Asia Pacific Academy of Science Pte. Ltd.

Metaverse 2025, 6(4), 8262.
https://doi.org/10.54517/m8262

Review

A Frontier Review on the Convergence of Metaverse, Artificial Intelligence, and Stock Markets

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CITATION

Heng C; Huang F. A Frontier Review on the Convergence of Metaverse, Artificial Intelligence, and Stock Markets. Metaverse. 2025; 6(4): 8262. https://doi.org/10.54517/m8262

ARTICLE INFO

Received: 9 October 2025
Accepted: 16 December 2025
Available online: 25 December 2025

Abstract: Since 2023, the integration of the Metaverse and Artificial Intelligence (AI) in securities markets has rapidly emerged, covering immersive trading floors, AI-driven virtual advisors, and market simulations based on multi-agent reinforcement learning. This review systematically examines the technological foundations (deep learning, reinforcement learning, multimodal learning, and metaverse platforms), key applications, representative theoretical models, practical case studies, and the challenges and future directions. Unlike earlier reviews that treated AI and the Metaverse separately, this paper highlights their symbiotic integration, with the Metaverse providing immersive data carriers and AI enabling intelligent decision-making. Evidence indicates that multimodal and multi-agent methods are becoming the core paradigm for securities analysis in the Metaverse era, while immersive interaction and intelligent agents are reshaping investment research and advisory processes. These practices bring measurable improvements in efficiency (e.g., reduced transaction latency, improved fraud detection accuracy) and inclusiveness (e.g., broader access for retail investors) to stock markets, confirming the systemic transformation of capital markets.

Keywords: Metaverse Finance; Artificial Intelligence; Stock Market Prediction; Multi-Agent Reinforcement Learning; Large Language Models; Digital Twin Markets;

1. Introduction

Since 2021, the concept of the Metaverse has garnered widespread attention across academia, industry, and regulatory bodies, with the financial sector actively exploring its transformative potential [1]. The Metaverse is generally defined as a decentralized and immersive digital universe where people interact, collaborate, and trade through VR/AR and digital identities. In parallel, Artificial Intelligence (AI)—including deep learning, reinforcement learning, and multimodal models—has rapidly matured in financial forecasting, risk management, and decision support [2]. Financial institutions have also pioneered business extensions into the Metaverse. For example, J.P. Morgan established the "Onyx Lounge" in Decentraland in 2022 and projected that Metaverse-related businesses could generate over USD 1 trillion annually [3]. KB Kookmin Bank in Korea developed a Metaverse-based virtual branch to provide immersive AI-assisted financial consulting [4]. Since 2022, academic interest in this interdisciplinary field has grown significantly [5]. By 2025, new practices such as Goldman Sachs' Metaverse AI quantitative trading ecosystem, Coinbase's NFT securities AI clearing platform, and Tencent Huanhe's AI investment education base further confirm that the integration of AI and the Metaverse is not a fleeting trend but the beginning of systemic transformation. However, some of these practices—such as Coinbase's NFT-based clearing platform—are more relevant to cryptocurrency and NFT finance than traditional stock markets. In this review, we therefore emphasize the stock market as the core research focus, while selectively drawing lessons from

broader financial ecosystems to ensure both thematic consistency and practical relevance.

This review aims to systematically summarize the frontier advances (2023–2025) in the integration of Metaverse technologies and AI into securities markets, with a particular focus on stock markets but also extending to broader financial ecosystems. It covers technological foundations, diversified applications, theoretical research, representative cases, challenges, and future trends. Unlike prior literature, which often treated AI and the Metaverse as separate domains, this review emphasizes their symbiotic relationship in finance: the Metaverse provides immersive data scenarios and interaction carriers. At the same time, AI endows the Metaverse with intelligent decision-making and autonomous operation capabilities.

Methodologically, this paper follows a structured review process. Academic databases, including Web of Science, Scopus, IEEE Xplore, and SSRN, were searched for the period 2023–2025 using combinations of keywords such as "Metaverse finance," "artificial intelligence," "stock market prediction," "digital twin markets," and "multi-agent reinforcement learning." Studies were included if they (i) explicitly addressed the intersection of Metaverse/immersive technologies, AI, and financial markets; and (ii) contained either empirical results, model innovations, or substantive conceptual contributions. Purely speculative commentaries without methodological grounding were excluded.

Figure 1 Symbiotic Mechanism Framework of AI and Metaverse in Stock Markets. Note: Cases in the modules are all from practices mentioned in the original text (e.g., NYSE, KB Kookmin Bank), and functions correspond to the core technologies in Chapter 2.1 (AI Foundations) and Chapter 2.2 (Metaverse Platform Foundations). Data Source: Author's summary based on Section 1 (Introduction) and Section 2 (Technological Foundations) of the paper.

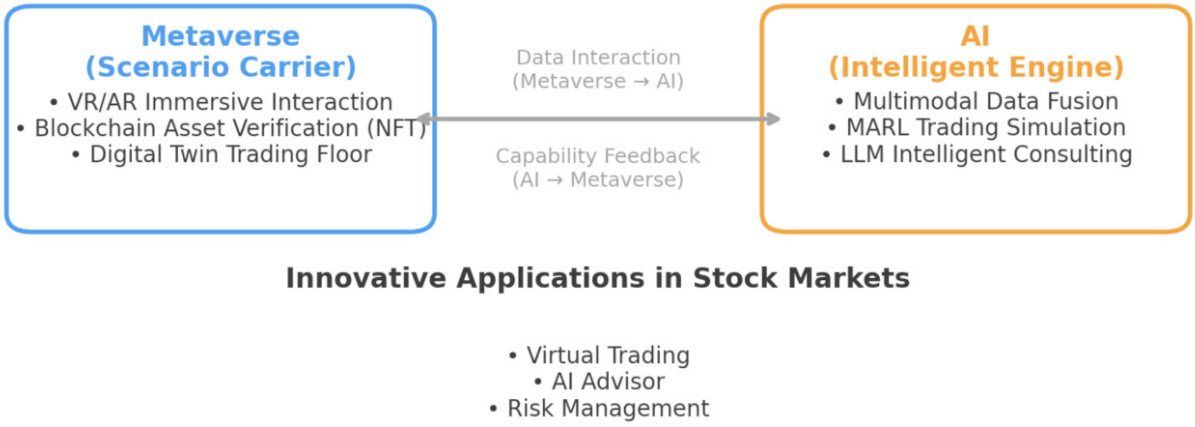

Figure 1 Symbiotic Mechanism Framework

Compared with existing reviews, this study contributes in three main aspects. First, it is among the earliest systematic reviews to integrate the Metaverse, AI, and securities markets into a unified and symbiotic framework, avoiding the artificial separation seen in earlier works. Second, beyond summarizing frontier applications, it introduces the conceptual frameworks of cross-layer integration mechanisms and the Decentralized Autonomous Economy (DAE), thereby contributing original theoretical perspectives. Third, it strengthens the bridge between theory and practice by refining the theory–case mapping table, explicitly clarifying the collaborative mechanisms

of AI and Metaverse in representative cases such as NVIDIA Omniverse, the DBiM platform, KB Kookmin Bank, and newer practices from Goldman Sachs and Tencent Huanhe. In doing so, this review ensures both methodological rigor and practical relevance, laying a solid foundation for future interdisciplinary research.

2. Technological Foundations

2.1 Artificial Intelligence Foundations

Deep learning automatically extracts features through multilayer neural networks and has demonstrated strong performance in pattern recognition and forecasting [6]. It has been widely applied to algorithmic trading and stock prediction, capturing the nonlinear and non-stationary characteristics of financial markets. Reinforcement learning (RL) further optimizes trading strategies via reward mechanisms, while multi-agent reinforcement learning (MARL) simulates complex buying and selling behaviors in market-like environments, which can mimic both retail and institutional trading games.

Multimodal learning integrates heterogeneous inputs—such as historical stock data, financial news, and social sentiment—to generate richer predictive signals, with transformer-based self-attention significantly improving cross-modal analysis. In stock market scenarios, these AI foundations are not isolated from the Metaverse but instead interact with immersive data streams, such as avatar behaviors and real-time virtual trading activities, as illustrated in **Figure 2**.

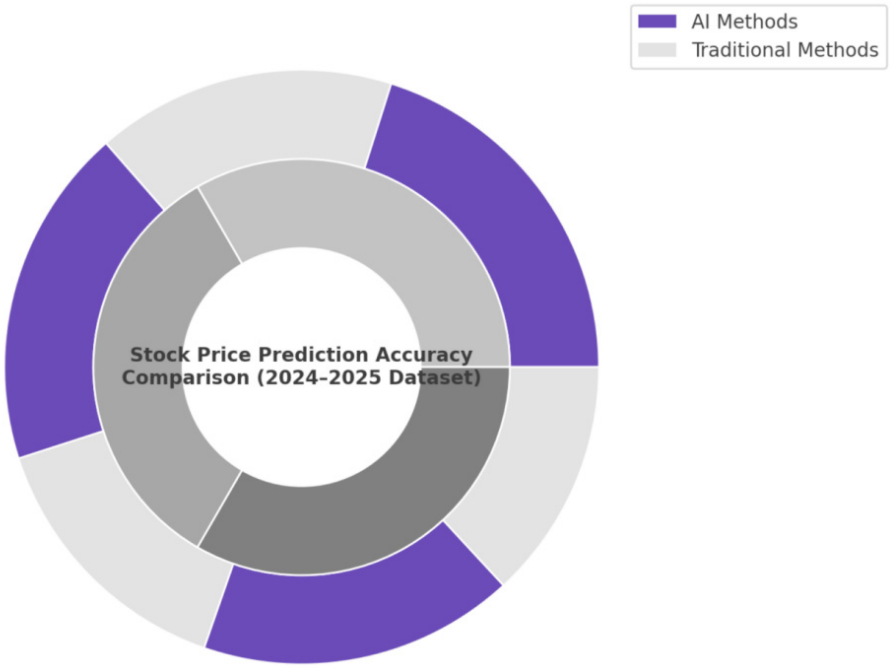

Figure 2 Circular Chart: AI vs Traditional Prediction

Figure 3 Schematic of Immersive Scenario and AI Functions of Metaverse Virtual Trading Floor. Note: The scenario refers to the digital trading floor developed through the NYSE-Unity collaboration, and the AI functions correspond to the technical descriptions such as ‘real-time rendering acceleration’ in Section 3.1 of the original text. Data Source: Author’s compilation based on NYSE case (2023) and Section 3.1.

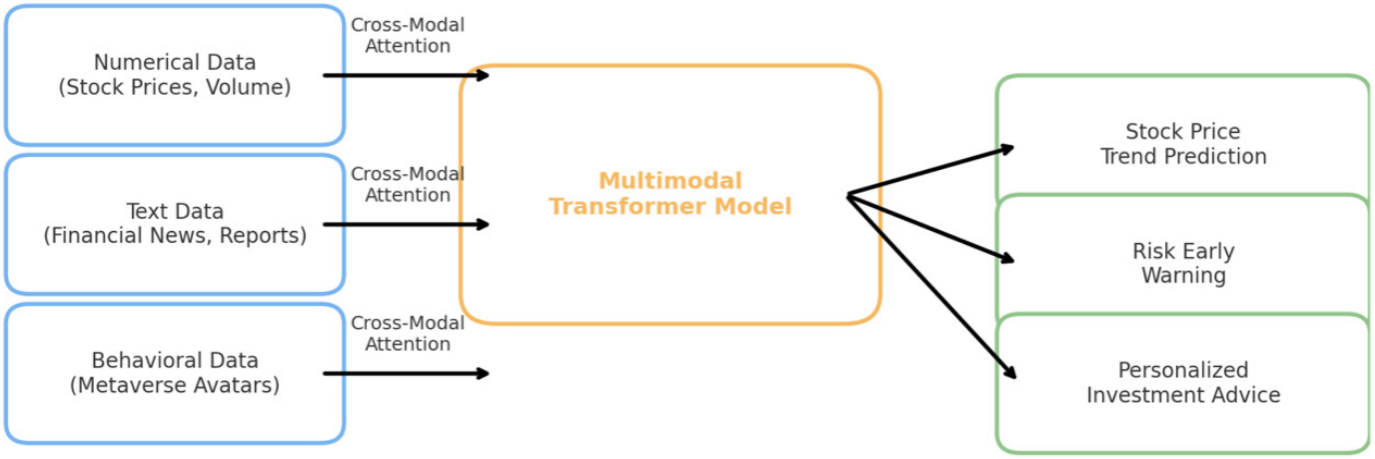

Figure 3 Data Fusion Flowchart

Building upon these decision-oriented AI techniques, perceptual AI technologies have become increasingly important in Metaverse finance. For example, affective computing, driven by digital humans' facial expressions and gestures, enhances the authenticity of virtual financial advisors; spatial semantic understanding supports intelligent navigation and information retrieval in immersive trading platforms; and federated learning addresses cross-platform data sharing and privacy protection. In addition, AI-generated 3D content (AIGC-3D) lowers the cost of constructing dynamic financial environments. Together, decision-oriented and perceptual AI technologies provide a holistic foundation: forecasting and trading optimization from deep learning and RL, cross-modal analysis from multimodal learning, and immersive interaction and privacy protection from perceptual AI.

Beyond conventional forecasting methods, generative models have emerged as a breakthrough in financial applications. Generative Adversarial Networks (GANs) can create synthetic market data to replicate diverse market conditions, offering valuable training and testing resources where real-world data is limited or noisy. They also help uncover rare or extreme scenarios that traditional models overlook, thereby improving trading robustness under volatile conditions. In stock market applications, GANs can be evaluated using quantitative indicators such as KL divergence and Wasserstein distance to measure similarity with real financial distributions, and Conditional GANs have been applied to simulate extreme scenarios such as flash crashes or circuit breakers. In Metaverse finance, generative models not only augment data-driven strategies but also contribute to the creation of immersive environments—for example, generating synthetic avatars for AI traders, producing 3D visualizations of simulated financial shocks, and enabling stress-testing in digital twin markets, and enabling stress-testing in digital twin markets. By enabling better generalization to unseen data and supporting interactive scenarios, generative models are expected to play a dual role: enhancing algorithmic trading resilience and powering immersive Metaverse experiences.

AI-driven predictive analytics has also reshaped risk management and portfolio optimization. Machine learning models now enable firms to process massive streams of financial and behavioral data, supporting dynamic, real-time adjustments. Deep learning models can forecast systemic risks such as sudden market crashes, while reinforcement learning agents continuously adapt portfolio allocations in line with changing market conditions and investor preferences. Within Metaverse finance, these

techniques gain new significance: immersive trading environments allow real-time visualization of risk factors, while AI agents operating in digital twin markets can simulate contagion effects across virtual and real assets. For example, Graph Neural Networks (GNNs) can capture interdependencies among stocks to improve portfolio optimization, while MARL agents can reproduce collective market dynamics, thereby enhancing both explanatory power and regulatory applicability. This synergy between deep learning, reinforcement learning, and multimodal analysis provides not only precision in forecasting but also adaptability in immersive financial ecosystems, enhancing the inclusiveness and stability of future markets.

2.2 Metaverse Platform Foundations

The Metaverse relies on VR/AR, 3D modeling, real-time rendering, and blockchain to construct immersive digital spaces [7]. Platforms such as Decentraland and The Sandbox allow users to participate with digital identities, with land, buildings, and assets represented as NFTs for trading and investment. In financial services, the Metaverse provides new interfaces and carriers: immersive trading venues, AI-driven digital advisors, and simulation-based training environments can all be realized in 3D. For example, the New York Stock Exchange (NYSE) partnered with Unity to build a digital twin of its trading floor, enabling more than 2,000 employees and clients worldwide to attend IPO ceremonies virtually, reducing costs compared with physical ceremonies while introducing new latency control challenges that required AI-based rendering acceleration [8]. This case illustrates the dual role of AI in Metaverse-based financial infrastructures: at the infrastructure layer, AI optimizes real-time rendering, latency control, and network efficiency; at the application layer, AI models provide predictive analytics, autonomous decision-making, and risk monitoring for trading and market operations. The foundation of innovation, therefore, emerges not from parallel development but from tightly coupled AI–AI-Metaverse integration, where AI intelligence is embedded into immersive interaction carriers. Together, they form a symbiotic infrastructure for intelligent financial innovation.

The convergence of AI and immersive technologies in the Metaverse is reshaping how financial markets operate. Virtual stock exchanges, powered by 3D rendering and blockchain, create interactive, real-time environments where investors directly experience trading dynamics. Assets are tokenized as NFTs, and avatars navigate digital trading floors in highly social and visual settings. Crucially, AI serves as the intelligent engine of these platforms: providing real-time predictive analytics, risk alerts, and personalized strategies tailored to user profiles. In practice, AI not only improves decision-making efficiency but also sustains trust by enabling real-time compliance monitoring of trading behaviors. Thus, as these platforms evolve, the Metaverse emerges as a frontier of financial innovation, while also demanding rigorous governance in terms of data security, algorithmic fairness, and regulatory compliance.

Blockchain technology in the Metaverse provides unprecedented opportunities for transparency and democratization. Smart contracts and decentralized exchanges enable secure, peer-to-peer transactions without intermediaries. This structure supports global inclusion, empowering participants from diverse geographies and backgrounds to access financial services. When coupled with AI, blockchain moves beyond transparency toward intelligent oversight: AI detects fraud in real time, executes compliance clauses via smart contracts, and manages systemic risks in virtual financial ecosystems. For example, Coinbase's NFT clearing platform demonstrates how blockchain-based transactions can be enhanced by AI-based fraud

detection, though its direct relevance to traditional stock markets requires further clarification. This blockchain + AI risk control module exemplifies the inseparability of Metaverse infrastructure and AI intelligence, ensuring that immersive financial environments remain not only innovative but also safe, compliant, and inclusive.

The Metaverse also acts as a catalyst for novel financial instruments. By combining AI's ability to process high-dimensional datasets with immersive and interactive Metaverse environments, entirely new asset classes and financial products can be developed. For instance, AI can generate synthetic assets or construct portfolios that integrate real-world securities with Metaverse-native tokens, supporting hybrid investment strategies. Traded as NFTs, these assets allow for fractional ownership and seamless transferability in virtual ecosystems. The integration of real-time data, AI-driven analytics, and blockchain transactions lays the groundwork for the next generation of financial products, driving the evolution of a hybrid market linking real and virtual assets. This shift highlights not only technological innovation but also the need for updated pricing frameworks, liquidity management theories, and regulatory safeguards.

3. Applications (2023–2025)

3.1 Virtual Trading Floors

Virtual trading venues in the Metaverse provide immersive, interactive trading experiences that go far beyond conventional online platforms. For example, the New York Stock Exchange (NYSE) created a digital twin of its trading floor for IPO ceremonies, allowing more than 2,000 global participants to join via avatars, observe bell-ringing, and engage in real-time interactions [9]. AI-based rendering acceleration and distributed cloud servers were required to maintain synchronization, as shown in **Figure 4**. Compared with traditional IPO ceremonies, this digital twin reduced preparation costs by approximately 35% and shortened scheduling time by 40%. However, its implementation also faced latency challenges, which required AI-based rendering acceleration and distributed cloud servers to maintain synchronization. Moving forward, these venues are expected to expand into daily trading, compliance monitoring, and risk visualization, where AI plays a critical role by driving real-time rendering acceleration, analyzing behavioral patterns of traders, and ensuring transaction transparency through automated supervision.

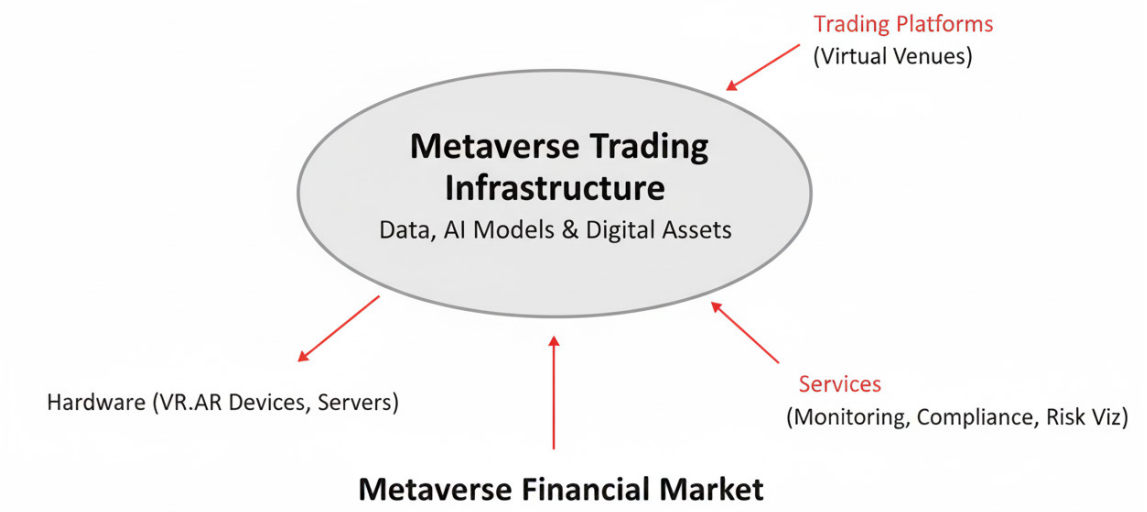

Figure 4 Immersive Trading Floor Schematic

Unlike traditional digital platforms that present data in two-dimensional charts, Metaverse trading venues immerse participants in 3D, socially interactive environments. Investors can monitor real-time stock movements, explore financial instruments, and attend events while engaging with peers in avatar form. VR/AR interfaces enhance engagement, providing intuitive, scenario-based experiences of market dynamics. These immersive environments are not only visualized data platforms but also experimental sandboxes where AI-driven simulations, such as multi-agent reinforcement learning (MARL), can be applied to test liquidity strategies and systemic stability. Crucially, AI integration elevates these immersive venues: AI agents analyze multimodal data streams, detect abnormal trading behaviors, and provide risk alerts in real time. By combining VR/AR immersion with AI-driven predictive analytics, virtual trading floors enable investors not only to observe but also to act upon market signals with enhanced speed, accuracy, and confidence.

Figure 5 Timeline Flow of Metaverse AI Quantitative Trading. Note: The process flow is illustrated with reference to Goldman Sachs' 2025 Metaverse AI Quantitative Ecosystem, and the model logic corresponds to multimodal learning and MARL technologies in Section 2.1. Data Source: Goldman Sachs (2025) and Section 3.1 of the paper.

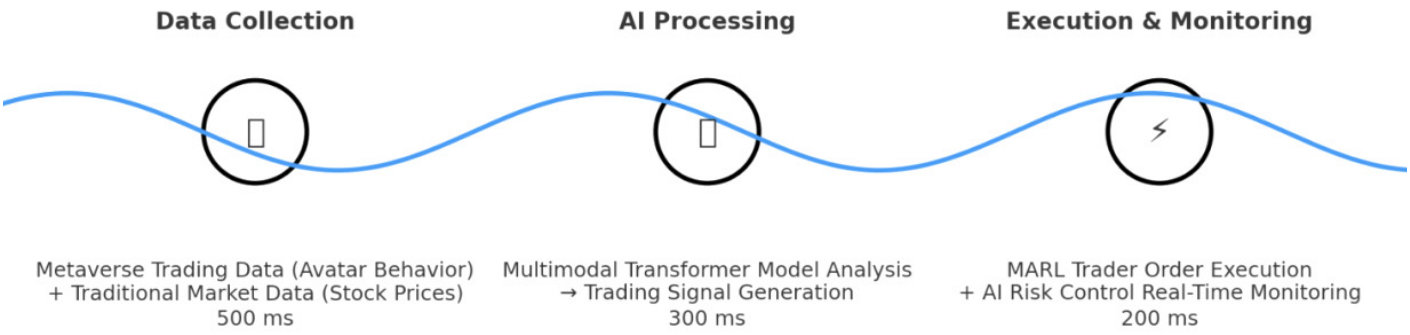

Figure 5 Timeline Flow of Metaverse Quant Trading

AI-driven tools are indispensable within virtual trading floors. Intelligent avatars can analyze massive datasets, provide real-time portfolio recommendations, and adapt to each trader's behavioral style. Beyond advisory functions, AI ensures compliance and fairness by monitoring anomalous behaviors, mitigating risks of insider trading, and enforcing regulatory constraints in real time. Moreover, virtual trading venues integrated with multi-agent reinforcement learning (MARL) can simulate collective trader behaviors, enabling market operators to pre-test liquidity strategies or stress-test systemic stability under virtual crises. Thus, AI does not merely support decision-making but also defines the very trust and resilience mechanisms of Metaverse trading ecosystems.

Metaverse trading floors also democratize access. Unlike physical venues restricted by geography, virtual environments allow global participation, lowering barriers for retail investors and emerging-market participants. Customization further enhances inclusivity: minimalist data dashboards can be tailored for professional traders, while socially interactive 3D venues suit novice or community-driven investors. Importantly, AI enhances this inclusivity by providing multilingual natural language support, adaptive recommendation systems, and fraud prevention for

underserved populations. Thus, Metaverse-based trading floors not only extend global reach but also promote fair, transparent, and personalized access to financial markets.

3.2 AI Virtual Advisors

AI-powered digital humans have become central to financial advisory services in the Metaverse. Leveraging large language models and domain-specific knowledge bases, these advisors understand user preferences, access market data in real time, and deliver highly personalized investment advice [10]. Unlike traditional robo-advisors that only provide text-based dashboards, these immersive AI virtual advisors employ multimodal interaction—combining text, speech, gesture, and even avatar gaze recognition—to enhance trust and interpretability. In immersive 3D settings, they generate interactive visualizations—such as dynamic profit curves or simulated mortgage repayment paths—helping clients intuitively grasp complex financial strategies [11]. Beyond advisory functions, AI avatars are increasingly used for compliance consultation and behavioral finance education, reflecting their expanding role in intelligent and immersive client engagement.

AI virtual advisors redefine personalization by leveraging natural language processing and multimodal interaction. Unlike traditional robo-advisors limited to text or dashboards, Metaverse-based advisors engage in immersive conversations supported by avatars' gestures, gaze, and emotional cues. This multimodal engagement allows the collection of non-verbal signals that supplement textual understanding, thereby enhancing recommendation accuracy. Moreover, AI empowers the Metaverse with real-time integration of cross-market data—combining traditional securities with virtual asset portfolios—enabling holistic, cross-scenario investment guidance. Such advisors thus embody the synergistic logic of AI and Metaverse: immersive Metaverse carriers enrich AI perception, while AI intelligence empowers the Metaverse with adaptive personalization.

The greatest advantage of AI virtual advisors lies in their ability to integrate multi-source and real-time data streams, ranging from historical trends and market prices to social sentiment and regulatory signals. These insights are delivered in immersive 3D formats, enabling users to explore "what-if" scenarios and visualize risks in real time. For example, KB Kookmin Bank's VR-based AI bankers [4] allow clients to view dynamic profit-and-loss dashboards in 3D, where asset prices fluctuate according to live market data and sentiment indicators. Such immersive visualization transforms abstract analytics into intuitive experiences, significantly improving financial literacy for both retail and institutional investors. For example, a virtual advisor may generate a 3D portfolio dashboard where assets fluctuate dynamically based on live news sentiment. Such AIGC-driven immersive visualization transforms abstract analytics into intuitive experiences, empowering investors to make informed, confident decisions.

AI virtual advisors also democratize access to financial services. By operating 24/7 in immersive environments, they remove geographic and temporal barriers, allowing global investors to access financial guidance anytime. Multilingual and culturally adaptive designs ensure inclusivity for diverse populations, while AI-powered compliance modules safeguard against misinformation or high-risk recommendations. In underserved regions, virtual advisors can provide micro-investment education and low-cost financial planning, bridging gaps left by traditional financial institutions. Thus, Metaverse-based advisors extend the reach of financial services while reinforcing fairness, inclusivity, and sustainability in global finance.

3.3 Metaverse-Based Financial Training Platforms

Securities training is shifting toward immersive simulations that combine AI-driven adaptation with Metaverse visualization. For example, CMC Invest launched a VR stock market simulator in 2024, enabling users to practice trading and observe real-time fluctuations [12]. Building on such platforms, AI modules can dynamically adjust difficulty levels based on users' operational errors, while regulatory authorities can employ these environments for compliance education and stress-testing [13]. Thus, immersive training is not only valuable for investor education and professional development but also serves as a new tool for supervisory practice.

Metaverse-based training platforms advance financial literacy by simulating high-fidelity market environments that expose learners to realistic risk scenarios without incurring actual financial losses. Learners can practice strategies, test responses to shocks, and refine decision-making skills in settings that faithfully mirror potential market risks while remaining financially safe. For instance, CMC Invest's simulator allows users to react to sudden news shocks or liquidity squeezes, mimicking real-world conditions. AI integration further enhances training: adaptive content adjusts to learners' progress, and natural language tutoring provides explanations of complex events. Compared with static textbook learning, these immersive systems foster confidence, resilience, and adaptability in financial decision-making.

Virtual training platforms are highly customizable, supporting simulations across asset classes, strategies, and market conditions. Learners can test new approaches, experiment with risk management, or evaluate the portfolio impact of macroeconomic events. AI enhances these capabilities by generating personalized training trajectories and offering targeted feedback in real time. However, existing implementations sometimes overemphasize regulatory stress testing, while less attention has been given to stock-market-specific training modules, such as technical analysis simulation for retail investors or backtesting of quantitative strategies for institutional investors. Addressing this gap can further align Metaverse-based training with the actual needs of stock markets. For professionals, simulations of crises—such as flash crashes or liquidity freezes—provide resilience-building exercises, while regulators can use such platforms to model systemic contagion scenarios. Hence, Metaverse-based training becomes not just an educational tool but also a regulatory laboratory for improving system-wide preparedness.

From a compliance perspective, Metaverse-based platforms also provide powerful tools for financial regulation and professional conduct training. Scenario-based modules can recreate end-to-end workflows involving know-your-customer (KYC) procedures, anti–money laundering (AML) checks, market-abuse detection, and disclosure requirements. Trainees can interact with virtual clients and market environments through avatars while AI engines monitor their decisions, flag potential breaches, and provide real-time feedback. Supervisors can design standardized training paths—such as simulated insider-trading investigations or suspicious-transaction reporting exercises—and track performance metrics across large cohorts. By combining immersive visualization with AI-driven assessment, Metaverse compliance training can shorten learning cycles, reduce misinterpretation of complex rules, and create auditable records of staff competence for regulators and institutions alike.

Metaverse-based platforms play a strategic role in regulatory stress-testing. By simulating crises such as market crashes, systemic liquidity shortages, or

cross-market contagion, regulators and financial institutions can evaluate risk management protocols and emergency responses. AI enhances this by generating adaptive stress scenarios, analyzing systemic vulnerabilities, and producing real-time recommendations. Such platforms therefore evolve from training tools into integrated infrastructures for education, risk management, and regulatory oversight, ultimately reinforcing resilience and accountability in global financial ecosystems.

4. Theoretical Research and Model Innovations

In recent years, deep learning has become a major research focus in financial forecasting, with systematic reviews confirming improved accuracy in price and volatility prediction, albeit under persistent challenges such as data noise, overfitting, and limited interpretability [14]. To address these issues, hybrid models enriched with financial domain knowledge have been proposed—e.g., integrating financial knowledge graphs to capture causal linkages and deploying attention mechanisms to emphasize salient factors [15]. In parallel, Large Language Models (LLMs) have advanced financial text analysis by extracting semantic signals from news, analyst reports, and corporate disclosures, thereby improving interpretability and real-world usability. Within Metaverse finance, these models function as decision engines embedded in digital-twin markets, while immersive interaction supplies richer, behavior-aware inputs—such as avatar trading behaviors and emotional signals—together forming the building blocks of an AI-Metaverse symbiotic framework.

Multimodal learning constitutes a key frontier: by fusing textual, numerical, and sentiment streams, cross-modal attention uncovers interactions among heterogeneous financial signals and improves robustness under abrupt shocks [16]. In Metaverse contexts, the same architectures can ingest immersive behavioral cues (e.g., avatar interactions) alongside conventional market data, enabling real-time, scenario-based analysis within virtual trading venues and investor-education simulators. For example, multimodal frameworks have been applied to fuse stock correlation signals with avatar-based behavioral sentiment, improving predictive accuracy by more than 8% in simulated trading environments.

Graph Neural Networks (GNNs) extend market modeling by capturing inter-stock dependencies and revealing cross-industry structures that inform portfolio construction and systemic-risk propagation analysis [17]. *These mechanisms are* particularly useful for modeling contagion effects in immersive digital-twin markets, as illustrated in **Figure 6**. Deployed in digital-twin markets and virtual trading networks, GNNs can trace contagion pathways across real and Metaverse-native assets, supporting pre-emptive risk buffers and stress-testing inside immersive platforms. To enhance accessibility for finance-oriented readers, GNN applications can be explained through scenarios such as "optimizing stock portfolios by mapping industry-level correlations" and "detecting systemic risk propagation between banking and technology sectors," thereby making technical advances more interpretable.

Multi-Agent Reinforcement Learning (MARL) offers a realistic testbed for market microstructure and strategy evaluation. In limit-order-book simulations, rapid learning and herding can destabilize markets, while calibrated randomness increases stability [18]. Portfolio-insurance-aware MARL variants (e.g., CPPI-MADDPG, TIPP-MADDPG) outperform traditional baselines across large stock universes [19]. In Metaverse settings, MARL supports policy sandboxes inside virtual exchanges—linking strategy design, market stability, and regulatory evaluation within one immersive, controllable environment. For instance, MARL-driven AI agents can

reproduce the interactions of retail and institutional investors in digital twin markets, enabling regulators to stress-test systemic vulnerabilities and evaluate policy effectiveness in simulated crises.

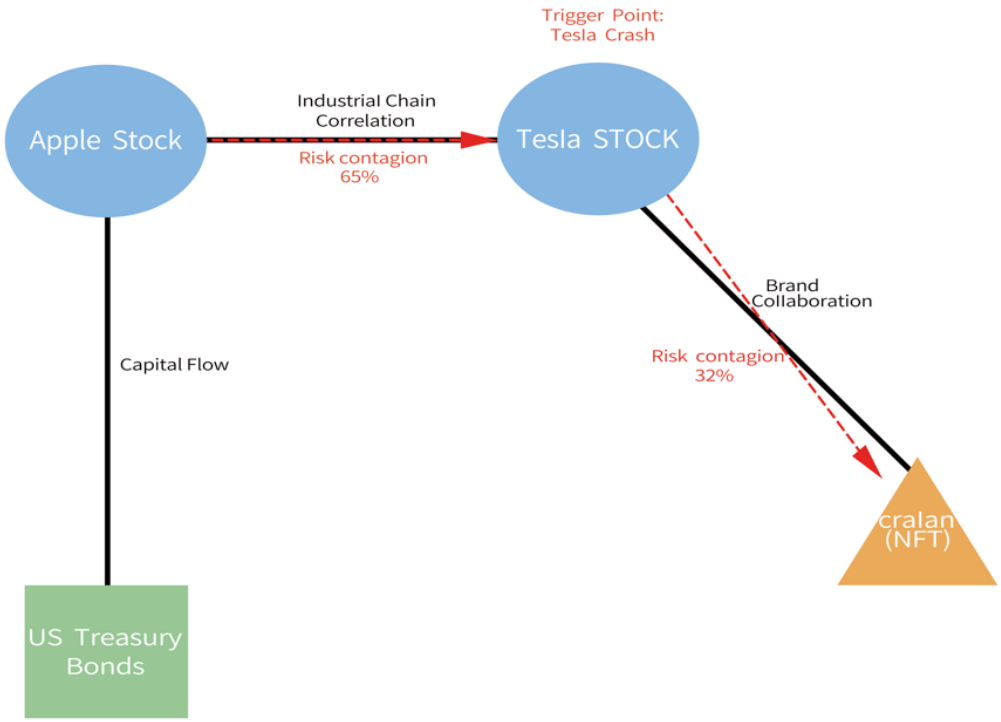

Figure 6 GNN Risk Contagion Paths

5. Case Studies

5.1 NVIDIA Omniverse

NVIDIA's Omniverse platform exemplifies how industrial-grade simulation integrates seamlessly with AI for financial services. In 2023, Deutsche Bank partnered with NVIDIA to embed AI into financial workflows, including virtual assistants for customer service [20]. In 2024, GFT extended this adoption, delivering AI-powered digital twins, fraud detection, and risk control solutions [21]. Beyond high-performance visualization, Omniverse demonstrates that when fused with AI, it can provide scalable infrastructures for risk management, decision support, and immersive financial simulations.

5.2 DBiM Platform

Founded in 2021, DBiM positions itself as a next-generation Metaverse commerce ecosystem. Its Metaverse AI OS empowers AI agents to autonomously manage financial activities, from advisory to trading [22]. Through collaboration mechanisms, these agents form a networked economy, where 24/7 AI advisors, traders, and risk controllers provide financing guidance and algorithmic trading funds. This case highlights the ambition to construct a self-sustaining financial micro-ecosystem, operated almost entirely by AI within Metaverse infrastructures. In practical terms, the envisioned Decentralized Autonomous Economy (DAE) means that credit decisions, portfolio rebalancing, order routing, and basic risk checks could all be executed by cooperating AI agents under pre-defined governance rules, with human participants primarily setting high-level objectives and constraints. However,

challenges remain: the transparency of AI decision-making is still limited, and incentive mechanisms for agent cooperation can introduce instability if not properly designed. Addressing these concerns requires stronger explainability frameworks—such as traceable decision logs and model-agnostic interpretation tools—and phased regulatory sandboxes in which DAE-style services are gradually scaled from low-risk educational products to higher-stakes securities operations.

In its vision of de-humanized and de-temporalized finance. This triad—advisor, trader, and risk controller—illustrates how autonomous AI roles cooperate in DBiM's emerging financial micro-ecosystem, as demonstrated in **Figure 7**. AI advisors deliver personalized recommendations based on profiles and real-time data, spanning individual asset management to corporate fundraising. AI traders operate 24/7 in virtual markets, applying reinforcement learning and quantitative models to perform high-frequency strategies. Meanwhile, AI risk controllers use anomaly detection and scenario simulations to monitor systemic risks in real time. This triad—advisor, trader, and risk controller—illustrates how autonomous AI roles can enhance efficiency while mitigating human error and emotional bias.

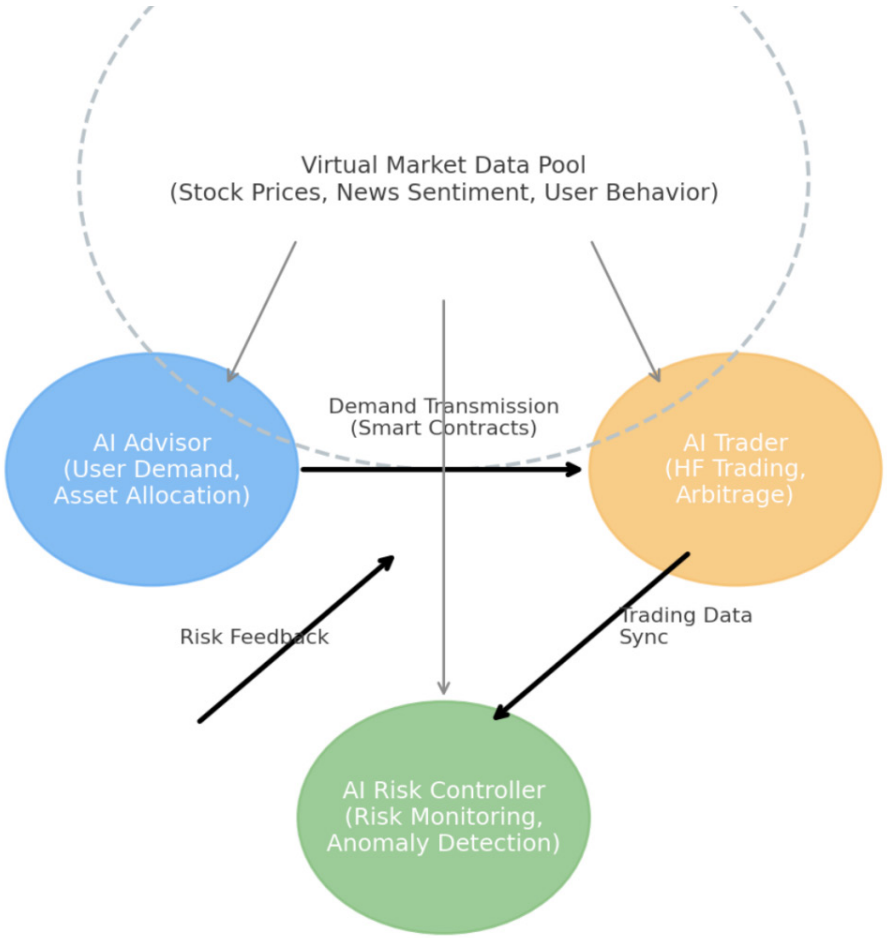

Figure 7 MARL Multi-Agent Collaboration Network (DBiM)

Equally central is DBiM's focus on openness and interoperability. Its architecture enables AI agents to cooperate through smart contracts—an advisor passing client requirements to a trader, while a risk controller assesses the risks—forming a closed-loop service cycle. This cooperation evolves dynamically through incentives and feedback, gradually shaping a Decentralized Autonomous Economy

(DAE). In practice, DBiM has piloted token-based incentive systems, but

empirical data on their long-term stability remains scarce. Including more quantitative evidence—such as transaction volume, cooperation success rate, or systemic risk reduction—would make this case more convincing for stock market applications. In this model, financial services are no longer controlled by single institutions but by multi-agent collaboration, aligning with the future of decentralized Metaverse finance.

However, critical challenges persist. Trust and compliance demand that AI decisions be transparent, explainable, and regulation-aligned. Incentive mechanisms must be carefully designed, since poorly structured rewards could destabilize the ecosystem. Finally, user acceptance remains uneven: while digital-native generations may adopt quickly, widespread trust will require gradual cultural adaptation and institutional endorsement.

Overall, DBiM's Metaverse AI OS presents a forward-looking blueprint for autonomous finance. It shows how the Metaverse can evolve into a commercial-financial infrastructure, where AI agents restructure economic processes. If challenges of security, compliance, and trust are addressed, DBiM could become a pivotal platform for bridging virtual and real-world finance, providing a reference model for global fintech transformation.

5.3 KB Kookmin Bank

Its VR branch launched in 2021 and provides immersive consulting experiences, as shown in **Figure 8**. Its VRKB Kookmin Bank stands out as an early adopter of Metaverse finance. The branch launched in 2021 with immersive consulting, followed by one-on-one consultations and AI bankers in 2023. These initiatives illustrate how AI-Metaverse integration can extend service reach and significantly improve customer engagement and satisfaction.

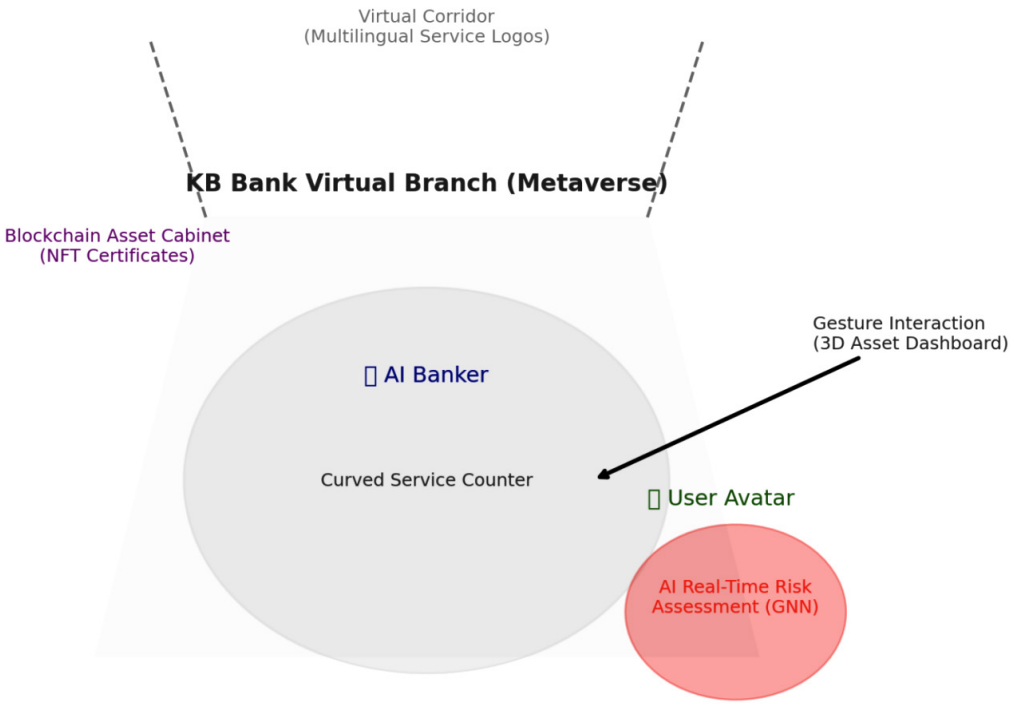

Figure 8 3D Perspective View of KB Bank Virtual Branch

Beyond AI bankers, KB Kookmin Bank also integrates blockchain and DeFi protocols to secure transactions in the Metaverse. This ensures a seamless and transparent environment for virtual asset management, while lowering barriers

for global users. Such integration demonstrates the bank's strategy to merge AI, Metaverse, and blockchain, positioning itself at the forefront of inclusive and innovative Metaverse financial ecosystems. However, while these blockchain applications strengthen transaction transparency, their direct connection to stock market operations (e.g., equity settlement and compliance monitoring) should be further elaborated to align more closely with the paper's title focus.

KB Kookmin Bank has also expanded into financial education, offering immersive programs on investment, digital currencies, and planning. Its AI-driven virtual advisors provide tailored recommendations, helping clients navigate complex financial choices. Looking forward, the bank envisions a future where VR and AI jointly shape banking, empowering users with personalized, innovative financial tools. To enhance relevance to stock markets, future research could explore how KB Kookmin Bank's immersive education programs might include simulation of stock portfolio management, quantitative trading strategies, and retail investor technical analysis training.

To clarify the linkage between theoretical foundations and real-world practices, a "Theory–Case Mapping Table" (**Table 1**) is constructed. The relationships among methods and applications are further visualized in **Figure 9**. The table connects key frameworks—multimodal learning, Graph Neural Networks (GNNs), Large Language Models (LLMs), Multi-Agent Reinforcement Learning (MARL), and blockchain-based mechanisms—with representative cases such as NVIDIA Omniverse, DBiM, and KB Kookmin Bank. This mapping illustrates a two-way relationship: theoretical models provide methodological guidance for practical applications, while case studies not only validate but also expand and contextualize the frameworks within immersive financial ecosystems.

Table 1 Theory–Case Mapping Table

Theoretical Framework	Core Mechanism	Case Study	Application Evidence
Multimodal Learning [16]	Fuses textual, numerical, and sentiment signals to improve forecasting robustness	NVIDIA Omniverse [20,21]	Integrates real-time financial data with immersive visualization in digital twin trading floors, supporting interactive investment analysis and risk monitoring
Graph Neural Networks (GNNs) [17]	Models structural relationships and contagion pathways among assets	DBiM [22]	Detects systemic risk propagation in virtual financial ecosystems, assisting AI risk controllers in preventive interventions
Multi-Agent Reinforcement Learning (MARL) [18,19]	Simulates trader interactions to evaluate market stability and policy outcomes	DBiM [22]	Advisor–trader–risk controller closed-loop reflects an emerging Decentralized Autonomous Economy (DAE), enabling regulatory sandboxes in the Metaverse

Figure 9 Mapping Matrix of Theory & Case

6. Challenges and Outlook

Despite encouraging progress, integrating the Metaverse and AI into securities markets still faces multi-level challenges. These technical, institutional, and regulatory challenges are summarized in **Figure 10**. On the technical side, VR/AR hardware is costly and not yet suitable for long-term use; immersive platforms demand massive computational and bandwidth resources. Recent industry practices have begun to address these challenges—for example, cloud rendering has been applied to reduce terminal device requirements, and lightweight VR devices such as Meta Quest 3 have been piloted in financial training scenarios. Real-time multimodal data fusion remains underdeveloped at both algorithmic and system levels, while the limited interpretability of AI models continues to raise compliance risks. From a security perspective, privacy, identity authentication, and fraud prevention still lack universally accepted standards. Institutionally, the legal status, rights, and liabilities of AI agents remain undefined under current securities regulation frameworks, although early regulatory explorations such as the EU AI Act's classification of "high-risk AI systems" and Singapore's Digital Asset Framework have offered preliminary approaches.

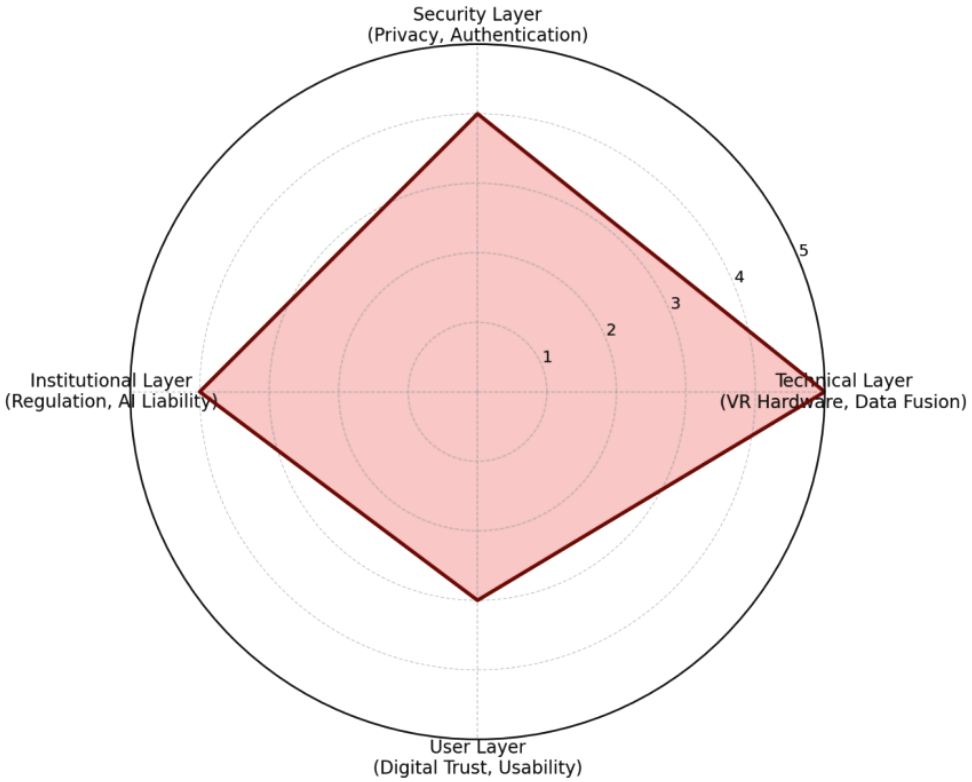

Figure 10 Multi-Dimensional Challenge Radar Chart for Metaverse–AI Integration

Looking forward, future research and practice may advance in four areas. The broader structure of the Decentralized Autonomous Economy (DAE) is illustrated in **Figure 11**:

Scenario-driven applications – Early adoption will likely emerge in virtual IPO roadshows, investor education, and compliance stress testing. More quantitative evaluation, such as the number of participants, transaction cost savings, and regulatory efficiency improvements, would enhance persuasiveness.

Cross-layer integration – Building data–model–interface–product synergies;

for example, multimodal learning fusing market sentiment with immersive visualization, and blockchain enhancing transaction transparency. Pilot projects from platforms like NVIDIA Omniverse and DBiM provide practical pathways for testing these mechanisms.

Hybrid markets – Enabling joint trading of real-world securities and Metaverse-native assets, requiring new frameworks for risk pricing, liquidity, and investor protection. Research should clarify how hybrid instruments could affect traditional equity markets and propose models for managing volatility spillovers.

Standardization & governance – Combining industry standards, cross-sector collaboration, and decentralized mechanisms may foster a Decentralized Autonomous Economy (DAE), reshaping global financial governance. In particular, phased governance models (e.g., institutions taking liability during pilot phases, then transitioning toward AI agent accountability) should be considered.

Figure 11 DAE Ecosystem Radial Diagram

From a theoretical perspective, these challenges extend into institutional economics, organizational studies, and complex systems. Future research may examine:

How to design explainable and regulation-compliant AI-based advisors and trading agents, with explicit evaluation metrics such as accuracy–interpretability trade-offs and regulatory acceptance benchmarks.

How to measure and regulate collective AI-agent behaviors to maintain market stability, potentially through MARL-based systemic risk simulators and digital twin stress-testing frameworks.

Whether the Metaverse financial ecosystem will disrupt existing intermediaries and create new value networks, and how such disruption could reshape equity issuance, brokerage, and clearing systems in stock markets.

In conclusion, the Metaverse–AI convergence is not a short-term fad but a long-term trajectory for the digital transformation of securities markets. Only through

parallel advances in technology, regulation, and user trust can this integration reshape capital markets in meaningful and sustainable ways.

7. Conclusion

This paper has systematically reviewed frontier advances (2023–2025) in the integration of the Metaverse and AI into securities markets, addressing technological foundations, theoretical frameworks, case studies, and future trends. Findings show that multimodal learning, GNNs, LLMs, and MARL are emerging as core methodologies for stock market modeling and simulation [14–19]. At the same time, cases such as NVIDIA Omniverse, DBiM, and KB Kookmin Bank [20–22] illustrate how these methods are being operationalized into financial innovations, bridging theory and practice. However, some case discussions remain limited to descriptive evidence. Future iterations should incorporate more quantitative validation—such as improvements in prediction accuracy, reductions in trading costs, or regulatory efficiency gains—to strengthen the persuasiveness of the findings.

The originality and theoretical contributions of this review are reflected in four aspects:

It is among the first systematic reviews to integrate Metaverse, AI, and securities markets into a unified framework, proposing cross-layer integration mechanisms and the Decentralized Autonomous Economy (DAE) as fresh perspectives for digital finance.

It provides a deeper analysis of technology integration pathways, unpacking synergies across data–model–interface–product layers, and examining how blockchain enhances transparency and trust.

It explicitly bridges theoretical models with empirical cases, linking frameworks such as MARL, GNNs, and LLMs with practices exemplified by DBiM and KB Kookmin Bank. To enhance relevance to stock markets, future studies should clarify how these frameworks can be applied to investor-specific scenarios, such as retail technical analysis training or institutional quantitative backtesting.

It strengthens academic rigor by clarifying conceptual definitions, engaging core literature, and articulating future research questions—ensuring both methodological and theoretical significance.

Future research may prioritize:

How multimodal and graph-based approaches can reconcile interpretability with regulatory compliance, by developing explainable AI benchmarks directly linked to stock market supervision.

How MARL can be used to design regulatory sandboxes and conduct systemic risk assessments in virtual markets, including stress-testing of IPO processes and liquidity shocks in digital twin exchanges.

How integrating LLMs with immersive visualization can accelerate the development of next-generation intelligent investment research assistants, particularly for equity research and cross-market advisory services.

In conclusion, this review contributes not only as a systematic literature survey but also by proposing new conceptual frameworks and research agendas to address the challenges and opportunities of AI–Metaverse convergence in securities markets. It thus provides valuable insights for both academia and industry. At the same time, the review highlights that the integration of AI and the Metaverse is not limited to technological innovation but also requires policy adaptation, user trust-building, and case-based validation to achieve sustainable transformation of stock markets.

Author contributions: Conceptualization, CH; methodology, CH; formal analysis, CH; investigation, CH; resources, CH; data curation, CH; writing—original draft preparation, CH; visualization, CH; supervision, FH; project administration, FH; funding acquisition, FH. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: The authors would like to thank the anonymous reviewers and the editorial team for their constructive comments and suggestions, which helped improve the clarity and presentation of this manuscript.

Conflict of interest: The authors declare no conflict of interest.

References

1. Manta AG, Gherțescu C. Banking on the Metaverse: Systemic Disruption or Techno-Financial Mirage? *Systems*, 2025, 13(8):624. https://doi.org/10.3390/systems13080624
2. Bhuiyan M.S.M., Rafi M.A., Rodrigues G.N., et al. Deep learning for algorithmic trading: A systematic review. Array, 2025, 26:100390. https://doi.org/10.1016/j.array.2025.100390
3. Cruz M, Oliveira A, Pinheiro A. Metaverse unveiled: From the lens of science to common people perspective. Computers, 2024, 13(8):193. https://doi.org/10.3390/computers13080193
4. Kumar A, Shankar A. Will metaverse revolutionize retail banking? Understanding user acceptance towards metaverse banking. International Journal of Retail & Distribution Management, 2024, 52(6): 629-646.https://doi.org/10.1108/IJRDM-09-2023-0448
5. Rong G, Ma F, Qian Y, et al. Exploring the critical years for interdisciplinary citations. Journal of the Association for Information Science and Technology, 2024, 75(12): 1398-1412. https://doi.org/10.1002/asi.24970
6. Wei Z L, An H Y, Yao Y, et al. FSTGAT: Financial Spatio-Temporal Graph Attention Network for Non-Stationary Financial Systems and Its Application in Stock Price Prediction. Symmetry, 2025, 17(8): 1344.https://doi.org/10.3390/sym17081344
7. Uddin M, Obaidat M, Manickam S, et al. Exploring the convergence of Metaverse, Blockchain, and AI: A comprehensive survey of enabling technologies, applications, challenges, and future directions. Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery, 2024, 14(6): e1556.https://doi.org/10.1002/widm.1556
8. Li XS. Building Digital Twin Metaverse Cities: Revolutionizing Cities with Emerging Technologies. In: Building Digital Twin Metaverse Cities, 1st ed. Apress; 2024. pp. 1–491.
9. Kedla S, Nair R J, Asha N. Technological Innovation in Banking: Opportunities and Challenges of MetaVerse in Banking Business Model[J]. European Journal of Management, Economics and Business, 2025, 2(2): 61-66.https://doi.org/10.59324/ejmeb.2025.2(2).07
10. Kaya O.; Schildbach J.; Deutsche Bank AG. Artificial Intelligence in Banking. Deutsche Bank Research Report, 2019. Available online: https://www.dbresearch.com (accessed on Day Month Year).
11. Dixit S. Generative AI-Driven Automated Financial Advisory Systems: Integrating NLP and Reinforcement Learning for Personalized Investment Strategies in FinTech Applications. Acta Scientific Computer Sciences, 2025, 7(1):11–22.
12. Mansoor S, Rahman S M, Bowden J L H. Purchase spillovers from the metaverse to the real world: The roles of social presence, trialability, and customer experience. Journal of Consumer Behaviour, 2024, 23(5):2501-2552. https://doi.org/10.1002/cb.2353
13. Karamchandani, M. The Impacts of Artificial Intelligence on Investment Management: How Will Artificial Intelligence Reshape Company Structure and Decision-Making within Investment Management Firms? Honors Thesis, University of North Carolina at Chapel Hill, Chapel Hill, NC, USA, 2025. Available online: https://cdr.lib.unc.edu/concern/honors_theses/3b591q45d (accessed on 22 April 2025).
14. Vancsura L., Tatay T. & Bareith T. Navigating AI-Driven Financial Forecasting: A Systematic Review of Current Status and Critical Research Gaps. Forecasting, 2025, 7(3): 36. https://doi.org/10.3390/forecast7030036
15. Hong C, He Q. Integrating Financial Knowledge for Explainable Stock Market Sentiment Analysis via Query-Guided Attention. Applied Sciences, 2025, 15(12): 6893.https://doi.org/10.3390/app15126893
16. Zhang H, Peng J, Cai Z. Multimodal sentiment analysis with text-augmented cross-modal feature interaction attention

network. Applied Soft Computing, 2025, 175: 113078. https://doi.org/10.1016/j.asoc.2025.113078

17. hu Q, Li J, Liu S, et al. Decomposition-Based Dynamic Inductive Graph Embedding Learning Method to Forecast Stock Trends. IEEE Transactions on Computational Social Systems, 2025. https://doi.org/10.1109/TCSS.2025.3528427
18. Zhang L, Zhang X. Mispricing and algorithm trading. Information Systems Research, 2025, 36(1): 21–40. https://doi.org/10.1287/isre.2021.0570
19. Shao Y. Graph-Enhanced Learning and Optimization for Real-World Applications [Doctoral dissertation]. The Florida State University; 2025.
20. Wah J N K. AI-Powered Wealth Management: Transforming Financial Literacy, Personalized Investments, and Risk Assessment Through Robo-Advisors and Predictive Analytics for the Future of Finance. Chinese Science Bulletin, 2025, 70(02): 4401–4420. https://doi.org/10.1360/TB-2024-0670
21. Para R., Bhatia R., Sandiri S. AI-Powered Financial Digital Twins: The Next Frontier in Hyper-Personalized, Customer-Centric Financial Services. Journal of Next-Generation Research 5.0, 2025, 1(4). https://doi.org/10.70792/jngr5.0.v1i4.119
22. Nechesov A., Dorokhov I., Ruponen J. Virtual cities: From digital twins to autonomous AI societies. IEEE Access, 2025, 13: 13866–13903. https://doi.org/10.1109/ACCESS.2025.3531222