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Blockchain Applications for Academic Credential Verification in Higher Education

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ABSTRACT

The rapid digitalization of higher education has brought about a greater demand for academic credential verification systems that are secure, dependable, and efficient. Conventional verification methods typically depend on centralized databases and manual procedures, which can lead to security risks, delays in administration, and chances for credential forgery. Blockchain technology has gained attention as a promising solution, as its decentralized architecture, cryptographic mechanisms, and tamper-resistant ledger enable more reliable and trustworthy credential management. **This study aims** to systematically review blockchain applications for academic credential verification in higher education and identify key technological benefits, implementation challenges, and emerging. A Systematic Literature Review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines to identify research directions. Relevant studies published between 2022 and 2026 were identified from Scopus, IEEE Xplore, ScienceDirect, and SpringerLink. From 125 initial records, 25 studies met the predefined inclusion and exclusion criteria and were included in the qualitative synthesis. **The reviewed studies** indicate that blockchain can enhance credential security, authenticity, transparency, and verification efficiency while reducing administrative burdens and credential fraud. **The reviewed studies** also highlight the use of permissioned and consortium blockchains, smart contracts, Decentralized Identity, Verifiable Credentials, and off-chain storage to support privacy and system performance. However, scalability, interoperability, regulatory compliance, privacy, implementation costs, and technical expertise remain significant barriers. **These findings** highlight blockchain's potential to support sustainable digital transformation and enhance the reliability, efficiency, and trustworthiness of academic credential verification in higher education.

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1. INTRODUCTION

The continued advancement of digital technologies has significantly transformed higher education, particularly in the management and verification of academic credentials, including diplomas, transcripts, and certificates [1, 2]. While digital platforms improve accessibility and operational efficiency, they also introduce

challenges related to security, authenticity, and credential fraud. Conventional verification processes are often inefficient, costly, and reliant on centralized databases, which can be susceptible to cyberattacks, data breaches, and unauthorized alterations [3]. In response, blockchain has emerged as a promising solution due to its decentralized and immutable characteristics, facilitating secure and transparent credential management while ensuring authenticity, data integrity, and traceability in higher education [4].

In recent years, universities, governments, and educational technology providers have explored blockchain-based credentialing systems to improve trust and efficiency in educational record management [5]. Several initiatives have demonstrated the potential of blockchain to issue tamper-resistant digital diplomas and enable instant verification of academic achievements. Despite these developments, existing studies remain fragmented across different educational contexts, blockchain platforms, and implementation approaches [6, 7]. Therefore, a comprehensive systematic review is needed to synthesize the existing literature, identify current research trends, evaluate implementation challenges, and propose future research directions for blockchain-based academic credential verification in higher education.

Beyond its technological benefits, blockchain-based academic credential verification can also contribute to the achievement of several Sustainable Development Goals (SDGs). In particular, it supports SDGs 4 (Quality Education) by improving the security and reliability of academic credentials, SDGs 9 (Industry, Innovation and Infrastructure) by encouraging the development of innovative digital verification systems, and SDGs 16 (Peace, Justice and Strong Institutions) by enhancing transparency, minimizing credential fraud, and fostering trust in educational institutions. Thus, the adoption of blockchain technology goes beyond technological innovation, contributing to the sustainable digital transformation of higher education [8].

The growing need for secure and dependable academic credential verification has exposed the limitations of conventional systems, which frequently depend on manual procedures, institutional intermediaries, and centralized databases, resulting in inefficiencies, verification delays, and potential security vulnerabilities [9, 10]. Although blockchain has been proposed as a promising solution, existing research remains fragmented across educational contexts and technological frameworks, highlighting the need for a systematic review to consolidate current evidence and evaluate blockchain-based credential verification in higher education [11, 12].

Several studies have examined blockchain applications in education, but most address broader educational contexts rather than specifically focusing on academic credential verification [13, 14]. Existing reviews also provide limited analysis of verification mechanisms, blockchain architectures, security and privacy, implementation challenges, and institutional implications. Moreover, the rapid development of blockchain technologies and digital credentialing platforms has introduced recent advancements that are not fully reflected in earlier reviews. Therefore, this study provides an updated and focused systematic synthesis by examining blockchain architectures, consensus mechanisms, decentralized identity frameworks, security and privacy considerations, implementation challenges, and future research directions for academic credential verification in higher education.

2. LITERATURE REVIEW

Blockchain is a decentralized distributed ledger technology that enables secure, transparent, and tamper-resistant management of records [15]. In contrast to conventional centralized databases, blockchain distributes data across multiple network nodes, reducing the risk of unauthorized alterations and single points of failure [16, 17]. Transactions recorded on the blockchain are validated through consensus mechanisms and cryptographically connected to preceding transactions, thereby maintaining data integrity, traceability, and trust. Blockchain is characterized by decentralization, transparency, immutability, security, and trustworthiness [18, 19]. These features have fueled the uptake of blockchain technology across a variety of industries, including supply chain management, education, healthcare, and finance.

2.1. Academic Credential Verification in Higher Education

Academic credentials, such as diplomas, transcripts, certificates, and professional qualifications, play a crucial role in validating an individual's educational achievements and qualifications [20]. Traditionally, academic credential verification has been performed manually by educational institutions or authorized third-party organizations. However, conventional verification processes face several challenges, including lengthy processing times, high administrative costs, document forgery, and difficulties in cross-border verification [21].

As higher education becomes increasingly globalized, the demand for secure, efficient, and reliable academic credential verification systems has increased substantially.

2.2. Blockchain Applications in Educational Credential Management

Blockchain has increasingly been recognized as an effective approach to the management and verification of academic credentials. Through blockchain-based systems, educational institutions can issue tamper-resistant digital credentials that can be securely and efficiently verified by employers, professional organizations, and government agencies [22, 23]. Several blockchain-based initiatives have been developed to support academic credential verification, enabling students to securely own, manage, and share their digital credentials while ensuring data integrity and authenticity [24, 25]. By reducing dependence on manual verification procedures, these systems can enhance operational efficiency while lowering the potential for credential fraud.

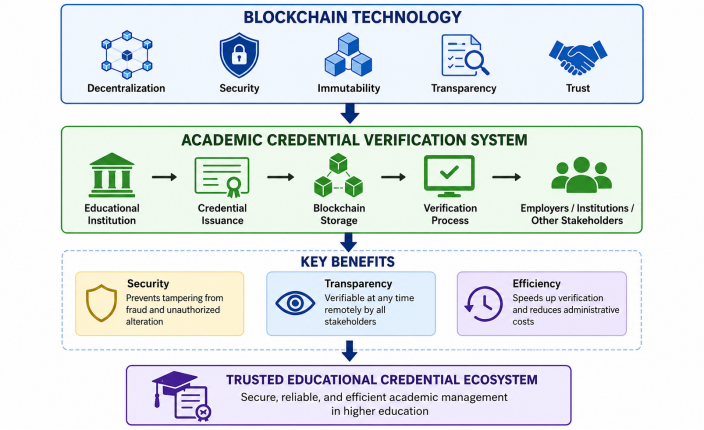


Figure 1. Conceptual Framework for Blockchain-Enabled Academic Credential Verification

Figure 1 illustrates the conceptual framework developed from the synthesis of the reviewed literature. The framework explains the relationship between blockchain technology, academic credential verification, implementation factors, and expected outcomes in higher education. It provides a structured basis for understanding how technological capabilities and contextual conditions jointly influence effective credential verification and digital transformation in higher education institutions.

2.3. Advantages of Blockchain-Based Credential Verification

Implementing blockchain technology for academic credential verification can offer significant advantages for higher education institutions and their stakeholders [26, 27]. Blockchain enhances security through cryptographic techniques and distributed ledger mechanisms that protect academic records from unauthorized modification, while its shared ledger improves transparency and trust among institutions, employers, and credential holders. It also reduces credential fraud by making forged or manipulated records more difficult to produce and accelerates verification by enabling efficient access to authenticated credentials, thereby reducing administrative delays and costs [28, 29]. Furthermore, blockchain supports student ownership and control of digital credentials, allowing them to securely share verified records with authorized parties when needed. These benefits demonstrate the potential of blockchain to transform conventional credential verification into a more secure, efficient, and trustworthy process [30, 31].

2.4. Challenges in Implementing Blockchain Technology in Higher Education

Despite its potential benefits, blockchain adoption in higher education faces several challenges. Scalability remains a major concern, as blockchain networks may experience performance limitations when handling large transaction volumes and user populations [32]. Interoperability is another challenge because different blockchain platforms may use diverse architectures and standards, limiting seamless data exchange. Regulatory and legal requirements, particularly regarding data protection and privacy, also require careful consideration. In addition, developing and maintaining blockchain infrastructure may require substantial financial investment and technical expertise, creating barriers for resource-constrained institutions [33, 34]. User awareness and acceptance may further hinder adoption, as students, administrators, and employers may have limited understanding of blockchain applications. Overcoming these challenges is crucial to ensuring the successful

implementation and long-term sustainability of blockchain-based systems for academic credential verification [35].

2.5. Existing Review Studies

A number of systematic literature reviews have examined the use of blockchain technology within the education sector. However, most existing studies examine blockchain from a broad educational perspective, including learning management systems, student records, digital certificates, and online learning environments [36, 37]. Only a limited number of review studies specifically focus on blockchain-based academic credential verification in higher education [38]. Furthermore, previous reviews rarely provide comprehensive discussions on blockchain architectures, consensus mechanisms, decentralized identity frameworks, security and privacy protection, and implementation challenges. Therefore, a comparison with previous review studies is necessary to demonstrate the contribution and novelty of the present study.

Table 1. Comparative Analysis of Prior Research on Blockchain-Based Verification of Academic Credentials

References	Year	Review Focus	Main Contribution	Research Gap
[39]	2025	Blockchain-based educational certification verification	Examined blockchain-based verification of IoT-based educational certifications and its alignment with SDGs.	Focused on IoT-based educational certifications rather than a comprehensive analysis of academic credential verification in higher education.
[40]	2025	Blockchain applications in education	Systematically reviewed functional, technical, and bibliometric trends of blockchain applications in education.	Covered blockchain applications in education broadly without specifically focusing on academic credential verification.
[41]	2025	Blockchain-based educational qualification management and verification	Developed a comprehensive blockchain-based system for managing and verifying educational qualifications to address credential forgery.	Focused on a specific blockchain-based qualification management system rather than synthesizing findings across existing studies.
[42]	2025	Blockchain-driven academic learning record management in higher education	Reviewed methodologies, applications, benefits, and challenges of blockchain for academic learning record management.	Broader focus on academic learning records and credit management rather than specifically synthesizing credential verification mechanisms.

Table 1 compares previous studies on blockchain applications in education and academic credential management with the present study. Previous studies have explored blockchain for educational certification, general educational applications, qualification verification, and academic learning record management. However, their research focuses vary and do not comprehensively address academic credential verification in higher education. Therefore, this study provides a focused systematic synthesis of blockchain-based academic credential verification by examining its applications, architectures, security and privacy aspects, implementation challenges, and future research directions.

3. RESEARCH METHODOLOGY

3.1. Research Design

This study investigates the use of blockchain technology for academic credential verification in higher education using a Systematic Literature Review (SLR) methodology. To guarantee an organized, transparent, and repeatable technique, the review procedure adheres to the Preferred Reporting Items for Systematic

Reviews and Meta-Analyses (PRISMA) criteria. Through this approach, relevant studies were systematically identified, screened, evaluated, and analyzed to synthesize existing knowledge and identify potential directions for future research.

3.2. Sources and Search Procedures

Relevant studies were identified through several reputable academic databases, namely Scopus, IEEE Xplore, ScienceDirect, and SpringerLink. These databases were selected because they provide extensive access to high-quality, peer-reviewed literature covering educational technology, blockchain, and information systems. The literature search employed a combination of keywords related to blockchain technology, academic credentials, verification systems, and higher education. The search strings were formulated to identify studies specifically addressing the use of blockchain technology for educational credential management and verification.

Table 2. Search Keywords and Databases

Database	**Search Keywords**
Scopus	"Blockchain" and "Academic Credential Verification"
IEEE Xplore	"Blockchain" and "Higher Education" AND "Credentials"
ScienceDirect	"Blockchain Technology" and "Digital Credentials"
SpringerLink	"Blockchain" and "Educational Credential Verification"

Table 2 presents the databases and search keywords used to identify relevant studies for this systematic literature review. Four reputable academic databases, namely Scopus, IEEE Xplore, ScienceDirect, and SpringerLink, were selected as the primary sources for retrieving relevant studies due to their comprehensive coverage of peer-reviewed literature in blockchain technology, educational technology, and information systems. The search keywords were carefully formulated using combinations of terms associated with blockchain, academic credentials, credential verification, and higher education. This search strategy was designed to ensure comprehensive coverage of studies relevant to blockchain-based academic credential verification systems.

3.3. Study Inclusion and Exclusion Criteria

To ensure the relevance and quality of the studies included in the review, predefined inclusion and exclusion criteria were established before the screening process. These criteria served as the basis for determining which studies met the requirements for inclusion in the final review.

Table 3. Inclusion and Exclusion Criteria

Inclusion Criteria	**Exclusion Criteria**
Studies published during the period from 2022 to 2026	Studies published prior to 2022
Studies written and published in English	Publications written in languages other than English
Peer-reviewed articles published in academic journals or conference proceedings	Editorials, book chapters, and opinion papers
Discusses blockchain applications in education	Unrelated to education or credential verification
Focuses on academic credential management or verification	Studies with insufficient information or inaccessible full text

As presented in Table 3, the inclusion and exclusion criteria were established and applied throughout the article screening process. The inclusion criteria were established to ensure that the analysis focused exclusively on recent, relevant, and high-quality studies. Accordingly, the review comprised English-language, peer-reviewed journal and conference publications that particularly looked at blockchain applications in the

maintenance and verification of educational credentials and were published between 2022 and 2026. In contrast, studies published before 2022, non-English publications, editorials, opinion papers, and articles unrelated to the research topic were excluded. These criteria helped ensure the relevance and reliability of the literature included in the review.

3.4. Study Selection Process

The literature search was conducted using four major academic databases: Scopus, IEEE Xplore, ScienceDirect, and SpringerLink. These databases were selected to ensure access to reliable, peer-reviewed literature relevant to educational technology, blockchain, and information systems. A structured keyword strategy was applied to locate relevant publications. The keywords covered several concepts, including blockchain technology, academic credentials, credential verification, and higher education. Search strings combining these terms were designed to retrieve studies that investigate the implementation of blockchain-based solutions for the management and verification of academic credentials 2.

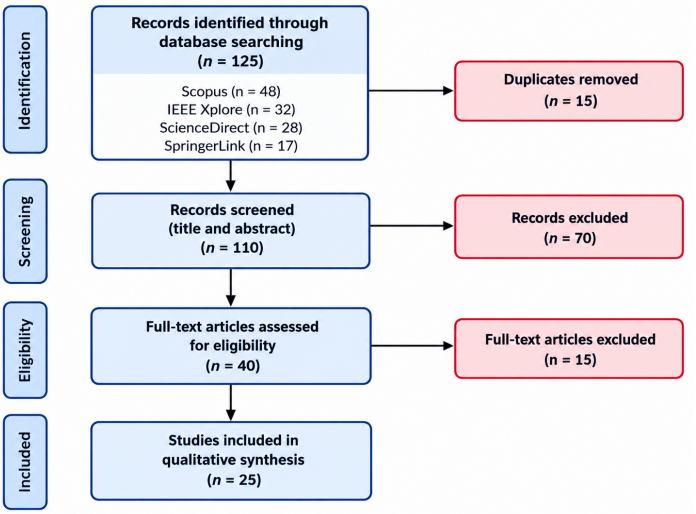


Figure 2. PRISMA-Based Flow Diagram for Study Selection

Figure 2 illustrates the PRISMA-based study selection process adopted in this review. The process comprises four sequential stages: identification, screening, eligibility assessment, and inclusion. Of the 125 records initially identified, duplicate and irrelevant studies were systematically removed according to the predefined inclusion and exclusion criteria, leaving 25 studies eligible for qualitative synthesis. This structured selection process enhances the transparency, reproducibility, and overall reliability of the literature review.

3.5. Data Extraction and Analysis

Figure 2 depicts the PRISMA-based procedure employed to identify and select studies for this review. The selection process was carried out through four main stages, namely identification, screening, eligibility evaluation, and inclusion. From the 125 records retrieved during the initial search, duplicate and unrelated studies were excluded in accordance with the established inclusion and exclusion criteria. Following the screening and eligibility assessment, 25 studies were retained for qualitative synthesis. This systematic approach supports a transparent, reproducible, and reliable review process.

4. RESULTS AND DISCUSSION

4.1. Study Selection Results

The literature search was conducted across four academic databases, namely Scopus, IEEE Xplore, ScienceDirect, and SpringerLink. After applying the predefined search keywords, a total of relevant studies were identified. Duplicate records were removed, and the remaining articles were screened based on their titles, abstracts, and full-text assessments according to the established inclusion and exclusion criteria. The final set of selected studies was included for qualitative analysis. The study selection process followed the

PRISMA framework to ensure transparency and consistency throughout the review process. The final collection of articles provided comprehensive insights into blockchain applications for academic credential verification in higher education.

4.2. Applications of Blockchain for Academic Credential Verification

The reviewed studies identify several key applications of blockchain technology in academic credential verification. Blockchain enables the issuance of tamper-proof digital diplomas and certificates, decentralized credential management, and efficient verification of academic records. These applications reduce reliance on centralized databases and administrative processes while strengthening trust and enabling students to securely control and share their credentials.

Table 4. Summary of Reviewed Studies

References	Year	Blockchain Platform	Dataset / Case Study	Methodology	Major Findings
[42]	2026	Ethereum	Higher education academic diplomas and credentials	Prototype Development and Practical Implementation	Enables secure and efficient diploma verification.
[43]	2025	Not specified	IoT-based educational certifications	System Development	Supports secure educational certification.
[44]	2025	Blockchain with zkEVM smart contracts	Academic records and credentials	System Design and Security Analysis	Enables privacy-preserving verification.
[45]	2026	Ethereum-compatible blockchain	Educational documents in higher education institutions in Kazakhstan	System Design and Practical Implementation	Provides traceable and tamper-resistant verification.
[46]	2025	Multi-blockchain architecture	GAVIN Project for academic information management	Prototype Development and Qualitative Evaluation	Improves credential verification but faces governance and GDPR challenges.
[47]	2025	Multiple blockchain approaches	Academic learning and credit records in higher education	Comprehensive Review	Improves record management but faces interoperability and scalability issues.
[48]	2025	Multiple blockchain platforms	Blockchain applications in education	Systematic Literature Review using PRISMA	Enhances security and data exchange but faces scalability and cost issues.
[49]	2024	BSV Blockchain	Academic certification	Case Study and System	Supports secure academic certification.
[50]	2026	Blockchain with smart contracts	Educational qualifications across multiple institutions and education levels	System Development and Performance Evaluation	Supports secure and efficient qualification verification.

Table 4 The reviewed studies collectively highlight the potential of blockchain technology for strengthening the management and verification of academic credentials and educational records. Overall, the findings indicate that blockchain can enhance the security, authenticity, transparency, and efficiency of credential verification. These improvements are supported by the integration of smart contracts, cryptographic mechanisms, decentralized data storage, and privacy-preserving approaches. However, challenges remain in scalability, interoperability, cost, privacy, and system complexity. Further research is therefore needed to address these

barriers and support large-scale adoption. Further research is therefore needed to address these barriers and support large-scale adoption, particularly by developing standardized frameworks, improving cross-platform compatibility, reducing implementation costs, and strengthening data protection mechanisms.

4.3. Benefits of Blockchain-Based Credential Verification

The reviewed literature identifies several key benefits of blockchain adoption in higher education, including enhanced security, transparency, and reduced credential fraud through immutable and verifiable records. Blockchain also improves administrative efficiency by streamlining verification processes and reducing operational costs. Additionally, it gives learners greater control over their academic credentials, enabling them to share verified qualifications with employers, institutions, and professional organizations more easily. This technology can also support lifelong learning by recording certificates, training achievements, and other educational experiences across different platforms. Overall, blockchain can strengthen the security, trustworthiness, accessibility, and efficiency of academic credential verification while promoting greater collaboration among educational stakeholders.

Table 5. Key Benefits, Challenges, and Future Research Trends

Aspect	Key Findings
Benefits	Improved security, transparency, and credential authenticity
Challenges	Scalability, interoperability, privacy, and implementation costs
Research Trends	DID integration, permissioned blockchain, smart contracts, AI integration

Table 5 summarizes the major benefits, implementation challenges, and emerging research trends identified from the reviewed studies. The synthesis indicates that while blockchain enhances credential security and transparency, future research should focus on improving interoperability, scalability, and privacy-preserving mechanisms. Further studies should also examine standardized frameworks, cross institutional integration, regulatory alignment, and practical deployment models to facilitate broader adoption across diverse higher education environments globally.

4.4. Technical Analysis of Blockchain Implementation

The reviewed studies indicate that private and consortium blockchains are more suitable for academic credential verification due to their enhanced privacy, access control, and institutional governance. Smart contracts facilitate automated credential issuance and verification, reducing manual procedures while preserving data integrity. Proof of Stake (PoS) and Practical Byzantine Fault Tolerance (PBFT) are commonly preferred over Proof of Work (PoW) because of their lower energy consumption, faster processing, and better scalability. Recent studies also incorporate Decentralized Identifiers (DIDs) and Verifiable Credentials (VCs) to strengthen identity management and enable secure credential sharing. Overall, effective blockchain-based credential verification requires appropriate architecture, consensus mechanisms, and identity management frameworks aligned with institutional needs.

4.5. Challenges and Limitations

Despite its advantages, several challenges hinder the widespread adoption of blockchain in higher education. Scalability and interoperability remain major concerns, particularly in processing large volumes of transactions across different platforms. Regulatory compliance and data privacy are also critical, while implementation costs and limited technical expertise may pose barriers for resource-constrained institutions. Therefore, successful adoption requires careful planning, stakeholder collaboration, and continuous technological development.

4.6. Security, Privacy, and Performance Considerations

The reviewed studies highlight security as a key advantage of blockchain-based academic credential verification. Through cryptographic hashing and immutable ledgers, blockchain prevents unauthorized modifications and reduces the risk of credential fraud, while permissioned blockchain networks combined with DID enable students to securely manage and share their academic credentials while protecting personal information.

To improve storage efficiency, several studies integrate blockchain with off-chain solutions such as the Inter-Planetary File System (IPFS), where only cryptographic references are stored on the blockchain. Regarding performance optimization, the reviewed literature suggests that permissioned blockchain platforms using PoS or PBFT provide better scalability, lower latency, and reduced energy consumption than PoW, making them more suitable for higher education credential verification systems. These approaches also support efficient data management, enhance system reliability, and facilitate secure interactions among students, educational institutions, accreditation bodies, and potential employers.

5. MANAGERIAL IMPLICATIONS

The results of this review highlight several practical considerations for stakeholders responsible for managing academic credentials. For higher education institutions, the adoption of blockchain-based verification systems could strengthen the protection, authenticity, and operational efficiency of academic records while providing a more reliable approach to credential management. While reducing administrative workloads, and collaborate with other institutions to establish interoperable digital credential ecosystems. Policymakers should develop standardized regulations and governance frameworks to support secure blockchain adoption, ensure data privacy compliance, and facilitate collaboration among educational institutions, accreditation agencies, and employers. Meanwhile, blockchain solution developers should prioritize scalability, interoperability, user-friendly interfaces, and integration with existing academic information systems, while adopting efficient consensus mechanisms and decentralized identity technologies to strengthen system performance, security, and privacy protection.

6. CONCLUSION

The systematic review demonstrates that blockchain technology has significant potential to enhance the verification of academic credentials in higher education. The reviewed studies show that blockchain supports secure, transparent, and efficient credential management through tamper-resistant digital credentials, decentralized management, smart contracts, and efficient verification mechanisms. The integration of DID, VCs, and off-chain storage further strengthens credential control, privacy, and system functionality. These findings indicate that blockchain technology can strengthen the integrity of academic records while making credential verification more efficient, reducing administrative workload, and helping prevent fraudulent credentials.

However, the adoption of blockchain-based credential verification remains subject to several challenges, particularly scalability, interoperability, regulatory compliance, privacy protection, implementation costs, and technical expertise. Effective implementation therefore requires appropriate blockchain architectures, efficient consensus mechanisms, interoperable standards, and collaboration among higher education institutions, accreditation agencies, employers, policymakers, and technology developers. Future research should focus on scalable and privacy-preserving architectures, decentralized identity integration, interoperability standards, and practical implementation across diverse higher education environments.

Overall, this review provides a focused synthesis of blockchain applications for academic credential verification and identifies key technological and organizational considerations for its adoption in higher education. Beyond technological benefits, blockchain-based credential verification can contribute to SDGs 4 (Quality Education) by supporting reliable and accessible academic credentials, SDGs 9 (Industry, Innovation and Infrastructure) through innovative digital. Thus, blockchain-based credential verification represents a promising component of sustainable digital transformation in higher education, provided that its implementation is supported by appropriate governance, interoperability, privacy, and technological development.

7. DECLARATIONS

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7.2. Author Contributions

Conceptualization: HH and AF; Methodology: SH; Software: KV; Validation: HH and AF; Formal Analysis: SH and KV; Investigation: SH; Resources: HH; Data Curation: AF; Writing Original Draft Preparation: SH; Writing Review and Editing: KV; Visualization: HH; All authors, HH, AF, SH, and KV 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] O. Strapchuk, M. Koniordos, S. Strapchuk, and V. Nitsenko, "Sustainable business models in the digital transformation of higher education: Evidence from ukraine," *Transformations and Sustainability*, vol. 1, no. 2, pp. 87–99, 2025.

[2] A. De Alwis, A. Shrestha, and T. Sarker, "Exploring governance for accreditation in the education sector using blockchain technology: a systematic literature review," *Discover Education*, vol. 4, no. 1, p. 57, 2025.

[3] U. Rahardja, Q. Aini, N. Lutfiani, F. P. Oganda, and A. Ramadan, "Blockchain application in education data security storage verification system," in *2022 1st International Conference on Technology Innovation and Its Applications (ICTIIA)*. IEEE, 2022, pp. 1–4.

[4] B. Kumar, H. Ali, I. Nassor, and J. Sandeep, "Blockchain technology in higher education: Opportunities, applications, and network security challenges," in *International Conference on Smart Cyber Physical Systems*. Springer, 2024, pp. 529–542.

[5] P. Rani, R. K. Sachan, and S. Kukreja, "A systematic study on blockchain technology in education: initiatives, products, applications, benefits, challenges and research direction: P. rani et al." *Computing*, vol. 106, no. 2, pp. 405–447, 2024.

[6] G. Fernández-Blanco, I. Froiz-Míguez, P. Fraga-Lamas, and T. M. Fernández-Caramés, "Design, implementation and practical energy-efficiency evaluation of a blockchain based academic credential verification system for low-power nodes," *Applied Sciences*, vol. 15, no. 12, p. 6596, 2025.

[7] N. S. A. A. Bakar, N. Yahya, N. B. Idris, Z. Zakaria, and M. A. M. Nordin, "Enhancing academic credential integrity through blockchain-based verification systems," in *New Trends in Intelligent Software Methodologies, Tools and Techniques: Proceedings of the 24th International Conference on New Trends in Intelligent Software Methodologies, Tools and Techniques (SoMeT_25)*. SAGE Publications 1 Oliver's Yard, 55 City Road, London, EC1Y 1SP, 2025, pp. 55–67.

[8] N. Ani, S. Millah, and P. A. Sunarya, "Optimizing online business security with blockchain technology," *Startupreneur Business Digital (SABDA Journal)*, vol. 3, no. 1, pp. 67–80, 2024.

[9] N. Nousias, G. Tsakalidis, G. Michoulis, S. Petridou, and K. Vergidis, "A process-aware approach for blockchain-based verification of academic qualifications," *Simulation Modelling Practice and Theory*, vol. 121, p. 102642, 2022.

[10] S. Mistretta, *Reimagining education: The role of E-learning, creativity, and technology in the post-pandemic era*. BoD–Books on Demand, 2024.

[11] H. A. Alsobhi, R. A. Alakhtar, A. Ubaid, O. K. Hussain, and F. K. Hussain, "Blockchain-based micro-credentialing system in higher education institutions: Systematic literature review," *Knowledge-Based Systems*, vol. 265, p. 110238, 2023.

[12] Y. Shino, H. Kenta, and I. K. Mertayasa, "Media promotional for art in tangerang city with audio visual adobe creative," *Aptisi Transactions on Technopreneurship (ATT)*, vol. 4, no. 2, pp. 192–204, 2022.
[13] H. Kusumah, M. Alghifari, E. S. N. Aisyah, W. N. Wahid, A. Rizky, and A. Adiwijaya, "Leveraging smartpls and ai for educational model optimization," in *2024 3rd International Conference on Creative Communication and Innovative Technology (ICCIT)*. IEEE, 2024, pp. 1–6.
[14] G. P. L. Permana and K. A. W. Martatika, "Potential and challenges of blockchain technology implementation in higher education: A systematic literature review," *Review of Management, Accounting, and Business Studies*, vol. 5, no. 1, pp. 57–67, 2024.
[15] A. Gunawan, M. M. Siahaan, R. Adyatama, T. Kerimbekov, and K. Vaher, "Distributed data integrity and decentralized storage leveraging ipfs in blockchain systems," *Blockchain Frontier Technology*, vol. 5, no. 2, pp. 158–171, 2026.
[16] D. Na, J. Kim, J. Jeon, and S. Park, "A federated blockchain architecture for file storage with improved latency and reliability in iot dapp services," *Sensors*, vol. 23, no. 20, p. 8569, 2023.
[17] A. A. Mawgoud, M. H. N. Taha, M. Loey, M. Hussain Malik, and N. E. Khalifa, "Enhancing data privacy and trust in e-learning: A blockchain-based access control protocol for cloud educational systems," *Concurrency and Computation: Practice and Experience*, vol. 37, no. 18-20, p. e70185, 2025.
[18] H. Guo and X. Yu, "A survey on blockchain technology and its security," *Blockchain: research and applications*, vol. 3, no. 2, p. 100067, 2022.
[19] A. Rizky, N. Lutfiani, W. S. Mariyati, A. A. Sari, and K. R. Febrianto, "Decentralization of information using blockchain technology on mobile apps e-journal," *Blockchain Frontier Technology*, vol. 1, no. 2, pp. 1–10, 2022.
[20] S. R. Gallagher, *The future of university credentials: New developments at the intersection of higher education and hiring*. Harvard Education Press, 2022.
[21] P. T. Mazumder, "Blockchain in trade finance: reducing fraud and improving efficiency through digital ledger technology," *Digital Finance*, vol. 7, no. 4, pp. 1043–1063, 2025.
[22] S. Babu, A. Anbumozhi, V. Kaliamoorthy *et al.*, "Blockchain for credentialing and academic record-keeping," in *Transforming Education With Data Science in the AI Era*. IGI Global Scientific Publishing, 2026, pp. 407–448.
[23] R. Ahli, M. F. Hilmi, and A. Abudaqa, "Moderating effect of perceived organizational support on the relationship between employee performance and its determinants: A case of entrepreneurial firms in uae," *Aptisi Transactions on Technopreneurship (ATT)*, vol. 6, no. 2, pp. 199–212, 2024.
[24] D. L. Silaghi and D. E. Popescu, "A systematic review of blockchain-based initiatives in comparison to best practices used in higher education institutions," *Computers*, vol. 14, no. 4, p. 141, 2025.
[25] V. Pradhan and P. Shah, "A comprehensive review and analysis of blockchain driven identity management solutions for enhancing security and transparency in education," *SN Computer Science*, vol. 6, no. 8, p. 924, 2025.
[26] A. Ayub Khan, A. A. Laghari, A. A. Shaikh, S. Bourouis, A. M. Mamlouk, and H. Alshazly, "Educational blockchain: A secure degree attestation and verification traceability architecture for higher education commission," *Applied Sciences*, vol. 11, no. 22, p. 10917, 2021.
[27] A. Maariz, M. A. Wiputra, and M. R. D. Armanto, "Blockchain technology: Revolutionizing data integrity and security in digital environments," *International Transactions on Education Technology (ITEE)*, vol. 2, no. 2, pp. 92–98, 2024.
[28] M. Corso, L. Ead, G. Brunton, S. Negrini, A. C. Tricco, and P. Côté, "Evaluating the accuracy of screening titles and abstracts for progressing to full text screening by one versus two independent reviewers: Part 1 of a meta-research study of rapid review methodological trade-offs," *Journal of Clinical Epidemiology*, p. 112248, 2026.
[29] S. M. Selvaraj, G. A. S. Thomas, S. Muthukaruppasamy, A. J. Anand, and S. Krishnan, "Blockchain in education: Revolutionizing credential verification and academic records," in *Smart Technologies for Sustainable Development Goals*. CRC Press, pp. 255–273.
[30] S. Jadon, H. M. Kumar, B. V. Kumar, S. A. Saher, S. Chandana, and P. B. Honnavalli, "A comprehensive survey on record management system using blockchain," *Cluster Computing*, vol. 29, no. 2, p. 98, 2026.
[31] F. E. Putra, M. Khasanah, and M. R. Anwar, "Optimizing stock accuracy with ai and blockchain for better inventory management," *ADI Journal on Recent Innovation*, vol. 6, no. 2, pp. 190–200, 2025.
[32] A. Mohammad and S. Vargas, "Challenges of using blockchain in the education sector: A literature

review," *Applied Sciences*, vol. 12, no. 13, p. 6380, 2022.
[33] M. Thanasi-Boçe and J. Hoxha, "Blockchain for sustainable development: a systematic review," *Sustainability*, vol. 17, no. 11, p. 4848, 2025.
[34] M. M. Siahaan, A. Sijabat, H. Samosir, R. Purba, and R. F. Terizla, "Enhancing hots and entrepreneurial competencies through avnet academic applications in english learning," *Aptisi Transactions on Technopreneurship (ATT)*, vol. 7, no. 1, pp. 206–216, 2025.
[35] M. Akhyar, T. M. F. Yoga, and E. Sukmawati, "Blockchain-based ubiquitous learning method towards higher education security," *Blockchain Frontier Technology*, vol. 1, no. 2, pp. 44–54, 2022.
[36] M. Zhao, W. Liu, A. N. M. Saif, B. Wang, R. A. Rupa, K. A. Islam, S. M. Rahman, N. Hafiz, R. Mostafa, and M. A. Rahman, "Blockchain in online learning: A systematic review and bibliographic visualization," *Sustainability*, vol. 15, no. 2, p. 1470, 2023.
[37] OECD, *Higher Education in Portugal*. Paris: OECD Publishing, 2024. [Online]. Available: https://www.oecd.org/en/publications/higher-education-in-portugal_49b1c7dc-en.html
[38] R. Suleiman, A. Maradapu Vera Venkata Sai, W. Yu, and C. Wang, "Blockchain for security in digital twins," *Future Internet*, vol. 17, no. 9, p. 385, 2025.
[39] M. Otroshcenko, O. Kramarenko, S. Hudkov, O. Maletova, and M. Utkina, "Digital transformation in academic libraries: implementing integrated research information systems for enhanced scholarly communication and institutional knowledge management," *Digital Library Perspectives*, vol. 42, no. 2, pp. 396–412, 2026.
[40] S. V. Seshanna, G. Gopalakrishnan, N. Anute, K. D. Reddy, M. Sharma, P. Selvakumar, and T. Manjunath, "Digital transformation and cybersecurity," in *User-centric cybersecurity implications for sustainable digital transformation*. IGI Global Scientific Publishing, 2026, pp. 1–30.
[41] C. Daah, "Blockchain-based zero trust threat detection framework for the finance industry network," Ph.D. dissertation, 2026.
[42] A. Rustemi and F. Dalipi, "From concept to practice: a blockchain-based solution for secure and efficient academic credentials in higher education," *IET Blockchain*, vol. 6, no. 1, p. e70030, 2026.
[43] S. Jeevan and S. Doss, "Blockchain for verifying iot-based educational certifications aligned with sustainable development goals," in *International Conference on Mathematical Modeling and Computational Science*. Springer, 2025, pp. 175–191.
[44] J. A. Berrios Moya, J. Ayoade, and M. A. Uddin, "A zero-knowledge proof-enabled blockchain-based academic record verification system," *Sensors*, vol. 25, no. 11, p. 3450, 2025.
[45] O. Ussatova, V. Karyukin, Y. Begimbayeva, G. Mutanov, Y. Kistaubayev, and M. Turdaliyev, "Application of blockchain technologies and smart contracts for the storage and verification of academic transcripts in the higher education systems," *Information*, vol. 17, no. 5, p. 478, 2026.
[46] C. Delgado-von Eitzen, L. Anido-Rifón, M. J. Fernández-Iglesias, and M. Ruiz-Molina, "Qualitative analysis of a blockchain-based system adoption for academic credentials verification that complies with the gdpr: Gavin project," *Applied Sciences*, vol. 15, no. 22, p. 11958, 2025.
[47] S. Chaudhari and M. Shirole, "Blockchain-driven academic learning record management in higher education: A comprehensive review of methodologies, applications, benefits, and challenges," *SN Computer Science*, vol. 6, no. 5, p. 427, 2025.
[48] A. Choudhary, M. Chawla, and N. Tiwari, "Analyzing functional, technical and bibliometric trends of blockchain applications in education: A systematic review," *Multimedia Tools and Applications*, vol. 84, no. 8, pp. 4003–4048, 2025.
[49] M. Al Hemairy, M. Abu Talib, A. Khalil, A. Zulfiqar, and T. Mohamed, "Blockchain-based framework and platform for validation, authentication & equivalency of academic certification and institution's accreditation: Uae case study and system performance (2022)," *Education and Information Technologies*, vol. 29, no. 14, pp. 18 203–18 232, 2024.
[50] S. H. Said, R. S. Sinde, E. M. Kosia, and M. A. Dida, "A comprehensive blockchain-based system for educational qualifications management and verification to counter forgery," *IEEE Access*, vol. 13, pp. 31 562–31 589, 2025.