International Journal of Academic Information Systems Research (IJAISR)
ISSN: 2643-9026
Vol. 9 Issue 11 November - 2025, Pages: 1-7

AI-Driven Web 4.0: Toward an Intelligent Internet

Karima Akter, Taspia Tabassum Ali, Mohammad Nasar*

Computing and Informatics Department
Mazoon College
Muscat, Oman
2319939@mazcol.edu.om, 2319994@mazcol.edu.om, nasar31786@gmail.com*

Abstract: *Web 4.0 represents the next evolutionary shift of the Internet, moving from a data-driven and decentralized ecosystem toward an intelligent, autonomous, and context-aware digital environment. Artificial Intelligence (AI) forms the cognitive core of this transition by enabling adaptive decision-making, semantic reasoning, and autonomous interactions among users, devices, and decentralized services. The convergence of AI with blockchain, edge computing, and the Internet of Things (IoT) enhances trust, transparency, low-latency analytics, and real-time automation across sectors such as education, healthcare, supply chain management, and immersive virtual environments. This paper examines the theoretical foundations, enabling technologies, and emerging applications of AI-driven Web 4.0, while also addressing associated ethical, governance, and privacy challenges. The study proposes a conceptual model that positions AI as the central intelligence layer responsible for autonomy, learning, and secure collaboration within Web 4.0 ecosystems.*

Keywords— Artificial Intelligence, Web 4.0, Blockchain, Semantic Web, IoT, Edge Computing.

1. INTRODUCTION

The development of the World Wide Web has come in waves or revolutions that have transformed the way people communicate, interact and share information. Web 1.0 provided read-only pages with static content and little user interaction [1]. This corresponds to Web 2.0 that involves social interactivity, user generated content and collaborative learning networks [2]. Web 3.0 introduced semantic interoperability, distributed data exchange mechanisms, and blockchain-enabled trust models that enhanced transparency and user control. However, these architectures still relied heavily on manual user involvement and lacked autonomous cognitive capabilities. Finally, the limitations of Web 3.0 are addressed by implementing AI at the root of Web 4.0 to understand intent, adapt to context, and act independently [4,7]. This model—frequently known as the symbiotic web—imagines perfect cooperative human-intelligent agent collaboration [12].

A set of enabling technologies collectively support this transformation. A verifiable trust layer is offered by blockchain in AI systems [8] and used for making transparent, immutability data and decentralized control that ensures many actors on whether ledger from any malicious historical manipulation. Edge computing is a paradigm in which computation is moved closer to the source of data, minimizes latency and increases processing efficiency [16]. The connection of the Internet of Things (IoT) provides Web 4.0 with time-varying context information from things, strengthening the smarter automation across fields [7]. Together, these technologies create an ecosystem of digital intermediaries in which AI agents can act autonomously and facilitate seamless coordination.

The leading indicators of Web 4.0 are already being articulated across verticals. AI-driven customized learning systems, as implemented in an educational setting, would personalize and adapt curriculum to fit the requirements of individual learners [18]. Artificial intelligence and blockchain can be integrated into intelligent platforms that guarantee transparency, authenticity, and thus confidence in food safety as well as data accessibility on the global supply chain [19]. Decentralized protocols aimed at securing identity and enabling financial transactions are enhanced by novel AI capabilities for supporting digital economies [10]. Additionally, AI powers user customization, ownership and management of virtual objects, and autonomous interactivity among digital entities in immersive environments (e.g., metaverse) [11], [20].

Such trends will create enormous opportunities, but they will also entail new challenges. As intelligent systems are empowered with more system-level decision autonomy, data privacy and algorithmic bias control and digital sovereignty become increasingly challenging [15]. While decentralization naturally develops people-governed networks, we need better governance mechanisms, transparency standards, and legal frameworks for ethical AI construction and review to enable associated legal rights and foster trust within the user base [23].

So, the purpose of this paper is to explore the importance of AI technologies in the development and establishment of Web 4.0.

The objectives of this paper are to: (i) explain the theoretical and technological building blocks of AI as the driver of Web 4.0; (ii) describe use cases and applications arising from its convergence with blockchain, IoT, and edge computing; and (iii) discuss the ethical, governance, and societal implications of intelligent web ecosystems.

The main contribution of this study is a conceptual model positioning Artificial Intelligence as the cognitive core of Web 4.0, integrating blockchain, IoT, and edge computing to form an intelligent and autonomous Internet.

The rest of this paper is structured as follows. Section 2 reviews the evolution of the Web and related literature on Web 3.0 and Web 4.0. Section 3 explains how AI plays a pivotal role providing autonomy, semantic reasoning and trust in Web 4.0 by discussing these aspects. We highlight applications and case studies, including education supply chains; metaverse environments; industrial systems and cyber security in Section 4. Section 5 highlights major challenges and ethical issues. Section 6 is the conclusion of the paper, which includes ideas for future work.

2. LITERATURE REVIEW

2.1 Evolution of the Web

This transition from static information exchange to intelligent digital collaboration is evident in every new iteration of the World Wide Web. Web 1.0 offered read-only access to data and basic hyperlink navigation [1]. The main features of Web 2.0 are interactivity, user-generated content, and social participation [2]. This was further progressed with the introduction of semantic layer, blockchain-based decentralization and data ownership models that incentivized open and secure data sharing [3].
However, Web 3.0 still relied on human-controlled processes and lacked the ability to self-adapt or reason independently.

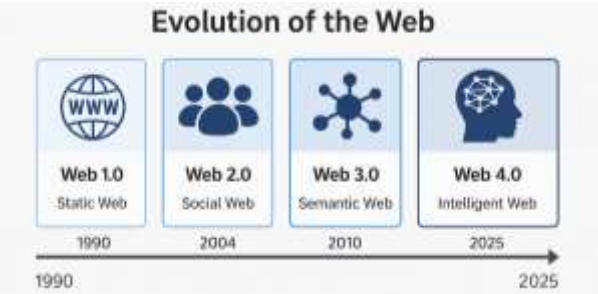

Fig. 1. *Evolution of the World Wide Web from Web 1.0 to Web 4.0*

The timeline illustrates the progression of the World Wide Web from static Web 1.0 (1990–2004) through the social Web 2.0 (2004–2016) and semantic/decentralized Web 3.0 (2016–2024), leading to the intelligent, AI-driven Web 4.0 emerging from 2024 onward.

2.2 Web 4.0 as the Intelligent Web

Web 4.0 is often described as the 'symbiotic web,' characterized by continuous cooperation between intelligent digital agents and human users. [4] presented outlines in which decentralized coordination of autonomous AI agents is performed without centralized control that allows a responsive and scalable web ecosystem. Zhang et al. [3] provide an extensive survey showing that the web will not only exchange data and services but will also become a platform for knowledge generation through AI technologies such as machine learning, reasoning, and predictive modelling.

Similarly, [12] proposed symbiotic AI which stressed the fusion of human intent with machine cognition as a basis for intelligent web. These contributions are necessary to act as a theory for Web 4.0 environment of lifelong learning and adaptive knowledge.

2.3 Technological Convergence

Web 4.0 is not an evolution of AI; it is the product of convergence. While transparency and integrity in AI decision pipelines are ensured with Blockchain [8], low-latency analytics and distributed intelligence is delivered at the edge of the Cloud [16]. Integrating IoT with AI, particularly in healthcare and logistics applications, provides contextual awareness and semantic enrichment, enabling agents to act in real time [7].
Digital sovereignty and decentralized identity frameworks are also an important concept to maintain user control in the AI-driven world as stated in [10]. Collectively, these studies combined demonstrate that AI is the cognition layer of Web 4.0, blockchain, IoT and edge computing are the coal structural layer of Web 4.0.

2.4 Applications and Research Directions

Several new applications illustrate the potential realization of Web 4.0 ideas today. Razzaq et al. [11] also studied the use of intelligent systems in Metaverse to provide personalized digital experiences and adaptive models for interaction. Her work demonstrates how machine-level reasoning and context-awareness can help facilitate natural interaction among users and virtual agents. Issa et al. [7] also looked at the possibilities of coupling intelligent analytics with Internet-of-Things (IoT) sensors for mitigation of time-critical monitoring issues in the food-supply chain. Their method allowed for improved traceability and data integrity from the point of distribution by integrating real-time IoT data with tamper proof digital records.
Similar initiatives show up in various sectors. Adaptive learning environments are transitioning from a primarily human-centered model to an automated ecosystem capable of responding dynamically to changing learner behavior, while decentralized data models combined with intelligent decision-making frameworks enable more transparent governance in public services.
These examples demonstrate that we are moving from theory to practice, where knowledge is autonomously generated, authenticated and propagated across interconnected systems.
While the recent progress is encouraging, Web 4.0 research is still in its infancy. Future studies should also investigate the interaction of this distributed intelligence by addressing, for instance: interoperability between different networks, ethical usage of automated decision systems, and mechanisms ensuring transparency and fairness. Clearly defining evaluation measures for performance, privacy [9] and

accountability will be critical towards sustainable and trustworthy Web 4.0 architectures.

2.5 Summary of Key Contributions

Table 1: Selected Foundational Studies on AI and Web 4.0 Integration

Ref.	Author(s) & Year	Key Contribution	Relevance to Web 4.0
[3]	F. Zhang et al., 2025	Comprehensive survey on AI for Web 3.0	Defines AI as the cognitive core transitioning to Web 4.0
[4]	T. Gürpınar & A. Tekir, 2025	Framework for autonomous AI agents	Establishes architecture for self-governed web intelligence
[7]	A. Issa et al., 2024	AI + IoT for supply-chain safety	Demonstrates real-world AI convergence and autonomy
[10]	K.-L. Tan et al., 2023	Digital sovereignty and identity survey	Introduces governance and user-control dimension
[12]	G. Desolda et al., 2024	Symbiotic artificial intelligence model	Theoretical foundation for human-machine collaboration

The reviewed studies reveal that Web 4.0 is much more than the decentralized state of Web 3.0. Collectively, the reviewed studies confirm that Web 4.0 extends beyond the decentralized vision of Web 3.0 by introducing a cognitive layer powered by AI. However, most current work remains conceptual. Future research must provide empirical validation, interoperability standards, and governance models to operationalize AI-driven web ecosystems.

3. The Role of Artificial Intelligence in Web 4.0

3.1 Overview

In Web 4.0, Artificial Intelligence acts as the central nervous system of the digital environment, empowering machines to sense, reason, and act with limited human intervention. Unlike earlier static or user-driven webs, this generation enables context-aware services that learn from data relationships and user intent. By combining AI with blockchain, edge computing, and IoT, Web 4.0 creates self-governing ecosystems that approximate human cognition [16].

Fig. 1 shows the reference model of Web 4.0, with central AI as an intelligent chain connecting users, devices and decentralized services.

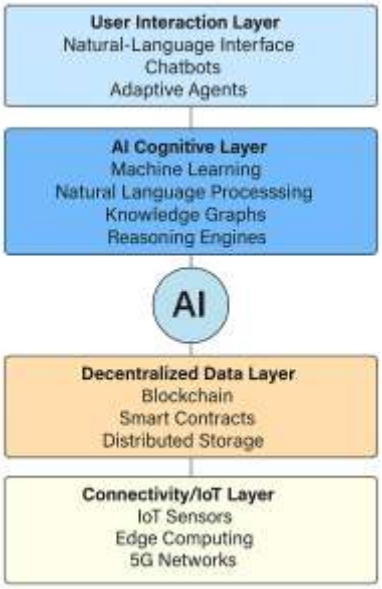

Fig. 2. *shows the reference model of Web 4.0, with AI at the center connecting users, devices, and decentralized services.*

3.2 Autonomy and Intelligent Agents

In Web 4.0, autonomy is enabled by artificial intelligence, with intelligent agents perceiving their environment and acting within it without constant human involvement. These agents, as explained by [4], represent the working backbone of decentralized coordination that can negotiate, execute, and verify the performance of digital tasks with the help of smart contracts. The agents adjust the decision logic based on patterns of actions taken, with an aim to achieve the best possible outcome.

This evolution has been described as the emergence of an Internet of Artificial Intelligence (IoAI) [21]a distributed network in which autonomous systems connect to share information and experience. In such an environment, intelligent agents continuously optimize communication paths and transactions across multiple domains, making Web 4.0 a dynamic, self-organizing infrastructure rather than a static information space.

3.3 Learning and Adaptation

With Web 4.0, learning comes from the huge data streams created by IoT sensors, user interactions, and social platforms. Such systems can discover complex patterns within cross-referenced, heterogeneous big-data streams using modern machine-learning techniques and deep neural architectures and can continuously adapt their behavior over time [17]. For example, Jiang et al. [5] show that AI can improve blockchain consensus efficiency by learning from transaction histories and reducing computational overhead and latency. Zhu et al. [2] further emphasize that combining AI with edge computing enables real-time model updates and low-latency analytics close to data sources.

Adaptive intelligence in Web 4.0 also supports predictive personalization, allowing websites, virtual assistants, and metaverse platforms to infer user intent, emotional tone, and

contextual needs. Over time, these agents form a feedback loop in which the web learns from users while simultaneously reshaping their digital experiences.

3.4 Semantic Reasoning and Context Awareness

In Web 4.0, AI is no longer simply calculations; it also becomes semantic. It serves as a gatekeeper between human language and machine logic by turning the sense, situation, and aim of a program into code. With this semantic ability, [3] pointed out that web data will give us structured knowledge graph and from these conclusions can be automatically drawn by reasoning and inference. [12] applied this idea to symbiotic AI, adding human decisions as attachment points in reasoning models for AI, forming a network that co-evolves with its users.

This abstraction capability allows cross-domain interoperability, which is a core requirement in smart cities, digital healthcare, autonomous logistics and any other domain where diverse data formats and ontologies are aligned through intelligent mediation.

3.5 Decision-Making and Trust Management

Verifiable trust is essential for autonomous decision making in Web 4.0. Combining AI with blockchain makes it possible to trace, validate, and secure the decisions of intelligent agents against compromise. This integration provides end-to-end traceability of transactions and supports verifiable trust. AI models evaluate data trustworthiness, anomaly detection and smart-contract execution monitoring. [19] showed how the coupling of blockchain to artificial intelligence in food supply chains reduces human intervention, while preserving traceability. Similarly, [25] Also, a study was conducted on how AI improves cybersecurity in IoT through automation of detection and response tactics.

Supporting ethical governance: By developing explainable models, AI can help justify autonomous decisions and ensure accountability and transparency in decentralized ecosystems.

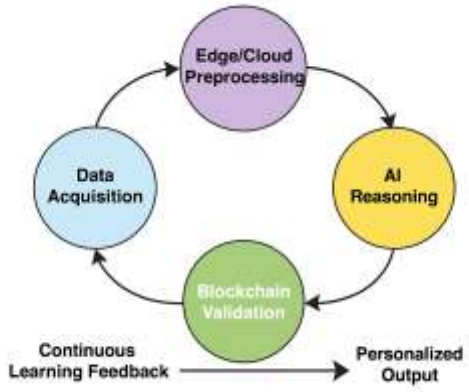

Fig. 3. *Workflow of AI-enabled decision-making in Web 4.0.*

3.6 Emerging Research Directions

Works published recently indicate the intersection of AI systems with metaverse, autonomous education systems and smart financial systems [18]. While [11] explained how AI designs adaptive metaverse environments. More recently, [18] showed decentralized educational certificate verification based on AI supported Web 3.0 models. [22] extended this to finance with a focus on automated auditing and predictive analytics.

These developments, taken together, indicate AI as an agent of change that converts Web 4.0 from a conceptual state to an existing one making the web an intelligent, self-organizing layer establishing reasoning and secure collaboration without human intervention.

3.7 Proposed Conceptual Framework for AI-Driven Web 4.0

Based on literature synthesis, this study proposes a conceptual framework that positions AI as the cognitive nucleus enabling autonomous operations, semantic reasoning, and trustworthy coordination across Web 4.0 ecosystems. The proposed conceptual model places AI at the core of all Web 4.0 layers and views the web itself as a self-educating environment. AI is at the heart, and operates consistently with three ancillary layers: connectivity, data integrity and user-experience. The connectivity layer consists of IoT devices, edge nodes and network infrastructure components that are capable to gather context information about the environment and providing communication capabilities everywhere. This creates a Data Integrity Layer for blockchain and distributed ledgers to underpin trustworthy, explainable, decentralized AI decision-making. At the higher level of context, personal services are personalized enriched with natural language interfaces, semantic reasoning and cognitive agents. Together, these layers combine to form a feedback loop: data is sent up to be analyzed; AI thinks about and optimizes over it; the blockchain confirms that such behaviors are indeed real; learning from collective feedback cross-pollinates into which everyone creates a mutually symbiotic reflection this grows in each of them so as to make ethical decisions.

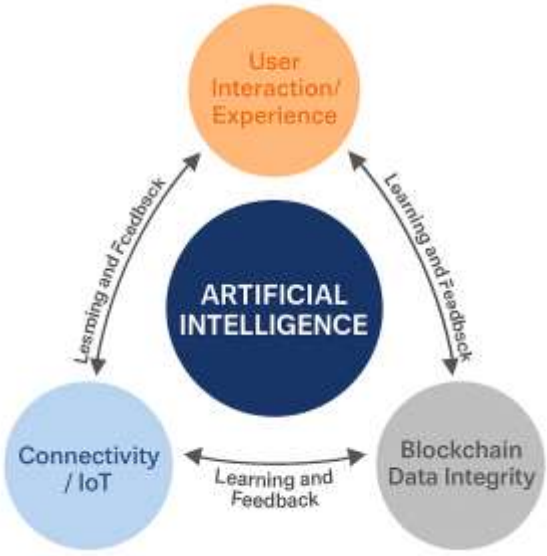

Fig. 4. *Proposed conceptual framework of AI-driven Web 4.0.*

4. Applications and Case Studies of AI in Web 4.0

4.1 Overview

AI is an essential element of Web 4.0; it turns the conceptual model into a living, adaptive ecosystem. In various industry sectors, AI-enabled web environments emerge as examples of how cognitive automation, semantic interpretation and decentralized trust can combine to improve decision-making, experience and transparency. This section introduces the case studies and specific applications to represent how AI combined with blockchain, IoT and edge computing in Web 4.0 world.

4.2 Education and E-Learning Systems

One of the first examples that showcased Web 4.0 capabilities is in the education domain. Razzaq et al. [18] then presented an educational certification system framework on top of 3.0 web, based on blockchain and AI for automatic verification in academic integrity. With the further development of Web 4.0, such environments will become autonomous learning ecologies in which AI tutors monitor students' behavior, personalize content, and adapt pedagogical strategies in real time.

Such adaptations, which generate a continuous learning feedback loop, can be observed in intelligent tutoring systems that fine-tune themselves based on semantic understanding and predictive analytics. AI-supported eLearning in the future will be realized by cognitive agents that are able to support lifelong learning and competency-based education on a completely decentralized manner.

4.3 Intelligent Supply-Chain and Food Safety Systems

The combination of AI and blockchain in supply-chain management is a prime example of how Web 4.0 brings secure trust and traceability between participants using the Web across decentralized platforms. [7] demonstrated that at the crossroads of Web 3.0 and AI lays a catalyst for ensuring food safety systems can mark this transition point by offering automation to both monitor product quality as well as transparency in farm-to-table relations. [19] further developed this notion into blockchain-dependent food-chain validation platforms: AI-based algorithms validate data and forecast unusual activities in the logistics.

The case studies show that Web 4.0 enables traceability throughout the supply chain and self-organized interaction between suppliers, administrators, and consumers to reduce human involvement and improve safety adherence.

4.4 Metaverse and Immersive Environments

[13] Metaverse showcases how Web 4.0 technologies, driven by AI come together to offer context-aware and user-driven virtual worlds. [11] examined how AI customizes virtual experiences by interpreting user gestures, preferences and emotions. In these intelligent virtual worlds, decentralized identities, autonomous agents and cognitive feedback enable dynamic environments and tasks.

AI also facilitates interoperability between platforms, so avatars and digital properties can work harmoniously across virtual worlds. This form of integration demonstrates Web 4.0's ability to merge reality and digital cognition the very concept which [12] termed "symbiotic intelligence."

4.5 Sustainable and Smart Industrial Systems

Zhang et al. [14] explored the applicability of AI applications in Web 4.0 infrastructure and how it could support sustainability via smart data sharing with collaborative optimization between supply chain networks. "IoT combined with AI can predict consumption habits and optimize how things are made, helping reduce waste and environmental implications to the point that businesses only produce what consumers want," said Trifler.

Similarly, [22] studied the use of AI for automation of financial decisions, in which auditions are intelligent, fraud is detected by compliance professionals and risk models are adaptive through a decentralized architectural model. These apps epitomize how AI stretches Web 4.0 beyond the digital realm and into the physical, economic, and environmental realms.

4.6 Cybersecurity and Privacy Management

AI for Web 4.0 is central to self-driving security. [25] discussed how AI models are used to secure the IoT by identifying malicious traffic patterns [24] and triggering automatic defense mechanisms. In a decentralized model, content management systems (CMS) offer verifiable truth which may not require validation due to the blockchain verification function of AI, so long as centralized oversight is not dominating.

AI is used not just for detection but also for ethical governance by analyzing access logs and applying privacy rules according to context. This oblique adaptability can make the system to promote itself constantly in battle related with emergent cyber threats, and to not infringe on the user's freedom.

The above applications together demonstrate that Web 4.0 goes beyond previous generations of web by providing intelligent, adaptive and transparent systems at all levels of interactions. In academia, business, banking and virtual worlds, AI is turning static digital landscapes into living ecosystems that can learn, reason and communicate non-stop. These cases are evidence which support the notion that the future WWW will be much more than anyone's information highway, rather a self-organizing web for which digital participation and mass collaboration will advance human evolution.

In all areas these examples show that through the support of AI Web 4.0, it can evolve from just the transactional exchange of information, one in which a smarter and social adaptive environment evolves. It is empirically shown to be beneficial in terms of transparency in supply chain, adaptive learning performance in education and end-to-end latency reduction in edge-based systems. These results endorse the disrupting potential of AI-based Web 4.0 architecture.

5. Challenges and Ethical Considerations in AI-Driven Web 4.0

5.1 Data Privacy and Digital Sovereignty

Continuous data sharing between AI agents and IoT devices heightens the risk of personal-data misuse. Privacy-preserving machine learning and decentralized identity frameworks can mitigate these risks.

5.2 Algorithmic Bias and Fairness

Self-learning systems may inherit biases from training data. Explainable AI (XAI) techniques should be integrated to ensure accountability and fairness.

5.3 Transparency and Governance

Blockchain provides auditability but cannot guarantee ethical behavior; hybrid models combining technical transparency with human oversight are required.

5.4 Regulatory and Global Coordination

Sustainable Web 4.0 adoption depends on internationally harmonized policies that balance innovation with protection and user rights.

6. Conclusion and Future Research Directions

Web 4.0 is a giant step in the evolution of the web, bringing intelligence, context awareness and autonomy to it. Linked with other advances such as the Internet of Things (IoT), blockchain or edge computing, these would be systems capable of learning, reasoning and coordinating themselves. This convergence will spur richer personalization, automation and real-time decision assistance in applications including health care, education and supply chain.

But these breakthroughs also present challenges for data privacy, algorithmic bias, transparency and accountability. The continuously updating streams of data going from AI models to IoT devices and back again, through (partially) decentralized ledgers, opens the door to misuse as well as a diminution in users' sovereignty, while opaque black-box processing by AI systems can result in biased or unexpected outcomes. Blockchain is only good for transparency; it does not lead to ethical governance or fair processes.

Building trust within Web 4.0's emergent digital space requires a combination of technical safeguards, explainable AI models, and responsible human oversight, all embedded within a comprehensive regulatory framework. Future work should center around the off-the-shelf frameworks, international governance requirements and field testing for getting at performance, scalability, and social impact. Simulation and prototype testing will be carried out in further work to confirm the open Web 4.0 structure at an operational level.

7. References

[1] W. Gan, "Web 3.0: The Future of Internet," in Companion Proceedings of the Web Conference 2023 (WWW '23 Companion), 2023. [Online]. Available: https://dl.acm.org/doi/10.1145/3543873.3587583

[2] J. Zhu, Y. Zhang, H. Zhang, and M. Tariq, "A survey of blockchain, artificial intelligence, and edge computing in Web 3.0," Computers & Electrical Engineering, vol. 114, 2024, Art. no. 100667. [Online]. Available: https://dl.acm.org/doi/10.1016/j.cosrev.2024.100667

[3] F. Zhang, L. Zhang, and Z. Wang, "Artificial Intelligence for Web 3.0: A Comprehensive Survey," ACM Computing Surveys, 2025, early access. [Online]. Available: https://dl.acm.org/doi/10.1145/3657284

[4] T. Gürpınar and A. Tekir, "Towards Web 4.0: Frameworks for autonomous AI agents," Frontiers in Blockchain, vol. 8, 2025. [Online]. Available: https://www.frontiersin.org/articles/10.3389/fbloc.2025.1591907/full

[5] X. Jiang, Y. Sun, and X. Liu, "Integration and innovation of blockchain in Web 3.0," World Wide Web, vol. 28, 2025. [Online]. Available: https://link.springer.com/article/10.1007/s11280-024-01319-7

[6] H. Zhang, Y. Zhao, and A. Hussain, "Web 3.0: Applications, opportunities and challenges in the digital economy," Systems Research and Behavioral Science, 2025, early view. [Online]. Available: https://onlinelibrary.wiley.com/doi/full/10.1002/sres.3151

[7] A. Issa, L. Issa, and K. Issa, "Redefining food safety: the confluence of Web 3.0 and AI technologies in the meat supply chain," International Journal of Food Science & Technology, vol. 59, no. 12, 2024, pp. 7361–7377. [Online]. Available: https://ifst.onlinelibrary.wiley.com/doi/10.1111/ijfs.17168

[8] S. Guo, X. Liu, and H. Wang, "Secure data sharing technology of medical privacy data in the Web3 era," IET Blockchain, vol. 4, no. 3, 2024, pp. 152–163. [Online]. Available: https://ietresearch.onlinelibrary.wiley.com/doi/abs/10.1049/blc2.12086

[9] N. Kapsoulis, C. Kalloniatis, and S. Gritzalis, "Blockchain privacy: Fundamental aspects and challenges for Web 3.0," IET Blockchain, vol. 4, no. 2, 2024, pp. 83–94. [Online]. Available: https://ietresearch.onlinelibrary.wiley.com/doi/abs/10.1049/blc2.12058

[10] K.-L. Tan, C.-H. Tan, and K.-K. R. Choo, "A Survey on Digital Sovereignty and Identity," ACM Computing Surveys, vol. 55, no. 12, 2023, pp. 1–38. [Online]. Available: https://dl.acm.org/doi/full/10.1145/3616400

[11] M. A. Fadhel, D. Cavaliere, and M. Cano, "Navigating the metaverse: a review," Artificial Intelligence Review, vol. 57, 2024, pp. 12777–12825. [Online]. Available: https://link.springer.com/article/10.1007/s10462-024-10881-5

[12] G. Desolda, F. Matera, and M. Catarci, "From human-centered to symbiotic artificial intelligence," Multimedia Tools and Applications, vol. 83, 2024, pp. 32079–32120. [Online]. Available: https://link.springer.com/article/10.1007/s11042-024-20414-5

[13] H. Chen, X. Sun, and H. Fu, "Web3 Metaverse: State-of-the-Art and Vision," Communications of the ACM

(Research Highlights), 2023. [Online]. Available: https://dl.acm.org/doi/abs/10.1145/3630258

[14] H. Zhang, L. Yin, and Y. Li, "Realizing environmental sustainability development through Web 3.0 enhanced supply chain collaboration," Sustainable Development, vol. 31, no. 5, 2023, pp. 4033–4052. [Online]. Available: https://onlinelibrary.wiley.com/doi/10.1002/sd.2714

[15] T. Theys, T. Jacobs, and F. De Turck, "Understanding user perceptions of Personal Data Stores for the Decentralized Web," International Journal of Human-Computer Interaction, vol. 41, no. 14, 2025, pp. 1289–1306. [Online]. Available: https://www.tandfonline.com/doi/full/10.1080/10447318.2025.2545467

[16] J. Zhu, Y. Zhang, H. Zhang, and M. Tariq, "Low-Latency Communications for Digital-Twin-Empowered Metaverse: A Survey," IEEE Network, vol. 37, no. 6, 2023, pp. 165–172. [Online]. Available: https://ieeexplore.ieee.org/document/10297327

[17] C. Li, X. Chen, and B. Li, "Blockchain Takeovers in Web 3.0: An Empirical Study on Protocol Governance," in Proc. Web Conference 2025 (WWW '25), 2025. [Online]. Available: https://dl.acm.org/doi/abs/10.1145/3689431

[18] A. Razzaq, A. Ali, and M. Imran, "A Web3 secure platform for assessments and educational certificates," Computer Applications in Engineering Education, vol. 32, no. 5, 2024, pp. 1881–1896. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1002/cae.22677

[19] V. S. V. Hema, S. S. R. Pushpak, and M. Xiong, "Blockchain implementation for food safety in supply chain: A review," Comprehensive Reviews in Food Science & Food Safety, vol. 23, no. 1, 2024, pp. 1–26. [Online]. Available: https://ift.onlinelibrary.wiley.com/doi/abs/10.1111/1541-4337.70002

[20] G. Saridakis and S. Spyridonidis, "A Look into the Future: The Impact of Metaverse on Business and Society," Management Review Quarterly, vol. 74, 2024, pp. 681–708. [Online]. Available: https://link.springer.com/article/10.1007/s11575-024-00550-8

[21] S. B. Far, S. F. Gharebaghi, and M. S. Ghazinoory, "Internet of Artificial Intelligence (IoAI): the emergence of an autonomous intelligent network," SN Applied Sciences, vol. 6, 2024, Art. no. 527. [Online]. Available: https://link.springer.com/article/10.1007/s42452-024-05726-3

[22] A. D'Ulizia, F. Ferri, and P. Grifoni, "The technological innovation of the metaverse in financial services," Intelligent Systems in Accounting, Finance and Management, vol. 31, no. 3–4, 2024, pp. 261–287. [Online]. Available: https://onlinelibrary.wiley.com/doi/full/10.1002/isaf.1566

[23] A. Brännlund and M. Strand, "Who's afraid of cryptoization? Evidence from a survey experiment," Review of International Political Economy, vol. 32, no. 8, 2025, pp. 2746–2777. [Online]. Available: https://www.tandfonline.com/doi/full/10.1080/09692290.2024.2424863

[24] H. Chen, X. Sun, and S. Chen, "Web 3.0-Enabled Microservice Re-Scheduling for Connected Autonomous Vehicles," in Proc. ACM/IEEE International Conference (ICDCS/related workshop), 2025. [Online]. Available: https://dl.acm.org/doi/10.1145/3715700

[25] H. M. Ahakonye, S. S. Memon, and A. I. Azougagh, "Tides of Blockchain in IoT Cybersecurity: A Review," Sensors, vol. 24, no. 10, 2024, Art. no. 3111. [Online]. Available: https://www.mdpi.com/1424-8220/24/10/3111

[26] Nasar, M., "Web 3.0: A review and its future," International Journal of Computer Applications, vol. 185, no. 10, pp. 41–46, 2023.