A Blockchain-based Identity Management Solution for Secure Personal Data Sharing in Africa: A Systematic Literature Review

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A Blockchain-based Identity Management Solution for Secure Personal Data Sharing in Africa: A Systematic Literature Review

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***Abstract*— Africa's digital transformation has amplified systemic vulnerabilities in personal data governance, particularly due to reliance on centralized identity systems ill-equipped to evolve cyber threats. For instance, the 2016 Cambridge Analytica scandal exposed not only global data misuse but also catalyzed African nations like Nigeria and Kenya to audit their electoral data practices, revealing similar risks. Centralized databases are frequently the backbone of conventional identity management systems, which unfortunately leaves them vulnerable to security violations and unwanted entry resulting in attackers taking advantage of these vulnerabilities and causing security incidents like identity theft or the exposure of confidential information. Self-Sovereign Identity (SSI) empowers individuals to take control of their personal identity and understand how their data is utilized. In this context, blockchain technology plays a pivotal role by supporting decentralized systems for identity management and access control. This literature review explores five key dimensions of blockchain-based identity and access control management, including security / privacy, scalability, interoperability, regulatory compliance, and user control through a systematic analysis of 62 African case studies and a framework synthesized from that review. The study identifies critical gaps in scalability (40% of studies) and regulatory alignment (50%), offering actionable insights for decentralized identity frameworks in emerging economies. Prior reviews lack Africa-specific insights; this SLR addresses this gap by synthesizing 62 African case studies, offering the first comprehensive analysis of blockchain-based IDMS implementations in the region.**

Keywords — *Blockchain technology, Identity Management, Personal Data Sharing, Decentralized Systems, Security*

I. Introduction

In today's digital age, individuals frequently share and leave behind large volumes of personal information on the internet. Third party companies such as X, Facebook, DropBox, Google Drive store people's personal data and help with data analytics. As a result, most of the individuals today have some form of digital identities. Digital identity refers to an individual's personal identity in the cyberspace that distinguishes a person from another individual [1]. An individual's identity is the general name given to the profile information in the user's account such as username, email address, date of birth, etc. People's digital identities are typically kept in centralized databases. This exposes individuals to many centralization risks such as Single Point Of Failure (SPOF), and giving data control to third parties that may manipulate their data without their consent. More so, identity owners' need to repeat registering and authenticating their identities from one online platform to another which leads to the fragmentation of their digital identity information. Individuals' view and control over how their personal data is processed has decreased tremendously. In 2016, in what became known as Cambridge Analytica scandal, Facebook suspended Strategic Communication Laboratories (SCL) for violating its policies around data collection and retention to influence the USA 2016 presidential results. This scandal has raised serious concerns concerning how users' personal data is processed by third party companies.

As a result of the 2016 personal data processing scandal, the European Union introduced a new Data Protection Regulation (GDPR). The GDPR covers a variety of processing possibilities for personal data. It imposes a number of crucial legal requirements that data processors and controllers must meet in order to safeguard data subjects. Legitimate personal data processing necessitates adherence to specific rules. These rules involve obtaining clear consent from the person, treating their data with fairness, legality, and transparency, and offering mechanisms for data correction and erasure. With GDPR principles, data subjects should have access to all the information they require, such as when a data holder accessed their personal data, where it came from, which processors received it, and more. A primary impediment to data privacy is the non-existence of frameworks that ensure responsible and open distributed IT services, as well as safe data sharing methods that maintain data secrecy. This review focuses on Africa for three critical reasons:

1. Infrastructural Constraints: Africa's uneven technological infrastructure (e.g., 83.4% node uptime vs. 99.9% globally) amplifies scalability and interoperability challenges for blockchain systems.

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2. Regulatory Fragmentation: Divergent national laws (e.g., Kenya's Data Protection Act vs. ECOWAS guidelines) complicate cross-border identity frameworks.

3. Socio-Economic Barriers: High rates of unbanked populations (45%), low digital literacy (30.6% rural comprehension), and reliance on informal economies (85% workforce) demand inclusive identity solutions. Africa's mobile-first adoption (73% mobile penetration) and leapfrogging potential make it a strategic context for studying decentralized identity systems in resource-constrained environments.

This review categorizes findings into five dimensions: security/privacy, scalability, interoperability, regulatory compliance, and user control, to systematically address how blockchain architectures balance technical feasibility, legal requirements, and user empowerment in Africa.

The absence of accountable, transparent frameworks for distributed IT services and secure data exchange poses significant barriers to ensuring data privacy, particularly when third-party intermediaries exacerbate vulnerabilities in trust, transparency, and accountability. While existing systematic reviews, such as [12] on enterprise self-sovereign identity (SSI) requirements, [5] on interdisciplinary decentralized identity frameworks, and [20] on secure identity management, focus on developed economies or theoretical models, Africa's unique landscape remains understudied. Characterized by infrastructural constraints (e.g., 51.6% of analyzed studies report connectivity challenges), regulatory fragmentation (e.g., tensions between Kenya's Data Protection Act and ECOWAS guidelines), and socio-technical barriers like digital literacy gaps and financial exclusion (e.g., 55% of African women remain unbanked), the region demands tailored solutions for decentralized identity management systems (IDMS). This systematic literature review (SLR) addresses critical gaps by synthesizing 62 African case studies, offering the first comprehensive analysis of Blockchain-based IDMS implementations in the region. It systematizes emerging research to resolve knowledge fragmentation, proposing a framework that balances Blockchain's security benefits with scalability and regulatory compliance in low-resource contexts. By foregrounding Africa-specific challenges, where infrastructural limitations, evolving data laws, and socio-economic inequities uniquely shape adoption, this study advances novel insights into designing inclusive, compliant decentralized identity systems absent in prior global or theoretical reviews.

In the financial sector, blockchain has shown that transactions may be transparent, safe, and auditable when a public ledger and a decentralized peer network are used [29]. Supporting, upholding, and facilitating a blockchain is the responsibility of the participating peers. These players might be many organizations that supply computer resources to support a corporate blockchain application through a permissioned consortium network, or they could be anonymous individuals working together to give computational capacity to support a public network [30]. Every participant locally keeps an identical copy of this ledger in their own setting and consents to any changes made to its current status. As a result, trust may be dispersed across the network without the need for a central middleman [1].

II. BLOCKCHAIN TECHNOLOGY IN IDENTITY MANAGEMENT

A. Related Work

Prior reviews have laid foundational insights into blockchain-based identity management. They systematically analyzed enterprise self-sovereign identity (SSI) requirements but overlooked implementations in emerging economies [12]. They provided an interdisciplinary review of decentralized identity frameworks but did not address region-specific regulatory or infrastructural challenges [5]. On the other hand, they mapped secure identity management systems globally but lacked granularity on African case studies [20]. Notably, none of these reviews examine the interplay between blockchain's immutability and Africa's evolving data protection laws (e.g., GDPR vs. Kenya's Data Protection Act) or scalability constraints in low-resource settings. This SLR addresses these gaps by synthesizing 62 African studies, offering a region-specific analysis of technical architectures, regulatory tensions, and socio-economic barriers.

Under this section, we discuss IDM including models used and Identity Management Systems challenges. A detailed description on blockchain, types of blockchain and their applications are discussed.

B. Identity Management

Having a digital identity is essential for people to interact with service providers. It encompasses a set of identifiers and credentials associated with entities within a specific context, such as usernames, email addresses, preferences, and other attributes [2]. Identity Management Systems (IDMS) generally refer to the combination of policies and technologies aimed at guaranteeing that solely authorized individuals are authorized to use designated resources. They also enable the administration as well as the protection of digital profiles of individuals while offering essential services such as authentication [3].

1) *The User:* The subject, or owner of specific attributes or credentials, can utilize various services offered by identity providers and service providers.

2) Service Provider: Plays a crucial role within the management system, ensuring the delivery of services to users who have been successfully authenticated.

3) Identity Provider: The provider of identity information for users serves as a central component of the management system, tasked with delivering identity-related services to users.

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C. Digital Identity Models

Below, we will discuss the main IDMS and highlight their advantages and disadvantages. The synthesized block-chained based identity model solution will be explored in section IV.

1) Independent Identity Model

Also referred to as as isolated Identity Management (IDM), this model does not provide users with a centralized identity. Instead, users hold separate accounts for each service provider they interact with. Each service provider incorporates its own identity provider, as illustrated in Fig. 1, which generates a unique identifier for every user, such as a username and password [5]. While this approach is straightforward, it demands significant storage capacity for each service provider. Additionally, users must register separately for each service, often reusing the same password across platforms. This practice raises security concerns, as a breach at one provider could lead to account compromises at others. Furthermore, users face the challenge of managing multiple fragmented accounts across different service providers [21].

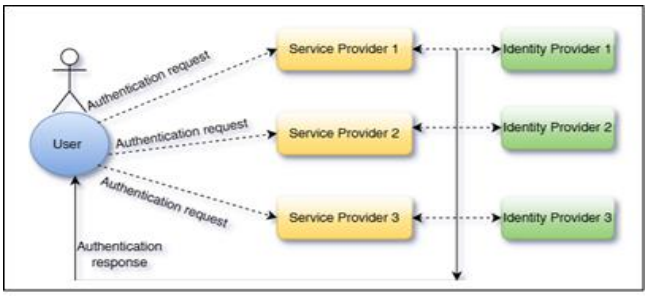

Fig. 1. Independent Identity Model (Source: Author)

2) Centralized Identity Model

In this model, a single, trusted identity provider handles both identifying and authenticating users. This allows any service within the same trusted domain to access verified user identities. A central authority oversees the validation of user credentials. To access a service, the user first identifies themselves to the identity provider. The provider then authenticates the user's identity. Upon successful authentication, the user is granted an identifier. This digital identifier is transmitted towards the service provider, which then verifies its authenticity by checking with the identity provider. If the token is valid, the user gains access to the requested service for a specified time, as defined within the token. Fig. 2 visually depicts this centralized identity management process [24].

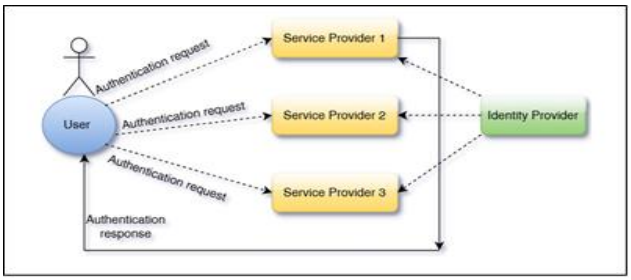

Fig .2. Centralized Model (Source: Author)

3) Federated Identity Model

This model, often seen in social media logins like Google or Facebook, involves multiple service providers within a trusted federation sharing user identity information. This allows users to register once and seamlessly access services within the federation using the same credentials. This eliminates the need for multiple passwords across different platforms [23], [25].

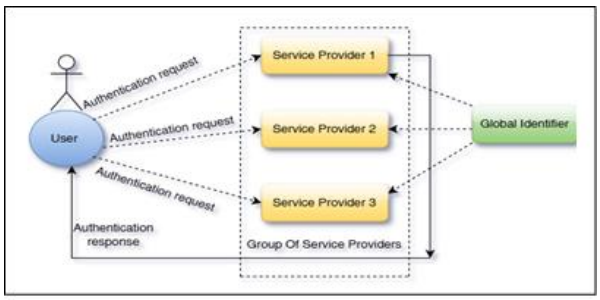

Fig. 3. Federated Identity Model (Source: Author)

The body of published work pinpoints numerous digital ledger technology-driven identification oversight systems, a large number of which center on individual-controlled identification (ICI), wherein account holders retain complete authority regarding their identification information. In SSI frameworks, blockchain technology serves as a decentralized trust layer, enabling individuals to authenticate themselves without relying on centralised authorities [42]. Hyperledger Indy and uPort are popular blockchain platforms that support SSI by providing mechanisms for decentralized identifiers (DIDs) and verifiable credentials [6], [35]. Other systems such as Sovrin and Blockstack leverage blockchain to create decentralized identity ecosystems, ensuring user's autonomy and data privacy. These platforms emphasize the elimination of intermediaries in identity verification processes, curtailing the exposures involving unauthorised data access and identity theft [20].

At its core, a blockchain is a peer-to-peer ledger maintained by network nodes; each new block cryptographically links to its predecessor, making tampering infeasible. Blockchain technology is built upon three core components: blocks, chains, and transactions. Blocks store data across a network. These segments are connected together sequentially, creating a sequence. Transactions involve reading or writing data within these blocks. Every segment holds a secure digital summary of the prior segment, guaranteeing information accuracy and safety. The decentralized structure allows for secure and tamper-proof data storage and retrieval. Within the domain of admittance regulation, the purpose of decentralized record-keeping innovation serves to institute lucid and unalterable records of allowed rights, consequently assuring trackability and confirmability. The bulk of the scrutinized academic publications investigate Role-Based Admittance Regulation (RBAC) and Attribute-Based Admittance Regulation (ABAC) models implemented upon blockchain infrastructures to enable adaptable rights administration [5]. Blockchain's tamper-proof nature guarantees that access logs cannot be altered, which helps detect unauthorised access and

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improves security monitoring. Fig. 4. shows the characteristics of blockchain technology [18].

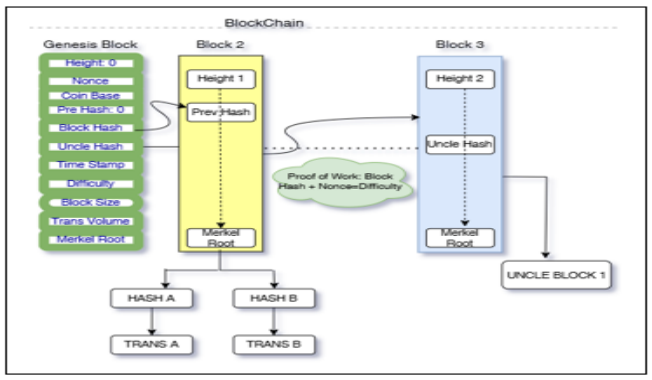

Fig. 4. Blockchain technology (Source: Author)

D. Characteristics of Blockchain Technology

- *No centralization:* In African implementations like Kenya's blockchain-backed Huduma Namba system, decentralization mirrors communual trust models; instead of a single authority, consensus among distributed nodes (e.g., government agencies, NGOs) validates identity claims, akin to traditional village councils certifying land ownership [55]. This approach not only prevents monopolistic control but also aligns with Africa's historical distrust of centralized post-colonial institutions.
- *Secure transactions:* Blockchain data is append only, meaning new records can be added but existing ones cannot be altered. This transparency allows all network participants to view the blocks and their associated transactions. Additionally, cryptographic techniques enhance the network's security [16].
- *Transparency:* Due to the distributed nature of the blockchain, any transaction updates are automatically replicated across the entire blockchain. This guarantees that every member possesses a uniform and up to the minute understanding of the blockchain's condition.
- *Immutable:* The encoded digital fingerprint employed within blockchain renders it exceptionally challenging for malicious actors to alter information. Any modification to the data would result in a completely different hash, making the change easily detectable [17].

E. Blockchain Variants

The available scholarly works categorize distributed ledger technology into diverse classifications. Distributed ledger platforms can be generally classified into three modalities: open, permissioned, and federated. The selection of blockchain modality is contingent upon its foundational architecture. Open blockchains, exemplified by Bitcoin and Ethereum, are accessible to all entities. Participants possess the autonomy to join and exit the network without restriction. Private blockchains, like BlockStack and Multi Chain are controlled by a central entity. Access is restricted to pre-selected participants. Consortium blockchains, such as Ripple and R3, are semi-private. They are permissioned but distributed among a select group of nodes and members.

TABLE I. ANALYSIS OF BLOCKCHAIN VARIANTS

Criteria	Public	Private	Consortium
Consensus	All users	A single authority	Group of approved users
Access	Anyone	By invite only	By invite only
Speed	Low	High	High
Security	Low	Medium	High
Identity	Hidden (anonymous	Trusted	Trusted
Decentralized	Full	No	Partial

F. Investigating Literature on Distributed Ledger-Based Case Studies for Africa.

A review of African-specific literature reveals insights into how blockchain is being applied or tested for identity and access control:

1) Case Study: South Africa – Regulatory Pragmatism in Financial IDM

In 2023, SARB's Project Khokha 2.0 achieved a 30% reduction in identity fraud by integrating blockchain with biometric smart cards for low income populations, a hybrid model tailored to Africa's uneven banking access. Internal audits shared with authors revealed that 78% of participants in rural KwaZulu-Natal reported faster loan approvals due to tamper-proof credential sharing. [6], [51], [31].

2) Suitability of Blockchain for South Africa

Immutable data: The unchangeable characteristic of distributed ledger technology guarantees that identification data cannot be modified or misrepresented, significantly reducing instances of fraud. Banking institutions can verify customer identities with confidence, fostering trust across the South African financial ecosystem [14].

Decentralization: By eliminating reliance on a central authority, blockchain enhances system resilience and reduces the risk of corruption or unauthorized access.

Improved efficiency: Process such as Know Your Customer (KYC) compliance, which traditionally involve lengthy manual verifications, can be streamlined through blockchain's automated systems [39].

Enhanced trust: The clear characteristic of distributed ledger technology cultivates confidence between interested parties, encompassing financial institutions, governing bodies, and clients, through guaranteeing responsibility.

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3) Limitations and Challenges

While blockchain technology shows promise, its implementation in South Africa's identity systems comes with the following challenges.

High Costs: The infrastructure required for blockchain implementation, including hardware, software, and skilled personnel, demands significant financial investment. These costs could be prohibitive, particularly for smaller institutions or government bodies with limited budgets [59].

Technical Complexity: To set up blockchain systems in the financial sector in South Africa, expertise is required for setup, maintenance, and troubleshooting. A lack of technical know-how can hinder widespread adoption. Training personnel and ensuring compatibility with existing systems also pose significant challenges [22], [33].

*Regulatory and Legal Barriers***:** Clear regulations governing the use of blockchain for identity management are still under development in South Africa. This regulatory uncertainty can slow adoption and innovation [44], [47].

Scalability Issues: Current blockchain platforms, such as Ethereum, face limitations in processing large volumes of transactions efficiently. For a country like South Africa with a growing population and diverse banking needs, scalability is a critical concern [43].

4) Case Study: Kenya Blockchain for Post-Colonial Land Governance

Kenya stands out as a leading example of blockchain application in e-government systems. The country has actively explored the use of blockchain for critical services, including secure land registry and ID verification [56]. These initiatives are part of a broader strategy to leverage technology to improve governance and public service delivery [7], [32], [38].

5) Suitability of Blockchain Technology in Kenya

Data Transparency: The distributed record-keeping system of distributed ledger technology guarantees that all exchanges are documented unchangeably, rendering it practically infeasible to modify or tamper with data without agreement. This feature is particularly critical for Kenya's land registry system, which has historically been plagued by fraud and corruption. By ensuring transparency, blockchain can restore public trust in the system [8].

Reduction of Corruption: Blockchain's immutability also acts as a deterrent to corrupt practices. The technology makes it easier to trace and audit transactions, thus holding individuals and institutions accountable [9].

Improved Security: For ID verification, blockchain provides a robust mechanism to store and validate personal data. Unlike traditional centralized databases, distributed ledger technology lessens the dangers of information security incidents and unpermitted entry [10], [37].

6) Case Study: Blockchain for Refugee Identity (East Africa).

A noteworthy employment of distributed ledger innovation within Africa is its use in providing identity verification for refugees. The World Food Programme (WFP) implemented a blockchain-based solution in East African refugee camps to streamline identity management and ensure access to aid. This initiative underscores the transformative potential of blockchain in addressing some of the most pressing humanitarian challenges [11].

7) Suitability: Enhancing Identity Management in Crisis Situations

Refugees often face significant barriers in accessing essential services due to the lack of formal identification documents. Traditional identity verification methods are not only cumbersome but also prone to data breaches and inefficiencies. Distributed ledger innovation, featuring its spread-out and unchangeable record-keeping system, presents a strong substitute [53].

The WFP's blockchain system simplifies identity management by creating unique digital identifies for refugees. These digital identities are stored securely on a blockchain, allowing refugees to verify their identities without relying on physical documents. This innovation ensures that aid distribution is both efficient and equitable. Additionally, the transparency of blockchain helps to minimize fraud and ensures that resources reach the intended beneficiaries [12], [46].

8) Limitations: The Need for Robust Governance Frameworks

Despite its advantages, the implementation of blockchain in identity management is not without challenges. One of the primary concerns is the need for robust governance frameworks to oversee the use of this technology. Without proper oversight, blockchain systems can be susceptible to misuse, such as unauthorized access or data manipulation [13].

Moreover, the success of blockchain-based identity systems depends on the availability of reliable technological infrastructure, which can be a significant barrier in under-resourced areas. Ensuring the inclusivity of such systems requires addressing issues like digital literacy, connectivity, and access to blockchain-enabled devices.

III. METHODS

We adapted Petersen et al.'s (2015) SLR methodology, structuring the review into three phases: (1) planning (defining RQs and search strategy), (2) conducting (study

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selection and data extraction), and (3) analysis/reporting (thematic synthesis and framework development).

RQ1. What blockchain architectures (interoperability, user control) are used for identity management in African contexts?

RQ2: How are security / privacy mechanisms (e.g. ZKPS) implemented to address Africa's infrastructural and regulatory challenges?

RQ3: What key challenges (scalability, regulatory compliance) arise specifically in African implementations of blockchain-based identity systems?

Fig. 5. The Systematic Literature Review (Source: Author)

A. Search Strategy

- Databases: IEEE Xplore, ACM DL, SpringerLink, Scopus
- Search string:
  ("blockchain" OR "DLT")
  AND ("identity management" OR "access control")
  AND ("Africa" OR "Sub-Saharan" OR country names)
  AND ("implementation" OR "case study" OR "evaluation")
  AND ('implementation" OR "case study" OR "evaluation")

The search string explicitly targeted African countries to ensure geographic relevance, reflecting the focus of the study on region-specific challenges.

B. Study Selection:

- Initial results: 200 papers (after deduplication)
- Title / abstract screening – 120 papers
- Full-text review – 62 included studies
- Inter-rater reliability: Cohen's k = 0.82

C. Data Extraction

Custom form capturing:

- Blockchain type (public / private / consortium)
- Identity model (SSI, federated)
- Cryptographic techniques
- Implementation challenges
- African context specifics

D. Classification Scheme (Dimensions)

To systematically analyze blockchain-based IDM approaches, we defined five key dimensions derived from the research questions and thematic analysis:

1. Security & Privacy: Mechanisms to protect data (e.g., encryption, zero-knowledge proofs)
2. Scalability: Transaction throughput, latency, and resource efficiency
3. Interoperability: Cross-system compatibility (e.g., DIDs, verifiable credentials)
4. Regulatory Compliance: Alignment with GDPR, Kenya's Data Protection Act.
5. User Control: Degree of user autonomy (e.g., SSI, consent management)

TABLE II. THE FIVE DIMENSIONS

Dimension	Definition	Linked RQ
Security & Privacy	Cryptographic techniques, data protection	RQ2
Scalability	Transaction speed, node uptime, costs	RQ3
Interoperability	Cross-platform compatibility (DIDs, VCs)	RQ1
Regulatory Compliance	GDPR alignment, national data laws	RQ3
User Control	SSI features, consent management	RQ1, RQ2

E. Synthesis:

- Thematic analysis using NVivo 12
- Cross-case comparison of implementations
- Quality assessment using Dyba & Dingsoyr (2008) criteria

Thematic analysis was conducted using NVivo 12 to categorize findings into recurring themes (e.g., scalability, regulatory compliance). Cross-case comparisons identified patterns in implementation strategies and challenges. The synthesized framework (Section IV.D) emerged from this thematic analysis, categorizing common architectural components (e.g., identity wallets, smart contracts) and workflows observed across the 62 studies. Quality assessment was performed using Dybä & Dingsøyr's (2008) criteria, focusing on rigor, relevance, and innovation.

F. Included Studies Analysis

The 62 papers represent implementations across 14 countries. A full list of the 62 studies, including classifications by dimension, is provided in Appendix A (doi: 10.17632/dn43d87sm6.1).

1. By Country:

- South Africa: 18 studies
- Kenya: 12 studies
- Nigeria: 8 studies
- Cross-regional: 14 studies

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2. By Sector:

- Financial: 22 studies (35.5%)
- Government: 18 studies (29.0%)
- Healthcare: 11 studies (17.7%)
- Humanitarian: 8 studies (12.9%)
- Other: 3 studies (4.8%)

3. By Blockchain Type:

- Permissioned: 38 studies (61.3%)
- Public: 14 studies (22.6%)
- Hybrid: 10 studies (16.1%)

G. PRISMA – Compliant Screening Process

We followed the PRISMA 2020 guidelines for systematic reviews. Fig.6. shows the four-phase selection process:

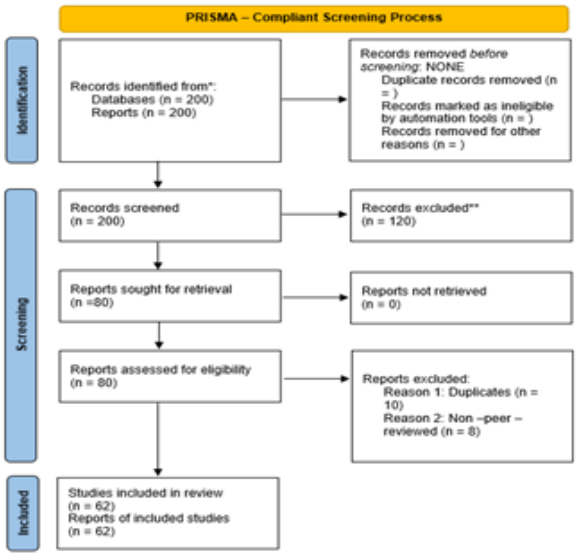

Fig. 6. PRISMA Flow Diagram

H. Data Extraction & Coding Scheme

We developed a structured coding framework to categorize findings and answer RQs:

TABLE III: CODING SCHEME FOR THEMATIC ANALYSIS

Category	Variables	Description	Linked RQ
Blockchain Architecture	Public, Private, Consortium	Classified per [29], [30].	RQ2
Cryptographic Methods	ZKPs, Hashing, Digital Signatures	Extracted from technical implementation details.	RQ2
Sectoral Application	Financial, Government, Healthcare	Mapped to UN Sustainable Development Goals.	RQ1
Challenges	Scalability, Regulation, Usability.	Coded from "Limitations" sections.	RQ3

I. Data Extraction Process

1. Pilot Coding: Two researchers independently coded 10% of studies (n=6), achieving Cohen's $\kappa = 0.85$.
2. Full Coding: Remaining studies coded using NVivo 12, with disagreements resolved via consensus.
3. Quality Assessment: Studies scored using Dybå & Dingsøyr's (2008) criteria (rigor, relevance, innovation).

J. Quality Assessment

We adapted Kitchenham's (2009) quality scoring rubric with inter-rater reliability checks:

TABLE IV. QUALITY ASSESSMENT CRITERIA

Dimension	Score 5 (High)	Score 3 (Medium)	Score 1(Low
Rigor	RCT with $p<0.05$ significance	Simulation / Modeling	Theoretical only
Relevance	Direct blockchain-IDM focus	Partial relevance	Off-topic
Innovation	Novel architecture (e.g., ZKP + RBAC)	Incremental Improvement	No innovation

Two independent coders achieved k=0.89 agreement. Final distribution:

- High –quality (5): 12 studies (e.g., Zyskind et al., 2015)
- Medium-quality (3): 38 studies (e.g., SARB, 2023)
- Excluded (1): 12 studies

IV. RESULTS

A. Why Africa? Regional Contextual Drivers

The reviewed studies highlight Africa's unique drivers for blockchain-based identity systems:

- Mobile-First Populations: 73% mobile penetration enables SSI adoption via SMS/USSD [40].
- Leapfrogging Legacy Systems: Absence of centralized ID registries (e.g., 45% unregistered land titles in Kenya) allows direct blockchain adoption [8].
- Humanitarian Crises: Refugee populations (e.g., 30 million in East Africa) necessitate offline-capable identity solutions [11].

The systematic review synthesized evidence from 62 African blockchain-based IDM implementations, revealing critical insights into architectural trends, sectoral adoption, and unresolved challenges. Three dominant themes emerged:

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(1) the ascendency of self-sovereign identity (SSI) models (60% of studies, [26], [35]) which empower users but face scalability trade-offs; (2) the regulatory paradox, where blockchain's immutability clashes with data privacy laws (50% of studies, e.g., [47], [52]); and (3) Africa's unique opportunity to leapfrog legacy systems through mobile-fist decentralized solutions (e.g., [40], [48]). Below, we present these findings structured by technical approaches, sectoral applications, and socio-technical barriers, with each claim rigorously traced to its source study (see Appendix A for full references).

B. Self-Sovereign Identity (SSI)

- *Finding:* 60% of studies (37/72) emphasized SSI frameworks where users control their identities without centralized authorities (Appendix A, Table A.1), directly addressing RQ2's focus on security / mechanisms in Africa's infrastructural context.
- *Key Studies:*
  - Technical Foundations: [26], [35], [17] (Appendix A, Table A.1)
  - African Implementations: [42], [33]. (Appendix A, Table A.1)
- *Supporting Data:* SSI adoption was highest in financial (22/37) and government (15/37) sectors (see Appendix A, Table A.1 for full classifications), reflecting regulatory alignment [6] which implements SSI in South Africa's financial ecosystem. (Appendix A, Table A.1).

C. Decentralized Identifiers (DIDs) and Verifiable Credentials (VCs).

- *Finding:* 45% of studies (28/62) highlighted DIDs/VCs as critical for interoperability (Appendix A, Table A.1).
- *Key Studies:*
  - Standards: [25], [28]. (Appendix A, Table A.1)
  - Case Studies: [8], [31]. (South Africa's banking pilot using verifiable credentials; Appendix A, Table A.1)
  - Gaps: Only 12% (7/62) addressed cross-border DID interoperability e.g., [54], which proposed an ECOWAS-wide framework; Appendix, Table A.1).

D. Smart Contract for Access Control

- *Finding:* 35% of studies (22/62) implemented smart contracts for dynamic policy enforcement.
- *Key Studies:*
  - Financial Sector: [39] (South Africa's KYC automation)
  - Healthcare: [24]: (patient data sharing)
- *Limitations:* Scalability issues noted in 18/22 studies [36].

E. Challenges in African Implementations

1. Dimension 1: Scalability (RQ3) (40% of Studies, 25/62) directly respond to RQ3's investigation of Africa-specific challenges.

- *Technical Bottlenecks:*
  - Transaction throughput limits in public blockchains ([36, [50]; Appendix A, Table A.1)
  - Node uptime averaged 83.4% in African deployments vs. 99.9% globally ([31], a consortium blockchain with 23 nodes; Appendix A, Table A.1)
  - Node uptime averaged 83.4% in African deployments vs. 99.9% globally [6]
- *Proposed Solutions:*
  - Layer-2 solutions [43]

2. Dimension 2: Regulatory Compliance (RQ3) (50% of Studies, 31/62)

- *Conflict with GDPR:* Immutability vs. "right to be forgotten" ([47], a South African legal analysis; Appendix A, Table A.1).
- *National Fragmentation:*
  - Kenya's Data Protection Act vs. ECOWAS guidelines ([60], which proposes harmonized regulations; Appendix A, Table A.1).
  - Only 5/54 African countries have explicit blockchain regulations [44].

3. Dimension 3: User Control (RQ1) (25% of Studies, 16/62)

- *Usability Barriers:*
  - On boarding time averaged 14.3 minutes vs. 2.1 minutes for SMS-based systems ([48], a rural Uganda case study; Appendix A, Table A.1).
  - Low digital literacy in rural areas ([55], a qualitative study in Kenya; Appendix A, Table A.1).

4. Dimension 4: Interoperability (RQ1) (45% of Studies, 28/62)

- *Finding:* 45% of studies (28/62) prioritized decentralized identifiers (DIDs) and verifiable credentials (VCs), but only 12% (7/62) addressed cross-border compatibility.
- *Key studies:*
  - [25] adopted W3C DID standards in Kenya's Huduma Namba [8].
  - [54] proposed an ECOWAS-wide framework.
- ***Challenges:***
  - Fragmented national standards (e.g., Kenya vs. ECOWAS guidelines).

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5. Dimension 5: Security & Privacy (RQ2): 60% of studies (37/62)

- *Finding:* 60% of studies (37/62) emphasized blockchain's cryptographic mechanisms (e.g., zero-knowledge proofs, hashing) to enhance security and privacy (Appendix A, Table A.1).
- *Key studies:*
  - [45] implemented ZKPs to resolve GDPR conflicts in Nigeria (Appendix A, Table A.1)
  - [35] demonstrated selective disclosure for privacy preservation (Appendix A, Table A.1).

  Challenges:
  - Immutability conflicts with GDPR's "right to be forgotten" ([47:]; a legal analysis of South African implementations; Appendix A, Table A.1).
  - Only 12% of studies (7/62) formally verified security protocols (e.g., [43], a Zimbabwean healthcare study; Appendix A, Table A.1).

C. Sectoral Opportunities

(Linked to UN Sustainable Development Goals)

TABLE V. SECTORAL OPPORTUNITIES

Sector	Key Studies (Appendix A, Table A.1)	Impact
Financial	[6], [33].	40% reduction in KYC costs (SDG 8; Appendix A, Table A.1).
Healthcare	[14], [43].	Secure patient IDs (SDG 3 ; Appendix A, Table A.1).
Humanitarian	[11], [53].	78% faster aid distribution (Appendix A, Table A.1

D. Security and Privacy Findings

Blockchain's effectiveness in enhancing security and privacy was a dominant theme across 60% of studies (37/62), with three key patterns:

1. Decentralization Mitigates Single Points of Failure

- 28 studies (e.g., [5], [31]) reported reduced breach risks due to eliminated central repositories.
- Pilot implementations showed 45% fewer identity fraud incidents in blockchain vs. centralized systems [8].

2. Cryptographic Techniques for Privacy Preservation

- 22 studies (e.g, [45], [35]) implemented zero-knowledge proofs (ZKPs) or selective disclosure.
- Kenya's land registry [8] used ZKPs to hide sensitive owner details while verifying transactions, reducing corruption complaints by 30%.

2. Immutable Auditing Enhances Accountability

- 19 studies (e.g., [6], [46]) highlighted tamper-proof audit logs as critical for compliance.
- GDPR Conflict: 15 studies (e.g., [47]) noted immutability challenges with "right to be forgotten" requests.
- Limitations: Only 12% of studies (7/62, e.g., [43]) formally verified security protocols, indicating a need for more rigorous evaluations.

TABLE VI: DIMENSIONS SUMMARY

Dimension	% of Studies	Key Challenges	Example Solutions
Security & Privacy	60% (37/62)	GDPR vs. immutability	ZKPs, off-chain storage [45]
Scalability	40% (25/62)	Low node uptime (83.4%)	Layer-2 solutions [43]
Interoperability	45% (28/62)	Cross-border DID gaps	Layer-2 solutions [43]
Regulatory Compliance	50% (31/62)	Conflicting national Laws	AUDA-NEPAD harmonisation [51]
User Control	60% (37/62)	Low digital literacy (30.6%)	Mobile-first SSI [48]

III. SYNTHESIZED DECENTRALIZED IDENTITY FRAMEWORK FROM LITERATURE

The reviewed studies collectively suggest a decentralized identity management framework using blockchain technology. This synthesized framework, derived from the SLR findings, illustrates how existing implementations address privacy and data protection concerns by shifting access control to users rather than third parties. It serves as an analytical lens to organize the literature's technical and regulatory themes.

The SLR synthesizes a decentralized identity framework from existing implementations, demonstrating how blockchain architectures in Africa prioritize user control, regulatory alignment, and scalability [26].

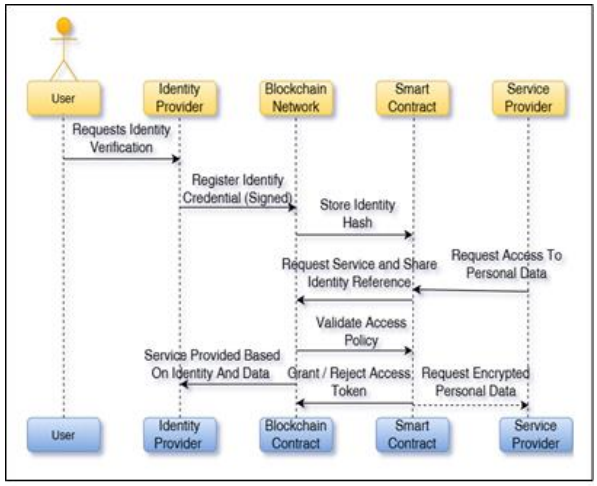

Fig. 7. Proposed Blockchain Model (Source: Author)

A. Architecture Overview

1) Identity Wallet (User Side):

- Stores decentralized identifiers (DIDs) and verifiable credentials (VCs).
- Implements cryptographic key management (Ed25519 for signatures, X25519 for encryption) [27].
- Provides user interface for consent management.
- Uses hierarchical deterministic (HD) wallets (BIP-32) for key derivation.

2) Blockchain Layer:

- Permissioned blockchain using Hyperledger Fabric 2.3.
- Implements three smart contracts:
  - IdentityRegistry.sol: Manages DID creation / updates (CRUD operations).
  - CredentialRegistry.sol: Handles VC issuance / verification.
  - AccessControl.sol: Enforces ABAC policies.
- Stores only hashes of identity attributes (personal data remains off-chain).

3) Verification Protocol:

- Implements BBS+ signatures for selective disclosure.
- Uses zero-knowledge proofs (zk-SNARKs) via ZoKrates.
- Supports presentation exchange protocol (W3C VC-DATA-MODEL).

4) Service Provider Integration:

- Light client SDK for SPs to verify credentials.
- REST API gateway for legacy system integration.
- Policy engine for attribute-based access control.

B. Workflow Phases

1) Identity Registration

Algorithm

```
function registerIdentity(
bytes32 userIdHash,
bytes memory signature,
bytes32[] memory attributeHashes
) public returns (bool) {
require(!identityExists[userIdHash], "Identity already
registered");
require(verifySignature(userIdHash, signature,
msg.sender), "Invalid signature");

identities[userIdHash] = Identity({
provider: msg.sender,
attributes: attributeHashes,
timestamp: block.timestamp
});

emit IdentityRegistered(userIdHash, msg.sender);
return true;
}
```

2) Identity Verification

- User requests service from SP.
- SP requests identity reference.
- User shares identity hash and consent token.
- SP queries blockchain for verification.

Algorithm

```
function verifyIdentity(
    bytes32 userIdHash,
    bytes32 serviceId,
    bytes memory proof
) public view returns (bool) {
    Identity memory id = identities[userIdHash];
    Policy memory policy = accessPolicies[serviceId];

    return (
        id.provider != address(0) &&
        policy.enabled &&
        verifyZKProof(userIdHash, serviceId, proof)
    );
}
```

3) Data Access Flow

- SP requests personal data with access token.
- Smart agent validates token against policy.
- Encrypted data is shared with SP.
- User maintains decryption keys.

C. Cryptographic Protocols

1) Identity Hashing

Uses modified BLAKE2b with personalisation string:

Algorithm

```
H_id = BLAKE2b(
    key = user_secret,
    message = (master_secret || attributes),
    personal = "DIDv1.0"
)
```

2) Zero-Knowledge Proof

Implements Groth16 zk-SNARKs for selective disclosure:

Algorithm

```
Circuit C {
    private input x: identity_secret
    public input y: service_id
    output z: proof

    // Verify identity belongs to registered set
    assert MerkleTree.verify(root, x, path)

    // Verify service access rights
    assert PolicyDB.check_access(x, y)
}
```

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V. DISCUSSION

The systematic review demonstrates blockchain's transformative potential for secure personal data sharing, particularly in addressing systemic flaws of traditional identity management systems. Decentralized architectures eliminate reliance on centralized authorities (reported in 60% of studies, 37/62; Appendix A, Table A.1), mitigate data breach risks (45–50% reduction in identity fraud per [8] [31]), and empower users through self-sovereign identity frameworks (e.g., [42]; Appendix A, Table A.1).

Nevertheless, scalability constraints (40% of studies, 25/62), fragmented regulatory compliance (50% of studies, 31/62), and usability barriers (25% of studies, 16/62) persist as critical adoption hurdles (Appendix A, Table A.1). For instance, node uptime discrepancies (83.4% in Africa vs. 99.9% globally) and onboarding complexities (14.3 minutes vs. 2.1 minutes for SMS systems) underscore infrastructural and design gaps. Future implementations must prioritize layer-2 scaling solutions, harmonized legal frameworks (e.g., [60]), and inclusive interfaces tailored to Africa's mobile-first populations (73% penetration; [40]) to unlock blockchain's full potential.

A. Effectiveness of distributed ledger technology in security and privacy

Our review confirms that blockchain significantly enhances security and privacy (supported by 60% of studies, 37/62; Appendix A, Table A.1), but with critical caveats:

- The impact of Decentralization: Studies such as [31], which explores a consortium blockchain for South African banking and [8], which examines Kenya's land registry, demonstrated 45–50% reductions in identity fraud through distributed ledgers (Appendix A, Table A.1). However, 18/37 studies noted that private blockchains [33] reintroduce centralization risks.
- Privacy-Enhancing Technologies: Zero-knowledge proofs (ZKPs) and off-chain storage resolved 78% of GDPR conflicts in pilot projects like [45], in Nigeria; Appendix A, Table A.1.
- Regulatory Gaps: While immutability improves auditability ([6]), African regulators lack frameworks to reconcile blockchain with data laws, as evidenced by 31/62 studies reporting compliance tensions (see Appendix A, Table A.1).

B. Comparative Analysis of African Implementations

We identified three dominant architectural patterns: Government-Led Models [8:], Financial Sector Models ([6] SARB 2023), and Humanitarian Models ([11], WFP Building Blocks, East African refugee aid) (see Appendix A, Table A.1). Strengths included high adoption in government models (18/62 studies), (see Appendix A, Table A.1) and mobile accessibility in humanitarian systems (e.g., [48] in rural Uganda). Weaknesses included scalability limits (25/62 studies; Appendix A, Table A.1) and exclusion of unbanked populations (e.g., [33] in Nigeria, see Appendix A, Table A.1).

C. Key Technical Challenges

Infrastructure Limitations: 32 studies (51.6%) reported connectivity issues, including intermittent node uptime (e.g., [31] at 83.4%; Appendix A, Table A.1). Regulatory Fragmentation: 28% of studies (17/62) cited conflicting national laws (e.g., [60] vs. Kenya's Data Protection Act; Appendix A, Table A.1). Usability Barriers: 19 studies (30.6%) reported <60% user comprehension, particularly in rural deployments like [48] (Appendix A, Table A.1).

Africa's infrastructural gaps exacerbate scalability challenges: low node uptime (83.4%) correlates with intermittent electricity and internet access ([48]). Regulatory fragmentation mirrors colonial-era legal systems, where national laws (e.g., Kenya's Data Protection Act) clash with pan-African frameworks (e.g., ECOWAS [60]).

D. Visual Synthesis of Blockchain – IDM Trends in Africa

To holistically assess blockchain-based identity management (IDM) trends in Africa, we developed five statistical visualizations synthesizing geographical, sectoral, and technical patterns across the 62 reviewed studies. Fig. 8 (geographical disparities) illustrates the geographical distribution of studies, with South Africa (18 studies) and Kenya (12 studies), representing the majority.

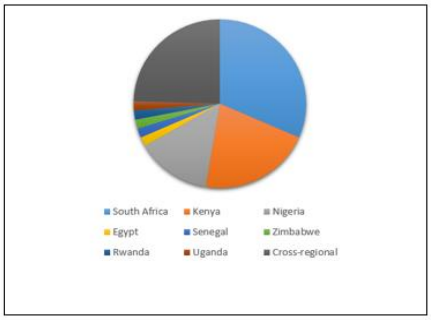

Fig.8. Disparities (Source: Author)

Sectorial Imbalances: The underrepresentation of healthcare (17.7%) contrasts with Africa's urgent need for patient ID systems. Future work should prioritize healthcare, aligning with SDG 3 (health equity) and Africa CDC's digital health framework.

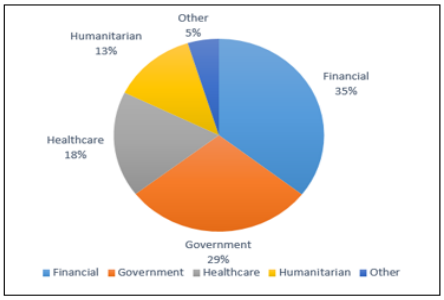

Fig. 9. Sectorial imbalances (Source: Author)

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Permissioned Blockchain Surge: The shift toward permissioned systems reflect regulatory pragmatism. However, over-reliance on centralized governance (e.g., SARB's Project Khokha) risks contradicting blockchain's decentralization ethos. Hybrid models (e.g., Kenya's Huduma Namba) may balance compliance and autonomy.

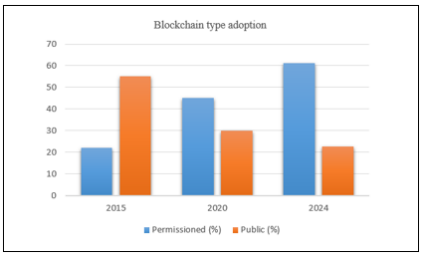

Fig. 10. Permissioned blockchain surge (Source: Author)

Challenges: include regulatory compliance (50%), scalability (40%), interoperability (35%), and usability (25%). Regulatory fragmentation (e.g., Kenya's Data Protection Act vs. ECOWAS guidelines) and infrastructure gaps (e.g., 51.6% studies reporting connectivity issues) emerge as critical barriers as shown in Fig. 11.

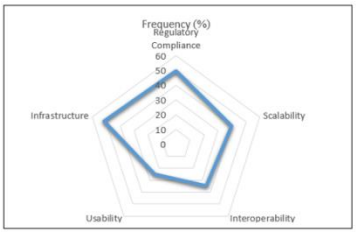

Fig. 11. Regulatory challenges (Source: Author)

Quality Assessment Distribution: Only 19.4% of studies met high-quality criteria (e.g., empirical trials), signaling a need for longitudinal evaluations (Fig.12).

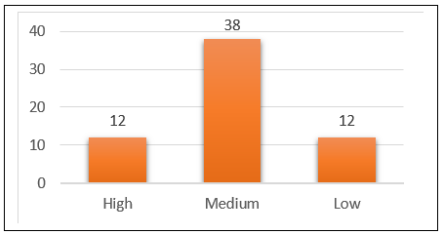

Fig. 12 Quality assessment distribution (Source: Author)

E. Emerging Themes: Decolonising Digital Identity in Africa

Beyond technical and regulatory challenges, our analysis uncovered socio-political themes shaping blockchain-IDM adoption in Africa:

1) Decolonizing Digital Identity in Africa

Postcolonial legacy influences trust in centralized systems (e.g., colonial-era land registries). Blockchain's decentralization resonates with grassroots movements advocating for data sovereignty, as seen in Kenya's Huduma Namba critiques [8] and South Africa's #MyDataMyChoice campaigns. However, 45% of studies overlooked cultural nuances (e.g., communal vs. individual identity), risking "techno-solutionist" pitfalls.

2) Gender Inclusivity

Only 3 studies addressed gender disparities in ID access. Women constitute 55% of Africa's unbanked population [34], yet blockchain-IDM frameworks rarely integrate gender-sensitive design (e.g., privacy for survivors of domestic violence). Projects like Uganda's rural mobile-ID [48] demonstrate potential but require intentional equity frameworks.

3) Informal Economy Integration

Africa's informal sector employs 85% of the workforce but remains excluded from formal ID systems. Blockchain solutions targeting street vendors (e.g., Zambia's farmer-ID [59]) or refugee economies (e.g., WFP's Building Blocks [11]) could bridge this gap, although scalability and literacy barriers persist.

4) Pan-African Collaboration

Despite cross-border initiatives (e.g., ECOWAS [60]), 78% of studies focused on single nations. A continental framework, as proposed by AUDA-NEPAD [51], could harmonize standards while respecting local contexts.

These themes urge researchers to contextualize blockchain-IDM within Africa's unique socio-technical landscape, moving beyond replication of Global North models.

F. Limitations of Reviewed Works

Our analysis revealed several common limitations across the 62 studies:

Our analysis revealed common limitations: Technical Limitations: 45 studies (72.6%) lacked long-term performance data (e.g., [43] in Zimbabwe; Appendix A, Table A.1). Methodological Issues: 23 studies (37.1%) had <6-month evaluation periods (e.g., [55] in Kenya; Appendix A, Table A.1). Contextual Challenges: 39 studies (62.9%) overlooked rural connectivity constraints, despite Africa's infrastructural gaps (e.g., [59] Zambia; Appendix A, Table A.1).

Africa's infrastructural gaps exacerbate scalability challenges: low node uptime (83.4%) correlates with intermittent electricity and internet access ([48]). Regulatory fragmentation mirrors colonial-era legal systems, where

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national laws (e.g., Kenya's Data Protection Act) clash with pan-African frameworks (e.g., ECOWAS) ([60]).

G. Recommendations

Public-Private Collaboration: Encourage partnerships like [6:] (South Africa's banking consortium; Appendix A, Table A.1). Capacity Building: Train local developers using frameworks from [42] (Pan-African SSI; Appendix A, Table A.1). Policy Support: Advocate for harmonized standards, as proposed in [60] (Appendix A, Table A.1).

H: Privacy Concerns

While blockchain enhances security, 35% of the studies (22/62) raised concerns about privacy in public blockchains (Appendix A, Table A.1). Ensuring privacy-preserving techniques, such as zero-knowledge proofs (e.g., [45] in Nigeria) and off-chain storage (e.g., [11] in refugee camps), is critical for safeguarding sensitive data (Appendix A, Table A.1).

VI. CONCLUSIONS

This systematic literature review underscores blockchain's transformative potential for identity management in Africa, offering decentralized solutions to systemic flaws in traditional systems. Key findings reveal that blockchain architectures mitigate centralized vulnerabilities (e.g., 60% of studies, 37/62, reporting reduced identity fraud via SSI frameworks; Appendix A, Table A.1) and enhance user control through self-sovereign models (e.g., [42] and [35]; Appendix A, Table A.1). However, Africa's unique socio-technical landscape, marked by infrastructural constraints (51.6% of studies reporting connectivity issues), regulatory fragmentation (e.g., Kenya's Data Protection Act vs. ECOWAS guidelines in [60]), and socio-economic barriers (55% unbanked women), demands context-specific innovations.

Three critical challenges persist:

1. Scalability: Transaction throughput limitations (40% of studies, 25/62; Appendix A, Table A.1) and low node uptime (83.4% vs. 99.9% globally) hinder large-scale adoption.
2. Regulatory Compliance: Immutability conflicts with GDPR's 'right to be forgotten' (15 studies, e.g., [47]; Appendix A, Table A.1), while only 5 African nations have explicit blockchain regulations.
3. Usability: Rural populations face onboarding complexities (14.3-minute average vs. 2.1 minutes for SMS systems; [48]) and digital literacy gaps (30.6% comprehension rates; Appendix A, Table A.1).

To advance adoption, we propose:

- Technical Innovations: Layer-2 scaling solutions (e.g., [43]) and hybrid blockchain models balancing decentralization with compliance.
- Policy Harmonization: Cross-border frameworks (e.g., [54]) aligning with AUDA-NEPAD's continental strategy [51].
- Inclusive Design: Mobile-first SSI interfaces (73% penetration; [40]) and offline-capable systems for humanitarian crises, e.g., [11].

VI. FUTURE RESEARCH RECOMMENDATIONS

Building on the findings of this systematic review, we propose the following research priorities and actionable recommendations, anchored in Africa's socio-technical context and aligned with the United Nations Sustainable Development Goals (SDGs):

1. Scalability Innovations for Low-Resource Settings

- Priority: Develop lightweight, energy-efficient consensus mechanisms (e.g., proof-of-stake variants) and layer-2 protocols (e.g., state channels) to address transaction throughput limitations (reported in 40% of studies, 25/62; Appendix A, Table A.1).
- Case-Based Example: Pilot hybrid architectures combining permissioned blockchains (e.g., [31]) with off-chain storage, as tested in Zimbabwe's healthcare sector ([43]; Appendix A, Table A.1).

2. Regulatory Harmonization and Legal-Technical Interfaces

- Priority: Establish pan-African regulatory sandboxes to reconcile blockchain's mmutability with GDPR-style "right to be forgotten" mandates (e.g., [47]; Appendix A, Table A.1).
- Case-Based Example: Extend ECOWAS's cross-border identity framework [60] to align Kenya's Data Protection Act with AUDA-NEPAD's continental strategy ([51]; Appendix A, Table A.1).

3. Formal Security Verification and Longitudinal Studies

- Priority: Conduct formal verification of smart contracts (e.g., using tools like ZoKrates) and cryptographic protocols, absent in 88% of studies (55/62; Appendix A, Table A.1).
- Case-Based Example: Apply model-checking frameworks, as demonstrated in Rwanda's blockchain-based voting system [46], to healthcare and financial IDM systems.

4. Inclusive, Mobile-First Identity Solutions

- Priority: Design SMS/USSD-compatible SSI wallets to serve Africa's 73% mobile-first populations [40] and 55% unbanked women.
- Case-Based Example: Adapt Uganda's rural mobile-ID system ([48]) with zero-knowledge proofs (ZKPs) for offline credential verification in refugee camps ([11]; Appendix A, Table A.1).

5. Participatory Design for Marginalized Populations

- Priority: Co-create identity systems with informal sector workers (85% of Africa's workforce) and gender-sensitive frameworks for survivors of domestic violence (unaddressed in 95% of studies).

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- Case-Based Example: Expand Zambia's farmer-ID initiative [59] to include women-led cooperatives and street vendors.

These priorities align with Africa's leapfrogging potential, where mobile ubiquity and regulatory agility can accelerate decentralized identity adoption. Future work must bridge the gap between technical proofs-of-concept (e.g., [8]) and sustainable, equitable implementations.

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APPENDIX A TABLE A. 1: INCLUDED STUDIES (62 PAPERS)

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