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Blockchain In Healthcare: An Applications, Security Challenges, and Future Directions

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Abstract **- Blockchain is being seen as a game changing tech to upgrade data security, transparency and operation efficiency in healthcare sectors. This agenda paper discusses the use of blockchain in critical areas in health care such as electronic health record (EHRs), clinical trials, insurance billing and pharmaceutical supply chain. The research is cantered on assessing workouts that blockchain could employ to protect patient data integrity, foster interoperability as well as automate pre-decisional tasks by using smart contracts. Although such decentralized detection system has the potential, free scale up is coming against a number of obstacles such as scalability, limitations, compliance of regulation, and security vulnerabilities in smart contracts and accesses control of data. Solving these difficulties, this study researches further advanced cryptographic techniques zero-knowledge proofs as well as combination which artificial intelligence and energy-efficient consensus models was done. This comprehensive review aims at creating a roadmap to enable safe, scalable, and patient-centric blockchain enabled care framework which is consistent with global set of the guidelines protecting world's privacy of medical information which enables seamless inter- operability between different medical ecosystems.**

Blockchain, Healthcare, Electronic Health Records (EHR), Smart Contracts, Data Privacy, Interoperability, Security Challenges, Regulatory Compliance, Artificial Intelligence, Zero-Knowledge Proofs, Consensus Mechanisms.

I. INTRODUCTION

The digitalization of the healthcare system is drastically changing the way medical data is raised, stored, retrieved, and used. With electronic medical records (EMRs), telemedicine and wearable devices, data-driven diagnosis, healthcare providers are using more digital infrastructure to improve care and efficiency of service. Assim que este mudanc¸a desvenda oportunidades para inovac¸a˜o e ainda melhores resultados, a u´nica obstaculo sugerem se o dom´ınio de dados seguranc¸a, privacidade, integridade e comodidade. On this occasion, Blockchain technology comes into play as a game changer having the potential to lead health and healthcare to a totally different transformation through enabling of decentralized, transparent and tamper proof mechanism for storing health records on blockchain.

The present healthcare system is mostly centralized. These systems frequently encounter challenges to ensure data integrity across institutional giants and disservice formulated interoperability, rest really restless, enlarged care, administrative burden and patient dissatisfaction. Further business is also booming at the local waste industry as Europop TRM – the European specialist in waste routed recovery TDs(*TOT Russian Dump sped a 15-40-variant truck – provided in the record period a delivery of vehicles to partner Liv Robert

Blockchain, initially widely known via cryptocurrencies such as Bitcoin, has started to change into general operation know-how with various applications in healthcare. Its basic advantage—immutable, distributed consensus, and cryptography's security—makes it an especially suitable candidate for developing secure, auditable, decentralized methodologies for handling the health-related information. Blockchain's node-to-node structure enables multiple nodes to validate each transaction or data upgrade, making the date to all intents and purposes, untamperable. Smart contracts, programmable scripts embedded into the blockchain, can perform automation in healthcare for insurance claims, billing and consent management, the high are dog operational costs can decrease and the mistake of the human ware reduced.

A. Overview of Blockchain Technology in Healthcare

The healthcare industry has a very difficult to get into ecosystem that involves patients ,providers ,payers ,regulators , and researchers , all of which are in need of accurate , secure and immediate medical information . Blockchain is capable to smoothly move this complexity, granting trust less access, when trust is ensured not with central authorities, but with consensium rules of block chain protocol itself. Patients have control over their personal health data, the option to grant of permissions selectively to healthcare providers, insurance companies or research institutions. Patient-centric data ownership model strikes a bargain of privacy and also enables active involvement by the patient in their health care.

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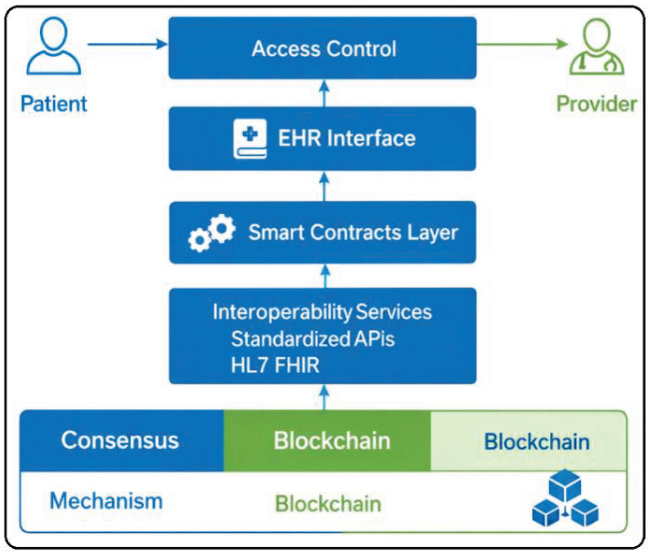

Fig. 1: Conceptual Blockchain Framework for Secure Healthcare Data Management

One of the most fascinating use cases of blockchain is the Electronic Health Records (EHRs) management. Traditional EHR systems have various drawbacks, namely data in inconsistent formats, ambiguity access control and dangers of data degradation. Blockchain-based EHRs can make certain data integrity by mentioning each access or update event in an immutable ledger that offers a whole audit trail. In addition, blockchain enables interoperability because it standardizes data exchange and allows secure exchange of data between organizations. This greatly can decrease medical errors, prevent duplicate diagnostic experience, and expensive diagnostic procedures, and save the patients a lot of emotional stress and, more important, provide patients and families with increased continuity of care.

For clinical trials and medical studies, blockchain can increase transparency and veracity by making dishonesty impossible and trailable plus obtaining consent and trail protocols. Smart contracts can also control for patient enrolment, consent revocations, data permission. This not only alone accelerates the work flow of the research but also resolutions ethical matters as well as fare integrity to the stake holder.

Blockchain use is beneficial to the pharmaceutical supply chain as well. Fake medicines are a major health risk and a huge economic problem worldwide, today. Blockchain can offer an end-to-end tracking system of pharma – from manufacturers to users – guaranteeing genuineness, and decreasing fake drugs circulation. That this level of visibility through the supply chain_PKTpocha´zet compliant regulatory and the public trust.

Despite the potential of blockchain in healthcare, however, it comes with a set of challenges. There are a few matters that, right now, overtake all of them: scalability, energy usage, regulatory, privacy, listed systems. Public blockchains, such as those of bitcoin and ethereum, have limited throughput and slow execution of transactions at the present time, unsuitable for healthcare applications that require real time oversight and action. Data Contract standards are more practical, but they raise legal problems when patients wish to delete or modify their data and have the right to do so, as according to GDPR.

To solve these problems, the research community is looking into more sophisticated solutions like zero-knowledge proofs (ZKP) for private data validation, off-chain storage for dealing with huge medical files and layer-2 scalability solutions such as sharding and sidechains. Additionally, hybrid blockchain structures combining the privacy of personal blockchains together with the openness of open ledgers are under consideration to offer trade-off between execution and safety. The combination of artificial intelligence (AI) with blockchain technology can also improve predictive diagnostics, automated fraud detection and personalized medicine, in that AI will be able to securely and compliantly process of large data sets.

This research proposal aims at doing a proper treatment of the applications that blockchain can currently use in health or has potential in health, the technical and regulatory barriers for health of interaction with it, and how to get some new framework to assemble blockchain and characteristics of AI, privacy-preserving encrypted algorithms and scalable architecture. By resolving these STTs this research provides input in construction of secure efficient and patient-centric health care systems that can be used by countries around the world.

In a nutshell blockchain carries the potential of solution to the yearslong suffering health industry regarding to the security, trenchancy & attributes of interoperability. Yet, the achievement of this potential will depend on transdisciplinary research that is not only led by technological innovation, but also thinks about the ethical, legal and policy in the backscatter. The ambition of this study is to strengthen this interdisciplinary agenda by offering a research/implementation roadmap that lengthen about the course of development of financially reliable and safe-and-sound block chain-enabled healthcare software systems.

B. Applications of Blockchain in Healthcare

This figure 2 shows the various uses of a block chain technology in the healthcare ecosystem. At the centre, Block chain in Healthcare" has links to important areas such as Electronic Health Records (EHR), telemedicine, drug supply chain management, clinical trials, health data exchange, Internet of Things (IoT) and remote monitoring, medical billing and insurance, interoperability, and patient data security. The diagram highlights the role of block chain in improving transparency, data integrity, security, traceability and interoperability across healthcare systems to facilitate secure and efficient management of medical data and services.

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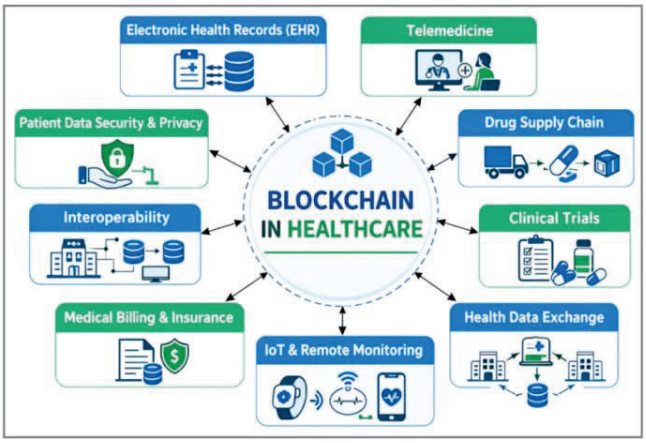

Fig. 2: Applications of Block chain in Healthcare Ecosystem

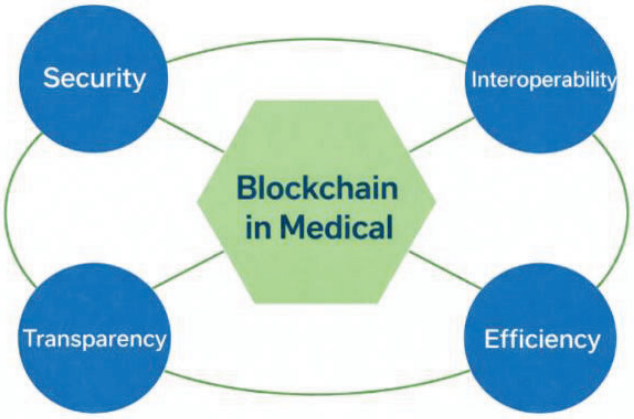

Fig. 3: Advantages of block chain in medical

C. *Advantages of Block Chain in Medical*

a. Improved Data Security and Integrity

Block chain provides unchanged ability and tamper-proof of the medical records by cryptographic hashing and decentralized validation. This goes a long way in preventing risks of unauthorized modification and cyber attacks in healthcare systems [3], [7], [12]. The distributed ledger architecture is what makes the clinical and administrative data trustworthy.

b. Secure Electronic Health Record (EHR) Management

Block chain facilitates interoperable and patient centered Electronic Health Records (EHRs) which allow safe sharing among healthcare providers while retaining ownership of data [3], [4], [8]. It adds a level of transparency and avoids duplication of medical records leading to a better continuity of care [13].

c. Enhances Interoperability

One of the major healthcare challenges is fragmented data systems. Block chain enables Health Information Exchange (HIE) between the institutions without any difficulty because of a decentralized data-sharing infrastructure [4], [8]. This results in decreased delays and better coordinated treatment planning.

d. Transparency in Clinical Trials

Block chain makes data more transparent and traceable in clinical trials, which makes sure that data from the research cannot be manipulated and selectively reported [6]. This has improvements for public trust and regulatory compliance.

e. Secure Telemedicine and Healthcare Remote

In the case of tele health ecosystems, secure authentication, encrypted communication and/or decentralized data management can be enabled by block chain, mitigating privacy risks associated with remote consultations [1], [2]. It builds patient-providers trust in digital healthcare platforms.

f. Supply Chain Traceability and Anti-Counterfeit

Block chain enhances transparency in the pharmaceutical supply chains by facilitating the end-to-end drug and medical device tracking [9]. This helps to reduce the circulation of counterfeit medicines and increases accountability among the stakeholders.

g. Privacy Preservation and Compliance with Regulations

Block chain frameworks can be developed to meet privacy requirements while ensuring transparency and openness with the use of permission networks and smart contracts [15]. It gives controlled data access and audit ability which addresses regulatory concerns [12].

h. Decentralism and Elimination of Intermediaries

By removing central authorities, block chain decreases the single points of failure and improves the reliability of the system [5], [7]. However, a careful consideration of consensus assumptions is needed in order to assure security robustness [14].

i. Modernization of Legacy Healthcare Systems

Block chain has the potential to update the outdated healthcare IT infrastructures with decentralized architectures [11] while integrating with the existing infrastructures. This enhances efficiency, reduces or enhances scalability, and digital transformation efforts.

Overall, block chain technology can help to provide improved security, interoperability, transparency, privacy protection, and supply chain traceability within healthcare ecosystems. These advantages, taken together, provide support for better patient outcomes, less fraud, and more trust throughout medical networks.

D. *Challenges of Block chain*

The figure 2 shows most of the major challenges associated with Block chain technology. At the centre is block chain,

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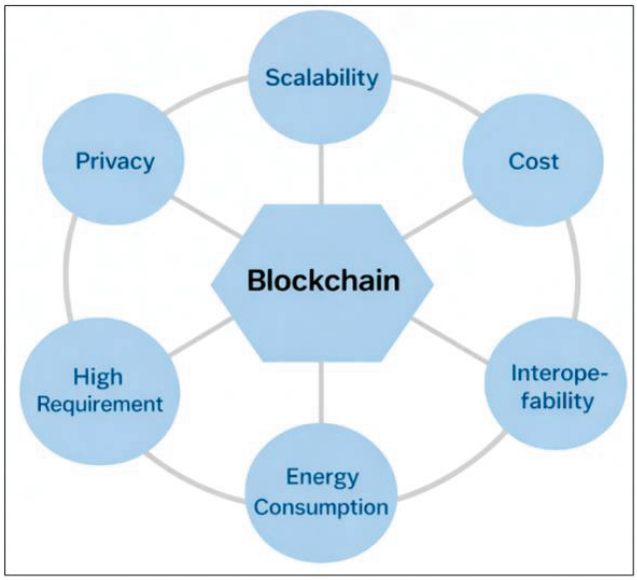

Fig. 4: Challenges of block chain

surrounded by huge issues such as scalability, privacy, cost, interoperability, energy and high resource requirements. These are interconnected challenges that demonstrate that there are technical, financial, and legal obstacles that must be overcome in order for block chain to be implemented effectively in healthcare systems.

a. Scalability Limitations

Blockchain networks suffer from a lack of transaction throughput and high latency that can become a limiting factor for large-scale healthcare deployment [12], [14]. As healthcare systems produce massive volumes of patient and clinical data, and as such scalability is an important technical bottleneck.

b. Privacy and Compliance with Governmental Regulations

Although transparency is increased by blockchain, strict regulations regarding healthcare (e.g. data protection and privacy laws) cause the friction between immutability and the ”right to modify or erase data” [15]. Compliance and governance issues surrounding the sharing of sensitive patient data over distributed ledgers have been a concern [8], [13].

c. Interoperate with Legacy Systems

Healthcare institutions depend on legacy systems of IT infrastructures that may not integrate seamlessly into blockchain frameworks [11]. The absence of standardized protocols for Health Information Exchange (HIE) make it difficult to adopt and achieve cross-platform communication [4].

d. High Implicational & Operational Costs

Blockchain solution deployments demand a lot of investment in terms of the infrastructure, manpower and reconfiguring the system [12]. Smaller healthcare providers may experience financial roadblocks to performing decentralized architectures.

e. Energy is used and Consensus Mechanisms

Some blockchain consensus protocols have high computational power consumption which raises the concern of energy efficiency and sustainability [14]. Healthcare environments demand the use of optimized and lightweight consensus models to ensure practical implementation.

f. Governance and Trust Model Problems

While blockchain eliminates central authorities, governance structures still need to include a definition of roles, permissions and resolution of disputes [5], [7]. Accountability in decentralized health care ecosystems is difficult to establish.

g. Data Storage Constraints

Storing large medical images (e.g. MRI, CT scans) directly on blockchain is impractical because of the storage limitation and cost [7]. It is often necessary to have buildings are a hybrid architecture of off-chain storage and on-chain verification.

h. Resistance to Adoption

Healthcare professionals may be resistant towards new technologies because of lack of awareness, technical complexity and uncertainty about benefits [8], [12]. Organizational change management is a key factor in successful deployment.

i. Security Vulnerabilities & Assumption of Honest Majority

Blockchain security relies on assumptions of consensus (e.g. majority honest nodes). Attacks like 51% attack or vulnerabilities in the smart contracts can cause a loss of reliability in the system [14].

Despite its potential to revolutionize healthcare, there are challenges to blockchain adoption in the health care field, concerning scalability, privacy compliance, interoperability, costs, governance and technical limitations. Addressing these barriers is of paramount importance to achieve secure and efficient decentralized healthcare ecosystems.

II. REVIEW OF EXISTING APPROACHES

Blockchain adoption in healthcare has been discussed in multiple areas such as telemedicine, electronic health records (EHR), supply chain management and data interoperability.

Early trailblazing work in blockchain-enabled healthcare was directed at secure telemedicine frameworks. It [1] proposed the concept of a decentralised telemedicine architecture to support smart Healthcare ecosystems with focus on some secure communication and data sharing. Similarly, [2] discussed the role of blockchain in telehealth systems which encompassed enhancements in trust and transparency and authentication mechanisms.

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Electronic Health Record (EHR) management is one of the most researched areas. Block chain integration in secure and patient-centric EHR systems was discussed [3]. This [4] proposed interoperability using blockchain to enable sharing of EHR among healthcare providers. Systematic and scoping reviews performed [5], [7], [13] examined existing block chain healthcare prototypes and found while the technology provides better transparency, there are limited options for using it in real world, where scalability is concerned.

Clinical trial transparency has also been tackled using Blockchain solutions. Hang et al. [6] proposed a clinical trial service platform based on a blockchain network to guarantee the integrity and traceability of clinical trial data. Meanwhile, [8] discussed the views of physicians about the adoption of blockchain-enabled Health Information Exchange (HIE), which revealed some optimism and also concerns about adopting this technology.

Beyond healthcare records, blockchain has been used in the area of supply chain management. This work [9] proposed a blockchain architecture to improve the transparency and traceability in supply chains which is directly applicable to pharmaceutical distribution systems. General blockchain technological frameworks and conceptual foundation are discussed in [10].

Newer studies are concentrating on updating the legacy healthcare systems and overcoming the challenges in implementing the systems. It [11] discussed the integration of blockchains with legacy infrastructures and [12] discussed some operational challenges and regulation barriers. Security assumptions and consensus vulnerabilities were analyzed in a critical manner by Han et al. [14], while regulatory compliance issues were reviewed [15].

Overall, the available approaches provide evidence of block chain's potential to improve security, transparency, and interoperability in healthcare. However there are still limitations in terms of scalability, regulatory ability, governance models and large-scale deployment that indicate that more practical and optimized frameworks are required.

III. PROBLEM STATEMENTS

Despite the increasing digitalization of healthcare, data sharing across healthcare organizations remains vulnerable to breaches, unauthorized access, and integrity loss. Centralized health information systems are susceptible to single points of failure, data tampering, and privacy violations. Blockchain technology offers a decentralized, secure alternative, yet its adoption is hindered by concerns about system performance, regulatory compliance, and integration complexity. There is a need for a comprehensive study to assess blockchain's current and potential applications in healthcare, and to propose a scalable, secure, and compliant framework suitable for real-world healthcare environments.

IV. OBJECTIVES OF THE STUDY

1. To investigate the role of blockchain in enhancing data security, privacy, and interoperability across healthcare systems.

2. To identify and analyze key challenges in the adoption of blockchain in healthcare, including technical, regulatory, and operational barriers.

3. To propose innovative solutions such as AI integration, zero-knowledge proofs, and scalable blockchain models for building secure and efficient healthcare data ecosystems.

V. LITERATURE REVIEW

Blockchain technology has gained considerable attention in the healthcare sector due to its potential to resolve persistent issues related to data integrity, privacy, and transparency. A growing body of literature highlights its capacity to establish trustless collaboration among healthcare entities by providing tamper-resistant and decentralized data systems. Abugabah et al. [1] introduced a decentralized telemedicine framework demonstrating the applicability of blockchain in supporting remote consultations and secure communication across healthcare systems. Similarly, Ahmad et al. [2] emphasized blockchain's relevance to telehealth, noting its capacity to protect real-time data generated from wearable sensors and remote monitoring systems.

One of the most prominent areas of blockchain application is electronic health records (EHRs). Capece and Lorenzi [3] discussed blockchain's role in improving EHR interoperability while reducing data redundancy and unauthorized access. Jabbar et al. [4] developed a prototype system to enhance EHR integrity and interoperability using blockchain, offering a solution for fragmented patient records across institutions. Chukwu and Garg [5] presented a systematic review of blockchain EHR frameworks and emphasized the importance of integrating permissioned blockchain for scalable and secure health data exchange.

The use of blockchain in clinical trials and research data has also been explored extensively. Hang et al. [6] proposed a blockchain-based clinical trial platform that improves transparency and participant consent management through smart contracts. Hasselgren et al. [7] provided a comprehensive review of blockchain in clinical research, highlighting its ability to ensure ethical compliance, prevent tampering with trial data, and support auditability. Esmaeilzadeh [8] investigated the use of blockchain to enhance health information exchange (HIE), revealing positive attitudes among physicians regarding the technology's ability to improve transparency while maintaining trust.

In terms of pharmaceutical supply chain management, Ghode et al. [9] designed a blockchain-based architecture that enhances transparency and traceability, reducing the circulation of counterfeit drugs. The study by Komalavalli et al. [10]

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TABLE I: Research Stages and Implementation Workflow

Stage	Activity Description	Purpose	Implementation Tools
1	Systematic Literature Review (SLR)	To gather and analyze existing research on blockchain in healthcare, identifying applications and limitations	Mendeley, Zotero, IEEE Xplore, PubMed, SpringerLink
2	Thematic Analysis and Taxonomy Development	To classify use cases, architecture types, and challenges in a structured format	NVivo (qualitative coding), Excel, Python (text mining)
3	Design of Proposed Framework	To develop a conceptual model integrating blockchain, AI, and privacy-preserving protocols	Lucidchart, Draw.io, Adobe Illustrator (for diagrams)
4	Prototype Implementation (Optional Phase)	To simulate and evaluate key features like smart contracts, privacy, and data integrity	Hyperledger Fabric, Ethereum Testnet (Rinkeby, Goerli), Solidity, Truffle Suite
5	Performance Analysis	To compare throughput, latency, and energy cost with existing methods	MATLAB, Python (NumPy, Matplotlib), Ganache CLI
6	Validation and Reporting	To validate framework alignment with healthcare requirements and summarize findings	MS Word, LaTeX, SPSS (if stakeholder survey used), Google Forms (for expert feedback)

detailed blockchain's fundamental mechanisms and its integration into supply chains to improve authentication, reduce fraud, and ensure efficient logistics in healthcare delivery.

Insurance claim processing is another area that benefits from blockchain integration. Aljaloud and Razzaq [11] demonstrated the automation of billing and insurance verification using smart contracts, which reduced administrative overhead and fraud. Attaran [12] explored blockchain's role in modernizing insurance systems, focusing on streamlining claims and reimbursement processes through transparent, rule-based execution.

Despite its promise, the adoption of blockchain in healthcare is fraught with challenges. Abu-Elezz et al. [13] provided a comprehensive scoping review identifying concerns about scalability, legal compliance, and data privacy. Han et al. [14] hallenged the assumptions about blockchain's security, showing how permissionless networks remain vulnerable to 51% attacks. Akanfe et al. [15] addressed regulatory frictions, proposing alignment strategies between blockchain platforms and privacy laws like GDPR and HIPAA to foster responsible innovation in healthcare.

Collectively, these studies underscore blockchain's transformative potential across multiple healthcare functions while acknowledging the technical, regulatory, and organizational barriers that must be overcome. A synthesis of these findings will inform the proposed framework to support secure, scalable, and compliant blockchain-based healthcare infrastructures.

VI. METHODOLOGY

This research employs a mixed-method approach combining systematic literature analysis, conceptual framework design, and exploratory modelling to fulfil the study's objectives: investigating blockchain's role in healthcare, analyzing challenges, and proposing secure, scalable, and patient-centric solutions. The methodology is structured across five key phases:

A. Expected Contributions

1. A comprehensive classification of blockchain-based healthcare applications.

2. Critical analysis of current technical, legal, and operational challenges.

3. A proposed hybrid model integrating blockchain, AI, and privacy-enhancing technologies tailored for healthcare.

4. Recommendations for policymakers and healthcare IT architects for secure and regulation-compliant blockchain adoption.

VII. RESEARCH GAP ANALYSIS

Despite the vast amount of research being conducted on the applications of blockchains in healthcare, there are still some critical gaps. Existing studies mainly confine with conceptual frameworks, pilot implementations, and prototype systems for telemedicine and smart healthcare ecosystem [1], [2]. While blockchain-based Electronic Health Record (EHR) systems have been proposed as an improvement for interoperability and patient-centric control [3], [4], so far the deployment on a large scale with the validation of performance is still limited [5], [7], [13].

Furthermore, most approaches prioritize transparency and security while not giving proper consideration to scalability and integration with legacy healthcare infrastructures [11], [12]. Practical problems of computation overhead, data storage constraints and governance mechanisms are usually discussed from a theoretical perspective, without empirical testing [14]. Regulatory compliance and privacy conflicts with immutable ledger architectures are yet to be resolved, especially in the context of changing data protection laws [15].

Although blockchain has shown promise in supply chain traceability and clinical trial transparency [6], [9] there are few studies providing comparative performance analysis and cost benefit evaluation in operational healthcare environments. Additionally, there is little research on integrating blockchain

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with other new technologies like AI and IoT for intelligent and automated healthcare systems.

Therefore, there is a large research gap on enabling the development, deployment, and research of scalable, interoperable, privacy compliant and practical deployable blockchain frameworks, validated by real world healthcare implementation and thorough performance evaluation.

VIII. CONCLUSION

The reviewed literature has shown that blockchain technology has attracted huge attention in the health care industry for enhancement of the security, transparency and interoperability. Studies on telemedicine frameworks [1], [2] signify the potential of using blockchain for building security in remote healthcare services. Research on Electronic Health Records (EHR) systems focus on decentralized and patient-centric management [3], [4], and systematic and scoping reviews prove a growing experimental adoption across healthcare domains [5], [7], [13]. Applications in clinical trials and Health Information Exchange (HIE) underpin the validity of the role of blockchain in ensuring data integrity and trust [6], [8].

Additionally, supply chain architectures based on blockchains are able to improve traceability and to reduce fraud in the pharmaceutical distribution [9]. Conceptual and technical bases presented in [10] contribute to its adaptability to different healthcare infra-structure. However, the modernization challenges, limitations of scalability, governance, and regulatory conflict issues remain a significant obstacle to its large-scale implementation [11], [12], [15]. Security assumptions and consensus vulnerabilities also need to be thought about carefully [14].

Overall, research on blockchain confirms the transformative potential of the technology in healthcare ecosystems, yet identifies continua that remain in terms of interoperability, real-world validation, regulatory alignment, and costs of deployment. Future work: Hick, F, Kimm, J.N, Burlund, V., Moscou-Schwainger, J-P. Blockchain for health: enabling patient-centric and privacy patience care. 2018Future research should work on scalable, privacy-compliant, and practical deployments of blockchain based frameworks customized for complex healthcare environments.

IX. FUTURE SCOPE

Although blockchain technology has shown great potential in the healthcare industry, there are several areas that need more research and development to facilitate any practical, large-scale use of the technology.

A. First of all, the scalability enhancement is still a priority. The future of consensus mechanisms should be oriented towards lightweight mechanisms and towards hybrid models which minimize the computation overhead while offering security and decentralization. Layer-2 solutions and permissioned blockchains models can potentially improve in healthcare environments in terms of transaction throughput.

B. Second, privacy-preserving mechanisms must be improved. Advanced cryptographic techniques like zero-knowledge proofs, homomorphic encryption and secure multi-party computation can be explored to balance blockchain immutability and healthcare data protection regulations.

C. Third, interoperability standards need to be established to provide seamless integration with existing hospital information systems and EHR platforms and Health Information Exchanges (HIEs). Standardized APIs and cross-chain communication protocols can provide broader adoption.

D. Fourth, future research should concentrate on real-world pilot tests and performance benchmarking to test for cost-effectiveness, energy efficiency, and system reliability under realistic conditions.

In addition, combining blockchain with Artificial Intelligence (AI), Internet of Things (IoT), and edge computing can also help us realize some intelligent healthcare monitoring, predictive analytics, and decision-making systems.

Finally, regulatory frameworks and governance models should be clearly defined in order to counterbalance the goals of decentralization, accountability, and compliance.