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Addressing the Scalability Trilemma for Mass Market Gamichain Applications

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ABSTRACT

The convergence of blockchain technology and gamification has led to the emergence of Gamichain ecosystems that are increasingly adopted in digital business environments to enhance user engagement, transparency, and value exchange. Despite this potential, the blockchain scalability trilemma, which involves trade offs between decentralization, security, and scalability, remains a critical barrier to the mass market adoption of Gamichain applications. **This study aims** to analyze how the scalability trilemma influences the feasibility of large scale Gamichain systems and to identify architectural strategies that enable high frequency transactions and large user participation while preserving system trust. **A qualitative conceptual** approach supported by comparative case analysis is employed, examining representative implementations such as Axie Infinity, STEPN, and Polygon based gaming platforms. **The analysis** evaluates existing scalability solutions including Layer 2 rollups, sharding mechanisms, and hybrid off chain and on chain architectures across key dimensions of security, decentralization, transaction throughput, and user experience. **The results** indicate that Layer 2 and hybrid architectures provide the most viable balance for mass market Gamichain deployment, as they significantly improve performance efficiency and transaction cost without substantially undermining decentralization and security guarantees. This study contributes an applied evaluation framework that connects blockchain scalability discourse with practical digital business requirements. **In conclusion**, scalable Gamichain adoption depends not only on technical scalability solutions but also on strategic architectural alignment with user experience optimization, regulatory readiness, and sustainable digital innovation, thereby supporting broader participation in the global digital economy.

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1. INTRODUCTION

The rapid growth of digital business ecosystems has intensified the demand for technologies that can simultaneously support large user bases, real time interactions, and secure value exchange. In this context, gamification has emerged as a powerful strategy to enhance user engagement, loyalty, and participation across digital platforms. At the same time, blockchain technology has gained prominence for its ability to provide transparency, decentralization, and trust through immutable ledgers and smart contracts. The convergence of

these two domains has led to the emergence of Gamichain systems, which integrate gamified mechanisms with blockchain based infrastructures to enable tokenized rewards, digital ownership, and verifiable interactions [1]. Despite their potential, Gamichain applications face significant limitations when scaled to mass market environments. Many blockchain networks struggle to accommodate high transaction volumes without sacrificing performance or increasing transaction costs. These challenges are commonly framed within the blockchain scalability trilemma, which posits that decentralization, security, and scalability cannot be fully optimized simultaneously. For Gamichain systems that rely on frequent micro transactions and seamless user experience, this trilemma becomes a critical bottleneck that directly affects adoption, retention, and platform sustainability. Existing blockchain infrastructures, particularly Layer 1 networks, often experience congestion, latency, and high fees during peak usage. Such constraints are incompatible with the requirements of large scale Gamichain applications, including digital games, loyalty platforms, and consumer engagement systems [2]. In response, various technical solutions have been proposed, such as Layer 2 scaling mechanisms, sharding, and hybrid off chain and on chain architectures. However, prior studies tend to examine these solutions in isolation or from a purely technical standpoint, with limited focus on their implications for gamified digital business ecosystems [3].

This paper addresses this gap by analyzing how different scalability strategies can mitigate the trilemma within the context of mass market Gamichain applications. Using a qualitative conceptual approach supported by comparative case analysis, the study evaluates prominent Gamichain related implementations to assess how architectural choices influence scalability, security, decentralization, and user experience. By synthesizing technical and strategic perspectives, this research aims to provide an applied framework that supports informed decision making for developers and digital business stakeholders [4–6].

Based on the challenges of blockchain scalability and the growing demand for mass market Gamichain applications, this study is guided by the following research questions. First, how does the blockchain scalability trilemma influence the performance, feasibility, and adoption of Gamichain systems in large scale digital business environments [7]. Second, what architectural and technical strategies, including Layer 2 solutions, sharding, and hybrid on chain and off chain models, are most effective in mitigating scalability constraints while maintaining acceptable levels of security and decentralization. Third, what are the strategic implications of these scalability solutions for user experience, platform sustainability, and digital business innovation in Gamichain ecosystems [8].

From a sustainability perspective, scalable Gamichain infrastructures also contribute to broader global development objectives. By enabling inclusive digital participation, decentralized economic activities, and innovation driven platforms, Gamichain systems align with Sustainable Development Goals, particularly SDG 9 on Industry, Innovation, and Infrastructure and SDG 8 on Decent Work and Economic Growth. Therefore, addressing scalability challenges in Gamichain ecosystems is not only a technical necessity but also a strategic step toward building resilient, innovative, and sustainable digital economies [9].

2. LITERATURE REVIEW

2.1. Gamification in Digital Business Ecosystems

Gamification has been widely recognized as an effective approach to enhance user engagement, motivation, and loyalty in digital environments. By integrating game elements such as points, rewards, levels, and challenges into non game contexts, gamification encourages sustained user participation and value co creation [10–12]. In digital business ecosystems, gamification has been applied in areas such as customer loyalty programs, online learning platforms, digital marketing, and platform based services. Prior studies suggest that gamified systems can positively influence user retention and behavioral outcomes when designed with clear incentives and feedback mechanisms. However, as user bases grow, maintaining system responsiveness and fairness becomes increasingly complex, particularly when gamification mechanisms involve real time reward distribution and transactional verification [13].

2.2. Blockchain Technology and Trust Mechanisms

Blockchain technology offers a decentralized and tamper resistant infrastructure that supports transparency, immutability, and trustless interactions [14]. Through the use of distributed ledgers and smart contracts, blockchain enables secure value exchange without reliance on centralized intermediaries. These characteristics make blockchain particularly attractive for gamified systems that require verifiable ownership of digital assets, transparent reward allocation, and resistance to fraud. Nevertheless, blockchain networks inherently

face performance limitations due to consensus mechanisms and network propagation delays. As transaction volumes increase, these limitations can lead to congestion and rising transaction costs, which directly affect usability and scalability [15–17].

2.3. The Blockchain Scalability Trilemma

The concept of the blockchain scalability trilemma highlights the fundamental trade offs between decentralization, security, and scalability. Existing literature emphasizes that optimizing one dimension often leads to compromises in the others. Highly decentralized and secure networks tend to suffer from limited throughput, while more scalable solutions frequently rely on reduced decentralization or alternative trust assumptions. This trilemma has been extensively discussed in the context of public blockchains, yet its implications for application specific systems such as Gamichain remain underexplored [18]. For mass market Gamichain applications that require high frequency micro transactions, the trilemma represents a critical design constraint rather than a theoretical concern [19].

2.4. Scaling Solutions for Gamichain Applications

To address scalability challenges, several technical solutions have been proposed in the literature. Layer 2 mechanisms, including rollups and sidechains, aim to offload transaction processing from the main chain while preserving security guarantees through periodic settlement [20]. Sharding introduces parallel processing by partitioning the network into smaller units, thereby increasing throughput. Hybrid on chain and off chain architectures separate user interaction logic from settlement layers to optimize performance and user experience [21, 22]. While these approaches show promise, studies often focus on technical efficiency without sufficiently considering gamification dynamics, user behavior, and digital business requirements.

2.5. Research Gap

Although prior research provides valuable insights into blockchain scalability and gamification independently, there remains a lack of integrated analysis that examines scalability solutions within mass market Gamichain ecosystems. Existing studies rarely evaluate how architectural trade offs affect user experience, engagement sustainability, and platform viability simultaneously. This gap highlights the need for a holistic framework that connects blockchain scalability strategies with gamified digital business objectives [23]. Addressing this gap forms the foundation of the present study.

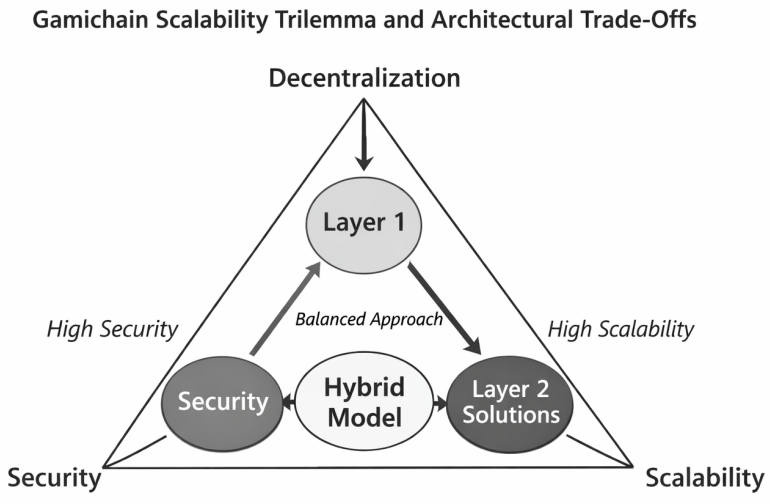

Figure 1. Gamichain Scalability Trilemma and Architectural Trade Offs

Figure 1 illustrates the conceptual representation of the Gamichain scalability trilemma and the associated architectural trade offs between decentralization, security, and scalability in mass market applications.

The triangular model visualizes how Layer 1 blockchain architectures prioritize security and decentralization but face limitations in transaction throughput, making them less suitable for high frequency gamified interactions. In contrast, Layer 2 solutions are positioned closer to scalability, highlighting their ability to significantly improve performance and reduce transaction costs, albeit with certain compromises in decentralization or governance assumptions. The hybrid model is depicted near the center of the triangle, representing a balanced architectural approach that combines off chain processing for user interactions with on chain settlement for asset ownership and verification [24]. This configuration demonstrates how hybrid architectures can mitigate the scalability trilemma by optimizing user experience while maintaining acceptable levels of security and trust, thereby offering a practical solution for sustainable, mass market Gamichain ecosystems [25, 26].

3. METHODOLOGY

3.1. Research Design

This study adopts a qualitative conceptual research design to systematically analyze blockchain scalability challenges within the context of mass market Gamichain applications. Rather than proposing a new technical protocol or algorithm, the research emphasizes the synthesis of existing theoretical frameworks and applied insights to develop a structured evaluative understanding of scalability strategies. This approach enables the integration of technical blockchain literature with perspectives from digital business and gamification studies, which are often examined separately [27]. A conceptual research design is particularly appropriate given the exploratory nature of the research questions, as it allows for critical comparison of architectural trade offs and strategic implications without relying on experimental implementation. By bridging interdisciplinary domains, this method supports a holistic analysis of how scalability solutions influence system performance, user experience, and adoption feasibility in Gamichain ecosystems [28].

3.2. Data Sources and Literature Selection

The analysis is grounded in a structured review of peer reviewed academic articles, industry reports, and authoritative technical documentation published between 2022 and 2026 to ensure relevance to current technological developments. Sources were systematically selected based on their direct contribution to discussions on blockchain scalability, gamification systems, distributed architectures, and digital business platforms. This selection process prioritizes studies that address performance, security, and architectural trade offs in large scale systems. In addition to scholarly literature, publicly documented case studies of prominent Gamichain related implementations were examined to contextualize theoretical insights within real world applications. These cases provide practical evidence of scalability challenges and solution strategies, enabling a more comprehensive understanding of how architectural decisions manifest in operational Gamichain environments.

3.3. Comparative Case Analysis

To contextualize theoretical insights, this study employs comparative case analysis of representative Gamichain applications, including Axie Infinity, STEPN, and Polygon based gaming platforms. These cases were selected due to their substantial user bases, intensive reliance on frequent micro transactions, and well documented scalability challenges observed during periods of rapid user growth. Each case is examined to analyze how specific architectural choices, such as the adoption of sidechains, hybrid on chain and off chain processing, or Layer 2 infrastructures, influence overall system performance and transaction throughput. In addition, the analysis evaluates the impact of these architectural decisions on transaction costs, user experience continuity, and the preservation of trust mechanisms under mass market conditions. By comparing diverse implementation strategies, the study provides a nuanced understanding of how scalability solutions shape operational efficiency and adoption feasibility in Gamichain ecosystems [29].

3.4. Analytical Framework

An evaluation framework is developed to systematically assess blockchain scalability strategies across four key dimensions: security, decentralization, scalability throughput, and user experience. Security refers to the system's capacity to prevent fraud, ensure data integrity, and protect digital assets through robust consensus and verification mechanisms. Decentralization captures the extent to which control, validation, and trust assumptions are distributed across network participants rather than concentrated in a limited set of actors. Scalability throughput evaluates the system's ability to process high transaction volumes with minimal latency,

which is particularly critical for Gamichain applications that depend on frequent and time sensitive interactions. User experience encompasses transaction cost visibility, system responsiveness, accessibility, and the degree to which technical complexity is abstracted from end users [30, 31]. By integrating these dimensions, the framework enables a systematic and comparative analysis of Layer 2 solutions, sharding approaches, and hybrid on chain and off chain architectures, supporting informed evaluation of architectural trade offs under mass market deployment conditions [32].

3.5. Data Analysis Procedure

The collected literature and case evidence are analyzed through a thematic synthesis approach to identify recurring patterns, relationships, and conceptual themes related to blockchain scalability in Gamichain systems. This process involves systematically examining how different scalability strategies address or exacerbate trade offs associated with the scalability trilemma, particularly in environments characterized by high transaction frequency and user interaction intensity. Identified themes are then mapped to core Gamichain operational requirements, including performance efficiency, trust preservation, and user engagement sustainability. The synthesized findings are subsequently interpreted to derive strategic implications for mass market adoption, architectural decision making, and long term digital business development, with particular attention to user experience challenges and accessibility considerations [33].

4. RESULTS AND DISCUSSION

The results of this study indicate that the blockchain scalability trilemma emerges as a critical constraint in the deployment of mass market Gamichain applications. Platforms that rely heavily on frequent micro transactions and real time user interactions tend to experience significant performance degradation when operating primarily on Layer 1 blockchain infrastructures. Network congestion, increased transaction latency, and escalating transaction fees not only reduce system efficiency but also disrupt the immediacy and continuity required by gamification mechanisms [34]. As gamified systems depend on timely feedback, rapid reward distribution, and seamless interaction cycles, such performance issues directly weaken user engagement and satisfaction. Furthermore, high operational costs and inconsistent transaction confirmation times discourage sustained participation and limit accessibility for broader user segments. These findings suggest that scalability challenges should be understood not merely as technical limitations but as strategic barriers that shape platform adoption, user retention, and long term viability [35]. Consequently, the inability to effectively manage scalability constraints undermines the competitive positioning of Gamichain platforms and restricts their potential to evolve into sustainable, mass market digital ecosystems.

Table 1. Comparison of Blockchain Scaling Solutions for Mass Market Gamichain Applications

Scaling Approach	Scalability Performance	Security Implication	Decentralization Impact	User Experience	Suitability for Gamichain
Layer 1	Low	High	High	Low	Limited
Layer 2	High	Medium to High	Medium	High	Suitable
Sharding	Medium to High	Medium	Medium to High	Medium	Emerging
Hybrid Model	High	High	Medium	Very High	Highly Suitable

Table 1 presents a comparative evaluation of major blockchain scaling solutions in the context of mass market Gamichain applications by assessing their performance across key dimensions, including scalability, security, decentralization, and user experience. The table shows that Layer 1 blockchains provide strong security and decentralization but suffer from limited scalability and suboptimal user experience due to high latency and transaction costs. Layer 2 solutions demonstrate substantial improvements in scalability and usability, making them more suitable for high volume gamified transactions, although they introduce moderate trade offs in decentralization [36]. Sharding approaches offer emerging scalability benefits by parallelizing transaction processing, yet their complexity and maturity level limit immediate adoption for real time Gamichain systems. Hybrid models achieve the most balanced outcome by combining high scalability and strong security with ac-

ceptable decentralization, thereby offering superior user experience and the highest suitability for mass market Gamichain deployment [37].

The comparative analysis further demonstrates that the adoption of Layer 2 scaling solutions leads to substantial improvements in transaction throughput and cost efficiency for Gamichain applications [38–40]. Platforms that implement rollups or sidechains are more capable of accommodating large user populations and high transaction frequencies while maintaining acceptable response times and lower operational costs. These improvements enhance system responsiveness and enable more fluid gamified interactions, which are essential for sustaining user engagement in mass market environments [41]. However, the analysis also reveals that such performance gains are frequently accompanied by trade offs related to decentralization and governance structures. Some Layer 2 implementations depend on a limited set of operators, validators, or sequencers, thereby introducing partial centralization and altering trust assumptions. This observation highlights that scalability enhancements often reconfigure, rather than fully resolve, the fundamental tensions articulated by the blockchain scalability trilemma, requiring careful architectural and governance considerations to balance performance with long term system integrity [42].

In addition, the findings reveal that hybrid on chain and off chain architectures provide a more balanced and practical approach for the development of mass market Gamichain systems. By separating system functions, where gameplay logic, user interactions, and real time computations are processed off chain while asset ownership, reward settlement, and verification mechanisms are maintained on chain, these architectures effectively combine performance efficiency with blockchain based trust [43, 44]. This separation allows platforms to significantly reduce transaction costs and minimize latency without sacrificing transparency and security for critical digital assets. Moreover, hybrid configurations facilitate seamless user onboarding by abstracting blockchain complexity from end users, thereby lowering entry barriers and supporting sustained participation. As a result, hybrid architectures emerge as a scalable solution that aligns technical performance with user experience requirements, making them particularly suitable for large scale Gamichain ecosystems operating in competitive digital business environments [45–47].

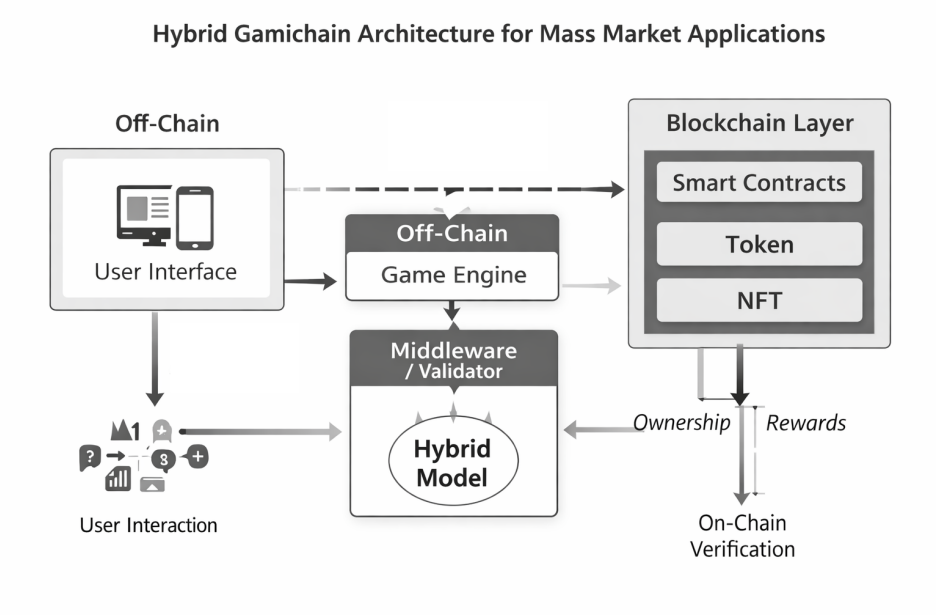

Figure 2. Hybrid Gamichain Architecture for Mass Market Applications

Figure 2 illustrates the Hybrid Gamichain Architecture designed to support mass market applications by separating user interaction processes from blockchain settlement layers. The diagram shows how user interactions and gameplay logic are handled primarily within the off chain environment through the user interface and game engine, enabling real time responsiveness and reduced transaction latency. These interactions are then coordinated by a middleware or validator layer, which acts as a bridge between off chain processes and the blockchain layer [48]. Critical components such as smart contracts, tokens, and non fungible tokens are

maintained on chain to ensure secure ownership, reward distribution, and verification. This architectural separation allows the system to achieve high scalability and improved user experience while preserving blockchain based trust and transparency, demonstrating how hybrid models effectively balance performance efficiency with security requirements in large scale Gamichain ecosystems [49, 50].

Table 2. Mapping of Scalability Solutions to Gamichain Requirements

Gamichain Requirement	Layer 1	Layer 2	Sharding	Hybrid Model
High transaction volume	Low	High	Medium	High
Low transaction cost	Low	High	Medium	High
Real time interaction	Low	High	Medium	High
Trust preservation	High	Medium	Medium	High
Mass market readiness	Limited	Good	Emerging	Excellent

Table 2 shows the mapping of various blockchain scalability solutions to the core operational requirements of Gamichain systems, providing a structured view of how each approach supports the mass market deployment. The table indicates that Layer 1 blockchains offer strong trust preservation but perform poorly in meeting requirements related to high transaction volume, low transaction cost, and real time interaction. Layer 2 solutions demonstrate improved capability in handling large scale transactions and reducing costs, making them more aligned with gamified environments that demand frequent user interactions. Sharding shows moderate effectiveness across most requirements but remains limited by implementation complexity and maturity. Hybrid models consistently achieve the strongest alignment with Gamichain requirements, particularly in balancing trust preservation, performance efficiency, and mass market readiness, highlighting their suitability as a scalable architectural strategy for large scale Gamichain applications [51].

From a security and governance perspective, the results emphasize that scalability oriented architectural choices introduce new risks that must be carefully managed. Reduced decentralization may increase vulnerability to operational failures or governance concentration, while off chain components require robust verification mechanisms to maintain trust. Therefore, effective Gamichain deployment depends on aligning scalability strategies with comprehensive security controls, transparent governance frameworks, and regulatory considerations [52].

Finally, the discussion highlights the broader digital business and sustainability implications of scalable Gamichain systems. By enabling inclusive participation, decentralized reward distribution, and innovative digital economic models, Gamichain infrastructures contribute to sustainable digital development. These outcomes align with Sustainable Development Goals, particularly SDG 9 through the promotion of resilient digital infrastructure and SDG 8 by supporting digital entrepreneurship and new forms of economic engagement. Consequently, addressing the scalability trilemma is essential not only for technical performance but also for the long term sustainability of digital business ecosystems.

5. MANAGERIAL IMPLICATIONS

5.1. Strategic Architecture Selection

Managers and platform owners should prioritize hybrid or Layer 2 based architectures when developing Gamichain applications for mass market deployment. Such architectures allow organizations to scale transaction capacity while maintaining essential trust mechanisms. Strategic architectural choices should be aligned with long term platform growth, anticipated user volume, and the intensity of gamified interactions to avoid costly redesigns at later stages.

5.2. User Experience as a Core Performance Metric

The results indicate that scalability decisions have a direct and measurable impact on user experience, particularly with respect to transaction latency, cost transparency, and the continuity of user interactions within Gamichain platforms. Delays in transaction confirmation, unpredictable fees, and fragmented interaction flows can disrupt the immediacy required by gamification mechanisms, thereby reducing user motivation and engagement. For this reason, managers should treat user experience indicators not merely as technical outcomes but as strategic performance metrics that influence retention, platform credibility, and long term adoption. By proactively aligning scalability strategies with user centered design principles, managers can ensure that tech-

nical constraints do not interrupt engagement cycles that are central to the effectiveness and sustainability of gamified digital ecosystems.

5.3. Cost Management and Sustainable Tokenomics

Scalable infrastructures enable significantly lower transaction costs, which are essential for sustaining token based reward systems in mass market Gamichain platforms. When transaction fees remain predictable and minimal, reward distribution mechanisms can operate efficiently without eroding user incentives or platform margins. Managers should therefore design tokenomics models that remain stable under conditions of high transaction volume and user growth, ensuring that rewards, issuance rates, and utility mechanisms are aligned with actual platform activity. Overreliance on high fees or speculative token appreciation may introduce volatility and undermine user trust, ultimately weakening long term platform credibility and economic sustainability.

5.4. Governance and Risk Management

As scalability enhancements may introduce partial centralization or increased reliance on off chain components, the establishment of clear and robust governance mechanisms becomes increasingly critical. Architectural choices that favor performance efficiency can alter trust assumptions and create new points of operational dependency, which must be managed proactively. Managers should therefore define transparent operational rules, clearly articulated roles for validators or operators, and formal decision making procedures to ensure accountability. In addition, continuous risk monitoring and audit processes are necessary to detect vulnerabilities, mitigate failures, and preserve system resilience as Gamichain platforms scale and evolve in mass market environments.

5.5. Regulatory and Compliance Readiness

Mass market Gamichain applications are likely to face increasing regulatory scrutiny, particularly in relation to digital assets, user transactions, and data governance. As platforms scale across jurisdictions, differences in regulatory frameworks can introduce legal uncertainty and operational complexity. Managers should therefore proactively incorporate compliance considerations into system architecture and governance design, such as auditability, reporting mechanisms, and configurable transaction controls. Early alignment with regulatory requirements enables smoother adaptation to policy changes, reduces compliance related risks, and supports sustainable cross border platform expansion without disrupting core Gamichain operations.

5.6. Alignment with Sustainable Digital Growth

Scalable Gamichain systems support inclusive digital participation by lowering technical and economic access barriers for a wider range of users. By enabling low cost transactions, seamless onboarding, and accessible reward mechanisms, these platforms create opportunities for diverse forms of digital economic activity, including play to earn models, digital entrepreneurship, and community driven ecosystems. Managers can leverage scalable Gamichain infrastructures to foster innovation driven growth while strengthening platform resilience. In doing so, they contribute to the development of sustainable digital business ecosystems that align with broader economic and social development objectives.

6. CONCLUSION

This study has explored the blockchain scalability trilemma as a central challenge in enabling mass market Gamichain applications within digital business ecosystems. By situating Gamichain at the intersection of blockchain technology and gamification, the paper demonstrates that scalability constraints are not merely technical inefficiencies but structural limitations that directly affect engagement mechanisms, transaction reliability, and platform sustainability. The findings emphasize that high latency, network congestion, and transaction costs associated with Layer 1 blockchains fundamentally undermine the real time interaction and reward immediacy required by gamified systems. As a result, addressing scalability becomes a strategic necessity for Gamichain platforms seeking long term adoption and competitive relevance in large scale digital environments.

The analysis further indicates that Layer 2 solutions and hybrid on chain and off chain architectures offer the most viable pathways to mitigating the scalability trilemma in Gamichain ecosystems. These approaches enable significant improvements in transaction throughput and cost efficiency while preserving essential security guarantees through on chain settlement and verification. Although trade offs related to decentralization and governance remain unavoidable, the study shows that such compromises can be managed through appropriate

architectural design and operational oversight. The evaluative framework proposed in this paper contributes to the literature by extending blockchain scalability discussions into the context of gamified digital business, providing a structured basis for aligning technical architecture with user experience and platform strategy.

Despite these contributions, this study is limited by its conceptual orientation and reliance on secondary case analysis. The absence of empirical validation restricts the ability to quantify performance gains or directly measure user engagement outcomes. Future research should incorporate quantitative performance benchmarks, experimental system evaluations, and user level behavioral data to validate and refine the proposed framework. In addition, further studies may investigate the role of artificial intelligence in adaptive scalability management, dynamic load balancing, and personalized reward optimization, thereby strengthening the capacity of Gamichain platforms to support sustainable, inclusive, and innovation driven digital economies.

7. DECLARATIONS

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7.2. Author Contributions

Conceptualization: AM; Methodology: MI; Software: HZ; Validation: Am and MI; Formal Analysis: HZ and AM; Investigation: MI; Resources: HZ; Data Curation: HM; Writing Original Draft Preparation AM and MI; Writing Review and Editing: HZ and AM; Visualization: MI; All authors, AM, MI and HZ have read and agreed to the published version of the manuscript.

7.3. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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The authors received no financial support for the research, authorship, and/or publication of this article.

7.5. Declaration of Conflicting Interest

The authors declare that they have no conflicts of interest, known competing financial interests, or personal relationships that could have influenced the work reported in this paper.

REFERENCES

[1] M. Al-Bassam, A. Sonnino, and V. Buterin, "Fraud and data availability proofs maximising light client security and scaling blockchains with dishonest majorities," *IEEE Security & Privacy*, vol. 20, no. 4, pp. 46–56, 2022.

[2] H. Wang, H. Li, A. Smahi, M. Xiao, and S.-Y. R. Li, "Gbt-chain: A system framework for solving the general trilemma in permissioned blockchains," *Distributed Ledger Technologies: Research and Practice*, vol. 3, no. 2, pp. 1–15, 2024.

[3] M. Principato, M. Babel, T. Guggenberger, J. Kropp, and S. Mertel, "Towards solving the blockchain trilemma: An exploration of zero-knowledge proofs," *ICIS 2023 Proceedings. https://aisel. aisnet. org/icis2023/blockchain/blockchain/5*, 2023.

[4] P. Tasca and C. J. Tessone, "A taxonomy of blockchain technologies principles of identification and classification," *Ledger*, vol. 7, pp. 1–39, 2022.

[5] S. Wahyuningsih, A. Sutarman, I. N. Hikam *et al.*, "Understanding purposeful leadership in entrepreneurial contexts: A bibliometric analysis," *Aptisi Transactions on Technopreneurship*, vol. 6, no. 2, pp. 213–230, 2024.

[6] H. Wang, D. He, and S. Zeadally, "Blockchain-based decentralized applications architecture security and scalability," *IEEE Communications Surveys & Tutorials*, vol. 25, no. 1, pp. 142–170, 2023.

[7] B. P. C. Teoh, "Navigating the blockchain trilemma: a supply chain dilemma," in *Advanced Maritime Technologies and Applications: Papers from the ICMAT 2021*. Springer, 2022, pp. 291–300.

[8] J. Bonneau and A. Miller, "Rollups and the future of blockchain scalability," *Communications of the ACM*, vol. 66, no. 5, pp. 50–58, 2023.
[9] M. Crosby, P. Pattanayak, and S. Verma, "Scalable blockchain systems for decentralized applications," *IEEE Computer*, vol. 56, no. 7, pp. 62–71, 2023.
[10] L. Xu, C. Wu, and Z. Chen, "Layer 2 blockchain solutions design principles and performance evaluation," *Future Generation Computer Systems*, vol. 139, pp. 48–61, 2023.
[11] T. A. D. Lael and D. A. Pramudito, "Use of data mining for the analysis of consumer purchase patterns with the fp-growth algorithm on motor spare part sales transactions data," *IAIC Transactions on Sustainable Digital Innovation*, vol. 4, no. 2, pp. 128–136, 2023.
[12] R. Belchior, A. Vasconcelos, and M. Correia, "A survey on blockchain interoperability past present and future trends," *IEEE Access*, vol. 11, pp. 32 801–32 825, 2023.
[13] J. Hamari, J. Koivisto, and H. Sarsa, "Gamification in digital platforms a systematic review," *Computers in Human Behavior*, vol. 139, 2023.
[14] S. Park and Y. Kim, "Gamification as a driver of user engagement in digital ecosystems," *Information & Management*, vol. 60, no. 2, 2023.
[15] Y. K. Dwivedi *et al.*, "Metaverse blockchain and digital business transformation," *International Journal of Information Management*, vol. 69, 2023.
[16] T. C. Husnadi, T. Marianti, and T. Ramadhan, "Determination of shareholders' welfare with financing quality as a moderating variable," *APTISI Transactions on Management*, vol. 6, no. 2, pp. 191–208, 2022.
[17] H. Treiblmaier and K. Mirkovski, "Blockchain and the future of digital business models," *Business & Information Systems Engineering*, vol. 65, no. 1, pp. 15–30, 2023.
[18] K. Zheng, Y. Zhu, and Z. Li, "Sharding-based blockchain scalability a comprehensive review," *IEEE Transactions on Network Science and Engineering*, vol. 10, no. 4, pp. 1891–1905, 2023.
[19] A. S. Anwar, U. Rahardja, and Q. Aini, "Blockchain-enabled trust systems in digital platforms," *Aptisi Transactions on Technopreneurship*, vol. 5, no. 2, pp. 120–132, 2023.
[20] J. Emblemsvåg and A. Osterlund, "How the energy trilemma can provide learning points between countries–the case for nuclear," *Internation Journal for Nuclear Power*, vol. 68, no. 2, pp. 31–42, 2023.
[21] PwC, "Digital assets and scalable blockchain infrastructure," 2022.
[22] A. S. Bist, V. Agarwal, Q. Aini, and N. Khofifah, "Managing digital transformation in marketing: Fusion of traditional marketing and digital marketing," *International Transactions on Artificial Intelligence*, vol. 1, no. 1, pp. 18–27, 2022.
[23] J. Werth, M. H. Berenjestanaki, H. R. Barzegar, N. El Ioini, and C. Pahl, "A review of blockchain platforms based on the scalability, security and decentralization trilemma." *ICEIS (1)*, pp. 146–155, 2023.
[24] A. K. Kar and S. Gupta, "Platform ecosystems and digital value creation," *Technological Forecasting and Social Change*, vol. 186, 2023.
[25] S. Akter and S. Reno, "Achieving scalable and decentralized blockchain systems: a filecoin-based solution to the blockchain trilemma," *Journal of King Saud University Computer and Information Sciences*, vol. 37, no. 6, p. 159, 2025.
[26] R. Supriati, S. A. Anjani, R. W. Anugrah, R. McCarthy *et al.*, "Enhancing network security with quantum cryptography: A study on future-proofing computer networks against quantum attacks," *Journal of Computer Science and Technology Application*, vol. 2, no. 1, pp. 24–35, 2025.
[27] M. Conti, E. S. Kumar, and C. Lal, "Security and privacy in scalable blockchain systems," *IEEE Security & Privacy*, vol. 21, no. 2, pp. 14–23, 2023.
[28] J. Sun, H. Yan, and K. Zhang, "Blockchain-based digital economy and sustainable development," *Sustainable Computing*, vol. 39, 2023.
[29] B. Teoh, "Solving the blockchain oracle problem to enable supply chain mass adoption," in *AIP Conference Proceedings*, vol. 2582, no. 1. AIP Publishing LLC, 2023, p. 020006.
[30] R. Beck and C. Muller-Bloch, "Blockchain as a foundational technology for digital ecosystems," *MIS Quarterly Executive*, vol. 22, no. 1, pp. 1–14, 2023.
[31] S. Wijaya, A. Husain, M. Laurens, and A. Birgithri, "ilearning education challenge: Combining the power of blockchain with gamification concepts," *CORISINTA*, vol. 1, no. 1, pp. 8–15, 2024.
[32] A. Abbasi and M. N. Humeidi, "Nexa: A blockchain architecture for secure and scalable ehr solutions—balancing blockchain trilemma, with a scalable public blockchain and threshold cryptography," 2026.

[33] Y. Wang and Z. Liu, "User experience challenges in blockchain-based applications," *Human–Computer Interaction*, vol. 39, no. 1, pp. 1–28, 2024.
[34] S. Saberi, M. Kouhizadeh, and J. Sarkis, "Blockchain technology and sustainable digital innovation," *International Journal of Production Research*, vol. 62, no. 2, pp. 455–470, 2024.
[35] N. Rožman, M. Corn, G. Škulj, T. Berlec, J. Diaci, and P. Podržaj, "Exploring the effects of blockchain scalability limitations on performance and user behavior in blockchain-based shared manufacturing systems: An experimental approach," *Applied Sciences*, vol. 13, no. 7, p. 4251, 2023.
[36] U. Nations, "Digital infrastructure and sustainable development goals," 2023.
[37] J. I. Senarathna, "Blockchain technology: A comprehensive review of architecture, consensus mechanisms, security, scalability solutions, and real-world applications for distributed systems," *Authorea Preprints*, 2025.
[38] M. Mittelviefhaus, "Optimal multi-energy hub design & operation: Addressing the trilemma of decarbonization, costs and security of supply," Ph.D. dissertation, ETH Zurich, 2022.
[39] A. Rizky, M. Z. Firli, N. A. Lindzani, S. Audiah, and L. Pasha, "Advanced cyber threat detection: Big data-driven ai solutions in complex networks," *Journal of Computer Science and Technology Application*, vol. 1, no. 2, pp. 136–143, 2024.
[40] S. Li and M. Zhao, "User experience design challenges in blockchain applications," *Journal of Systems and Software*, vol. 192, 2022.
[41] W. Xu and Y. Huang, "Blockchain-based gaming ecosystems and scalability challenges," *Entertainment Computing*, vol. 43, 2022.
[42] N. Kumar and R. Singh, "Performance evaluation of decentralized applications on blockchain," *Future Internet*, vol. 14, no. 10, 2022.
[43] J. Ferreira and P. Martins, "Hybrid blockchain architectures for scalable digital platforms," *IEEE Systems Journal*, vol. 17, no. 2, pp. 2841–2852, 2023.
[44] Y. Chen and L. Zhou, "Performance analysis of rollup-based blockchain scalability," *Concurrency and Computation Practice and Experience*, vol. 35, no. 18, 2023.
[45] M. R. Islam and A. Rahman, "Blockchain adoption challenges in large-scale digital systems," *Information Systems Frontiers*, vol. 25, no. 4, pp. 1091–1106, 2023.
[46] P. Wells, G. Probert, D. Marke, and C. Konopka, "Position paper on applications of smart contracts and blockchain technology," *Blockchain Frontier Technology*, vol. 3, no. 1, pp. 48–53, 2023.
[47] J. Huang and W. Li, "Blockchain infrastructure for metaverse and gamified platforms," *IEEE Network*, vol. 37, no. 4, pp. 64–71, 2023.
[48] A. Alshamrani and J. Park, "Trust management in scalable blockchain ecosystems," *Computers & Security*, vol. 124, 2023.
[49] T. Nguyen and M. Le, "Tokenomics design for sustainable blockchain platforms," *Technological Forecasting and Social Change*, vol. 189, 2023.
[50] Ministry of Communication and Information Technology of the Republic of Indonesia, "National digital transformation framework for sustainable digital economy," 2022, government policy document, go.id domain.
[51] D. Lee and M. Park, "Layer 2 ecosystems and decentralized application performance," *Future Generation Computer Systems*, vol. 150, pp. 312–324, 2024.
[52] N. Abdullah and F. Hassan, "Blockchain infrastructure and sustainable digital economies," *Sustainable Computing*, vol. 42, 2024.