du et al., 2023; Hennig-Thurau et al., 2022; Oh et al., 2023; Wang et al., 2022)
3D immersive content, body-tracking data metrics, and cognitive enhancement and data sharing technologies assist blockchain-based metaverse platforms and the virtual environment of the metaverse.	Bojic, 2022; Huynh-The et al., 2023b; Shi et al., 2023a
Virtual machine interoperability, Internet of Things sensing infrastructures, and immersive visualization systems optimize digitally-networked mediated spaces. Interoperable extended reality environments require artificial vision systems, data processing algorithms, voice recognition software, and 3D immersive content.	Daneshfar and Jamshidi, 2023; Kral et al., 2022; Meng et al., 2023; Shi et al., 2023b
Sensory data mining techniques, metaverse assets and services, and virtual twin and holographic imaging technology articulate immersive virtual environments.	Chen, 2022; Musova et al., 2022; Venugopal et al., 2023; Wu et al., 2023
The virtual environment of the metaverse and immersive 3D worlds require data sharing and digital twin technologies, real-time sensor and captured image data, and computational intelligence tools.	Bordegoni and Ferrise, 2023; Nagendran et al., 2022; Perkins, 2022; Zyda, 2022
Immersive virtual worlds develop on geolocation data mining and tracking, photorealistic synthetic imagery, motion capture suits, and visual cognitive algorithms.	Faraboschi et al., 2022; Popp and Cuțitoi, 2022; Vidal-Tomás, 2023

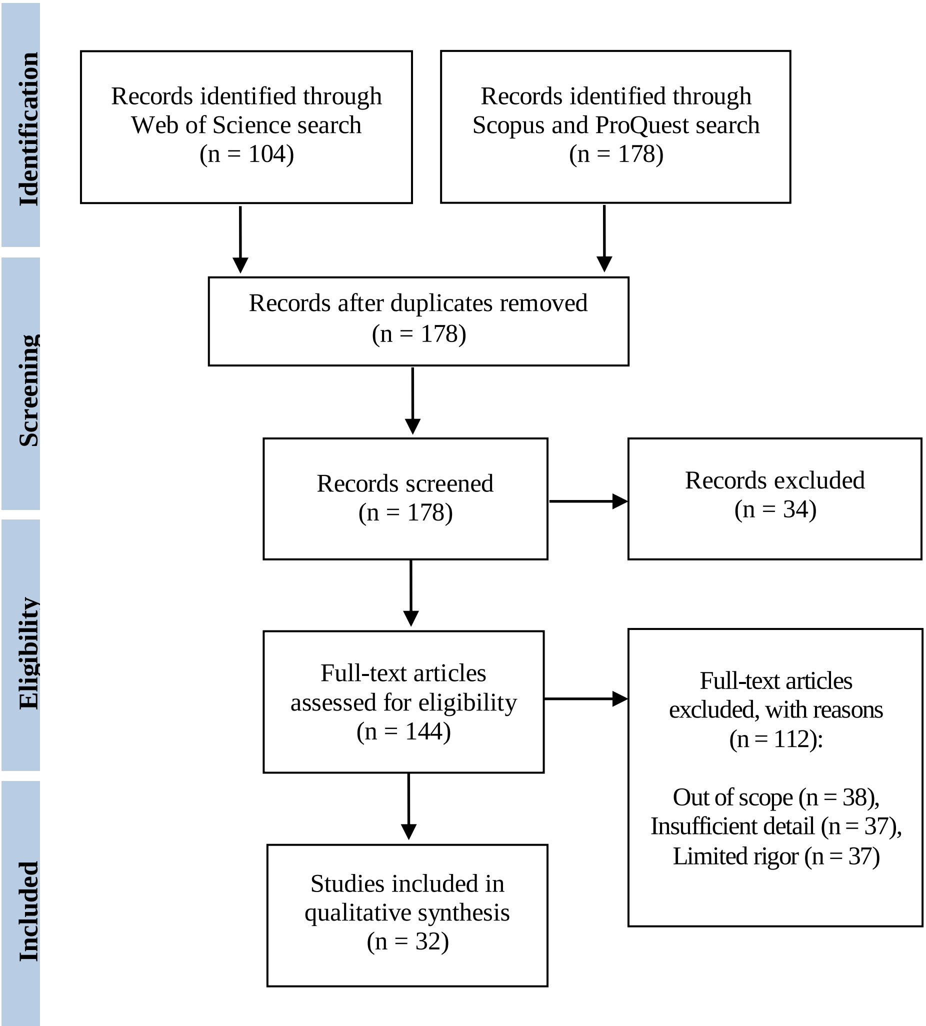

Figure 5 PRISMA flow diagram describing the search results and screening.

Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines were used that ensure the literature review is comprehensive, transparent, and replicable. The flow diagram, produced by employing a Shiny app, presents the stream of evidence-based collected and processed data through the various steps of a systematic review, designing the amount of identified, included, and removed records, and the justifications for exclusions.
To ensure compliance with PRISMA guidelines, a citation software was used, and at each stage the inclusion or exclusion of articles was tracked by use of custom spreadsheet. Justification for the removal of ineligible articles was specified during the full-text screening and final selection.

To ensure first-rate standard of evidence, a systematic search of relevant databases including peer-reviewed published journal articles was conducted using predefined search terms, covering a range of research methods and data sources. Reference lists of all relevant sources were manually reviewed for additional relevant citations.

Titles of papers and abstracts were screened for suitability and selected full texts were retrieved to establish whether they satisfied the inclusion criteria. All records from each database were evaluated by using data extraction forms. Data covering research aims, participants, study design, and method of each paper were extracted.

The inclusion criteria were: (i) articles included in the Web of Science, Scopus, and ProQuest databases, (ii) publication date (2022–2023), (iii) written in English, (iv) being an original empirical research or review article, and (v) particular search terms covered; (i) conference proceedings, (ii) books, and (iii) editorial materials were eliminated from the analysis.

Distiller SR screened and extracted the collected data.

SRDR gathered, handled, and analyzed the data for the systematic review, being configured as an archive and tool harnessed in data extraction through transparent, efficient, and reliable quantitative techniques. Elaborate extraction forms can be set up, meeting the needs of research questions and study designs.

AMSTAR evaluated the methodological quality of systematic reviews.

Dedoose analyzed qualitative and mixed methods research.

ROBIS assessed the risk of bias in systematic reviews.

AXIS evaluated the quality of cross-sectional studies.

The quality of academic articles was determined and risk of bias was measured by MMAT, that tested content validity and usability of selected studies in terms of screening questions, type of design, corresponding quality criteria, and overall quality score.

Figure 6 Screening and quality assessment tools

4. Multisensor Fusion and Spatial Computing Technologies, Contextual Data Monitoring and 3D Generative Modeling Tools, and Machine Learning-based Sentiment and Immersive Visual Analytics in the Virtual Economy of the Metaverse

Deep learning-based generative and interconnected sensor networks, 3D immersive content, and virtual holographic objects (Ahn et al., 2023; Li et al., 2023; McStay, 2023; Xu et al., 2023) configure photo-realistic simulation environments and the virtual economy of the metaverse. Data mining and simulation modeling tools, multisensor fusion and spatial computing technologies, and user journey and real-time predictive analytics articulate immersive hyper-connected virtual spaces. Real-time event analytics, blockchain token-based digital assets, and 3D immersive virtual reality and haptic feedback technologies enable immersive and interoperable spaces.

Decentralized 3D digital worlds and extended reality environments (Egliston and Carter, 2022; Park and Kim, 2023; Zhang et al., 2022) integrate immersive metaverse and remote sensing technologies, spatial computing devices, and blockchain token-based digital assets. Blockchain and virtual twin technologies, contextual data monitoring and 3D generative modeling tools, smart sensor devices, and machine learning-based sentiment and immersive visual analytics assist intelligent simulation environments.

Environment perception and implantable intra-body sensors, computer vision and data processing algorithms, and 3D modeling and image recognition technologies (Ersoy and Gürfidan, 2023; Huynh-The et al., 2023a; Mourtzis et al., 2022) further synthetic reality spaces and immersive digital worlds. Real-time predictive and big geospatial data analytics, context recognition and immersive decentralized networking tools, and eye-tracking and 3D vision technologies enable immersive interconnected virtual worlds. (Table 3)

Table 3 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Deep learning-based generative and interconnected sensor networks, 3D immersive content, and virtual holographic objects configure photo-realistic simulation environments and the virtual economy of the metaverse.	Ahn et al., 2023; Li et al., 2023; McStay, 2023; Xu et al., 2023
Decentralized 3D digital worlds and extended reality environments integrate immersive metaverse and remote sensing technologies, spatial computing devices, and blockchain token-based digital assets.	Egliston and Carter, 2022; Park and Kim, 2023; Zhang et al., 2022
Environment perception and implantable intra-body sensors, computer vision and data processing algorithms, and 3D modeling and image recognition technologies further synthetic reality spaces and immersive digital worlds.	Ersoy and Gürfidan, 2023; Huynh-The et al., 2023a; Mourtzis et al., 2022

5. Metaverse Engagement Metrics, 3D Modeling and Simulation Technologies, and Data Mining and Virtual Navigation Tools in Digitally-Networked Mediated Spaces

Interconnected virtual worlds and synthetic digitally-mediated environments (Du et al., 2023; Hennig-Thurau et al., 2022; Oh et al., 2023; Wang et al., 2022) develop on virtual twin and wearable scent technologies, 3D dynamic scene modeling and real-time data tracking tools, and metaverse engagement metrics. 3D modeling and simulation technologies, data mining and virtual navigation tools, and photorealistic synthetic imagery shape extended reality environments. Digital twin and immersive 3D technologies, biometrics data fusion, mobile location analytics, and Internet of Things sensing infrastructures are instrumental in digital hyper-realistic worlds.

3D immersive content, body-tracking data metrics, and cognitive enhancement and data sharing technologies (Bojic, 2022; Huynh-The et al., 2023b; Shi et al., 2023a) assist blockchain-based metaverse platforms and the virtual environment of the metaverse. Digital twin and cognitive enhancement technologies, 3D immersive content, visual perception and operational modeling tools, and interactional and contextual data optimize extended reality environments.

Virtual machine interoperability, Internet of Things sensing infrastructures, and immersive visualization systems (Daneshfar and Jamshidi, 2023; Kral et al., 2022; Meng et al., 2023; Shi et al., 2023b) optimize digitally-networked mediated spaces. The blockchain-based virtual economy integrates remote sensing and ontology-based semantic technologies, visual analytics systems, geolocation data mining and tracking, and 3D holographic avatars. Interoperable extended reality environments require artificial vision systems, data processing algorithms, voice recognition software, and 3D immersive content. (Table 4)

Table 4 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Interconnected virtual worlds and synthetic digitally-mediated environments develop on virtual twin and wearable scent technologies, 3D dynamic scene modeling and real-time data tracking tools, and metaverse engagement metrics.	Du et al., 2023; Hennig-Thurau et al., 2022; Oh et al., 2023; Wang et al., 2022)
3D immersive content, body-tracking data metrics, and cognitive enhancement and data sharing technologies assist blockchain-based metaverse platforms and the virtual environment of the metaverse.	Bojic, 2022; Huynh-The et al., 2023b; Shi et al., 2023a
Virtual machine interoperability, Internet of Things sensing infrastructures, and immersive visualization systems optimize digitally-networked mediated spaces.	Daneshfar and Jamshidi, 2023; Kral et al., 2022; Meng et al., 2023; Shi et al., 2023b

6. Intelligent Sensing and Convolutional Neural Networks, Metaverse Assets and Services, and Cognitive Neuro-Engineering and Spatial Computing Technologies in Immersive Digital Worlds

Sensory data mining techniques, metaverse assets and services, and virtual twin and holographic imaging technology (Chen, 2022; Musova et al., 2022; Venugopal et al., 2023; Wu et al., 2023) articulate immersive virtual environments. Extended reality environments require image recognition and immersive 3D technologies, interconnected sensor networks, biometric and behavioral data, and voice recognition software. Sensory data and text mining techniques, networked embedded sensing and spatial computing devices, and predictive modeling processes shape 3D computer-generated virtual environments.

The virtual environment of the metaverse and immersive 3D worlds (Bordegoni and Ferrise, 2023; Nagendran et al., 2022; Perkins, 2022; Zyda, 2022) require data sharing and digital twin technologies, real-time sensor and captured image data, and computational intelligence tools. Immersive 3D environments necessitate cognitive neuro-engineering and spatial computing technologies, intelligent sensing and convolutional neural networks, voice recognition software, and haptic bodysuits. Interoperable extended reality environments integrate immersive decentralized networking and simulation modeling tools, biometric and behavioral data, and convolutional neural and wireless sensor networks.

Immersive virtual worlds (Faraboschi et al., 2022; Popp and Cuțitoi, 2022; Vidal-Tomás, 2023) develop on geolocation data mining and tracking, photorealistic synthetic imagery, motion capture suits, and visual cognitive algorithms. Performance capture and 3D virtual immersive technologies, machine learning algorithms, multi-sensory extended reality, and cloud computing machines are pivotal in immersive digital worlds. Sensor data fusion, virtual holographic objects, and deep generative modeling techniques configure extended reality and ambient intelligence environments. (Table 5)

Table 5 Synopsis of evidence as regards focus topics and descriptive outcomes (research findings)

Sensory data mining techniques, metaverse assets and services, and virtual twin and holographic imaging technology articulate immersive virtual environments.	Chen, 2022; Musova et al., 2022; Venugopal et al., 2023; Wu et al., 2023
The virtual environment of the metaverse and immersive 3D worlds require data sharing and digital twin technologies, real-time sensor and captured image data, and computational intelligence tools.	Bordegoni and Ferrise, 2023; Nagendran et al., 2022; Perkins, 2022; Zyda, 2022
Immersive virtual worlds develop on geolocation data mining and tracking, photorealistic synthetic imagery, motion capture suits, and visual cognitive algorithms.	Faraboschi et al., 2022; Popp and Cuțitoi, 2022; Vidal-Tomás, 2023

7. Discussion

I integrate my systematic review throughout research indicating how digital twin and immersive 3D technologies, biometrics data fusion, mobile location analytics, and Internet of Things sensing infrastructures are instrumental in digital hyper-realistic worlds. My research complements recent analyses clarifying how data mining and simulation modeling tools, multisensor fusion and spatial computing technologies, and user journey and real-time predictive analytics articulate immersive hyper-connected virtual spaces. I elucidate, by cumulative evidence, previous research demonstrating how sensory data and text mining techniques, networked embedded sensing and spatial computing devices, and predictive modeling processes shape 3D computer-generated virtual environments.

8. Synopsis of the Main Research Outcomes

Blockchain and virtual twin technologies, contextual data monitoring and 3D generative modeling tools, smart sensor devices, and machine learning-based sentiment and immersive visual analytics assist intelligent simulation environments. Sensor data fusion, virtual holographic objects, and deep generative modeling techniques configure extended reality and ambient intelligence environments.

9. Conclusions

Relevant research has investigated whether interoperable extended reality environments require artificial vision systems, data processing algorithms, voice recognition software, and 3D immersive content. This systematic literature review presents the published peer-reviewed sources covering how interoperable extended reality environments integrate immersive decentralized networking and simulation modeling tools, biometric and behavioral data, and convolutional neural and wireless sensor networks. The research outcomes drawn from the above analyses indicate that real-time predictive and big geospatial data analytics, context recognition and immersive decentralized networking tools, and eye-tracking and 3D vision technologies enable immersive interconnected virtual worlds.

10. Limitations, Implications, and Further Directions of Research

By analyzing only articles published between 2022 and 2023 in journals indexed in the Web of Science, Scopus, and ProQuest databases, relevant sources on digital twin and metaverse technologies, geospatial simulation and sensor fusion tools, and object perception and motion control algorithms in immersive hyper-connected virtual spaces may have been excluded. Limitations of this research comprise particular kinds of publications (original empirical research and review articles) discounting others (conference proceedings articles, books, and editorial materials). The scope of my study also does not move forward the inspection of decentralized 3D digital worlds and extended reality environments.

Subsequent analyses should develop on deep learning-based generative and interconnected sensor networks, 3D immersive content, and virtual holographic objects. Future research should thus investigate geolocation data mining and tracking, photorealistic synthetic imagery, motion capture suits, and visual cognitive algorithms. Attention should be directed to environment perception and implantable intra-body sensors, computer vision and data processing algorithms, and 3D modeling and image recognition technologies.

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Compliance with ethical standards

This article does not contain any studies with human participants or animals performed by the author. Extracting and inspecting publicly accessible files (scholarly sources) as evidence, before the research began no institutional ethics approval was required.

Data availability statement

All data generated or analyzed are included in the published article.

Funding information

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Author contributions

The author confirms being the sole contributor of this work and approved it for publication. The author takes full responsibility for the accuracy and the integrity of the data analysis.

Conflict of interest statement

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Disclosure by the editors of record

The editors declare no conflict of interest in the review and publication decision regarding this article.

Transparency statement

The author affirms that the manuscript represents an honest, accurate, and transparent account of the research being reported, that no relevant aspects of the study have been left out, and that any inconsistencies from the research as planned (and, if significant, registered) have been clarified.

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