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UNLOCKING BLOCKCHAIN ADOPTION IN HEALTH SYSTEMS: WHAT WORKS, WHERE AND WHY

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Comunicação:
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UNLOCKING BLOCKCHAIN ADOPTION IN HEALTH SYSTEMS: WHAT WORKS, WHERE AND WHY

Objetivo do estudo
Analisar como combinações de fatores tecnológicos, organizacionais e ambientais impulsionam a adoção do blockchain em saúde. Propor e validar um framework decisório, fundamentado no Modelo TOE, por meio de fsQCA com evidências setoriais.

Relevância/originalidade
Apresenta uma perspectiva inovadora que integra bibliometria, análise temática e fsQCA para explicar a adoção do blockchain em sistemas de saúde. A abordagem configuracional identifica múltiplos caminhos viáveis, gerando evidências para teoria, gestão e políticas em contextos regulados.

Metodologia/abordagem
O estudo foi estruturado em três etapas sequenciais. Incluiu mapeamento bibliométrico na Scopus, com análise de tendências, fontes e coocorrência de palavras-chave. Posteriormente, realizou-se codificação qualitativa no NVivo e aplicação de fsQCA, com testes de robustez e sensibilidade.

Principais resultados
Benefícios tecnológicos emergem como fator determinante na adoção de blockchain em saúde. Quatro combinações distintas de fatores TOE levam ao sucesso, confirmando múltiplos caminhos viáveis e dependentes de alinhamentos ou compensações moldados pelo contexto organizacional e regulatório.

Contribuições teóricas/metodológicas
Integra o Modelo TOE à perspectiva configuracional, refinando sua aplicação em contextos regulados de saúde digital. Demonstra a utilidade do fsQCA para identificar múltiplos caminhos de adoção, fortalecendo sua aplicabilidade em estudos de inovação tecnológica e políticas setoriais.

Contribuições sociais/para a gestão
Fornece um framework diagnóstico para gestores e formuladores de políticas em saúde, permitindo planejamento sensível ao contexto. Favorece ampliação de serviços em contextos de poucos recursos, fortalece governança de dados, reduz atritos organizacionais e promove equidade, confiança e segurança do paciente.

Palavras-chave: Blockchain , Sistemas de Saúde, Adoção de Tecnologia, Modelo TOE , fsQCA

UNLOCKING BLOCKCHAIN ADOPTION IN HEALTH SYSTEMS: WHAT WORKS, WHERE AND WHY

Study purpose
Analyze how combinations of technological, organizational, and environmental factors drive blockchain adoption in healthcare. Propose and validate a decision framework, grounded in the TOE model, through fsQCA using sector-specific evidence.

Relevance / originality
Presents an innovative perspective integrating bibliometrics, thematic analysis, and fsQCA to explain blockchain adoption in healthcare systems. The configurational approach identifies multiple viable pathways, generating evidence for theory, management, and policy in regulated contexts.

Methodology / approach
The study was structured in three sequential stages. It included bibliometric mapping from Scopus, with analysis of trends, sources, and keyword co-occurrence. Subsequently, qualitative coding in NVivo and fsQCA application were undertaken, with robustness and sensitivity testing.

Main results
Technological benefits emerge as a key driver of blockchain adoption in healthcare. Four distinct TOE factor combinations lead to success, confirming multiple viable pathways dependent on alignments or trade-offs shaped by organizational and regulatory context.

Theoretical / methodological contributions
Integrates the TOE model with a configurational perspective, refining its application in regulated digital health contexts. Demonstrates fsQCA's utility in identifying multiple adoption pathways, strengthening its applicability in technological innovation research and sectoral policy studies.

Social / management contributions
Provides a diagnostic framework for healthcare managers and policy-makers, enabling context-sensitive planning. Supports service expansion in resource-constrained settings, strengthens data governance, reduces organizational frictions, and promotes equity, trust, and patient safety.

Keywords: Blockchain, Health Systems, Technology Adoption, TOE Framework, fsQCA

UNLOCKING BLOCKCHAIN ADOPTION IN HEALTH SYSTEMS: WHAT WORKS, WHERE AND WHY

1. Introduction

Health systems represent one of the most complex and sensitive sectors in contemporary society (Corte-Real et al., 2022). They operate under intense pressure from chronic underfunding, operational inefficiencies, regulatory fragmentation, demographic shifts, and persistent risks to data and infrastructure security (Joshi & Sharma, 2023; Yadav et al., 2023). Fraud, opacity in procurement, and administrative irregularities may account for substantial losses in public and private health spending, weakening institutional trust and care delivery (Alshamsi et al., 2024). At the same time, digital vulnerabilities intensify. Electronic health records have become prime targets for cyberattacks, often valued far above financial data due to their detailed and personal nature (Alshamsi et al. 2024; Sharma et al. 2023).

The COVID-19 pandemic exposed systemic fragilities in health systems worldwide (Yadav et al., 2023). Digital infrastructures failed to support real-time monitoring, vaccine logistics and cross-border coordination of care (Corte-Real et al., 2022). In response, health authorities and public agencies began to call for data architectures that ensure interoperability, auditability and distributed trust. These principles have guided recent initiatives, such as organ transplant coordination in the Gulf region (Alzahrani et al., 2023) and secure vaccination record exchange across jurisdictions (Yadav et al., 2023). However, such requirements contrast with the fragmented and siloed design of most hospital information systems (Nicolai et al., 2023).

This misalignment between institutional needs and technological capacity has intensified the search for alternative digital solutions. Blockchain has emerged as a candidate to address key management concerns such as data integrity, access control and coordination across actors. Practical applications reinforce this potential. In pharmaceutical supply chains, blockchain has been used to enhance traceability and combat drug counterfeiting, especially for generic medications (Sun et al., 2024). In public health, it has enabled the cross-border exchange of vaccination records, supporting data integrity and interoperability (Yadav et al., 2023).These cases reflect the growing strategic relevance of blockchain for digital health governance.

Despite the growing number of pilot initiatives, implementation outcomes remain inconsistent. Recent reviews identify persistent challenges, including interoperability limitations, low organizational readiness, regulatory ambiguity and the absence of clear value propositions to stakeholders (Alzahrani et al., 2023; Balasubramanian et al., 2021). Many studies report technical or conceptual promise but do not clarify the conditions under which adoption succeeds. Furthermore, few contributions offer a cohesive explanatory model capable of capturing how technological systems, organizational structures and external environments jointly influence blockchain implementation in healthcare settings (Balasubramanian et al., 2021).

To address this gap, the present study asks: what combinations of technological, organizational and environmental factors lead to successful blockchain adoption in healthcare? The analysis uses the Technology–Organization–Environment (TOE) framework (Tornatzky & Fleischer, 1990). It follows a sequential mixed-methods design. The approach includes bibliometric mapping, qualitative content analysis and fuzzy-set Qualitative Comparative Analysis (fsCQA). The study has two goals. The first is to identify where and how blockchain empirically adds value in clinical, organizational and humanitarian settings. The second is to develop a decision-oriented framework. This framework links context-specific condition profiles with adoption strategies supported by empirical evidence.

By moving beyond scattered empirical findings, this study offers a structured explanation of how blockchain implementation occurs in healthcare, a context where innovation often encounters regulatory, institutional, and infrastructural constraints. Its originality lies in applying a rarely used methodological combination in the healthcare blockchain literature and in extending the TOE framework with a configurational perspective. By capturing multiple viable adoption pathways (equifinality) and linking them to tailored managerial strategies, the study bridges empirical analysis and actionable guidance for decision-makers.

2. Theoretical Background

Blockchain is a digital infrastructure that enables multiple actors to record and validate transactions in a decentralized environment, without relying on a central authority (Stafford & Treiblmaier, 2020). Initially introduced for digital currencies, the technology has evolved into a broader class of systems designed to promote transparency, data integrity and coordination in distributed networks (Alzahrani et al., 2023). Rather than centralizing information in a single institution, blockchain replicates it across nodes in a network, where updates are confirmed by consensus and stored immutably (Alshamsi et al., 2024; Stafford & Treiblmaier, 2020). Once validated, records become tamper-resistant and permanently auditable (Sun et al., 2024). In healthcare, this architecture supports a range of applications, including clinical data governance, drug traceability and inter-organizational authentication of medical records (Alzahrani et al., 2023; Balasubramanian et al., 2021).

Recent research highlights a growing focus on blockchain integration in healthcare. This interest intensified after the structural weaknesses exposed by the COVID-19 pandemic (Govindarajan et al., 2025). Blockchain is being explored for its ability to improve traceability, security and data integrity in health information systems. Systematic reviews and patent analyses, published in recent years, confirm growing interest in using distributed ledger technologies to solve problems in data sharing, identity management and institutional coordination (Govindarajan et al., 2025; H. Hu et al., 2023). Applications include secure access to medical records, vaccine tracking and automated patient consent (Govindarajan et al., 2025). These use cases build on the immutability and auditability of blockchain to strengthen trust in digital health environments.

Empirical studies illustrate the practical impact of blockchain in healthcare. In India, cold-chain platforms using blockchain and the Internet of Things (IoT) supported the maintenance of stable temperatures for vaccine doses during field monitoring (Yadav et al., 2023). In Europe, permissioned ledgers support portable health identification documents (IDs) that comply with the General Data Protection Regulation (GDPR) and ensure cross-border access to care (Corte-Real et al., 2022). Hospitals have adopted non-fungible tokens (NFTs) to manage the resale of refurbished equipment, improving traceability and reducing delays in asset turnover (Alshamsi et al., 2024). In forensic settings, blockchain has been used to secure dental records for disaster victim identification, where auditability and access control are essential (Nuzzolese, 2020).

Multi-country case syntheses identify interoperability gaps, regulatory misalignment and limited digital readiness as dominant inhibitors to blockchain adoption in healthcare (Boumezbeur & Zarour, 2022). While technical maturity has advanced, barriers such as legacy infrastructure, stakeholder resistance and fragmented policy landscapes continue to limit broader uptake (Viswanathan & Lakshmi, 2024). Although recent studies demonstrate blockchain's value for data protection and consent management, few contributions have integrated these capabilities into cohesive models that explain how adoption varies across institutional and geographic contexts (Boumezbeur & Zarour, 2022; Viswanathan & Lakshmi, 2024).

Technology adoption depends not only on technical performance but also on compatibility with organizational structures and external conditions (Tornatzky & Fleischer, 1990). In primary-care settings, electronic health record (HER) initiatives show that fragmented governance, limited leadership support, and workforce gaps hinder implementation even when systems are technically sound (Balasubramanian et al., 2021). Similar patterns appear in blockchain adoption for elder care, where organizational readiness, trust in technology, and information security drive adoption intent, while privacy concerns have little effect (Meier et al., 2021). These findings highlight how internal capacity, institutional environment, and technological design jointly shape implementation outcomes.

The TOE framework offers a structured basis for studying adoption but often applies a linear logic that can overlook the configurational complexity of real-world settings (Alzahrani et al., 2023; Fiss, 2011; Wei et al., 2024). From a complexity perspective, adoption results from interdependent combinations of technological, organizational, and environmental factors—a logic of equifinality demonstrated in digital transformation research (Sabuncu & Bilgehan, 2024; Shen et al., 2023). This perspective aligns with set-theoretic approaches such as fsQCA, which can capture multiple causal configurations (Fiss, 2011; Zheng et al., 2021).

3 Methodology

This study applies a sequential mixed-methods design to examine blockchain adoption in healthcare. The approach unfolds in three interlinked phases. First, a bibliometric scan traces the thematic evolution of the field. Second, a theoretically relevant subset of studies is selected for in-depth coding to extract TOE-related benefits and barriers. Third, fsQCA assesses whether specific combinations of these conditions are consistently associated with successful implementation. Prior studies in domains such as green innovation (Jiao et al., 2020), alliance performance (Zheng et al., 2021) and digital servitisation (Sjödin et al., 2023) have shown that fsQCA is effective in revealing equifinal pathways in complex socio-technical contexts. Building on those insights, this study adapts the method to the less-explored intersection between blockchain and healthcare, where adoption mechanisms remain poorly understood. The full sequence is summarized in Figure 1, which illustrates the progression from bibliometric analysis to thematic coding and finally to configurational modelling, with iterative feedback supporting refinement across stages.

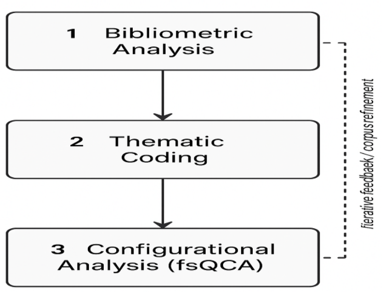

Figure 1. Sequential three-stage design integrating bibliometric mapping, thematic coding, and fsQCA

We retrieved the initial corpus from Scopus using the query TITLE-ABS-KEY (blockchain AND health), which targets literature explicitly addressing blockchain in health-related contexts. Truncation (i.e., health**) was intentionally avoided to reduce semantic noise from broadly related terms such as healthiness or healthtech, in line with recommended precision-first search strategies (Cooper et al., 2018). Scopus was selected as the sole database due to its broad and curated coverage of peer-reviewed literature in business, management, and social sciences, and its suitability for bibliometric workflows (Martín-Martín et al., 2021). While multi-database searches may increase recall, relying on a single high-quality source is appropriate when coverage is sufficient and filtering criteria are applied consistently (Bramer et al., 2017).

The temporal window (2019–2025) was selected based on evidence that blockchain applications began expanding significantly beyond finance into sectors such as healthcare, public services, and supply chains around 2019 (Shen et al., 2023) . The initial query returned 7,988 documents. To ensure thematic focus and analytical consistency, filters were applied for publication year, language (English), document type (articles only), and subject areas (Business, Management and Accounting; Social Sciences; and Decision Sciences—the latter included to capture decision-making and adoption frameworks). After all criteria were applied, the final dataset comprised 456 peer-reviewed articles.

Working from a single database eliminated the need for deduplication. The exclusion and filtering process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework to ensure procedural transparency and reproducibility (Page et al., 2021). This final dataset served as the empirical base for the bibliometric and lexical analyses conducted in the next stage, using the Bibliometrix R package and its web interface Biblioshiny. The filtering process is summarized in Figure 2.

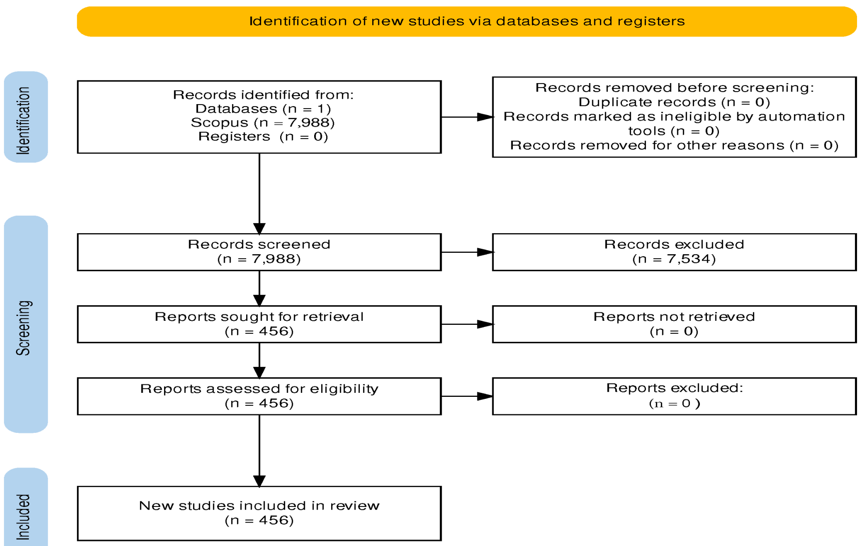

Figure 2. PRISMA flow diagram of the literature search and selection

We used the Bibliometrix R package (version 4.2) to conduct the keyword co-occurrence analysis through its web interface, Biblioshiny (Aria & Cuccurullo, 2017). R is an open-source environment for statistical computing that has become a standard tool in empirical research across the social sciences and management (Aria & Cuccurullo, 2017). In addition to constructing the co-occurrence network, we extracted bibliometric indicators such as publication trends, citation frequencies and keyword distributions to support the descriptive overview presented in Section 4.1. Author-supplied keywords that appeared in at least five documents were used to generate the network. We identified community structure using the Louvain modularity algorithm with a resolution parameter of 1.0. This parameter controls cluster granularity: higher values produce smaller, more detailed groups, while lower values create broader aggregations.

The final graph contained 50 nodes, meaning 50 distinct keywords, and 217 edges, meaning 217 keyword pairs that co-occurred at least once. The network's modularity score was 0.42. Modularity quantifies how much more densely connected the nodes are within clusters than between clusters; values above about 0.30 usually indicate a well-defined community structure, so a score of 0.42 suggests that the clusters are meaningful. Louvain partitioned the network into three cohesive keyword communities. These clusters were interpreted with the Technology–Organization–Environment framework, providing the thematic scaffolding for subsequent qualitative coding and configurational analysis.

The sample comprises 15 healthcare studies, with five articles selected from each of the three keyword clusters using a composite indicator of citation count and PageRank centrality. This ensured balanced thematic coverage while meeting fsQCA small-N standards for case-oriented research (Fiss, 2011).Calibration followed the (Zheng et al., 2021),adapted for fuzzy sets, with thresholds derived from qualitative coding in NVivo, a software for systematic analysis of qualitative data. The fsQCA, implemented in R, applied a consistency threshold of 0.80, and robustness checks varied thresholds by ±0.05, yielding no substantive changes in solutions and confirming consistency without logical contradictions. The final solution reached an overall consistency of 0.91, meaning the solutions accurately represent most observed successful cases. Section 4.3 presents additional details of the fsQCA procedure.

The analysis tested model robustness through triangulation across methods and sensitivity checks. It found no contradictory configurations in the truth table. The solution remained stable under minor adjustments to analytical parameters. The sample size and design met established criteria for fsQCA and aligned with empirical precedents. These procedures reinforced the validity of the identified configurations.

4 Results

This section presents the empirical findings of the study, combining bibliometric, qualitative, and configurational analyses. We begin by mapping the knowledge base on blockchain applications in healthcare using structured metadata retrieved from Scopus and processed through the Bibliometrix R package and its web interface, Biblioshiny (Aria & Cuccurullo, 2017). These tools support descriptive profiling of the field through publication trends, citation performance, authorship patterns, and keyword structures. This evidence defines the empirical scope of the literature and informs the thematic coding and configurational modelling that follow.

4.1 Annual Growth and Bibliometric Profile

Academic interest in blockchain-enabled healthcare has grown steadily in recent years. As shown in Figure 3, annual scientific output increased from 11 documents in 2019 to 114 in 2024. This expansion reflects a compound annual growth rate of 29.13%. The sharp rise after 2021 coincides with the post-COVID-19 period, often viewed as a turning point for digital health. The pandemic exposed gaps in interoperability, patient identification, and supply chain coordination, prompting new investments in distributed ledger technologies (Yadav et al., 2023). Recent reviews confirm that this shift accelerated experimentation and funding in the health-blockchain space (Govindarajan et al., 2025). The lower count for 2025 is likely due to incomplete indexing at the time of analysis.

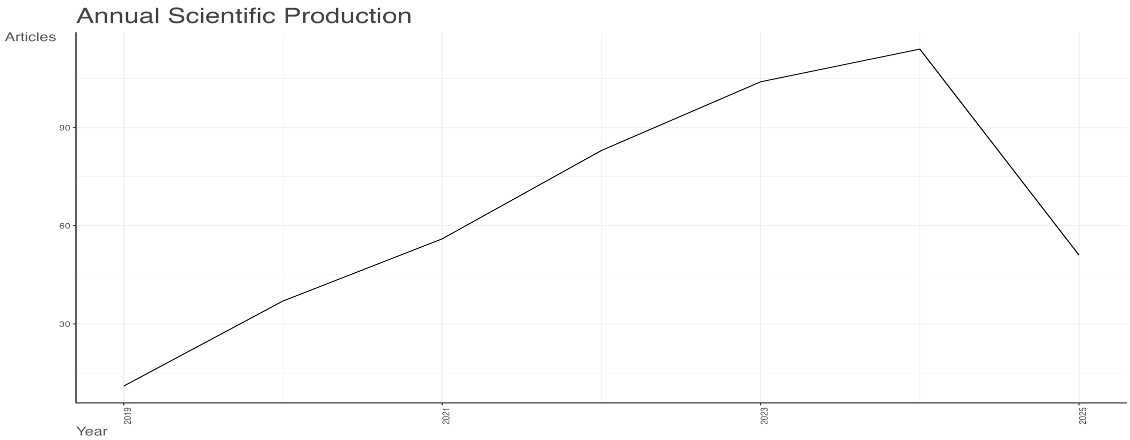

Figure 3. Annual publications on blockchain in healthcare (2019–2025). Data from Scopus via Bibliometrix. Lower value in 2025 reflects partial indexing.

The dataset comprises 456 peer-reviewed documents indexed in Scopus between 2019 and 2025, spanning 232 scholarly outlets. Authorship patterns reveal a high level of collaboration. A total of 1,536 unique authors contributed to the corpus, with an average of 3.76 co-authors per article. International collaboration accounts for 32.89% of the publications. This level of cross-border co-authorship aligns with previous findings on emerging digital domains, where complexity often drives networked research practices (Rejeb et al., 2021).

The thematic structure is broad. The 2,831 author-supplied keywords point to recurring concepts such as security, traceability, interoperability, patient data, governance, and digital identity. This lexical diversity reflects the field's multidisciplinary nature, spanning technical, organizational, and regulatory subdomains (Boumezbeur & Zarour, 2022).

Despite its relatively recent emergence, the literature already demonstrates academic traction. The average document age is 2.29 years, and the mean number of citations per article is 28.92. Together, these indicators suggest that research on blockchain in healthcare is moving beyond conceptual exploration toward more structured and programmatic inquiry. This evolution justifies the deeper analytical stages that follow in this study.

4.2 Thematic Analysis

This section shifts from descriptive profiling to the conceptual structure underlying the field. We analyze patterns of keyword co-occurrence to identify thematically cohesive domains in the literature. The resulting map, shown in Figure 4, was generated using Biblioshiny with the parameters detailed in the Methodology section. It translates co-occurrence frequencies into a network structure that reveals how research activity clusters around specific areas of inquiry. The graph displays three densely connected communities, each corresponding to a dominant thematic axis. These clusters, colour-coded in blue, red and green, exhibit strong internal cohesion and serve as analytical entry points for the next stage. Interpreted through the TOE framework, they guide the discussion that follows, where each cluster is examined in terms of its core concepts, representative studies, and relevance to blockchain adoption in healthcare contexts.

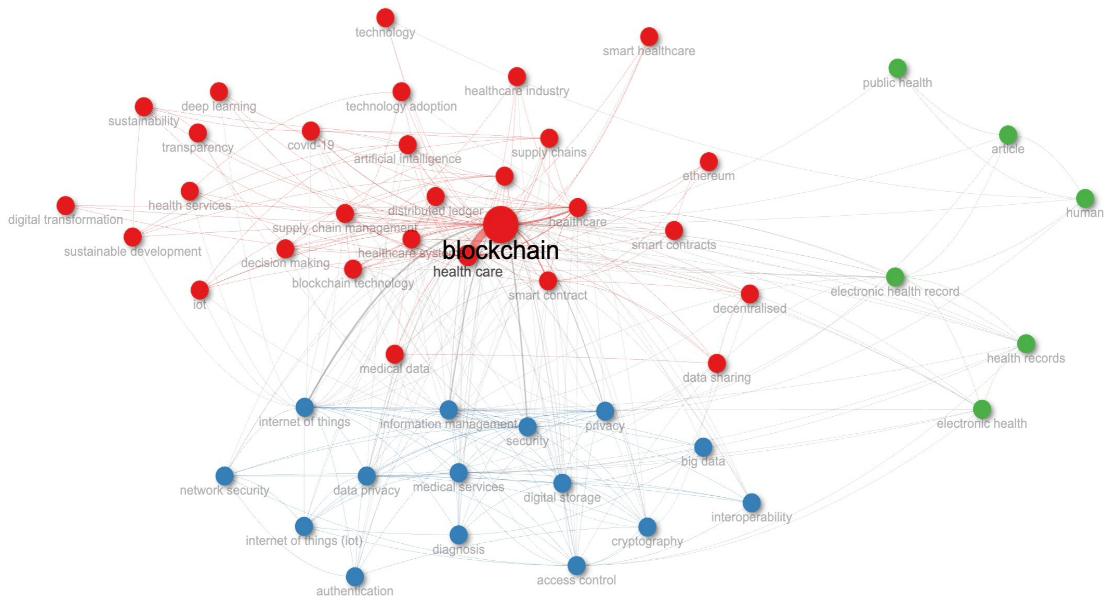

Figure 4. Keyword co-occurrence network (50 nodes; 217 edges; min. 3 edges) from the study's Scopus dataset (2019–2025), generated in R/Biblioshiny using the Louvain algorithm, showing three clusters. Node size = keyword frequency; edge weight = co-occurrence strength.

Technological cluster (Blue): securing system-level functionality through architectural innovation

The technological cluster displays a balanced lexical structure, where several core terms share centrality without one dominating the theme. In keyword co-occurrence networks, PageRank measures the relative structural importance of a term based on its connections to other central nodes. Here, keywords such as security (PageRank = 0.025), privacy (0.024), and interoperability (0.021) anchor the cluster's conceptual core. These terms form a dense and cohesive group that bridges related topics such as cryptography (0.020) and access control (0.018), reinforcing the architectural focus of the cluster.

Empirical studies within this group explore how blockchain design affects implementation in healthcare. Several contributions focus on cryptographic protocols that support secure, privacy-preserving data exchange in decentralized environments (Zou et al., 2021). Others propose modular infrastructures, including multi-chain configurations that separate public and private records to improve traceability and reduce latency (J. Hu et al., 2024). Research also investigates device-level integrity and real-time authentication using lightweight consensus protocols and access tokens in Internet of Medical Things (IoMT) applications (Akkaoui, 2023). Additional work demonstrates how smart contracts can automate role-based access and encode disease-specific permissions, embedding institutional protocols into blockchain logic (Azbeg et al., 2023).

Together, these findings highlight the technical affordances and constraints that shape adoption. Benefits include tamper-evident storage, cryptographic assurance, and decentralized auditability. Key barriers persist, however, around scalability, legacy-system integration, and energy overhead. The thematic emphasis of this cluster aligns with the Technology dimension of the TOE framework, where adoption depends on what blockchain can enable, constrain, or require from digital health infrastructure.

Operational cluster (Red): redesigning organizational processes for blockchain integration

The organizational cluster is anchored by blockchain, the most central term in the entire co-occurrence network (PageRank = 0.040). It links a dense set of concepts with high structural relevance, including healthcare systems (0.020), supply chain management (0.015), decision making (0.014), and distributed ledger (0.014). These terms concentrate around institutional routines, infrastructure, and operational coordination. Their configuration reflects how blockchain is framed not only as a technology, but as a mechanism for managing process flows and organizational complexity.

Studies in this group examine healthcare organizations as the main arena for blockchain implementation. One contribution explores the integration of blockchain and artificial intelligence in hospital triage systems, identifying clinical benefits but highlighting misalignment with internal routines as a key barrier (Joshi & Sharma, 2023). Another presents a smart contract architecture for managing medical equipment, showing how automation in leasing, resale and certification improves traceability and reduces asset losses (Alshamsi et al., 2024). Research on vaccine logistics in India demonstrates the potential of blockchain for monitoring and fraud prevention, but points to low readiness and fragmented data as limiting factors (Yadav et al., 2023).Additional analysis of hospital supply chains shows that siloed data flows and hierarchical approval systems constrain deployment, even where technical feasibility is high (Joshi & Sharma, 2023). A broader synthesis across cases identifies weak governance structures and lack of managerial support as common inhibitors to adoption (Viswanathan & Lakshmi, 2024).

These findings indicate that adoption hinges less on technical readiness and more on organizational capacity. Blockchain alters how decisions are made, how workflows are coordinated, and how responsibilities are distributed. It requires restructuring institutional logic, not just adapting systems. Within the TOE framework, this cluster exemplifies the Organization dimension, where internal alignment, role clarity, and managerial engagement define the conditions for successful integration.

Environmental cluster (Green): mediating global access and public value through blockchain infrastructures

The environmental cluster interprets blockchain as a response to macro-level challenges that lie outside organizational boundaries. Unlike the other clusters, its focus is not on internal processes or technical design, but on public access, policy alignment, and system-wide equity. Keywords such as electronic health record (PageRank = 0.023), health records (0.015), and electronic health (0.015) anchor the network. Others—like public health, article, and human—reinforce a broad concern with institutional fragmentation, demographic pressure, and mobility. The distribution is even, with no dominant node, indicating a diffuse but cohesive thematic structure shaped by environmental constraints.

Studies in this cluster examine how blockchain supports access, coordination, and rights across jurisdictional and institutional borders. One contribution proposes digital health identities for migrants and displaced persons, enabling cross-border data portability and inclusion (Corte-Real et al., 2022). Another explores encrypted dental records as a basis for disaster victim identification, involving hospitals, coroners, and forensic teams (Nuzzolese, 2020). A third study presents a hybrid architecture that combines encrypted cloud storage with Ethereum-based smart contracts to manage access permissions and legal compliance (Boumezbeur & Zarour, 2022). Additional research shows how blockchain-linked credentials with biometric input can enable civil registration and health insurance eligibility for undocumented individuals (Nuzzolese, 2020). Evidence from humanitarian zones highlights the use of smart contracts for authorizing vaccination record sharing across fragmented systems (Ungar & Seymour, 2024).

These contributions show that blockchain operates here not as a clinical tool or internal platform, but as an infrastructure for navigating institutional gaps and legal fragmentation. It enables coordination between actors, supports regulatory compliance, and expands entitlements. Within the TOE framework, this cluster reflects the Environmental dimension: it captures the influence of external conditions—legal, humanitarian, and systemic—on blockchain adoption.

The green cluster expands the scope of analysis by foregrounding legal, humanitarian and systemic factors that shape blockchain implementation beyond organizational boundaries. Alongside the technical and operational themes identified in the first two clusters, this broader perspective completes the mapping of adoption conditions. The resulting structure aligns with the TOE framework and provides a grounded basis for the configurational analysis that follows.

4.3 Configurational validation using fsQCA

This stage completes the analytical sequence by testing whether the conceptual patterns identified earlier translate into consistent adoption scenarios. The process builds cumulatively on the preceding stages: bibliometric mapping, thematic clustering and qualitative coding. As described in Section 4.2, the thematic analysis revealed three core domains—technological, organizational and environmental—which served as a framework for coding the cases in NVivo. Each of the fifteen articles was coded using a predefined node set that captured both benefits and barriers within each TOE dimension. These codes were converted into six fuzzy-set conditions: technological benefits (T-BEN), technological barriers (T-BAR), organizational benefits (O-BEN), organizational barriers (O-BAR), environmental benefits (E-BEN), and environmental barriers (E-BAR). Calibration thresholds and condition definitions are reported in the Methodology

fsQCA was applied to test whether specific combinations of these conditions consistently explain successful implementation. In this context, success refers to cases where blockchain moved beyond conceptual or pilot stages and demonstrated operational integration, institutional uptake, or sustained use in healthcare contexts. fsQCA enables a configurational view of causality, identifying multiple sufficient combinations of conditions rather than isolating net effects. In this study, it also serves as a structural validation of the thematic architecture developed in earlier stages.

Technological benefits emerged as a quasi-necessary condition (incl.=0.94), suggesting that advantages related to security, privacy, or architectural design are almost always present in successful adoption scenarios. The truth table retained configurations using a minimum consistency threshold of 0.80. Minimization yielded four sufficient solutions. The model achieved an overall solution consistency of 0.91, indicating strong explanatory reliability.

Table 1 presents these four configurations. Each scenario reflects a distinct pathway linking combinations of enabling and constraining conditions to successful adoption. "Consistency" shows how reliably each configuration leads to the outcome, while "Coverage" reflects the proportion of explained cases. Representative studies are listed for each solution.

Table 1. Sufficient configurations explaining successful blockchain adoption

Path & Scenario tag	Core conditions	Consistency	Coverage	Representative cases
Full Alignment (S1)	T-BEN ∧ T-BAR ∧ O-BEN ∧ ¬O-BAR ∧ E-BEN	1.00	0.20	Hospital pilot with stakeholder support (Zou et al., 2021); integrated system with alignment (Boumezbeur & Zarour, 2022)
Enabled but Constrained (S2)	T-BEN ∧ T-BAR ∧ O-BAR ∧ E-BEN ∧ E-BAR	0.86	0.60	Traceability platform with training gaps (Yadav et al., 2023); systems facing internal resistance (Joshi & Sharma, 2023); technical base with low readiness (Viswanathan & Lakshmi, 2024)
Lean, Externally Enabled (S3)	T-BEN ∧ ¬T-BAR ∧ ¬O-BEN ∧ ¬O-BAR ∧ E-BEN ∧ ¬E-BAR	1.00	0.10	Vaccine delivery via external blockchain with minimal internal IT (Yadav et al., 2023)
Institutional Adoption (S4)	¬T-BEN ∧ ¬T-BAR ∧ O-BEN ∧ ¬O-BAR ∧ E-BEN ∧ E-BAR	1.00	0.10	Compliance-led rollout of cross-border patient ID system (Corte-Real et al., 2022)

[1]Symbols: "∧" = presence; "¬" = absence of the condition.
Source: Developed by the authors based on fsQCA results generated using the QCA package in R.

The four configurations reveal distinct pathways to successful blockchain adoption. S1 (Full TOE alignment) shows that balanced enablement across technological, organizational and environmental dimensions leads to ideal implementation conditions. S2 (Enabled but constrained) indicates that even when external and technical supports are in place, organizational barriers can delay or distort adoption. S3 (Lean, externally enabled) reflects cases where minimal internal complexity and strong environmental support are sufficient, even in the absence of organizational investment. S4 (Institutional adoption) demonstrates that alignment between organizational readiness and environmental drivers can enable adoption without strong technological triggers. Taken together, these results confirm that adoption depends not on individual variables but on coherent, compensatory configurations shaped by context.

5. Discussion

The study reveals a structured path from conceptual mapping to implementation logic. Bibliometric profiling traced the evolution of blockchain research in healthcare and uncovered a dispersed but maturing knowledge base. Thematic clustering organized this base into three consistent domains aligned with the Technology–Organization–Environment framework. Qualitative coding confirmed that benefits and barriers grouped naturally within these dimensions. The fsQCA extended the analysis by identifying four distinct combinations of these factors that consistently explain adoption outcomes. These layers together demonstrate that blockchain adoption is not linear or isolated, but conditional on how enabling elements compensate for barriers across domains.

The configurational analysis confirms that blockchain adoption follows an equifinal logic (Wei et al., 2024).Rather than depending on a single factor, implementation occurs through distinct combinations of technological, organizational, and environmental enablers. The fsQCA identified four sufficient pathways, each marked by a unique balance of benefits and constraints. Some routes reflect full alignment across dimensions, while others show that external pressure or structural simplicity can compensate for internal gaps. This reinforces the view that adoption is not linear but conditional driven by how different forces interact within a given context. Similar dynamics have been observed in digital transformation studies where institutional variability alters adoption trajectories (Jiao et al., 2020; Zheng et al., 2021). Importantly, the truth table also revealed several configurations that did not lead to successful outcomes. These combinations typically lacked organizational capacity or misaligned internal features with environmental demands. As reported in Section 4.3, such cases highlight that adoption fails not simply due to missing resources, but when enabling conditions do not outweigh systemic or internal barriers. The presence of both successful and unsuccessful profiles reinforces the importance of fit, not only readiness, in digital innovation strategies. These findings not only validate equifinal logic but also lay the foundation for a practical framework that connects empirical insights to implementation strategy.

To translate these findings into actionable insight, we developed a decision framework based on the cumulative results of the study (see Table 2). The framework integrates thematic clustering, qualitative coding, and configurational modelling to support healthcare managers in selecting context-appropriate blockchain adoption strategies. It builds on the Technology–Organization–Environment structure and uses the empirically derived configurations from the fsQCA to define diagnostic categories. Rather than suggesting a single optimal path, the framework highlights multiple empirically supported configurations that align internal capabilities with external demands.

To avoid redundancy with the analytical corpus used in the fsQCA, the illustrative cases in Table 2 are drawn from external peer-reviewed studies that reflect similar adoption logics. These articles were selected through a structured screening of recent literature and were not part of the original configurational analysis. Their inclusion serves a dual purpose: first, to demonstrate the practical applicability of each adoption pathway beyond the study sample; and second, to reinforce the external validity of the framework by showing that comparable condition profiles have been observed and tested in independent empirical contexts. This separation between analytical data and illustrative benchmarks ensures methodological transparency while enhancing the generalizability and practical utility of the proposed framework.

Table 2. Integrated Decision Framework for Blockchain Adoption (TOE–fsQCA)

Path & Scenario tag	Tech safeguards?	Org. resources?	External pressure?	Implementation focus	Illustrative case
Full Alignment (S1)	✓	✓	—	Scale integrated pilot	Blockchain-based EHR improved access and interoperability under institutional support (Viswanathan & Lakshmi, 2024)
Enabled but Constrained (S2)	✓	✗	±	Invest in change management and skills	Precision health project with strong tech but coordination gaps (Ganguly, 2024)
Lean, Externally Enabled (S3)	✓	✗	✗	Deploy SaaS in agile environments	IoT–blockchain vaccine tracking in rural areas via cloud support (H. Hu et al., 2023)
Institutional Adoption (S4)	✗	✗	✓	Meet minimum standards first, scale later	GDPR-compliant patient data apps adopted under regulatory pressure in low-readiness contexts (Stafford & Treiblmaier, 2020)

Legend: ✓ = condition present; ✗ = condition absent; — = not decisive; ± = moderate or uncertain influence.
Source: Developed by the authors based on thematic clustering (Bibliometrix), NVivo coding, and fsQCA analysis in Sections 4.2–4.3

These results informed a decision framework that links the fsQCA-derived configurations to practical adoption scenarios. Structured around the three TOE dimensions, it offers four validated routes supported by benchmark cases from external studies.

The *Full TOE alignment* path (S1) reflects complete synergy across the TOE dimensions. It is exemplified by a blockchain-based EHR system that improved patient data access and sharing through strong technical infrastructure, active leadership, and incentive-based engagement. The *Enabled but constrained* path (S2) includes cases where robust blockchain architectures faced internal resistance, as seen in precision healthcare projects that encountered difficulties related to training, stakeholder coordination, and organizational readiness despite sound technical design and blockchain infrastructure. (Ganguly, 2024). The *Lean, externally enabled* path (S3) appears in settings with minimal internal complexity but strong support from external actors, such as the deployment of blockchain–IoT vaccine tracking systems in rural areas, where agile SaaS-based solutions operated independently of sophisticated in-house infrastructure (H. Hu et al., 2023). The *Institutional adoption* path (S4) is illustrated by compliance-oriented implementations of blockchain platforms driven by regulatory mandates, such as GDPR-aligned patient data sharing applications adopted even in low-readiness contexts (Stafford & Treiblmaier, 2020).

The four adoption configurations identified in this study reflect not only technical and organizational capacity, but also deeper institutional and structural dynamics. In particular, institutional theory (Merk & Hoefer, 2024; Mishra et al., 2025) helps explain why adoption pathways such as Institutional adoption (S4)—marked by strong external pressure and low internal capacity—still succeed. These may represent cases of coercive compliance, where organizations adopt blockchain to meet legal or normative mandates rather than internal strategic alignment. Conversely, pathways like Enabled but constrained (S2), where technical infrastructure is present but organizational readiness is low, highlight the importance of absorptive capacity (Duchek, 2013) that is, the ability to internalize and apply external innovations. These insights suggest that successful adoption depends not only on readiness, but on how organizations are embedded in institutional environments and equipped to learn and adapt.

From a managerial perspective, the four adoption paths in Table 3 translate the decision framework into actionable priorities for healthcare settings. Grounded in the fsQCA results and structured by the TOE framework, these priorities indicate how different types of healthcare organizations can align technological, organizational, and environmental conditions to enable blockchain adoption. Each path reflects a distinct balance of enablers and barriers, guiding managers in tailoring strategies to their specific context.

Table 3. Managerial priorities for each adoption path in healthcare settings

Path & Scenario tag	Managerial focus in healthcare
Full Alignment (S1)	Hospitals and integrated networks: balance investment across technology, staff capacity, and regulation; secure institutional incentives before scaling.
Enabled but Constrained (S2)	Healthcare organizations and regional providers: strengthen governance and coordination; address training gaps to maximize technical returns.
Lean, Externally Enabled (S3)	Low-resource healthcare settings: build vendor partnerships and use cloud platforms to deliver services without heavy internal IT.
Institutional Adoption (S4)	Public healthcare authorities: use regulatory mandates to initiate adoption; build internal capacity gradually for sustainability.

Note. Developed by the authors based on the integrated decision framework (TOE–fsQCA), with healthcare focus from benchmark cases and literature.

These priorities reinforce that adoption depends on fit, not formula. The framework guides managers in aligning local conditions with feasible strategies, supporting targeted and realistic planning across diverse healthcare systems.

6. Conclusion

This study examined the conditions under which blockchain adoption succeeds in healthcare. Using a sequential design that combined bibliometric mapping, thematic clustering, and fuzzy-set configurational analysis, the results demonstrate that adoption does not depend on isolated factors. Instead, successful outcomes emerge from specific alignments across technological, organizational, and environmental domains.

The findings refine the Technology–Organization–Environment framework. Benefits and barriers group naturally within the three dimensions, but implementation only occurs when enabling conditions outweigh systemic and internal constraints. The fsQCA identified four sufficient configurations for adoption, each reflecting a distinct pattern of trade-offs. These results reinforce the principle of equifinality: multiple viable paths can lead to similar outcomes when conditions are appropriately aligned.

In practical terms, the study delivers a diagnostic framework to support decision-making by healthcare managers and policy actors. By linking empirical condition profiles to implementation strategies, it enables context-sensitive planning. Benchmark cases illustrate how specific configurations shape adoption logic, offering actionable guidance for hospitals, clinics, and public health agencies.

These findings also carry social implications. Applying the integrated decision framework, as structured in Table 2, can broaden service reach in resource-constrained settings through external partners and cloud delivery. Stronger data governance improves transparency and public accountability and protects patient privacy. Reducing organizational frictions and investing in workforce capability lowers operational errors and delays. Overall, framework-guided adoption supports equity, trust and patient safety.

As with all small-N comparative studies, this research has limitations, including the modest sample size and reliance on secondary data. Even so, the multi-method design provides a robust foundation for theorizing blockchain adoption in complex institutional environments. Future research could expand the empirical base through longitudinal or cross-national studies, evaluate cost-effectiveness, or explore synergies with adjacent technologies such as artificial intelligence (AI), federated learning, and self-sovereign identity—particularly in low-resource settings.

More broadly, the findings confirm that blockchain adoption in healthcare is not linear, but conditional and context-sensitive. Success depends on how technology, organizational capacity, and external forces interact, requiring not just readiness, but institutional alignment and adaptive capability. Advancing this field will demand greater integration of configurational and institutional perspectives to capture the full socio-technical complexity of digital health transformation.

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