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Deep Generative Modeling and Virtual Machine Remote Monitoring Tools, Cyber-Physical Cognitive and Synthetic Data-based Autonomous Production Systems, and Neural Machine and Virtual Plant Floor Networks in Artificial Intelligence-based Digital Twin Industrial Metaverse

Ștefan Gabriel Burcea[1], Cristian Florin Ciurlău[2], Marcela Cristina Hurjui[3], Donatella Privitera[4], and Bianca-Florentina Nistoroiu[1]

ABSTRACT. The purpose of this study is to examine artificial intelligence-based digital twin industrial metaverse and immersive 3D worlds for connected machines and objects. Throughout May 2024, a quantitative literature review of the Web of Science, Scopus, and ProQuest databases was performed, with search terms including "artificial intelligence-based digital twin industrial metaverse" + "deep generative modeling and virtual machine remote monitoring tools," "cyber-physical cognitive and synthetic data-based autonomous production systems," and "neural machine and virtual plant floor networks." As research published in 2022 and 2023 was inspected, only 175 articles satisfied the eligibility criteria, and 20 mainly empirical sources were selected. Data visualization tools: Dimensions (bibliometric mapping) and VOSviewer (layout algorithms). Reporting quality assessment tool: PRISMA. Methodological quality assessment tools include: Colandr, DistillerSR, Eppi-Reviewer, Nested Knowledge, ROBIS, and SluRp.
JEL codes: D53; E22; E32; E44; G01; G41

Keywords: deep generative modeling; virtual machine remote monitoring; cyber-physical cognitive and synthetic data-based autonomous production; neural machine and virtual plant floor; artificial intelligence; digital twin industrial metaverse

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[1]Bucharest University of Economic Studies, Bucharest, Romania, stefan.burcea@amp.ase.ro, nistoroiubianca@yahoo.com.
[2]"Dimitrie Cantemir" Christian University, Bucharest, Romania, cristianciurlau@yahoo.com (corresponding author).
[3]Stefan cel Mare University of Suceava, Romania, marcela.hurjui@usm.ro.
[4]University of Catania, Italy, donatella.privitera@unict.it.

1. Introduction

Machine vision and collaborative intelligence tools, cognitive computing and immersive holographic imaging technologies, and cyber-physical production and multi-sensor fusion systems further metaverse-based industrial services in decentralized 3D digital worlds. The purpose of our systematic review is to examine the recently published literature on artificial intelligence-based digital twin industrial metaverse and integrate the insights it configures on deep generative modeling and virtual machine remote monitoring tools, cyber-physical cognitive and synthetic data-based autonomous production systems, and neural machine and virtual plant floor networks. By analyzing the most recent (2022–2023) and significant (Web of Science, Scopus, and ProQuest) sources, our paper has attempted to prove that deep learning-based ambient sound processing and 3D virtual reality simulation tools, Industrial Internet of Things, and cyber-physical production and location-aware networked systems can be leveraged in digital twin factories in immersive virtual spaces. The actuality and novelty of this study are articulated by addressing sensory data mining techniques, digital twin simulation and virtual machine remote monitoring tools, geospatial big data analytics, and photorealistic synthetic images and data, that is an emerging topic involving much interest. Our research problem is whether simulation and modeling technologies, virtual reality-embedded digital twins, and spatio-temporal fusion and semantic 3D mapping algorithms optimize photorealistic synthetic imagery in hyper-immersive simulated environments..

In this review, prior findings have been cumulated indicating that cyber-physical system-based smart manufacturing in simulated 3D modeling and extended reality environments necessitates industrial digital twins, machine vision and 3D virtual scanning technologies, and geospatial intelligence and digital twin modeling tools. The identified gaps advance extended reality and cognitive modeling technologies, geolocation data mining and tracking tools, and big data computing and location-aware networked systems. Our main objective is to indicate that semantic network representations in hyper-realistic 3D worlds integrate deep learning-assisted digital twins, artificial intelligence-powered prediction and deep learning-based predictive analytics modeling tools, and mobile location analytics. This systematic review contributes to the literature on artificial intelligence-based digital twin industrial metaverse and immersive 3D worlds for connected machines and objects by clarifying that generative artificial intelligence-powered humanoid robots, 3D modeling and simulation technologies, and visual data mining and deep learning-based ambient sound processing tools optimize immersive hyper-connected virtual spaces and interconnected digital realms. This research endeavors to elucidate whether simulated machines and factories in the industrial metaverse develop on deep generative modeling and edge computing tools, neural machine and virtual plant floor networks, and digital twin and immersive 3D technologies.

2. Theoretical Overview of the Main Concepts

The manuscript is organized as following: theoretical overview (section 2), methodology (section 3), cyber-physical cognitive and synthetic data-based autonomous production systems in virtual plant floor networks (section 4), cyber-physical system-based smart manufacturing in simulated 3D modeling and extended reality environments (section 5), multi-digital twin cooperation and metaverse virtual services in immersive and interactive 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 May 2024, a quantitative literature review of the Web of Science, Scopus, and ProQuest databases was performed, with search terms including "artificial intelligence-based digital twin industrial metaverse" + "deep generative modeling and virtual machine remote monitoring tools," "cyber-physical cognitive and synthetic data-based autonomous production systems," and "neural machine and virtual plant floor networks." As research published in 2022 and 2023 was inspected, only 175 articles satisfied the eligibility criteria, and 20 mainly empirical sources were selected (Tables 1 and 2). Data visualization tools: Dimensions (bibliometric mapping) and VOSviewer (layout algorithms). Reporting quality assessment tool: PRISMA. Methodological quality assessment tools include: Colandr, DistillerSR, EppiReviewer, Nested Knowledge, ROBIS, and SluRp (Figures 1–6).

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

Topic	**Identified**	**Selected**
artificial intelligence-based digital twin industrial metaverse + deep generative modeling and virtual machine remote monitoring tools	60	7
artificial intelligence-based digital twin industrial metaverse + cyber-physical cognitive and synthetic data-based autonomous production systems	58	7
artificial intelligence-based digital twin industrial metaverse + neural machine and virtual plant floor networks	57	6
Type of paper		
Original research	140	15
Review	18	5
Conference proceedings	13	0
Book	2	0
Editorial	2	0

Source: Processed by the authors. Some topics overlap.

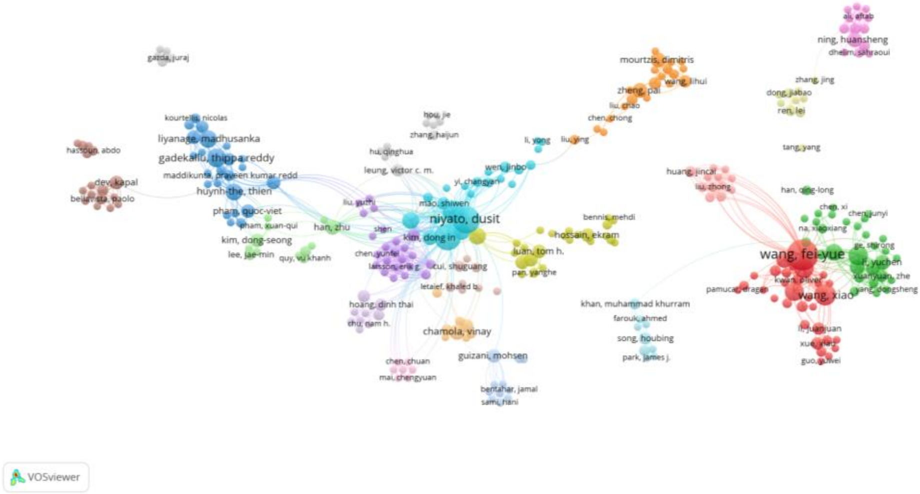

Figure 1. VOSviewer mapping of deep generative modeling and virtual machine remote monitoring tools, cyber-physical cognitive and synthetic data-based autonomous production systems, and neural machine and virtual plant floor networks in artificial intelligence-based digital twin industrial metaverse regarding co-authorship.

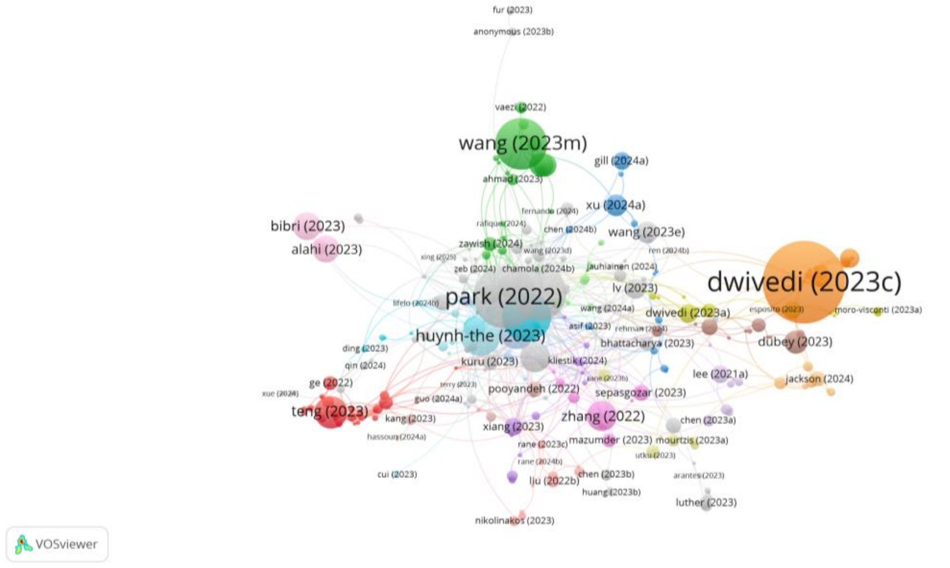

Figure 2. VOSviewer mapping of deep generative modeling and virtual machine remote monitoring tools, cyber-physical cognitive and synthetic data-based autonomous production systems, and neural machine and virtual plant floor networks in artificial intelligence-based digital twin industrial metaverse regarding citation.

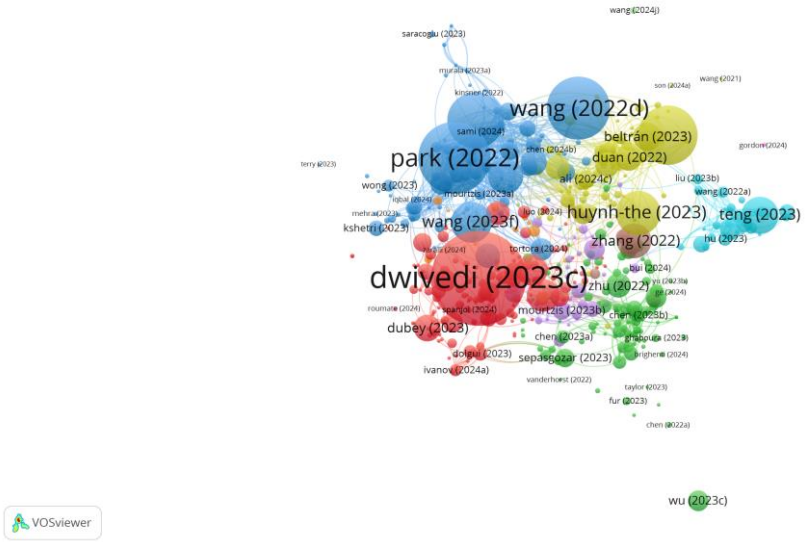

Figure 3. VOSviewer mapping of deep generative modeling and virtual machine remote monitoring tools, cyber-physical cognitive and synthetic data-based autonomous production systems, and neural machine and virtual plant floor networks in artificial intelligence-based digital twin industrial metaverse regarding bibliographic coupling.

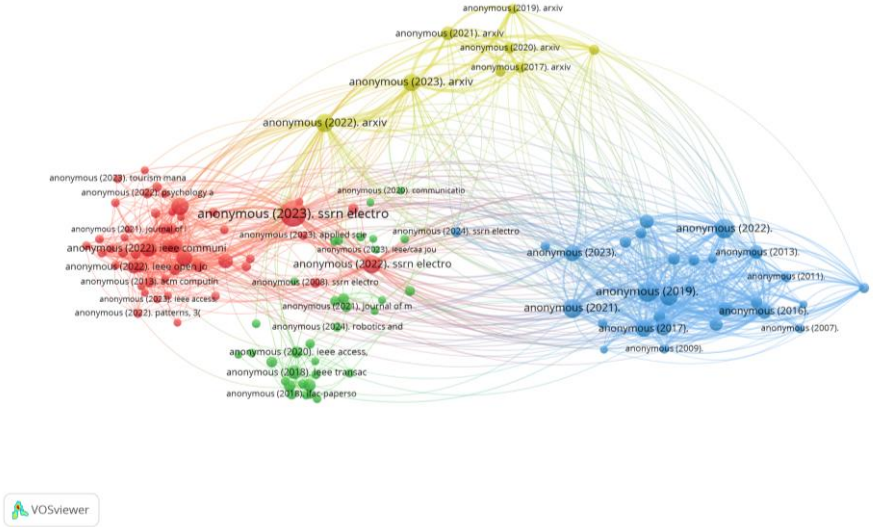

Figure 4. VOSviewer mapping of deep generative modeling and virtual machine remote monitoring tools, cyber-physical cognitive and synthetic data-based autonomous production systems, and neural machine and virtual plant floor networks in artificial intelligence-based digital twin industrial metaverse regarding co-citation.

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

Digital twin modeling and edge computing tools, cognitive robotic process automation, and bio-inspired computation and predictive modeling techniques are pivotal in artificial intelligence-based digital twin industrial metaverse and immersive 3D worlds for connected machines and objects.	Aldridge et al., 2022; Magalhães et al., 2022; Tlili et al., 2023
Cyber-physical cognitive and synthetic data-based autonomous production systems, digital twin modeling and simulation tools, and immersive extended reality and big data-driven planning technologies shape smart production logistics in artificial intelligence-based digital twin industrial metaverse.	Chang et al., 2022; Rejeb et al., 2023; Xiang et al., 2024
Cyber-physical system-based smart manufacturing in immersive virtual spaces require sensory data mining techniques, digital twin simulation and virtual machine remote monitoring tools, geospatial big data analytics, and photorealistic synthetic images and data.	Atkinson, 2023; Mourtzis et al., 2023; Wang et al., 2022
3D computer vision-based production and virtual modeling technologies, Internet of Things-based decision support and blockchain-based decentralized metaverse systems, and big data processing and geospatial mapping tools configure 3D simulation spaces.	Kshetri, 2023; Stevens, 2023; Xinyi et al., 2023
Extended reality and cognitive modeling technologies, geolocation data mining and tracking tools, and big data computing and location-aware networked systems assist immersive industrial services and cloud computing machines in digitally-networked mediated spaces.	Atkinson, 2023; Mourtzis et al., 2023; Wang et al., 2022
Semantic-based cognitive technologies, 6G-enabled edge artificial intelligence and data processing tools, and visual perception and predictive maintenance algorithms can be deployed in computer graphics-based photorealistic imagery in 3D digital environments.	Chen et al., 2023; Starly et al., 2023; Wu et al., 2023
Image-based visual computing and multi-sensory extended reality technologies, machine learning-based production planning and multimodal generative artificial intelligence systems, and wearable Internet of Things devices enable metaverse virtual services.	Kaarlela et al., 2023; Stary, 2023; Tlili et al., 2023
Sensory data mining techniques, artificial intelligence-powered prediction and 3D image modeling tools, and mobile location analytics shape multi-digital twin cooperation and metaverse virtual services in immersive and interactive virtual environments.	Aldridge et al., 2022; Magalhães et al., 2022; Tlili et al., 2023
Mobile robotic manufacturing and brain-inspired cognitive systems, edge intelligence and computing blockchains, and virtual immersive and dynamic routing technologies enhance metaverse digital asset management in augmented reality environments.	Bhattacharya et al., 2023; Nagy et al., 2022; Zaidan et al., 2023

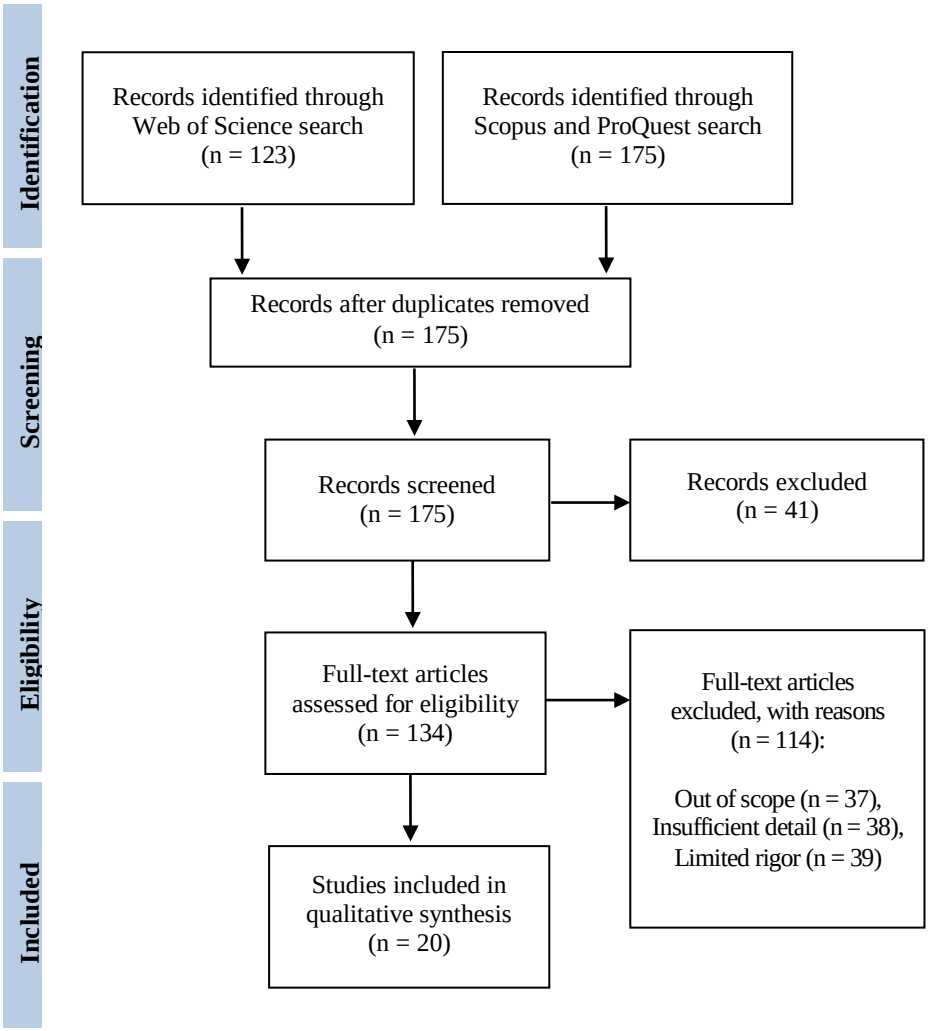

Figure 5 PRISMA flow diagram describing the search results and screening.

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.

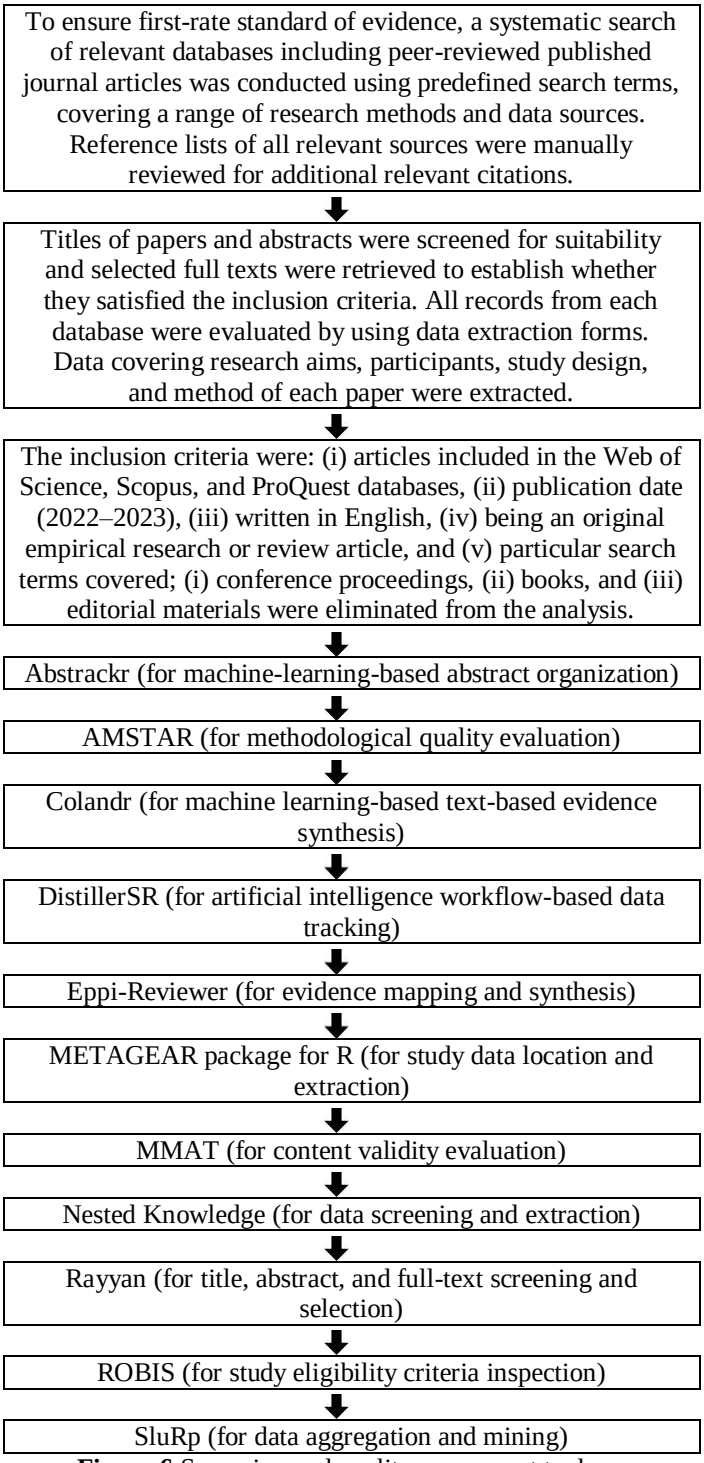

Figure 6 Screening and quality assessment tools

4. Cyber-Physical Cognitive and Synthetic Data-based Autonomous Production Systems in Virtual Plant Floor Networks

Digital twin modeling and edge computing tools, cognitive robotic process automation, and bio-inspired computation and predictive modeling techniques (Aldridge et al., 2022; Magalhães et al., 2022; Tlili et al., 2023) are pivotal in artificial intelligence-based digital twin industrial metaverse and immersive 3D worlds for connected machines and objects. Graphics processing unit-based virtual machines, motion capture and 3D immersive virtual reality technologies, and visual localization and mapping devices articulate 5G-based mobile robot management in photorealistic virtual reality environments.

Cyber-physical cognitive and synthetic data-based autonomous production systems, digital twin modeling and simulation tools, and immersive extended reality and big data-driven planning technologies (Chang et al., 2022; Rejeb et al., 2023; Xiang et al., 2024) shape smart production logistics in artificial intelligence-based digital twin industrial metaverse. Simulation and modeling technologies, virtual reality-embedded digital twins, and spatio-temporal fusion and semantic 3D mapping algorithms optimize photorealistic synthetic imagery in hyper-immersive simulated environments.

Cyber-physical system-based smart manufacturing in immersive virtual spaces (Atkinson, 2023; Mourtzis et al., 2023; Wang et al., 2022) require sensory data mining techniques, digital twin simulation and virtual machine remote monitoring tools, geospatial big data analytics, and photorealistic synthetic images and data. Simulated machines and factories in the industrial metaverse develop on deep generative modeling and edge computing tools, neural machine and virtual plant floor networks, and digital twin and immersive 3D technologies. (Table 3)

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

Digital twin modeling and edge computing tools, cognitive robotic process automation, and bio-inspired computation and predictive modeling techniques are pivotal in artificial intelligence-based digital twin industrial metaverse and immersive 3D worlds for connected machines and objects.	Aldridge et al., 2022; Magalhães et al., 2022; Tlili et al., 2023
Cyber-physical cognitive and synthetic data-based autonomous production systems, digital twin modeling and simulation tools, and immersive extended reality and big data-driven planning technologies shape smart production logistics in artificial intelligence-based digital twin industrial metaverse.	Chang et al., 2022; Rejeb et al., 2023; Xiang et al., 2024
Cyber-physical system-based smart manufacturing in immersive virtual spaces require sensory data mining techniques, digital twin simulation and virtual machine remote monitoring tools, geospatial big data analytics, and photorealistic synthetic images and data.	Atkinson, 2023; Mourtzis et al., 2023; Wang et al., 2022

5. Cyber-Physical System-based Smart Manufacturing in Simulated 3D Modeling and Extended Reality Environments

3D computer vision-based production and virtual modeling technologies, Internet of Things-based decision support and blockchain-based decentralized metaverse systems, and big data processing and geospatial mapping tools (Kshetri, 2023; Stevens, 2023; Xinyi et al., 2023) configure 3D simulation spaces. Machine vision and collaborative intelligence tools, cognitive computing and immersive holographic imaging technologies, and cyber-physical production and multi-sensor fusion systems further metaverse-based industrial services in decentralized 3D digital worlds.

Extended reality and cognitive modeling technologies, geolocation data mining and tracking tools, and big data computing and location-aware networked systems (Atkinson, 2023; Mourtzis et al., 2023; Wang et al., 2022) assist immersive industrial services and cloud computing machines in digitally-networked mediated spaces. Cyber-physical system-based smart manufacturing in simulated 3D modeling and extended reality environments necessitates industrial digital twins, machine vision and 3D virtual scanning technologies, and geospatial intelligence and digital twin modeling tools.

Semantic-based cognitive technologies, 6G-enabled edge artificial intelligence and data processing tools, and visual perception and predictive maintenance algorithms (Chen et al., 2023; Starly et al., 2023; Wu et al., 2023) can be deployed in computer graphics-based photorealistic imagery in 3D digital environments. Dynamic routing and tactile sensing technologies, ambient sound recognition software, and deep learning-based image processing and spatial cognition algorithms can be harnessed in industrial data semantics in immersive virtual environments. (Table 4)

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

3D computer vision-based production and virtual modeling technologies, Internet of Things-based decision support and blockchain-based decentralized metaverse systems, and big data processing and geospatial mapping tools configure 3D simulation spaces.	Kshetri, 2023; Stevens, 2023; Xinyi et al., 2023
Extended reality and cognitive modeling technologies, geolocation data mining and tracking tools, and big data computing and location-aware networked systems assist immersive industrial services and cloud computing machines in digitally-networked mediated spaces.	Atkinson, 2023; Mourtzis et al., 2023; Wang et al., 2022
Semantic-based cognitive technologies, 6G-enabled edge artificial intelligence and data processing tools, and visual perception and predictive maintenance algorithms can be deployed in computer graphics-based photorealistic imagery in 3D digital environments.	Chen et al., 2023; Starly et al., 2023; Wu et al., 2023

6. Multi-Digital Twin Cooperation and Metaverse Virtual Services in Immersive and Interactive Virtual Environments

Image-based visual computing and multi-sensory extended reality technologies, machine learning-based production planning and multimodal generative artificial intelligence systems, and wearable Internet of Things devices (Kaarlela et al., 2023; Stary, 2023; Tlili et al., 2023) enable metaverse virtual services. Generative artificial intelligence-powered humanoid robots, 3D modeling and simulation technologies, and visual data mining and deep learning-based ambient sound processing tools optimize immersive hyper-connected virtual spaces and interconnected digital realms.

Sensory data mining techniques, artificial intelligence-powered prediction and 3D image modeling tools, and mobile location analytics (Aldridge et al., 2022; Magalhães et al., 2022; Tlili et al., 2023) shape multi-digital twin cooperation and metaverse virtual services in immersive and interactive virtual environments. Deep learning-based ambient sound processing and 3D virtual reality simulation tools, Industrial Internet of Things, and cyber-physical production and location-aware networked systems can be leveraged in digital twin factories in immersive virtual spaces.

Mobile robotic manufacturing and brain-inspired cognitive systems, edge intelligence and computing blockchains, and virtual immersive and dynamic routing technologies (Bhattacharya et al., 2023; Nagy et al., 2022; Zaidan et al., 2023) enhance metaverse digital asset management in augmented reality environments. Semantic network representations in hyper-realistic 3D worlds integrate deep learning-assisted digital twins, artificial intelligence-powered prediction and deep learning-based predictive analytics modeling tools, and mobile location analytics. (Table 5)

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

Image-based visual computing and multi-sensory extended reality technologies, machine learning-based production planning and multimodal generative artificial intelligence systems, and wearable Internet of Things devices enable metaverse virtual services.	Kaarlela et al., 2023; Stary, 2023; Tlili et al., 2023
Sensory data mining techniques, artificial intelligence-powered prediction and 3D image modeling tools, and mobile location analytics shape multi-digital twin cooperation and metaverse virtual services in immersive and interactive virtual environments.	Aldridge et al., 2022; Magalhães et al., 2022; Tlili et al., 2023
Mobile robotic manufacturing and brain-inspired cognitive systems, edge intelligence and computing blockchains, and virtual immersive and dynamic routing technologies enhance metaverse digital asset management in augmented reality environments.	Bhattacharya et al., 2023; Nagy et al., 2022; Zaidan et al., 2023

7. Discussion

We integrate our systematic review throughout research indicating how cyber-physical system-based smart manufacturing in simulated 3D modeling and extended reality environments necessitates industrial digital twins, machine vision and 3D virtual scanning technologies, and geospatial intelligence and digital twin modeling tools. Our research complements recent analyses clarifying how simulation and modeling technologies, virtual reality-embedded digital twins, and spatio-temporal fusion and semantic 3D mapping algorithms optimize photorealistic synthetic imagery in hyper-immersive simulated environments. We elucidate, by cumulative evidence, previous research demonstrating how deep learning-based ambient sound processing and 3D virtual reality simulation tools, Industrial Internet of Things, and cyber-physical production and location-aware networked systems can be leveraged in digital twin factories in immersive virtual spaces.

8. Synopsis of the Main Research Outcomes

Dynamic routing and tactile sensing technologies, ambient sound recognition software, and deep learning-based image processing and spatial cognition algorithms can be harnessed in industrial data semantics in immersive virtual environments. Graphics processing unit-based virtual machines, motion capture and 3D immersive virtual reality technologies, and visual localization and mapping devices articulate 5G-based mobile robot management in photorealistic virtual reality environments.

9. Conclusions

Relevant research has investigated whether machine vision and collaborative intelligence tools, cognitive computing and immersive holographic imaging technologies, and cyber-physical production and multi-sensor fusion systems further metaverse-based industrial services in decentralized 3D digital worlds. This systematic literature review presents the published peer-reviewed sources covering how semantic network representations in hyper-realistic 3D worlds integrate deep learning-assisted digital twins, artificial intelligence-powered prediction and deep learning-based predictive analytics modeling tools, and mobile location analytics. The research outcomes drawn from the above analyses indicate that simulated machines and factories in the industrial metaverse develop on deep generative modeling and edge computing tools, neural machine and virtual plant floor networks, and digital twin and immersive 3D technologies.

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 generative modeling and virtual machine remote monitoring tools, cyber-physical cognitive and synthetic data-based autonomous production systems, and neural machine and virtual plant floor networks in artificial intelligence-based digital twin industrial 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).

Subsequent analyses should develop on image-based visual computing and multi-sensory extended reality technologies, machine learning-based production planning and multimodal generative artificial intelligence systems, and wearable Internet of Things devices. Future research should thus investigate cyber-physical cognitive and synthetic data-based autonomous production systems, digital twin modeling and simulation tools, and immersive extended reality and big data-driven planning technologies.

Ștefan Gabriel Burcea, https://orcid.org/0009-0007-5329-5550
Cristian Florin Ciurlău, https://orcid.org/0000-0003-4172-8236
Marcela Cristina Hurjui, https://orcid.org/0009-0003-3579-9414
Donatella Privitera, https://orcid.org/0000-0002-1290-5451
Bianca-Florentina Nistoroiu, https://orcid.org/0009-0001-7047-7459

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
This paper is part of a collective SLR RT, and thus a somewhat standard structure and a list of reliable data visualization and (reporting and methodological) quality assessment tools have been provided.

REFERENCES

Aldridge, S., Geambazi, P., and Alexandru, B. (2022). "Multi-Modal Synthetic Data Fusion and Analysis, Virtual Immersive and Cognitive Neuro-Engineering Technologies, and Bio-inspired Computational Intelligence and Deep Learning Algorithms in the Industrial Metaverse," *Journal of Self-Governance and Management Economics* 10(4): 22–36. doi: 10.22381/jsme10420222.

Atkinson, D. (2023). "Virtual Modeling and Immersive Holographic Imaging Technologies, Cloud-based Digital Twin Manufacturing and Visual Perceptive Systems, and Bio-inspired Computational Intelligence and Context Awareness Algorithms in the Industrial Metaverse," *Journal of Self-Governance and Management Economics* 11(1): 73–88. doi: 10.22381/jsme11120235.

Bhattacharya, P., Saraswat, D., Savaliya, D., Sanghavi, S., Verma, A., Sakariya, V., et al. (2023). "Towards Future Internet: The Metaverse Perspective for Diverse Industrial Applications," *Mathematics* 11(4): 941. doi: 10.3390/math11040941.

Chang, L., Zhang, Z., Li, P., Xi, S., Guo, W., Shen, Y., et al. (2022). "6G-Enabled Edge AI for Metaverse: Challenges, Methods, and Future Research Directions," *Journal of Communications and Information Networks* 7(2): 107–121. doi: 10.23919/JCIN.2022.9815195.

Chen, Y. Huang, W., Jiang, X., Zhang, T., Wang, Y., Yan, B., et al. (2023). "UbiMeta: A Ubiquitous Operating System Model for Metaverse," *International Journal of Crowd Science* 7(4): 180–189. doi: 10.26599/IJCS.2023.9100028.

Kaarlela, T., Padrao, P., Pitkäaho, T., Pieskä, S., and Bobadilla, L. (2023). "Digital Twins Utilizing XR-Technology as Robotic Training Tools," *Machines* 11(1): 13. doi: 10.3390/machines11010013.

Kshetri, N. (2023). "The Economics of the Industrial Metaverse," *IT Professional* 25(1): 84–88. doi: 10.1109/MITP.2023.3236494.

Magalhães, L. C., Magalhães, L. C., Ramos, J. B., Moura, L. R., de Moraes, R. E. N., Gonçalves, J. B., et al. (2022). "Conceiving a Digital Twin for a Flexible Manufacturing System," *Applied Sciences* 12(19): 9864. doi: 10.3390/app12199864.

Mourtzis, D., Angelopoulos, J., and Panopoulos N. (2023). "The Future of the Human–Machine Interface (HMI) in Society 5.0," *Future Internet* 15(5): 162. doi: 10.3390/fi15050162.

Nagy, M., Kubala, P., Tucmeanu, E. R., and Mișa, A. (2022). "Metaverse-based Industrial Services, Ambient Intelligence and Simulation Modeling Tools, and Brain-inspired Cognitive and Empathetic Computing Systems across 3D Digital Twin Factories," *Journal of Self-Governance and Management Economics* 10(4): 7–21. doi: 10.22381/jsme10420221.

Rejeb, A., Rejeb, K., and Treiblmaier, H. (2023). "Mapping Metaverse Research: Identifying Future Research Areas Based on Bibliometric and Topic Modeling Techniques," *Information* 14(7): 356. doi: 10.3390/info14070356.

Starly, B., Koprov, P., Bharadwaj, A., Batchelder, T., and Breitenbach, B. (2023). "'Unreal' Factories: Next Generation of Digital Twins of Machines and Factories in the Industrial Metaverse," *Manufacturing Letters* 37: 50–52. doi: 10.1016/j.mfglet.2023.07.021.

Stary, C. (2023). "Digital Process Twins as Intelligent Design Technology for Engineering Metaverse/XR Applications," *Sustainability* 15(22): 16062. doi: 10.3390/su152216062.

Stevens, A. (2023). “Cognitive Artificial Intelligence and Remote Sensing Algorithms, Virtual Immersive and Spatial Computing Technologies, and 3D Image Modeling and Digital Twin Simulation Tools in the Industrial Metaverse,” *Economics, Management, and Financial Markets* 18(1): 73–88. doi: 10.22381/emfm18120235.

Tlili, A., Huang, R., and Kinshuk (2023). “Metaverse for Climbing the Ladder toward ‘Industry 5.0’ and ‘Society 5.0’?,” *The Service Industries Journal* 43(3/4): 260–287. doi: 10.1080/02642069.2023.2178644.

Wang, Y., Tian, Y., Wang, J., Cao, Y., Li, S., and Tian, B. (2022). “Integrated Inspection of QoM, QoP, and QoS for AOI Industries in Metaverses,” *IEEE/CAA Journal of Automatica Sinica* 9(12): 2071–2078. doi: 10.1109/JAS.2022.106091.

Wu, D., Yang, Z., Zhang, P., Wang, R., Yang, B., and Ma, X. (2023). “Virtual-Reality Interpromotion Technology for Metaverse: A Survey,” *IEEE Internet of Things Journal* 10(18): 15788–15809. doi: 10.1109/JIOT.2023.3265848.

Xiang, W., Yu, K., Han, F., Fang, L., He, D., and Han, Q.-L. (2024). “Advanced Manufacturing in Industry 5.0: A Survey of Key Enabling Technologies and Future Trends,” *IEEE Transactions on Industrial Informatics* 20(2): 1055–1068. doi: 10.1109/TII.2023.3274224.

Xinyi, T., Juuso, A., Riku, A.-L., Chao, Y., Pauli, S., and Kari, T. (2023). “TwinXR: Method for Using Digital Twin Descriptions in Industrial eXtended Reality Applications,” *Frontiers in Virtual Reality* 4: 1019080. doi: 10.3389/frvir.2023.1019080.

Zaidan, A. A., Alsattar, H. A., Qahtan, S., Deveci, M., Pamucar, D., and Hajiaghaei-Keshteli, M. (2023). “Uncertainty Decision Modeling Approach for Control Engineering Tools to Support Industrial Cyber-Physical Metaverse Smart Manufacturing Systems,” *IEEE Systems Journal* 17(4): 5303–5314. doi: 10.1109/JSYST.2023.3266842.