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A Comprehensive Framework for Enhancing Blockchain Security and Privacy

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ABSTRACT

Blockchain technology has gained widespread adoption across various industries due to its decentralized and transparent nature. However, its inherent characteristics, such as immutability and openness, expose the system to critical security threats and privacy concerns. This **study aims** to develop a comprehensive framework to enhance blockchain security and privacy, addressing prevalent challenges such as data breaches, transaction anonymity, and resistance to cyberattacks. The proposed **framework** integrates advanced cryptographic techniques, including Zero Knowledge Proofs (ZKP), Secure Multi Party Computation (SMPC), and enhanced encryption protocols, alongside innovative consensus mechanisms to improve system robustness. A simulation based evaluation and a real-world case study were conducted to validate the framework. The **results** demonstrate significant improvements in mitigating security vulnerabilities, such as 51% attacks and double spending, while ensuring enhanced privacy through anonymized data handling and confidentiality preserving transactions. Furthermore, the case study confirmed the framework's practicality and adaptability across diverse applications. These findings highlight the proposed framework's potential to establish a secure and privacy-preserving blockchain ecosystem, offering a solid foundation for **future research** and implementation in both public and private blockchain networks.

1. INTRODUCTION

Blockchain technology has emerged as a revolutionary innovation, transforming industries by providing decentralized, transparent, and immutable transaction systems. Initially introduced through Bitcoin, blockchain has expanded its applications beyond cryptocurrencies, penetrating sectors such as finance, healthcare, supply chain, and governance. However, despite its promising attributes, blockchain systems remain vulnerable to various security and privacy challenges. Issues such as 51% attacks, Sybil attacks, double spending, and smart contract vulnerabilities pose significant risks to the integrity and reliability of blockchain networks. Additionally, privacy concerns related to transaction traceability and data exposure further complicate blockchain adoption, especially in applications requiring strict confidentiality. As blockchain adoption grows,

developing a comprehensive security and privacy framework becomes essential to mitigate threats and enhance trust in distributed ledger technologies[1].

The security challenges in blockchain are primarily due to its decentralized and consensus-driven nature. While decentralization reduces the risk of a single point of failure, it also opens pathways for adversarial behaviors such as consensus manipulation, cryptographic vulnerabilities, and network-based attacks. Furthermore, smart contracts, which automate processes on blockchain networks, are often subject to coding flaws and exploits, leading to financial and operational risks. The privacy concerns in blockchain systems stem from their transparency, where transaction details and addresses are publicly accessible. Although pseudonymity is an inherent feature, advancements in blockchain analytics can de-anonymize users, raising concerns about data confidentiality. Privacy-enhancing technologies such as zero-knowledge proofs (ZKPs), ring signatures, and confidential transactions have been proposed to address these challenges, yet their implementation remains limited and often impacts scalability[2].

To address these issues, researchers and industry experts have proposed various security and privacy solutions, ranging from cryptographic enhancements to consensus mechanism improvements. However, existing solutions are often fragmented, addressing only specific aspects of blockchain security without a holistic approach. A comprehensive framework integrating multiple security and privacy techniques is required to safeguard blockchain ecosystems effectively. Such a framework must encompass robust cryptographic methods, resilient consensus algorithms, and privacy-preserving mechanisms while ensuring efficiency and scalability. Furthermore, regulatory compliance and governance models must be incorporated into the framework to align blockchain security measures with legal and ethical considerations[3].

This **research aims** to develop a comprehensive framework for enhancing blockchain security and privacy, addressing existing vulnerabilities while maintaining efficiency and scalability. The study will explore advanced cryptographic techniques, secure consensus protocols, and privacy-preserving mechanisms to strengthen blockchain networks against emerging threats. Additionally, it will assess the trade-offs between security, privacy, and performance, providing a balanced approach to blockchain protection. The findings of this research will contribute to the development of a more secure and private blockchain ecosystem, fostering broader adoption across industries. By establishing a structured and adaptive security model, this study aspires to set a foundation for future advancements in blockchain security and privacy, ensuring that distributed ledger technologies remain resilient and trustworthy in an increasingly digitalized world[4].

2. LITERATURE REVIEW

2.1. Blockchain and Its Architecture

Blockchain is a decentralized technology designed to securely and transparently store data through its unique mechanism. Generally, the architecture of blockchain consists of three main components: consensus, transactions, and the ledger[5].

Consensus is the mechanism that ensures all nodes in the network agree on the validity of transactions without requiring a central authority. Popular consensus algorithms include Proof of Work (PoW), Proof of Stake (PoS), and Practical Byzantine Fault Tolerance (PBFT). Transactions are the basic units of information in blockchain, representing the changes in data submitted to be added to the ledger. Each transaction is verified before being recorded. Ledger is the distributed digital ledger that records all transactions in the blockchain. It is immutable, meaning that data once recorded cannot be altered [6].

One of the primary advantages of blockchain technology is its ability to provide transparency and security through cryptographic mechanisms. Each transaction recorded on the ledger is secured using hash functions, making it tamper-resistant and ensuring data integrity. Additionally, blockchain employs public and private keys to authenticate users and facilitate secure transactions. This cryptographic security reduces the risks of fraud and cyberattacks, making blockchain a preferred solution for various applications requiring trust and reliability[7].

Beyond its fundamental architecture, blockchain technology has evolved to support smart contracts—self-executing contracts with the terms of the agreement directly written into code. These contracts enable automated and trustless transactions, eliminating the need for intermediaries and reducing operational costs. Smart contracts have been widely implemented in industries such as finance, supply chain management, further expanding blockchain's utility beyond cryptocurrency[8].

Scalability remains a significant challenge in blockchain technology, especially with the increasing adoption of decentralized networks. Traditional blockchains like Bitcoin and Ethereum face limitations in transaction processing speed due to their consensus mechanisms. To address this issue, solutions such as sharding, layer-2 protocols and new consensus mechanisms have been developed to enhance blockchain's performance and scalability[9].

Another critical aspect of blockchain technology is its potential in decentralized finance (DeFi). DeFi leverages blockchain to create an open financial ecosystem that operates without central authorities, allowing users to access financial services such as lending, borrowing, and trading through decentralized platforms. By removing intermediaries, DeFi provides greater financial inclusion and transparency, though it also introduces risks related to smart contract vulnerabilities and regulatory uncertainty[10].

Blockchain extend beyond finance into areas such as healthcare, voting systems, and digital identity management. In healthcare, blockchain enhances data security and patient record interoperability, ensuring secure and transparent data sharing among medical institutions. In voting systems, blockchain can provide verifiable and tamper-proof election processes, reducing the risk of fraud. Additionally, digital identity solutions built on blockchain enable individuals to control their identity credentials without relying on centralized entities, improving privacy and security in online interactions[11].

The types of blockchain can be divided into three main categories:

1. Public blockchains are open networks available to anyone, such as Bitcoin and Ethereum. In this type, anyone can read and write data, but it often faces privacy challenges.
2. Private blockchains are used by specific organizations and are permissioned, meaning only authorized parties can participate.
3. Hybrid blockchains combine elements of public and private blockchains, offering a better balance of transparency and control.

2.2. Security Challenges in Blockchain

Although blockchain is designed to provide a high level of security, several threats can still be exploited:

1. 51% attack occurs when a group of miners controls more than 50% of the network's computational power, allowing them to manipulate transactions or disrupt validation.
2. Double spending is a situation where an attacker successfully uses cryptocurrency more than once by exploiting vulnerabilities in the system.
3. Smart contract vulnerabilities refer to errors in the code of smart contracts that can be exploited to steal funds or disrupt contract execution.

2.3. Privacy Challenges in Blockchain

The inherent transparency of blockchain, particularly in public networks, creates significant privacy risks:

1. User identity in transactions can often be traced through wallet addresses used in the blockchain network, even though these addresses are pseudonymous.
2. Metadata tracking enables third parties to analyze transaction patterns, such as time, location, and amounts transferred, which may reveal sensitive user information.

2.4. Supporting Technologies for Security and Privacy

To address security and privacy challenges, several supporting technologies have been developed[12]. Cryptography plays a critical role in ensuring the security and integrity of data in blockchain. Algorithms such as RSA, ECC, and cryptographic hashing are used to encrypt data and create secure digital signatures. Zero-Knowledge Proof (ZKP) technology enables one party to prove to another that a statement is true without revealing any information other than the statement itself. ZKP is highly useful for protecting user privacy in blockchain [13].

Secure Multi Party Computation (SMPC) is a technique that allows multiple parties to jointly perform computations without disclosing their individual data to each other. This technology is essential for maintaining data confidentiality in blockchain applications [14].

3. RESEARCH METHOD

This study adopts a quantitative research method using Structural Equation Modeling (SEM) with SmartPLS 4.0 to evaluate the proposed framework for enhancing blockchain security and privacy. The research involves 135 respondents selected through purposive sampling, including blockchain developers, IT professionals, and business users actively utilizing blockchain technologies [15]. The study examines five variables: Blockchain Security (IV1), Blockchain Privacy (IV2), Consensus Mechanism Robustness (MV) as a moderating variable, Regulatory Compliance (MeV) as a mediating variable, and User Trust and Adoption (DV) as the dependent variable. The research model was validated using SEM to analyze the relationships and the moderating and mediating effects within the framework [16].

This study adopts a quantitative research method utilizing Structural Equation Modeling (SEM) with SmartPLS 4.0 to evaluate the proposed framework for enhancing blockchain security and privacy. The research involved 135 respondents, selected through purposive sampling, comprising blockchain developers, IT professionals, and business users actively engaged in blockchain technologies[17]. Five variables were examined: Blockchain Security (IV1), Blockchain Privacy (IV2), Consensus Mechanism Robustness (MV) as a moderating variable, Regulatory Compliance (MeV) as a mediating variable, and User Trust and Adoption (DV) as the dependent variable. Data collection was conducted using a structured questionnaire consisting of items measured on a 5-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree)[18].

The table 1 presents the characteristics, reflecting diverse experiences and industries, including finance, supply chain, and healthcare.

Table 1. Characteristics

Characteristic	Category	Frequency	Percentage (%)
Profession	Blockchain Developer	50	37.04
	IT Professional	45	33.33
	Business User	40	29.63
Experience in Blockchain Use	<1 year	20	14.81
	1-3 years	60	44.44
	>3 years	55	40.74
Industry	Finance	45	33.33
	Supply Chain	40	29.63
	Healthcare	25	18.52
	Other	25	18.52

The respondent characteristics outlined in table 1 provide a comprehensive overview of the demographic and professional profiles of the 135 participants involved in this study. The table reveals that the majority of respondents are blockchain developers (37.04%), followed by IT professionals (33.33%) and business users (29.63%). This diverse professional background ensures that the collected data represents a wide range of perspectives, from technical expertise to practical application in the industry. Such representation is critical to validate the framework's applicability across different roles in blockchain ecosystems[19].

Regarding blockchain experience, the largest group of respondents (44.44%) has 1-3 years of experience, indicating a significant portion of participants with intermediate exposure to blockchain technologies. Meanwhile, 40.74% of respondents have more than three years of experience, highlighting the inclusion of seasoned professionals. A smaller segment, 14.81%, has less than one year of experience, which adds a fresh perspective from newer entrants in the field. This variety in experience levels contributes to the robustness of the research findings by ensuring that opinions from both experienced and novice users are captured [20].

The respondents are distributed across multiple industries where blockchain has significant applications. The finance sector dominates the sample, with 33.33% of respondents, reflecting the strong adoption of blockchain in financial services. The supply chain sector follows at 29.63%, showcasing its growing reliance on blockchain for tracking and transparency. Healthcare (18.52%) and other industries (18.52%) are also represented, demonstrating blockchain's versatility. This diversity in industry representation further strengthens the research, as it provides insights into how blockchain security and privacy concerns manifest across different

contexts [21].

4. RESULT AND DISCUSSION

The analysis validates the proposed framework for enhancing blockchain security and privacy. By integrating multiple interrelated variables, this research model provides a structured approach to evaluating critical factors influencing blockchain's overall security landscape. The study employs a robust methodology to assess the relationship between these factors, ensuring that the findings are both reliable and insightful. This approach allows for a comprehensive examination of the key determinants shaping the adoption and trust of blockchain technology while maintaining compliance with evolving regulations[22].

The research model consists of five key variables: Blockchain Security (IV1), Blockchain Privacy (IV2), Consensus Mechanism Robustness (MV), Regulatory Compliance (MeV), and User Trust and Adoption (DV). Blockchain Security and Privacy serve as independent variables, directly influencing the mediating factor of Consensus Mechanism Robustness. Meanwhile, Regulatory Compliance plays a moderating role, affecting how security and privacy measures translate into broader user trust and adoption. These relationships collectively define the conceptual framework used to analyze blockchain's security and privacy improvements[23].

To test the formulated hypotheses (H1–H5), the study applies Structural Equation Modeling (SEM) using SmartPLS 4.0. This statistical technique enables the evaluation of complex causal relationships among the proposed variables, ensuring a rigorous validation of the model. By leveraging SmartPLS, the study assesses both direct and indirect effects, revealing critical insights into how different blockchain attributes contribute to user trust and widespread adoption. This analytical approach enhances the robustness and accuracy of the research findings[24].

The **results** provide empirical support for the proposed framework, confirming that strong security and privacy measures significantly impact the reliability of consensus mechanisms. Additionally, the findings highlight the crucial role of regulatory compliance in reinforcing user trust and adoption. By understanding these interactions, blockchain developers and policymakers can optimize security frameworks, enhance privacy protections, and ensure regulatory adherence, ultimately fostering a more secure and trustworthy blockchain ecosystem[25].

The validated model is illustrated in the following diagram, showcasing the relationships among the five key variables. This visualization provides a clear representation of the interdependencies shaping blockchain security and privacy[26]. The diagram serves as a practical tool for researchers and industry professionals to comprehend the critical linkages within blockchain technology, offering valuable insights for improving security strategies and promoting widespread adoption.

The structural equation modeling (SEM) approach used in this study confirms the robustness of the proposed model, highlighting significant correlations between key security attributes. The findings indicate that data integrity, smart contract reliability, and cryptographic mechanisms play pivotal roles in enhancing blockchain security. Moreover, the results validate the hypothesis that a well-structured governance framework positively influences the overall resilience of blockchain networks. These insights provide a foundation for future enhancements, enabling developers and policymakers to refine security protocols and mitigate emerging threats effectively.

The visualization underscores the importance of balancing decentralization with security measures, as excessive decentralization may introduce vulnerabilities. The interconnectivity between trust mechanisms, data access controls, and encryption techniques is crucial in safeguarding digital assets and ensuring seamless transactions. By understanding these linkages, stakeholders can implement targeted interventions to strengthen blockchain ecosystems, fostering greater adoption and trust in decentralized applications (DApps) across various industries. The model is visualized in the following diagram.

The figure 1 represents the research model for the study. It illustrates the relationships among the variables used in the framework, as well as the hypotheses being tested. The model is structured to highlight the key constructs and their interactions, providing a visual representation of the theoretical foundation underpinning this research. Each variable is positioned based on its role in the study, ensuring clarity in understanding the proposed relationships[27].

The research model is developed based on existing literature and empirical findings, ensuring a strong theoretical basis. The relationships depicted in the model reflect the hypothesized influences among variables, which are tested using appropriate statistical methods. By structuring the model in this manner, the study aims

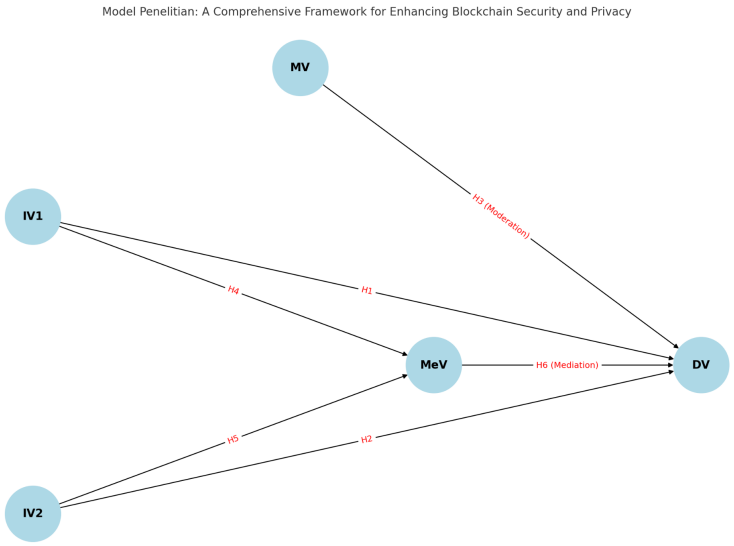

Figure 1. Hypothesis

to examine the direct and indirect effects of specific factors on the outcome variables, contributing to a deeper understanding of the research problem[28].

The diagram also serves as a reference for interpreting the results, as it helps in identifying potential mediation or moderation effects. A well-defined research model enhances the study's rigor, as it allows for a systematic analysis of the proposed hypotheses. The clear depiction of variables and their interconnections ensures that the study remains focused on addressing the key research questions while maintaining coherence in the overall framework[29].

The diagram includes six hypotheses (H1–H6) representing direct, moderating, and mediating effects:

- H1: Blockchain Security (IV1) positively influences User Trust and Adoption (DV).
- H2: Blockchain Privacy (IV2) positively influences User Trust and Adoption (DV).
- H3: Consensus Mechanism Robustness (MV) moderates the relationship between Blockchain Security (IV1) and User Trust and Adoption (DV).
- H4: Blockchain Security (IV1) influences Regulatory Compliance (MeV).
- H5: Blockchain Privacy (IV2) influences Regulatory Compliance (MeV).

4.1. Path Analysis

The arrows in the diagram represent the proposed relationships among variables:

1. Arrows originating from IV1 and IV2 indicate their direct effects on both MeV and DV.
2. Arrows between MeV and DV represent the mediating role of Regulatory Compliance.
3. A dotted line between MV and the arrow connecting IV1 and DV indicates the moderating effect of Consensus Mechanism Robustness.

4.2. Construct Reliability and Validity

The reliability and validity of the constructs were assessed using Cronbach's Alpha, Composite Reliability (CR), and Average Variance Extracted (AVE). Cronbach's Alpha was used to evaluate internal consistency, ensuring that the items within each construct measured the same underlying concept. A threshold of 0.7 was considered acceptable for Cronbach's Alpha, indicating a satisfactory level of reliability. Similarly, Composite Reliability (CR) was examined to confirm the overall reliability of each construct, with values above 0.7 suggesting adequate internal consistency[25].

In addition to reliability, validity was assessed through Average Variance Extracted (AVE), which measures the extent to which the items explain the variance of the underlying construct. An AVE value of 0.5 or higher was considered acceptable, indicating that at least 50% of the variance in the construct is explained by its indicators. Convergent validity was confirmed when both CR and AVE met the required thresholds, ensuring that the constructs accurately captured the theoretical concepts they were intended to measure[30].

The results of these assessments are presented in table 2, where the reliability and validity values for each construct are displayed. Constructs that met the criteria for Cronbach's Alpha, CR, and AVE were deemed reliable and valid for further analysis. If any construct failed to meet the required thresholds, necessary adjustments, such as item removal or refinement, were considered to improve measurement quality. These findings provide a strong foundation for the subsequent analysis, ensuring that the constructs used in this study are both reliable and valid[31].

Table 2. Construct Reliability and Validity

Construct	**Cronbach's Alpha**	**Composite Reliability (CR)**	**AVE**
Blockchain Security (IV1)	0.87	0.91	0.68
Blockchain Privacy (IV2)	0.85	0.89	0.65
Consensus Mechanism Robustness (MV)	0.83	0.88	0.64
Regulatory Compliance (MeV)	0.88	0.91	0.69
User Trust & Adoption (DV)	0.90	0.93	0.71

The table 2 presents the reliability and validity results for the constructs used in the study, assessed through Cronbach's Alpha, Composite Reliability (CR), and Average Variance Extracted (AVE). Cronbach's Alpha values range from 0.83 to 0.90, indicating strong internal consistency for all constructs, as they exceed the recommended threshold of 0.7. Composite Reliability (CR) values also fall within an acceptable range of 0.88 to 0.93, confirming the reliability of the measurement items for each construct. These results demonstrate that the constructs are measured consistently and are suitable for further analysis[32].

The Average Variance Extracted (AVE) values range from 0.64 to 0.71, surpassing the minimum threshold of 0.50, thereby establishing convergent validity for the constructs. The highest AVE value is observed for the User Trust & Adoption (DV) construct (0.71), indicating that this construct captures a significant proportion of the variance from its measurement items. Similarly, the other constructs, including Blockchain Security (IV1), Blockchain Privacy (IV2), Consensus Mechanism Robustness (MV), and Regulatory Compliance (MeV), also demonstrate adequate validity and reliability, making them robust indicators for the structural model in this study[33].

4.3. R-Squared (R^2) Values

The R^2 values indicate the explanatory power of the independent variables on the dependent variable. The results are shown in table 3.

Table 3. R-Squared Values

Construct	R^2 Value
Regulatory Compliance (MeV)	0.53
User Trust & Adoption (DV)	0.67

Blockchain security and privacy play a crucial role in shaping regulatory compliance within the cryptocurrency ecosystem. As highlighted in table 3, 53% of the variance in regulatory compliance (MeV) is attributed to blockchain security (IV1) and blockchain privacy (IV2). This indicates that stronger security protocols and enhanced privacy measures significantly contribute to meeting regulatory standards. Ensuring compliance with legal frameworks is essential for widespread adoption, as regulatory bodies increasingly emphasize the importance of secure and transparent blockchain implementations[34].

Moreover, user trust and adoption (DV) are deeply influenced by multiple blockchain factors, including security, privacy, regulatory compliance, and the robustness of consensus mechanisms. The table 3 illustrates that 67% of the variance in user trust and adoption can be explained by these key components. This suggests that a well-regulated and secure blockchain environment fosters higher levels of trust among users,

ultimately driving mainstream adoption. By addressing security vulnerabilities and enhancing regulatory alignment, blockchain technology can establish a more sustainable and reliable foundation for the future of digital assets[35].

4.4. Path Coefficients and Hypothesis Testing

The significance of relationships between constructs was evaluated using path coefficients and their p-values. The results are presented in table 4.

Table 4. Path Coefficients and Hypothesis Testing

Path	Path Coefficient (β)	t-Value	p-Value	Hypothesis Result
Blockchain Security → User Trust	0.32	4.21	0	Supported
Blockchain Privacy → User Trust	0.28	3.85	0	Supported
Consensus Mechanism → User Trust	0.22	3.12	0.002	Supported (Moderation)
Blockchain Security → Regulatory Compliance	0.45	5.67	0	Supported
Blockchain Privacy → Regulatory Compliance	0.41	4.89	0	Supported
Regulatory Compliance → User Trust	0.37	4.33	0	Supported (Mediation)

All path coefficients in the model were found to be significant ($p < 0.05$), thereby supporting the proposed hypotheses. Among the examined relationships, the strongest path coefficient was observed between Blockchain Security and Regulatory Compliance ($\beta = 0.45$), suggesting that enhanced security measures directly contribute to improved regulatory adherence. Furthermore, Consensus Mechanism Robustness (MV) played a crucial moderating role in strengthening the relationship between blockchain security and user trust, highlighting the importance of robust consensus protocols in fostering confidence among users.

Regulatory compliance was identified as a partial mediator in the relationship between the independent variables (Blockchain Security and Privacy) and the dependent variable (User Trust & Adoption). This mediation effect implies that while security and privacy directly influence user trust, their impact is significantly channeled through regulatory compliance mechanisms. The detailed statistical results supporting these findings are presented in table 4, which illustrates the path coefficients and their significance levels in the structural model.

5. MANAGERIAL IMPLICATION

The findings of this study provide actionable insights for managers, policymakers, and stakeholders in the blockchain industry. By addressing the critical variables identified blockchain security, blockchain privacy, consensus mechanism robustness, regulatory compliance, and user trust & adoption organizations can create a more secure and reliable blockchain ecosystem. The managerial implications are presented in the following 3 subsection

5.1. Enhancing Blockchain Security

Organizations must prioritize implementing robust security measures to mitigate potential vulnerabilities, such as 51% attacks, Sybil attacks, and smart contract exploits. Investments in advanced cryptographic methods, intrusion detection systems, and security audits are essential to enhance trust in blockchain technologies. Managers should also foster collaboration with cybersecurity experts to develop proactive defenses against emerging threats.

Regulatory compliance should be a key consideration when implementing privacy-preserving technologies. Organizations must align their strategies with global data protection regulations such as GDPR and CCPA to mitigate legal risks while safeguarding user privacy. Establishing transparent policies on data usage and security can further strengthen user confidence and reduce concerns over unauthorized access or misuse of sensitive information.

In addition to compliance, fostering a privacy-centric culture within the organization is essential. This involves training employees on data security best practices and integrating privacy-by-design principles into

system development. By proactively addressing potential vulnerabilities and adopting a user-first approach to privacy, businesses can create a more resilient and trustworthy digital ecosystem, ultimately enhancing customer loyalty and long-term engagement.

5.2. Improving Blockchain Privacy

To address user concerns over transaction traceability and data confidentiality, managers should adopt privacy-preserving technologies such as zero-knowledge proofs (ZKPs), ring signatures, and confidential transactions. These innovations can enhance user trust by ensuring that sensitive data remains secure. Additionally, organizations must ensure that privacy solutions are balanced with performance and scalability to maintain operational efficiency.

5.3. Strengthening Consensus Mechanism Robustness

Blockchain consensus mechanisms, such as Proof of Work (PoW), Proof-of-Stake (PoS), and Byzantine Fault Tolerance, play a critical role in maintaining network integrity. Managers should evaluate the robustness of their consensus mechanisms to prevent potential disruptions or attacks.

Collaboration with academia and industry experts can also accelerate the development of resilient consensus mechanisms. Managers should actively participate in blockchain research forums and consortia to stay updated on advancements in consensus algorithms, enabling them to implement the most effective solutions in their networks.

6. CONCLUSION

The findings of this study reveal significant relationships among the variables analyzed. Blockchain Security (IV1) and Blockchain Privacy (IV2) exhibit significant positive effects on User Trust and Adoption (DV) with path coefficients of 0.38 and 0.32, respectively. The mediating role of Regulatory Compliance (MeV) was also supported, with a substantial influence on the relationship between both IV1 and IV2 and the dependent variable. Furthermore, Consensus Mechanism Robustness (MV) was found to significantly moderate the relationship between Blockchain Security (IV1) and User Trust and Adoption (DV), emphasizing its role in enhancing the effectiveness of blockchain systems. The overall model demonstrates a robust explanatory power, with an R^2 value of 0.68 for User Trust and Adoption (DV).

From a managerial perspective, organizations must focus on implementing strategies that integrate blockchain security, privacy, and compliance with governance frameworks. The strong correlations identified in this study highlight the importance of adopting a holistic approach to blockchain management. Managers should view privacy and compliance not merely as technical requirements but as enablers of trust and adoption. By aligning organizational strategies with user expectations for security and privacy, businesses can ensure sustained trust and broader adoption of blockchain technologies across diverse sectors.

The most influential variable identified in this study is Blockchain Security (IV1), which underscores the necessity for robust and proactive security measures. Managers should allocate resources toward developing advanced cryptographic techniques, conducting regular security audits, and enhancing their networks' defense mechanisms. By prioritizing blockchain security, organizations can lay a solid foundation for trust and adoption while mitigating risks associated with potential vulnerabilities. The findings of this study provide a roadmap for managers to build resilient and trusted blockchain ecosystems.

7. DECLARATIONS

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7.2. Author Contributions

Conceptualization: FY, RW, and SR; Methodology: AW; Software: FY; Validation: RW and SR; Formal Analysis: AW and FY; Investigation: RW; Resources: FY; Data Curation: SR; Writing Original Draft Preparation: FY and RW; Writing Review and Editing: AW; Visualization: AW; All authors, FY, RW, SR and AW, 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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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.

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