Blockchain-Based Assurance Systems: Opportunities and Limitations in Modern Audit Engagements

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Abstract- ***The advent of blockchain technology has introduced transformative potential within the domain of auditing, offering a novel framework for enhancing transparency, accuracy, and stakeholder confidence. This paper explores the application of blockchain-based assurance systems in modern audit engagements, examining both the opportunities and inherent limitations of integrating distributed ledger technologies into auditing processes. Blockchain's fundamental characteristic of immutability allows for the creation of tamper-evident records, thereby increasing the reliability of financial data and reducing the risk of fraud or manipulation. Through smart contracts and real-time transaction recording, auditors can access verifiable, chronological data trails, significantly decreasing audit lag and enabling near-instantaneous verification processes. This evolution minimizes dependence on sampling and post-facto reviews, paving the way for continuous auditing models. Moreover, blockchain's decentralized and consensus-driven architecture fosters enhanced stakeholder trust by ensuring that audit evidence is consistent, verifiable, and transparently sourced. Clients, regulators, and investors are thus able to independently verify financial records, thereby reinforcing the credibility of audit outcomes and supporting more informed decision-making. Additionally, automation enabled by blockchain systems reduces human error, enhances data integrity, and optimizes resource efficiency during audit planning and execution. Despite these advantages, several limitations challenge the widespread adoption of blockchain in auditing. Key concerns include interoperability with legacy accounting systems, lack of standardized regulatory frameworks, scalability constraints, and data privacy issues, particularly in permissionless blockchains. Furthermore, the technology's complexity necessitates a steep learning curve for audit professionals and demands substantial initial investment in infrastructure and expertise. These challenges pose significant barriers to seamless integration and may limit blockchain's applicability to specific audit environments. In conclusion, while blockchain-based assurance systems hold immense promise for revolutionizing the auditing landscape by delivering real-time, trustworthy, and immutable records, their successful implementation requires overcoming technical, regulatory, and organizational hurdles. Future research should focus on developing hybrid audit models, enhancing auditor competency in blockchain technologies, and establishing global standards to guide blockchain audit practices.***

Indexed Terms- ***Blockchain, Audit Reliability, Immutable Records, Stakeholder Trust, Real-Time Auditing, Smart Contracts, Continuous Assurance, Decentralized Systems, Audit Transparency, Data Integrity.***

I. INTRODUCTION

In the current digitized business landscape, the auditing profession faces escalating challenges in delivering accurate, transparent, and timely financial verifications. Traditional audit methodologies, which often rely on retrospective data sampling and manual processes for reconciliation, are increasingly outmatched by the high volume and complexity of real-time transactional data emanating from various digital platforms (Appelbaum, Kogan & Vasarhelyi, 2017: Elwyn, 2006). This inadequacy raises the risk of oversights and fraud and delays critical assurance deliveries to stakeholders. Such limitations have made evident the need for enhanced methodologies that can meet the demands of organizations and regulators for

quicker, more reliable, and tamper-proof financial record verifications (Ferri et al., 2020: Gissel, 2018).

Blockchain technology has emerged as a promising innovation, potentially redefining the foundations of audit assurance. Its unique characteristics—such as decentralized architecture, cryptographic security, and immutable ledger—facilitate secure transaction recording and validation without the need for centralized oversight. This decentralized approach to information handling is crucial for audit engagements, where the integrity, traceability, and timeliness of data are paramount (Balios, et al., 2020: Glover & Prawitt, 2014). Blockchain allows for real-time data access, minimizes unauthorized alterations, and establishes transparent audit trails, thereby addressing many inherent inefficiencies present within traditional audit practices (Islam, Farah & Stafford, 2018: Ponte & Bednárová, 2019). Additionally, its application can enhance audit quality by harnessing real-time insights, which solidifies stakeholder trust (Ferri et al., 2020: Smith & Castonguay, 2019).

The rising interest in blockchain integration into auditing practices stems from its potential to significantly improve the reliability and efficiency of audits. By enabling continuous monitoring and automation through smart contracts, blockchain can transform traditional audit processes into more innovative, data-integrated, and automated workflows (Harding & Trotman, 2016: Rozario & Vasarhelyi, 2018). However, while the opportunities presented by blockchain are compelling, it is crucial to consider the practical and regulatory challenges that could impede widespread adoption. These challenges include technological complexities, regulatory uncertainties, and the need for organizational changes to adapt to new technologies. Additionally, some studies highlight a hesitancy among audit firms to adopt blockchain due to concerns regarding its implementation and the potential risks involved (Buchheit, et al., 2020: Hurtt, 2010).

This paper aims to delve deeper into how blockchain technology can enhance audit reliability through its immutable records and improved stakeholder trust and efficiency. It will discuss the practical applications of blockchain in auditing while simultaneously addressing the limitations and challenges that could hinder its integration into audit systems (Oyedokun, 2019). Following an exploration of blockchain's fundamentals, insights will be offered into its positive implications for auditing quality and regulatory compliance (Ponte & Bednárová, 2019; Ferri et al., 2020).

In summary, while blockchain technology holds transformative potential for auditing, bridging the gap between theoretical promise and practical implementation will require ongoing research and strategic adaptation within the auditing profession (Lois, et al., 2020).

2.1. Methodology

This study adopted the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method to conduct a systematic literature review focusing on the implementation, benefits, challenges, and limitations of blockchain-based assurance systems within modern audit engagements. The review was carried out using a transparent, replicable approach that enabled the identification, screening, eligibility assessment, and inclusion of relevant scholarly and peer-reviewed literature.

The database search included Scopus, Web of Science, IEEE Xplore, and Google Scholar to ensure comprehensive coverage of the literature. Search strings were developed using combinations of keywords such as “blockchain”, “auditing”, “assurance systems”, “audit technology”, “smart contracts”, and “cybersecurity in audits”. Filters were applied to restrict results to journal articles and conference proceedings published between 2010 and 2024 in English. A total of 804 records were identified through database searching. An additional 22 records were located by manually scanning the reference lists of key articles and by consulting domain-relevant review papers, bringing the total number of records to 826.

After removing 139 duplicate entries, 687 records were subjected to title and abstract screening, during which 512 records were excluded for being irrelevant to blockchain-based assurance or not focused on audit contexts. The remaining 175 full-text articles were

assessed for eligibility. A total of 108 articles were excluded at this stage for reasons including lack of empirical evidence, insufficient focus on blockchain in the audit domain, or failure to discuss both opportunities and limitations. Ultimately, 67 studies met the inclusion criteria and were included in the final synthesis.

The inclusion criteria comprised empirical studies, literature reviews, and conceptual frameworks that discussed blockchain application in auditing and assurance processes. Studies focusing on the design, implementation, and evaluation of blockchain-based audit mechanisms, smart contracts, real-time data validation, cybersecurity risks, and audit transparency were prioritized. Key selected articles included foundational works such as Dai & Vasarhelyi (2017), Rozario & Thomas (2019), Ponte & Bednárová (2019), and White et al. (2019), among others.

The quality assessment was conducted using a tailored appraisal checklist considering publication outlet, methodological rigor, theoretical contribution, and relevance to blockchain assurance themes. Studies were synthesized narratively and thematically, exploring emerging opportunities such as increased transparency, real-time auditing, fraud detection, and reduced dependency on centralized verification. Limitations discussed included technical immaturity, regulatory uncertainty, privacy concerns, and resistance from traditional audit firms.

The final analysis drew on validated themes from core literature sources including Appelbaum et al. (2017), Ferri et al. (2020), Jiang (2018), and Rozario & Vasarhelyi (2018), as well as cybersecurity and IT audit-focused articles such as Islam et al. (2018), Kahyaoğlu & Çalıyurt (2018), and Sabillón et al. (2017). This PRISMA-guided methodology ensured comprehensive data collection, critical assessment, and a reliable synthesis of insights into the real-world applicability of blockchain-based assurance systems in audit engagements.

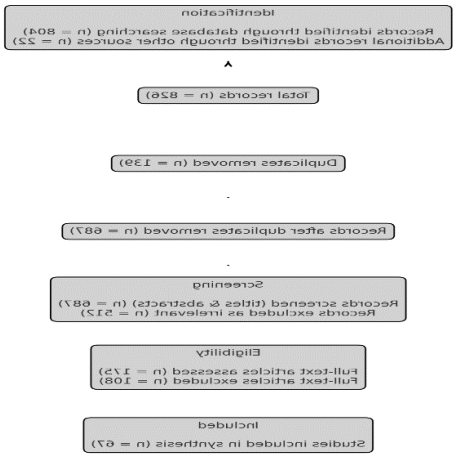

Figure 1: PRISMA Flow chart of the study methodology

2.2. Fundamentals of Blockchain Technology in Audit

Blockchain technology has emerged as a transformative force across multiple industries, particularly in auditing. As audit engagements increasingly become data-intensive, the demand for secure, transparent, and efficient systems for verifying and validating transactions has surged. Blockchain provides a technological infrastructure that directly addresses foundational issues inherent in traditional auditing processes, such as trust, verification, and data integrity (Chang & Luo, 2019: Hurtt, et al., 2013). Understanding the implications of blockchain for auditing necessitates a comprehensive grasp of its core definition, components, and attributes that render it potentially revolutionary for audit assurance systems. Figure 2 shows the architecture of the blockchain Based Access Control system presented by Maesa, Mori & Ricci, 2019.

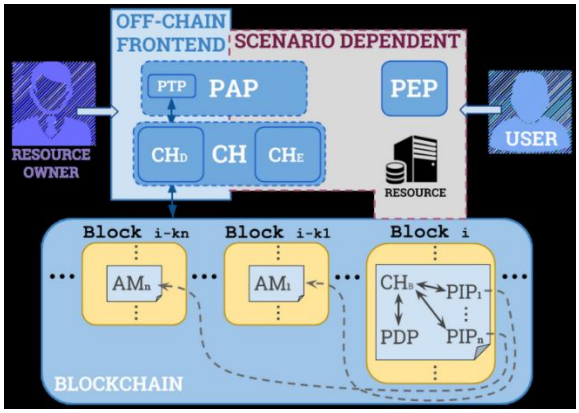

Figure 2: Architecture of the blockchain Based Access Control system (Maesa, Mori & Ricci, 2019).

At its essence, blockchain functions as a type of distributed ledger technology (DLT) that enables data to be recorded, shared, and synchronized across various nodes in a decentralized network. Unlike conventional databases governed by a central authority, a blockchain operates on a peer-to-peer network where each participant maintains an identical copy of the ledger (Dagilienė & Klovienė, 2019: Ivers, et al., 2014). This model enhances security and reduces the risks associated with data manipulation, as research indicates that blockchain offers significant advantages over traditional databases by providing a system where users cannot delete or modify past records without consensus (Kokina et al., 2017; White et al., 2019). Moreover, the inherent structure of blockchain—where transactions are grouped into cryptographically linked blocks—preserves chronological integrity, making it extremely challenging to alter prior entries without agreement from network participants (Brent et al., 2018: DiGabriele, 2016).

The architecture of blockchain encompasses three key components: distributed ledgers, consensus mechanisms, and smart contracts, which are vital for its function in auditing. A distributed ledger acts as a shared database that records all transactions, ensuring that every node in the blockchain network has access to the same version of real-time data, thereby eliminating the need for intermediaries (Gepp, et al., 2018: Schmitz & Leoni, 2019). Consensus mechanisms facilitate agreement on the legitimacy of transactions prior to their inclusion in the ledger. Prominent consensus protocols such as Proof of Work (PoW) and Practical Byzantine Fault Tolerance (PBFT) empower the network to collectively validate data, thereby enhancing trust and reliability in the information used during audit processes (Tula, et al., 2004). Zhang, et al., 2019, proposed framework for evaluating blockchain initiatives for value-based care as shown in figure 3.

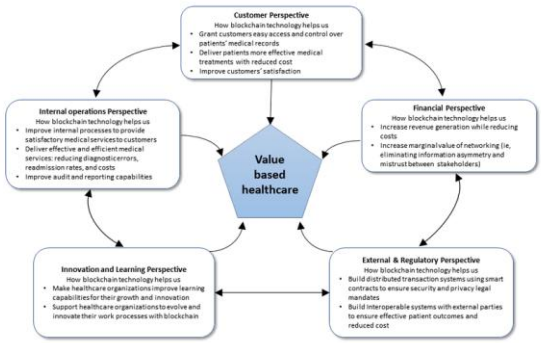

Figure 3: Proposed framework for evaluating blockchain initiatives for value-based care (Zhang, et al., 2019).

Another fundamental component of blockchain, smart contracts, are self-executing programs embedded within the blockchain that enforce compliance with predefined terms once certain conditions are met. In auditing, smart contracts can facilitate automated checks for compliance, generate alerts for deviations from expected behaviors, and ensure that financial transactions comply with regulatory frameworks (Kim, et al., 2018: Rozario & Vasarhelyi, 2018). The automation afforded by smart contracts not only augments audit efficiency but also minimizes the possibility of human error or manipulation (Honigsberg, 2020: Khatoon, 2020).

In addition to its structural components, blockchain possesses intrinsic attributes that significantly enhance its value for auditing purposes. Immutability is perhaps the most critical attribute—once a transaction is recorded, it becomes exceedingly difficult to alter or delete past entries without consensus from the network. This characteristic underpins the integrity of historical records, providing auditors with a reliable, tamper-evident source of data crucial for effective audit trails (Rozario & Thomas, 2019: DeCovny, 2015). Furthermore, the transparency associated with blockchain—where transactions are visible to all

participants in public blockchains—affords auditors unprecedented access to real-time data, thereby bolstering anomaly detection, transaction tracking, and fraud prevention (Schmitz & Leoni, 2019; Rozario & Thomas, 2019).

Decentralization, another significant attribute of blockchain, mitigates risks associated with data manipulation prevalent in traditional auditing where the entity being audited often controls the data. By dispersing data ownership and verification responsibilities across an independent network, blockchain enhances objectivity in the audit process and enables continuous auditing capabilities (Ayman et al., 2019: Lois, et al., 2020). Consequently, auditors can conduct real-time assessments, moving away from retrospective sampling methods that have traditionally characterized auditing practices (Dai & Vasarhelyi, 2017: Lowe, et al., 2017).

As blockchain technology continues to evolve and integrate into auditing processes, it prompts a fundamental reevaluation of traditional audit practices. The auditor's role shifts from manually sampling and reconciling financial records to monitoring and designing automated audit functions within blockchain systems (White et al., 2019; Khatoon, 2020). This necessitates a skill shift for auditors, requiring them to appraise not only financial records but also the integrity of the underlying blockchain infrastructure (Ríkharðsson, Singh & Best, 2019).

In conclusion, the core components and attributes of blockchain—distributed ledgers, consensus mechanisms, smart contracts, immutability, transparency, and decentralization—offer a robust foundation for enhancing modern audit engagements. They effectively address many systemic challenges faced in traditional audits, paving the way for secure, real-time, and tamper-proof assurance systems (Kusumawati & Syamsuddin, 2018: Mamahit & Urumsah, 2018). As the profession continues to adapt alongside emerging technologies, blockchain stands as a pivotal tool poised to redefine audit reliability, enhance stakeholder confidence, and bolster the overall integrity of financial reporting.

2.3. Opportunities for Audit Enhancement through Blockchain

Blockchain technology signifies a transformative potential for enhancing audit processes by addressing critical issues related to trust, timeliness, and transparency in financial transactions. The structural and functional characteristics of blockchain offer auditors novel tools that enhance the reliability of financial records, facilitate real-time verification, and ultimately foster greater confidence among stakeholders (Perdana, Rob & Rohde, 2018: Rahman, 2020: Sestino, et al., 2020). The application of blockchain in auditing is grounded in three central areas of opportunity: creating immutable audit trails, reducing audit lag through real-time data access, and enhancing stakeholder trust and transparency in financial disclosures.

One of the key advantages of blockchain in auditing is its ability to generate immutable audit trails. Traditional audit systems often depend on fragmented data sources and manual reconciliations, which are susceptible to tampering and errors. In contrast, blockchain's architecture ensures that each transaction is logged in a permanent, chronological ledger that cannot be altered retroactively without the consensus of the network (Ponte & Bednárová, 2019; Schmitz & Leoni, 2019). This tamper-proof nature of blockchain recordkeeping significantly strengthens the reliability of data available for audits, greatly diminishing opportunities for fraud or unauthorized manipulations. For instance, firms like Deloitte have begun utilizing blockchain for asset custody tracking, enabling auditors to access a continuous, trustworthy stream of verified data, thus eliminating the need for time-consuming manual sampling techniques (Landis-Lewis, et al., 2015: Sow & Gehrke, 2019).

In addition to promoting data integrity, blockchain also mitigates audit lag by enabling instantaneous recording and verification of transactions. Traditional auditing practices frequently suffer from delays due to manual evidence collection and the retrospective nature of audits which often provide outdated information (Rusmin & Evans, 2017: Sun, 2019). By allowing transactions to be recorded and verified in real-time across a distributed ledger, blockchain empowers auditors to adopt continuous audit

methodologies (Steinbart, et al., 2018). As noted by researchers, blockchain-based platforms can monitor real-time financial activities, ensuring compliance and promoting immediate identification of discrepancies (Dai & Vasarhelyi, 2017: Maradona, 2020). This shift from episodic audits to continuous oversight significantly enhances the timeliness and relevance of audit findings, aligning them more closely with operational realities.

Furthermore, blockchain's implementation of smart contracts provides a powerful mechanism to automate compliance checks directly within transaction processes. These self-executing contracts facilitate the embedding of predefined conditions into transactions, ensuring that necessary approvals are verified before transactions are validated (Arayssi, Jizi & Tabaja, 2020: Sun & Vasarhelyi, 2018). For example, a smart contract could mandate dual authorization for transactions that exceed certain thresholds, effectively reducing risk and increasing efficiency within audit processes (McDonald, Charles & Gafni, 2011: Zyskind et al., 2015). This capability aids auditors in efficiently ascertaining compliance and enhances the overall reliability of internal control systems.

Lastly, the application of blockchain technology cultivates stakeholder trust and transparency in corporate disclosures. In an era marked by skepticism towards financial reports, blockchain allows for the independent validation of financial data without bias from corporate management (Cucari, Falco & Orlando, 2017: Tiwari & Debnath, 2017). By granting stakeholders limited access to specific segments of a company's blockchain ledger, transparency evolves into a verifiable attribute rather than a voluntary disclosure (Noviyanti & Winata, 2015: Ølnes et al., 2017). This democratization of audit evidence increases accountability, particularly in industries subject to stringent regulatory oversight, and aligns with the expectations of investors who are increasingly integrating ESG (Environmental, Social, Governance) criteria into their assessments (Ponte & Bednárová, 2019: Yuara, Ibrahim & Diantimala, 2019).

Despite the evident advantages, the integration of blockchain into auditing processes necessitates a shift in auditors' mindsets and methodologies. As auditors transition from traditional, document-heavy practices to data-integrated approaches, they will need to familiarize themselves with concepts of blockchain technology, systems architecture, cybersecurity, and data governance (Adiloğlu & Güngör, 2019: Schmitz & Leoni, 2019). The pathway towards effective blockchain adoption in auditing requires significant investment in training and interdisciplinary collaboration among auditors and IT professionals.

In conclusion, blockchain technology presents profound opportunities for enhancing audit processes by addressing fundamental shortcomings in traditional systems. The innovative attributes of blockchain—namely, immutability, real-time processing, and enhanced transparency—empower auditors to deliver more accurate, timely, and trustworthy assurance (Aliyu, et al., 2020: Diamantopoulou, Tsohou & Karyda, 2020). While challenges in skill acquisition and integration persist, the trajectory of ongoing blockchain adoption suggests a future where auditing evolves into a proactive and responsive paradigm, improving overall trust and efficiency in financial processes (Veenstra & Ellemers, 2020).

2.4. Limitations and Challenges

Despite the transformative potential of blockchain-based assurance systems, significant limitations and challenges hinder their integration into mainstream audit practices. These challenges include technical constraints, regulatory uncertainties, and professional skill deficits that affect the effectiveness and sustainability of this technology in auditing environments.

One of the most pressing limitations is the integration of blockchain systems with legacy enterprise resource planning (ERP) and accounting software. Organizations typically rely on well-established digital infrastructures customized over years, which often lack compatibility with blockchain technologies (Drivas, et al., 2020: Ramasubramanian, Ranasinghe & Ellison, 2011: Zhao, et al., 2018). As Gauthier and Brender discuss, the complexity involved in data migration, reengineering processes, and developing interfaces to synchronize these traditional systems with blockchain creates both technical and financial challenges that can deter firms from adoption. Furthermore, the integration difficulty is compounded by the absence of standardized application

programming interfaces (APIs). This reality illustrates why many organizations hesitate to proceed with blockchain adoption.

In addition to technical hurdles, cultural and institutional resistance to change significantly impacts the integration of blockchain functionalities within traditional audit firms. The auditing profession has long been characterized by conservative practices and established standards, which can lead to reluctance to adopt innovative technologies (Schmitz & Leoni, 2019: Islam, Farah & Stafford, 2018). Perera and Abeygunasekera discuss concerns about potential job displacement within traditional accounting roles prompted by automated blockchain systems as sources of resistance. This inertia can stem from a lack of understanding of blockchain's benefits or fear of losing control over auditing processes. Consequently, organizations often face internal barriers that inhibit proactive technological adaptation.

Regulatory uncertainties present another major obstacle to the adoption of blockchain in auditing. Unlike conventional audits governed by established international standards, blockchain-based assurance lacks universally accepted protocols for evidence collection, evaluation, and reporting (Joshi, Elluri & Nagar, 2020: Tan & Low, 2019). As highlighted by Georgiou et al., this regulatory vacuum leaves auditors vulnerable to legal challenges, particularly when blockchain-derived findings may be contested in legal or regulatory scenarios. The complexity increases in multi-jurisdictional blockchain networks, raising questions of liability, data ownership, and compliance that vary across regions (Hew et al., 2020: Setiyawati, Iskandar & Putri, 2020). This regulatory ambiguity further complicates the business case for adopting blockchain technologies in auditing contexts.

Moreover, scalability and privacy issues are significant limitations, especially within public blockchain environments. While providing transparency and immutability, public blockchains often struggle with high transaction volumes typical in corporate auditing (Longo et al., 2019: Soleymani, et al., 2019). Longo et al. argue that the performance bottlenecks associated with public blockchains can hinder their practicality in real-time auditing scenarios, making alternatives necessary (Kahyaoğlu & Çalıyurt, 2018: Stevens, Moroney & Webster, 2019). Privacy remains a critical concern, particularly regarding compliance with data protection laws such as GDPR. The open-access nature of public blockchains often conflicts with requirements for safeguarding sensitive financial information, thereby limiting their application in many auditing contexts. While permissioned blockchains can alleviate privacy issues, they tend to sacrifice the decentralization that is paramount for trust (Lankton, Price & Karim, 2020: Schmitz & Leoni, 2019).

The availability of skills and resources to implement blockchain effectively also presents challenges. Auditors are typically not trained in cryptographic protocols or smart contract logic, necessitating significant upskilling across the profession. The transition to a blockchain-integrated audit environment calls for new training programs and collaboration with IT professionals, but such initiatives require substantial financial and time investments. While the initial blockchain adoption costs can be significant, particularly for smaller enterprises, the lack of a clear business case reinforces hesitance toward substantial investment in blockchain technologies (Lewallen, 2020: Tan & Low, 2019).

Lastly, the immutable nature of smart contracts raises auditability concerns. Although they offer promising solutions for automating compliance, their complexity and opacity demand auditors to possess specialized knowledge for effective evaluation (Rozario & Vasarhelyi, 2018: Sabillón, et al., 2017). The potential for bugs and errors within smart contracts poses new risks in ensuring audit quality, requiring the development of tailored review practices that extend beyond traditional auditing methodologies (Rozario & Vasarhelyi, 2018: Szymczak, et al., 2014).

In conclusion, while the potential of blockchain to revolutionize the auditing profession is well recognized, its integration is constrained by multifaceted challenges stemming from technical, regulatory, and cultural dimensions. Addressing these hurdles demands collaborative efforts among stakeholders in the auditing field, regulatory authorities, and providers of blockchain technology to fully realize the benefits of this innovative tool for

assurance systems (Sardi, et al., 2020: Tejedor-Sojo, Creek & Leong, 2014).

2.5. Case Studies and Industry Applications

The implementation of blockchain-based assurance systems in audit engagements signifies a transformative shift from theoretical discussions to practical applications, particularly in notable professional services firms and tech-savvy enterprises. Several case studies from the Big Four accounting firms—Deloitte, Ernst & Young (EY), PricewaterhouseCoopers (PwC), and KPMG—alongside pilot projects from specialized audit platforms, illuminate the benefits and challenges associated with blockchain adoption in auditing (Pirotti & Roknifard, 2020; Cheng & Huang, 2019). These practical applications exhibit how blockchain technology can bolster audit reliability, enhance operational efficiencies, and foster trust in financial reporting, while also uncovering various technological, regulatory, and organizational challenges that may impede its broader implementation (Li et al., 2020: Sulistyowati, Handayani & Suryanto, 2020).

One significant example of blockchain application in the audit domain is Deloitte's engagement with distributed ledger technology (DLT) to streamline transaction verification and financial recordkeeping. Deloitte has made substantial investments in blockchain R&D, establishing global blockchain labs that create prototypes simulating blockchain environments for audits (Pirotti & Roknifard, 2020: Cheng & Huang, 2019). A noteworthy pilot included an internal blockchain system that automated audit processes through real-time transaction validation, allowing auditors access to comprehensive and immutable transaction data. This innovation minimized the necessity for manual sampling and reconciliations, enabling Deloitte's auditors to prioritize higher-risk areas and conduct more analytical reviews. The result is a shift from a retrospective audit approach to proactive risk assessments, leveraging blockchain's real-time data capabilities (AlKetbi, et al., 2014: Jiang, 2018).

EY has demonstrated its leadership in blockchain auditing, notably through initiatives aimed at cryptocurrency audits. The "Blockchain Analyzer," a tool developed by EY, equips auditors to collect and scrutinize blockchain transaction data across public networks such as Bitcoin and Ethereum. This tool enhances auditors' capacity to assess cryptocurrency ownership and validate balances in alignment with audit requirements (Pirotti & Roknifard, 2020: Cheng & Huang, 2019). An exemplary case involved a project with a European government utilizing EY's OpsChain platform to trace public fund distributions, thereby enhancing transparency and preventing misuse of funds. This highlights blockchain's utility in advancing not only financial audits but also accountability in public sectors (Chang & Luo, 2019: Cheng & Huang, 2019). Architecture of the blockchain based Access Control Service customized for the smart resource reference scenario. PEP BASE and PAP BASE represent the logic operations of traditional PEP and PAP performed by the smart resource presented by Maesa, Mori & Ricci, 2019, is shown in figure 4.

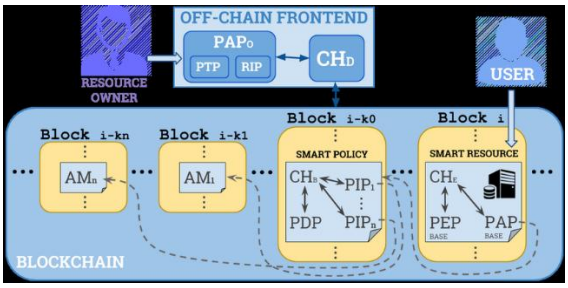

Figure 4: Architecture of the blockchain based Access Control Service customized for the smart resource reference scenario. PEP BASE and PAP BASE represent the logic operations of traditional PEP and PAP performed by the smart resource (Maesa, Mori & Ricci, 2019).

PwC has also advanced its audit and assurance services through blockchain technology, creating a tracking solution that aligns transactions on blockchain networks with audit criteria. In a notable case involving a cryptocurrency firm, traditional audit techniques fell short due to the complexities inherent in blockchain transactions. PwC's strategies included custom blockchain tools that allowed comprehensive validation of digital asset flows and assurances over financial statement components. They have further established guidelines for auditing blockchain systems and smart contracts, facilitating best practices in this nascent field (Jiang, 2018; Pirotti & Roknifard, 2020).

KPMG has emphasized building enterprise-level assurance frameworks, collaborating with major technology players to create blockchain solutions specifically for sectors like telecommunications. Their partnership with Microsoft and others aimed to develop a platform that improves transparency in high-volume intercompany transactions, thereby minimizing errors in reconciliations (Askary, Goodwin & Lanis, 2012: Cheng & Huang, 2019). This response to the challenges of high-frequency transaction environments showcases the potential of blockchain to facilitate efficient audit processes while providing a verifiable transaction trail (Ciołek, 2017: Pirotti & Roknifard, 2020).

Beyond the Big Four, the emergence of dedicated blockchain platforms signifies a broader industry trend towards technology-enhanced auditing. Platforms like Confirm and Chainalysis Reactor exemplify the functionality of specialized tools for auditing cryptocurrency transactions and establishing compliance and fraud detection trails in digital finance (Colquhoun, et al., 2016: Pirotti & Roknifard, 2020). In supply chain auditing, IBM's Food Trust illustrates blockchain's application in quality assurance and regulatory compliance within industries like food distribution, demonstrating how this technology ensures transparency and efficiency (Cheng & Huang, 2019: Hu, et al., 2020). Similarly, VeChain's partnership with DNV solidifies blockchain's role in providing assurance across various product attributes, extending the audit scope to include environmental, social, and governance (ESG) factors (Betti & Sarens, 2020: Pirotti & Roknifard, 2020).

The implications of these developments are profound, indicating that blockchain technology might fundamentally reshape audit practices across various sectors. Although challenges remain—such as integration with legacy systems, professional skill gaps, and evolving legal frameworks—early successes from pilot projects suggest a promising path forward for blockchain in assurance practices (Cooke, et al., 2018: Rozario & Vasarhelyi, 2018). The case studies from these leading firms underscore blockchain's transition from theoretical potential to operational reality in modern auditing, paving the way for standardized methodologies and cross-sector partnerships aimed at enhancing integrity, transparency, and efficiency in the auditing landscape (Cheng & Huang, 2019; Pirotti & Roknifard, 2020).

2.6. Future Directions

The future of blockchain-based assurance systems in audit engagements is poised to be profoundly influenced by a convergence of advancing technologies, collaborative actions among professionals, and evolving regulatory landscapes. Early pilot projects indicate that blockchain has the potential to enhance audit reliability, transparency, and efficiency. However, to institutionalize these gains, it is imperative to address various structural, legal, and methodological gaps that hinder widespread adoption throughout the auditing profession.

Three major developments are anticipated to play significant roles in shaping this future: the creation of hybrid assurance models, the formulation of standardized audit frameworks by professional bodies, and substantial research into specialized blockchain audit toolkits. Hybrid assurance models, in particular, represent a promising direction for incorporating blockchain into traditional auditing practices. These models combine blockchain's strengths—such as decentralization and immutability—with established audit techniques. The synergistic approach means that blockchain can serve as a data verification layer while traditional methods interpret the data's context, which is essential in financial statements and compliance frameworks (Ponte & Bednárová, 2019; Schmitz & Leoni, 2019; Liu et al., 2019). For instance, blockchain could validate the authenticity of financial transactions without completely switching to a blockchain-only audit process, which may not be feasible for many organizations currently reliant on legacy ERP systems. Instead, firms can implement blockchain selectively in critical areas such as revenue recognition or contract compliance (Schmitz & Leoni, 2019; Liu et al., 2019).

Professional and regulatory bodies like the International Federation of Accountants (IFAC) and the American Institute of Certified Public Accountants (AICPA) have started to address the need for audit frameworks specifically tailored to blockchain technologies. Their efforts include defining how blockchain data should be treated as audit evidence, auditing smart contracts, and establishing how audit opinions may reflect findings from distributed ledger

environments (Schmitz & Leoni, 2019; Rozario & Vasarhelyi, 2018). Such initiatives are crucial for building a shared vocabulary and mutual understanding necessary for effective blockchain audit engagements that meet global standards of quality. For instance, the guidance published by the AICPA serves to clarify the complexities involved in verifying ownership of digital assets and navigating consensus mechanisms inherent to blockchain, underscoring the importance of formalized standards in enhancing audit quality and trust in blockchain contexts (Ponte & Bednárová, 2019; Rozario & Vasarhelyi, 2018).

Moreover, the advancement of research into blockchain audit toolkits is essential for developing user-friendly tools that can facilitate audits within blockchain environments. These toolkits are expected to encompass capabilities for data extraction, verification, anomaly detection, and risk assessment, employing artificial intelligence and machine learning to bolster auditing effectiveness (Cooke, et al., 2018: Schmitz & Leoni, 2019). Investigations into automated audit agents that can monitor transactions in real-time offer substantial promise in reducing reliance on traditional manual data analysis, thus enhancing the role of auditors by providing ongoing insights and the ability to flag potential issues proactively.

As the practical application of blockchain technology grows, its potential role in enhancing sustainability and assurance of environmental, social, and governance (ESG) reporting is also worth exploring. Blockchain's transparency is well-suited for tracking ESG metrics within supply chains, allowing for expanded assurance services that align with rising demands for non-financial reporting verification. Collaboration between academic institutions, audit firms, and technology providers will be pivotal in advancing the research agendas necessary for equipping the auditing profession to meet these challenges effectively.

In summary, the convergence of hybrid assurance models, the establishment of standardized audit frameworks, and the ongoing development of specialized blockchain audit toolkits represent essential pillars that will shape the future of blockchain-based assurance systems in audit engagements. By navigating these avenues, the profession can enhance reliability, transparency, and stakeholder trust, reaffirming its role in ensuring accountability in an increasingly complex digital landscape. Education and continuous capacity-building efforts will further support auditors in adapting to and excelling within this transformed assurance environment (Eissa, 2020: Haapamäki & Sihvonen, 2019).

2.7. Conclusion

Blockchain-based assurance systems represent a significant paradigm shift in the way audit engagements are conceived, executed, and valued. With their inherent features of immutability, transparency, and decentralization, blockchain technologies offer auditors powerful tools to enhance data integrity, reduce fraud risks, enable real-time verification, and build stronger stakeholder trust. These capabilities mark a departure from traditional audit approaches that rely heavily on retrospective sampling, manual reconciliations, and delayed reporting. Blockchain facilitates continuous auditing, automates compliance through smart contracts, and provides auditors with access to complete, tamper-proof transaction histories, thus increasing the overall credibility and efficiency of assurance activities.

However, alongside its promising opportunities, blockchain's integration into auditing is not without serious limitations. Practical challenges such as the lack of interoperability with legacy ERP systems, the resistance to change among traditional firms, and the steep learning curve for audit professionals highlight the complexity of implementing blockchain at scale. Additionally, the absence of standardized regulatory frameworks, jurisdictional inconsistencies, and data privacy concerns continue to hinder universal adoption. Issues surrounding scalability and the auditability of smart contracts further complicate its operationalization in diverse industry contexts. These limitations suggest that while blockchain can revolutionize audit engagements, its adoption must be strategically managed, informed by both technological readiness and institutional will.

Moving forward, collaborative innovation among auditors, technologists, regulators, and standard-setting bodies is essential. It is only through joint

efforts that the auditing profession can establish robust frameworks, develop hybrid assurance models that bridge the old and the new, and produce reliable toolkits tailored to blockchain environments. Regulatory evolution will also be critical in providing legal clarity, protecting data rights, and ensuring that blockchain-derived audit evidence is recognized and enforceable across jurisdictions.

Ultimately, blockchain is more than a technical upgrade; it represents a fundamental rethinking of audit assurance in the digital age. By embracing its strengths while actively addressing its limitations, the profession can reshape auditing into a more transparent, resilient, and forward-looking discipline—capable of meeting the demands of increasingly complex and data-driven global economies.

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