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AI AND BLOCKCHAIN FRAMEWORK FOR HEALTHCARE APPLICATIONS

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Abstract. *Artificial Intelligence (AI) has impacted global economy, workforce productivity, smart health, smart cities, smart transport, and much more to come. Large Language Models (LLM) such as ChatGPT and Google's Gemini, have been widely adopted in various applications. Blockchain Technology stands as a towering disruptor in today's tech landscape, offering assurances of enhanced security and scalability for various applications. Within the realm of healthcare, its adoption has surged, spanning from streamlined record-keeping to bolstered clinical trials, fortified medical supply chains, and vigilant patient monitoring. These applications harness the intrinsic attributes of blockchain to elevate standards of safety, privacy, and security within the healthcare sector. The combined power of AI and blockchain has the potential to revolutionize healthcare delivery, ensuring improved security, transparency, and efficiency. Nevertheless, Porru et al. [1] have highlighted deficiencies in the processes, tools, and techniques within this domain. Hence, this paper aims to furnish a structured framework that ensures both security and sustainability in the development of healthcare blockchain applications. This paper also provides an overview of societal impact on both technologies. This article has evolved best practice guidelines and a systematic development framework for AI-Blockchain integration, known as AI-BlockchainOps. This research has also developed a reference architecture, exemplifying the modeling of an Electronic Health Record (EHR) using BPMN and simulation. Within this Electronic Health Record (EHR) scenario encompassing 100 user requests, the simulation absorbed 97.09% of cloud resources, with 76.33% allocated to knowledge discovery, and a utilization rate of 93.20% for blockchain scientists, alongside various other contributing factors.*

Key words: *AI, Blockchain, Secure and Sustainable Software Engineering Framework for AI-Blockchain (AI-BlockchainOps), Smart Contract, Requirements Engineering for AI-Blockchain (RE-AIBC).*

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1. INTRODUCTION

Artificial Intelligence (AI) has emerged as a revolutionary force, reshaping various facets of human existence. Its impact extends beyond technological advancements, reaching into the realms of the global economy, societal structures, and healthcare systems. This article explores the profound effects of AI in these three critical domains, supported by relevant data and citations. One of the main aims of this paper is to identify mutual benefits of AI and Blockchain, and vice versa. AI has the potential to provide predictions for patients with severe conditions, determining the likelihood of recurrence and suggesting preventative measures. However, AI faces challenges such as hallucinations and data bias. Therefore, Blockchain can contribute to protecting patients' data by enhancing security and privacy, which are key benefits of integrating Blockchain in AI applications. Let us look at Transformative Impact of Artificial Intelligence on the Global Economy, Societal Change, and Healthcare briefly as follow:

I. Impact on the Global Economy: The integration of AI into various industries has catalyzed unprecedented economic growth. According to a report by PwC [21], AI is expected to contribute $15.7 trillion to the global economy by 2030, making it the single most significant driver of economic expansion. Automation, powered by AI, has increased efficiency, reduced operational costs, and improved productivity across sectors. For instance, the manufacturing sector has witnessed a surge in productivity due to AI-driven automation. A study by the McKinsey Global Institute indicates that AI applications in manufacturing could generate up to $2.6 trillion in value by 2030. Similarly, AI-powered analytics in finance has enhanced decision-making processes, leading to more accurate predictions and risk assessments.

II. Societal Change: The societal landscape is undergoing a profound transformation due to AI, affecting the nature of work, education, and social interactions. Automation and AI technologies have altered the job market, creating a demand for new skill sets. The World Economic Forum estimates that by 2025, AI will create 12 million more jobs than it displaces, but workers will need to adapt to evolving roles and acquire new skills. Education, too, is experiencing a paradigm shift with AI. Personalized learning platforms use AI algorithms to tailor educational content to individual student needs, enhancing the overall learning experience. This adaptive learning approach has the potential to bridge educational gaps and promote inclusivity.

In terms of social interactions, AI-powered algorithms in social media platforms and recommendation systems have shaped user experiences. While these technologies enhance user engagement, concerns about privacy, algorithmic bias, and the echo-chamber effect have also arisen.

III. Impact on Healthcare: AI impact on healthcare is transformative, influencing diagnostics, treatment plans, and patient care. AI algorithms analyze vast datasets, enabling more accurate and timely diagnoses. For instance, IBM's Watson for Oncology processes medical literature, clinical trial data, and patient records to recommend personalized cancer treatment plans.

Moreover, AI facilitates predictive analytics in healthcare, helping identify potential outbreaks and enabling proactive measures. The COVID-19 pandemic showcased the importance of AI in epidemic control and response, as AI models were used to track the spread of the virus and predict its impact on healthcare resources. Artificial Intelligence stands as a technological juggernaut, with far-reaching implications for the global economy, societal structures, and healthcare systems. The data and citations presented affirm the positive contributions of AI to economic growth, societal evolution, and healthcare advancements. While recognizing these benefits, it is crucial to address ethical considerations, regulatory frameworks, and the need for responsible AI deployment to ensure a future where AI enhances human well-being across diverse domains.

Now let us look at *the Revolutionary Impact of Blockchain on the Global Economy, Societal Change, and Healthcare*:

Blockchain technology, initially devised as the underlying framework for cryptocurrencies like Bitcoin, has transcended its origins to become a transformative force in diverse sectors. This essay delves into the far-reaching impacts of blockchain on the global economy, societal structures, and healthcare, supported by pertinent data and citations. Some of the effects of blockchain impacts are as follow:

I. Impact on the Global Economy: Blockchain impact on the global economy is characterized by increased transparency, efficiency, and security. The World Economic Forum estimates that by 2025, 10% of the global GDP will be stored on blockchains or blockchain-related technology. The decentralized nature of blockchain reduces the need for intermediaries, streamlining transactions and reducing costs. Smart contracts, a feature of blockchain, automate and enforce contract execution without the need for intermediaries. According to a Deloitte report, smart contracts can reduce transaction costs by 40–80%. This has significant implications for industries like finance, supply chain, and international trade, where blockchain enhances trust and reduces fraud.

II. Societal Change: Blockchain technology has the potential to bring about profound societal change by reshaping trust mechanisms, ensuring data integrity, and fostering decentralized governance. Decentralized identity systems, enabled by blockchain, empower individuals to control and manage their personal data securely. The World Bank reports that 1.1 billion people globally lack a legal identity, and blockchain offers a solution to address this gap. In governance, blockchain's transparent and tamper-resistant nature can enhance accountability and reduce corruption. For instance, Estonia has implemented a blockchain-based e-governance system that ensures the integrity of government records and facilitates efficient public service delivery.

III. Impact on Healthcare: In healthcare, blockchain is revolutionizing data management, security, and interoperability. The decentralized and immutable nature of blockchain ensures the integrity of health records, reducing the risk of data breaches. According to a report by BIS Research, the global blockchain in healthcare market is projected to reach $5.6 billion by 2025. Blockchain facilitates the creation of a patient-centric healthcare ecosystem where individuals have greater control over their health data. This can lead to improved care coordination, faster access to medical records, and more personalized treatment plans. The use of blockchain in pharmaceutical supply chains also ensures the authenticity and traceability of drugs, reducing the prevalence of counterfeit medications.

The rise of blockchain technology has marked a significant shift, reshaped not only the global economy and societal frameworks but also revolutionized healthcare systems worldwide. The referenced data vividly illustrates its concrete advantages, including heightened transparency, efficiency, and security, evident across diverse sectors. Nonetheless, hurdles like scalability concerns, regulatory frameworks, and the need for heightened public awareness remain critical focal points that demand attention to fully unleash the transformative power of blockchain technology. As society continues to embrace decentralized and transparent solutions, the transformative impact of blockchain on the global stage is poised to accelerate, ushering in an era of enhanced trust, efficiency, and inclusivity.

Therefore, this article explores the integration of Artificial Intelligence (AI) and Blockchain in healthcare applications, emphasizing the transformative benefits of blockchain technology. The paper presents a state-of-the-art analysis, examines current research challenges, conducts a critical review of existing literature, and compares various approaches in a tabular format. The objective is to provide insights into the synergies between AI and blockchain, their potential impact on the healthcare industry, and a roadmap for future research.

Within this context, notable aspects emphasized in this article encompass:

- A substantial contribution towards the integration of AI and blockchain within healthcare, characterized by embedded security measures, reusability, and sustainability principles.
- Some of the key findings on AI and blockchain integration are security, privacy-preservation personalization which are important for healthcare.

There *key research challenges* need to be addressed:

- What are the key challenges of AI algorithms, safety, security, privacy, governance, ethics of AI for healthcare applications?
- What are the key challenges of Blockchain: safety, security, privacy, governance, ethics of Blockchain for healthcare applications?
- What is the systematic framework for the development of AI and Blockchain dApps?
- How do we integrate four key connected technologies such as Internet of Things (IoT), also known as BIoT (Blockchain IoT), Blockchain Technology, Artificial Intelligence (AI) and Cybersecurity. These four key technological integrations is also known as IBAC (IoT-Blockchain-AI-Cybersecurity)?

In this context this article structured as follow: Section 1 provides introduction and challenges to AI-Blockchain integration and its benefits, Section 2 provides key challenges and critical evaluation of the existing approaches on AI and Blockchain integration in healthcare. Section 3 proposes an innovative framework for developing AIOps and BIOps integrated and is known as AI-BlockchainOps (AI-BcOps). Finally, Section 4 presents the application of AI-BlockchainOps with a case study on Electronic Health Records (EHRs) using Business Process Modelling Notation (BPMN) & simulation.

2. Integration of AI and Blockchain in Healthcare

The integration of Artificial Intelligence (AI) and Blockchain in healthcare applications, emphasize the transformative benefits of blockchain technology. The paper presents a state-of-the-art analysis, examines current research challenges, conducts a critical review of existing literature, and compares various approaches in a tabular format. The objective is to provide insights into the synergies between AI and blockchain, their potential impact on the healthcare industry, and a roadmap for future research [3-19].

The healthcare industry is experiencing a paradigm shift with the convergence of AI and blockchain technologies. Blockchain, known for its secure and transparent decentralized ledger, offers unique advantages to healthcare applications. This paper examines the current landscape and outlines the key objectives of integrating AI and blockchain in healthcare settings. Blockchain's benefits in healthcare include enhanced data security, interoperability, transparent and auditable transactions, and patient-centric data management. The distributed ledger technology addresses issues related to data privacy, integrity, and accessibility, fostering trust among stakeholders. Current advancements in AI and blockchain applications for healthcare involve predictive analytics, patient data management, drug traceability, and supply chain optimization. Notable initiatives such as MedRec [22] and MedicalChain [23] have demonstrated the potential of combining AI and blockchain to improve patient outcomes and streamline healthcare operations.

Blockchain represents a decentralized and distributed digital ledger technology that securely documents and authenticates transactions across a network of computers. At its core, blockchain incorporates a distributed system of record known as blocks, offering explicit support for security, verifiability, and provenance. Each transaction is assigned a unique hash, ensuring its immutability and traceability, preventing any unauthorized alterations, it provides embedded business terms via the notion of smart contracts, and it provides verification mechanism using consensus & agreements. Its key characteristics include:

- Decentralization: Blockchain operates on a peer-to-peer network, eliminating the need for a central authority or intermediary.
- Immutability: Once data is logged onto a block, altering, or tampering with it becomes exceedingly difficult, thereby ensuring a robust level of security and trust.
- Transparency: All participants in the network have access to the same data, promoting transparency and accountability.
- Security: Cryptography is used to secure transactions, ensuring that only authorized parties can access and modify the information.
- Consensus Mechanism: A consensus algorithm is employed to validate transactions, ensuring agreement among participants on the state of the ledger.
- Smart Contracts: Self-executing contracts with the terms of the agreement directly written into code, automating, and enforcing contractual obligations.

The key characteristics are illustrated in Figure1. These characteristics make blockchain a robust and reliable technology for various applications, from financial transactions to supply chain management and beyond.

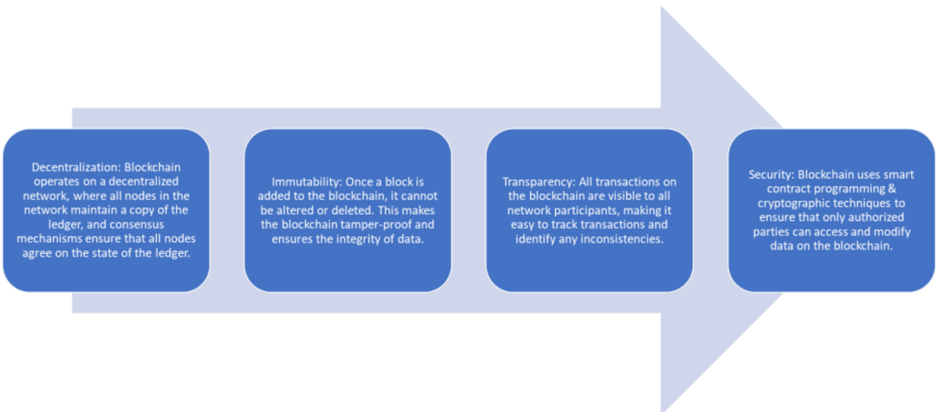

Fig. 1 The key Characteristics of Blockchain

However, there are research challenges that need to be investigated**.** Despite the promising prospects, challenges such as scalability, interoperability, regulatory compliance, and ethical considerations persist. This section explores the hurdles researchers face when developing and implementing AI and blockchain solutions in healthcare. A comprehensive literature review assesses the strengths and limitations of current studies, highlighting methodologies, findings, and gaps in knowledge. Citations throughout this section provide a thorough examination of the scholarly landscape. A tabular comparison of existing approaches categorizes AI and blockchain integration strategies in healthcare. This comparative analysis aids in understanding the varied methodologies, key features, and performance metrics of different frameworks. Table 1 shows the critical review of the AI and Blockchain integration in healthcare [2-22].

Table 1 Critical comparison of AI and Blockchain Integration

Study	AI Integration	Blockchain Implementation	Key Findings
Study 1 [4-5]	Algorithmic diagnosis	Permissioned blockchain	Improved patient record security
Study 2 [7-8]	Natural language processing	Smart contracts	Enhanced drug traceability
Study 3 [10-14]	Predictive analytics	Public blockchain	Interoperability challenges addressed

As shown in Table 1, there were three studies conducted on healthcare applications, AI integration on algorithmic diagnosis for study 1, blockchain implementation was permissioned blockchain and the key finding was improved patient record security. Similarly for study 2, the key findings were enhanced drug traceability, and the key finding for study 3 is the interoperability challenges addressed.

This section succinctly summarizes the major findings, trends, and insights derived from the critical review and comparative analysis, providing a quick reference for readers. In conclusion, the integration of AI and blockchain in healthcare presents a promising avenue for innovation. While challenges persist, ongoing research efforts continue to refine methodologies and address obstacles. The synergistic potential of AI and blockchain holds the promise of transforming healthcare delivery, guaranteeing advancements in security, transparency, and operational efficiency.

Thang N. Dinh and My T. Thai [2] has proposed two types of AI and Blockchain impacts namely, *AI for Blockchain* which aims to promote AI for the benefits of blockchain for its improved knowledge with AI integration, and *Blockchain for AI* which promotes privacy, safety, and security of AI applications. The two types of classifications are illustrated in Table 2.

Table 2 Classification of AI and Blockchain Integration

AI for Blockchain	Blockchain for AI
Secure and scalable blockchains	Secure data sharing and marketplace for AI
Automated referee and governance	Decentralized computing for AI
Privacy-preserving personalization	Explainable AI
	Coordinating untrusting devices

This section provides a summary of the characteristics of AI and blockchain, critically evaluating the necessity for their integration and highlighting mutual benefits, particularly in healthcare applications. The following sub-sections will compare AI for Blockchain versus Blockchain for AI, exploring their advantages in business, enriching our lives, sustainability, security, and privacy.

2.1. AI for Blockchain

AI for blockchain represents an innovative synergy between artificial intelligence (AI) and blockchain technology, introducing transformative characteristics to enhance various aspects of decentralized systems. One key aspect is the focus on secure and scalable blockchains. The integration of AI in blockchain systems aims to bolster security measures through advanced cryptographic techniques and consensus algorithms, ensuring the integrity of transactions and protection against malicious activities. Simultaneously, the implementation of scalable solutions, such as sharding and layer-two protocols, addresses the challenge of accommodating a growing number of transactions without compromising performance.

Another significant facet of AI for blockchain is the development of automated referee and governance systems. By harnessing AI capabilities, these systems streamline decision-making processes, ensuring transparency, efficiency, and tamper-resistant governance. The introduction of smart contracts and decentralized consensus mechanisms helps to automate and enhance referee functions, contributing to fair and accountable decision outcomes across diverse domains.

Privacy-preserving personalization is another critical dimension of AI for blockchain. This involves leveraging AI algorithms within blockchain frameworks to tailor user experiences while safeguarding individual privacy. Techniques such as federated learning and differential privacy allow systems to glean insights from user data without compromising sensitive information, striking a balance between personalization and data protection.

In summary, AI for blockchain embodies a convergence of cutting-edge technologies, emphasizing secure and scalable blockchains, automated referee and governance systems, and privacy-preserving personalization. These characteristics collectively contribute to the evolution of decentralized systems, fostering trust, efficiency, and innovation across a spectrum of applications. Enhancing Secure and Scalable Blockchains, Automated Referee and Governance, and Privacy-Preserving Personalization are discussed with their characteristics [6-10]:

2.1.1. Secure and Scalable Blockchains

Secure and scalable blockchains play a pivotal role in the evolution of decentralized technologies, ensuring the robustness and efficiency of digital ecosystems. Security is paramount in preserving the integrity of transactions and safeguarding sensitive information. To achieve this, secure blockchains employ advanced cryptographic techniques and consensus algorithms that resist malicious attacks and unauthorized access. Scalability, conversely, tackles the issue of managing a burgeoning volume of transactions and users without sacrificing operational speed. Advancements like sharding and layer-two solutions facilitate the scalability of blockchain networks, empowering them to process higher transaction volumes while upholding minimal delays. Achieving the optimal equilibrium between security and scalability is paramount in instilling confidence in decentralized systems and maximizing their impact across diverse sectors, ranging from finance to healthcare and beyond. As blockchain technology evolves, the quest for secure and scalable solutions remains paramount, driving broader adoption and catalyzing innovation. Some of the benefits of AI for Blockchain applications include:

a. Security Enhancement: Implementing AI in blockchain technology contributes to robust security measures. Machine learning algorithms can detect and prevent potential security threats by analyzing patterns and anomalies in real-time. According to a report by MarketsandMarkets, the blockchain security market is projected to reach $1.1 billion by 2026, driven by the increasing adoption of AI for securing blockchain networks.

b. Scalability Solutions: Blockchain networks often face scalability challenges as transaction volumes increase. AI-driven solutions, such as sharding and consensus algorithms optimization, enhance scalability. For instance, Ethereum 2.0 incorporates a sharding mechanism, utilizing AI to distribute the workload across multiple shards. This approach improves transaction throughput, enabling the network to handle more transactions per second.

2.1.2. Automated Referee and Governance

Automated referee and governance systems represent a significant advancement in leveraging technology to streamline decision-making processes in various domains. These systems, powered by artificial intelligence and blockchain technologies, aim to automate and enhance the referee functions and governance mechanisms. They provide transparent, efficient, and tamper-resistant solutions for managing disputes, overseeing compliance, and ensuring accountability. As highlighted [2], such automated systems not only expedite decision-making but also contribute to reducing bias and increasing the overall fairness of governance processes. By integrating smart contracts and decentralized consensus mechanisms, these systems uphold a high level of transparency and trust in decision outcomes. The synergy of AI and blockchain in automated referee and governance not only marks a technological milestone but also establishes a foundation for fair and accountable systems across diverse sectors [2]. The characteristics of automated referee and governance system are:

a. Decentralized Autonomous Organizations (DAOs): AI plays a pivotal role in the development of DAOs, enabling automated governance mechanisms [24-25]. These DAOs use smart contracts and AI algorithms to make decisions without centralized control. Aragon, a blockchain-based platform, utilizes AI for decision-making within decentralized organizations. This autonomous governance approach enhances transparency and reduces the potential for human bias. However, it is also a major issue for lawyers on code of law versus code as law.

b. Smart Contract Auditing: AI-driven tools are employed for auditing smart contracts, ensuring their compliance with predefined rules and security standards. Quantstamp [20], a blockchain security firm, utilizes machine learning algorithms to analyze and audit smart contracts, enhancing their reliability and reducing vulnerabilities. Automated auditing mechanisms contribute to the overall governance and security of blockchain networks.

2.1.3. Privacy-Preserving Personalization

Privacy-preserving personalization represents a crucial frontier in the intersection of technology and user-centric services. As digital platforms increasingly rely on personal data to tailor experiences, concerns about privacy have grown in tandem. This paradigm seeks to harmonize the benefits of personalized services with a commitment to safeguarding user privacy. Techniques such as federated learning and differential privacy play pivotal roles in this context, allowing systems to glean insights from user data without directly accessing sensitive information. By implementing privacy-preserving personalization, platforms can offer tailored recommendations, content, and services while minimizing the risk of unauthorized access or misuse of personal data. Striking this delicate balance fosters a more trusting and mutually beneficial relationship between users and digital platforms, addressing contemporary concerns surrounding privacy in the era of advanced personalization algorithms [15-37]. Privacy-preserving personalization is one of the key benefits of AI for blockchain applications, and it is particularly crucial in healthcare applications, where health data is more sensitive and costly. Some of the characteristics of privacy-preserving personalization are:

a. Homomorphic Encryption: AI and blockchain synergy enhance privacy-preserving personalization through techniques like homomorphic encryption. This allows computations to be performed on encrypted data without decrypting it, ensuring privacy. Homomorphic encryption is particularly valuable in healthcare applications, where sensitive patient data can be analyzed for personalized treatment without compromising confidentiality.

b. Zero-Knowledge Proofs: Zero-knowledge proofs, a cryptographic method, serve to validate information's authenticity without disclosing the underlying data. Zcash [26], a privacy-focused cryptocurrency, utilizes zero-knowledge proofs to enable private transactions. Integrating AI with zero-knowledge proofs enhances the efficiency of privacy-preserving algorithms, ensuring personalized services without compromising user privacy.

The integration of AI with blockchain technology brings forth a new era of secure and scalable blockchains, automated governance, and privacy-preserving personalization. The cited data highlights the growing market for blockchain security, emphasizing the importance of AI-driven solutions. As these technologies continue to evolve, they hold the potential to redefine how transactions are secured, decisions are made within decentralized systems, and personalization is achieved without compromising user privacy. The synergy between AI and blockchain represents a powerful force for innovation in the digital landscape.

2.2. Blockchain for AI

Blockchain for AI represents a pioneering fusion of two transformative technologies, promising to reshape the landscape of artificial intelligence (AI). Several key characteristics distinguish this integration, unveiling novel possibilities for secure and collaborative AI applications. Firstly, blockchain facilitates secure data sharing and establishes a marketplace for AI. Through the decentralized and immutable nature of blockchain, individuals and organizations can securely share data without compromising its integrity. Smart contracts, self-executing agreements on the blockchain, enable transparent and traceable transactions, fostering a trustworthy marketplace for AI datasets and models.

Decentralized computing for AI is another crucial characteristic. Blockchain provides a distributed and resilient infrastructure, allowing AI computations to be processed across a network of nodes rather than relying on a centralized server. This not only enhances the scalability of AI applications but also mitigates the risk of a single point of failure, contributing to more robust and efficient AI systems.

Explainable AI, an imperative for building trust in AI models, is facilitated by blockchain's transparency. The decentralized ledger ensures that the decision-making processes of AI algorithms can be audited and understood. This characteristic is essential, especially in critical domains where transparency and accountability are paramount.

Coordinating untrusting devices is a notable feature of Blockchain for AI, addressing the challenge of collaboration among devices that may not inherently trust each other. Through blockchain's consensus mechanisms and cryptographic principles, devices can engage in collaborative AI tasks without relying on a central authority, fostering trust and coordination in decentralized environments.

In summary, Blockchain for AI introduces a new paradigm characterized by secure data sharing, decentralized computing, explainable AI, and the coordination of untrusting devices. This convergence holds promise for revolutionizing how AI systems operate, emphasizing transparency, collaboration, and security in the rapidly evolving landscape of artificial intelligence. Facilitating Secure Data Sharing, Decentralized Computing, Explainable AI, and Coordinating Untrusting Devices are discussed as follow with their relevant characteristics presented in Table 2 [10-19]

2.2.1. Secure Data Sharing and Marketplace for AI

Secure data sharing and marketplace for AI represent a groundbreaking development at the intersection of artificial intelligence (AI) and blockchain technologies. This innovative integration addresses the critical need for a trusted environment where organizations and individuals can securely exchange AI-related data and models. The decentralized and tamper-resistant nature of blockchain ensures the integrity and confidentiality of shared data, fostering a secure ecosystem for transactions.

In this context, blockchain's smart contracts play a pivotal role by automating and enforcing agreements between parties. These self-executing contracts enable transparent and traceable exchanges, establishing a marketplace where participants can confidently share, buy, or sell AI datasets and models. Utilizing the security capabilities inherent in blockchain, including cryptographic methods and consensus protocols, the marketplace guarantees the preservation of data integrity and the execution of transactions with a robust level of trust.

This paradigm shift not only enhances the efficiency of AI collaborations but also opens new avenues for innovation by democratizing access to diverse and high-quality AI resources. The secure data sharing and marketplace for AI exemplify a transformative approach to fostering collaboration, transparency, and trust in the dynamic landscape of artificial intelligence. It consists of the following characteristics:

a. Data Security and Privacy: Blockchain provides a secure and transparent framework for data sharing in AI applications. By utilizing decentralized ledgers, sensitive data can be shared among multiple parties while maintaining privacy. Ocean Protocol is an example of a blockchain-based platform that enables secure and privacy-preserving data sharing for AI. It facilitates the creation of data marketplaces where individuals and organizations can share and monetize their data securely.

b. Tokenization and Incentives: Blockchain allows for the creation of tokenized ecosystems that incentivize data contributors and AI developers. SingularityNET [27], a decentralized AI platform, employs blockchain to facilitate a marketplace for AI services. Users can access and purchase AI algorithms using blockchain-based tokens, ensuring a fair and transparent exchange of value within the ecosystem.

2.2.2. Decentralized Computing for AI

Decentralized computing for AI marks a significant advancement in the realm of artificial intelligence (AI), leveraging the capabilities of blockchain technology to redefine how AI computations are performed and managed. Unlike traditional centralized models, where AI tasks are typically processed on powerful servers, decentralized computing distributes the computational load across a network of interconnected nodes.

In this paradigm, blockchain provides a decentralized and distributed infrastructure that facilitates the execution of AI algorithms across multiple nodes. This approach enhances the scalability of AI applications, allowing them to handle larger datasets and more complex computations. Furthermore, it mitigates the risks associated with a single point of failure, as the decentralized nature of the network ensures that no individual node has control over the entire system.

Decentralized computing for AI aligns with the principles of blockchain, promoting transparency, security, and trust. With smart contracts and consensus mechanisms, nodes in the network collaborate to validate and execute AI computations. The transparency of blockchain technology ensures that the entire process, from data input to the output of AI models, is traceable and auditable, addressing concerns related to accountability and fairness.

This innovative approach to decentralized computing not only enhances the efficiency of AI systems but also aligns with the principles of decentralization, providing a foundation for more resilient and democratized AI applications. It represents a paradigm shift in how AI computations are orchestrated, fostering a new era of collaboration and scalability in artificial intelligence. It consists of the following characteristics.

a. Distributed Processing: Blockchain enables decentralized computing for AI tasks, distributing the computational load across a network of nodes. Golem is a blockchain-based platform that allows users to rent their computing power for AI tasks. This decentralized approach enhances the scalability and efficiency of AI computations by leveraging a distributed network of resources.

b. Federated Learning: Blockchain supports federated learning, a decentralized machine learning approach where models are trained across multiple devices without centralized data aggregation. This ensures privacy and security, as demonstrated by projects like Oasis Labs [28]. Their blockchain platform facilitates federated learning scenarios, enabling AI models to be trained on user devices without compromising data privacy.

2.2.3. Explainable AI

Explainable AI (XAI) is a critical aspect of artificial intelligence that focuses on making the decision-making processes of AI models understandable and interpretable by humans. In traditional machine learning models, particularly deep neural networks, the decision-making processes can be complex and often referred to as "black boxes," meaning it's challenging to understand why a model arrives at a specific outcome.

Explainable AI aims to address this opacity by providing insights into how an AI model reaches its conclusions or predictions. This transparency is essential, especially in sensitive applications such as healthcare, finance, and criminal justice, where understanding the rationale behind AI decisions is crucial for building trust and accountability.

There are various techniques within Explainable AI, ranging from simpler models that are inherently more interpretable, to methods that generate post-hoc explanations for complex models. By providing insights into feature importance, decision rules, or the inner workings of a model, Explainable AI empowers users to understand and trust AI systems, ultimately facilitating their adoption in real-world scenarios.

In addition to addressing trust and accountability concerns, Explainable AI also plays a role in identifying biases in models and helps to ensure fairness in AI applications. As AI continues to integrate into various aspects of our lives, the emphasis on Explainable AI becomes increasingly important for responsible and ethical deployment of artificial intelligence technologies. Ramachandran [38] discusses a detailed framework for XAI and reference architecture. It consists of the following characteristics.

a. Transparency and Accountability: Blockchain transparent and immutable nature addresses the challenge of explainability in AI. AI models often operate as "black boxes," making it difficult to understand their decision-making processes. By recording AI model training and decision logs on a blockchain, stakeholders can audit and trace the model's behavior. This promotes transparency and accountability in AI systems.

b. Proof of Trust: A combination of blockchain and AI can establish a "proof of trust" mechanism. NeuroChain [29-30], for instance, integrates AI algorithms with blockchain to create a consensus algorithm based on participants' reputation. This approach enhances the trustworthiness of AI systems, as nodes with a proven track record are given more influence in the decision-making process.

2.2.4. Coordinating Untrusting Devices

Coordinating untrusting devices is a significant challenge in decentralized systems and is particularly relevant in the context of blockchain and distributed technologies. In scenarios where devices need to collaborate, but do not inherently trust each other, coordinating their actions becomes a critical consideration.

Blockchain technology plays a crucial role in addressing this challenge by providing a secure and transparent framework for coordination. Through consensus mechanisms and cryptographic principles, blockchain establishes a trustless environment where devices can interact and coordinate without relying on a central authority. Smart contracts, self-executing contracts with coded rules, further automate and enforce agreements, enabling seamless coordination among untrusting devices.

This approach is especially valuable in Internet of Things (IoT) applications, where diverse devices with varying levels of trustworthiness need to collaborate for a common goal. By leveraging blockchain's decentralized nature, devices can securely exchange information, verify the integrity of data, and participate in collaborative tasks without compromising security.

The coordination of untrusting devices is pivotal in ensuring the reliability and effectiveness of decentralized systems. It not only enhances the security of interactions but also promotes transparency and accountability, aligning with the principles of trustless collaboration that blockchain brings to the forefront of modern technological ecosystems. It consists of the following characteristics.

a. Interoperability and Trustless Collaboration: Blockchain facilitates coordination among untrusting devices by providing a trustless environment for collaboration. IOTA [31-32], a distributed ledger technology, employs a directed acyclic graph (DAG) structure called the Tangle. This allows devices to transact and share data without the need for a centralized authority, promoting trustless and secure interactions among untrusting devices.

b. Smart Contracts for Coordination: Smart contracts on blockchains enable automated and secure coordination among untrusting devices. Ethereum, for instance, supports smart contracts that can automate processes and transactions without relying on a centralized entity. This decentralized approach ensures the reliability of interactions among devices without the need for central authority.

Blockchain's integration with AI introduces a paradigm shift in how data is shared, computations are performed, and trust is established in AI ecosystems. The examples and cited data illustrate the real-world applications of blockchain for secure data sharing, decentralized computing, explainable AI, and coordinating untrusting devices. As these technologies continue to evolve, the synergy between blockchain and AI holds the promise of creating more transparent, secure, and efficient AI systems that cater to the evolving needs of the digital landscape. Furthermore, applications become complex with AI, Blockchain and IoT technologies integration. Therefore, we need a systematic framework to standardize the process and development. The following section presents a systematic framework.

3. AI-BlockchainOps – Continuous Delivery of AI and Blockchain Integration

AI and blockchain can deliver secure, sustainable, and reusable applications in healthcare where the success of the AI in terms of its prediction models and the success of the blockchain in terms of its smart contract can be merged to benefit each other. Therefore, this article introduces the notion of AI-BlockchainOps (AI-BcOps) that outlines the integration of artificial intelligence (AI) and blockchain operations. This section provides a conceptual framework that organizations might follow when integrating AI and blockchain technologies into their operations. This framework would involve aspects of both AI operations (AI Ops) and blockchain and IoT (BIOps) operations. This is shown in Figure 2.

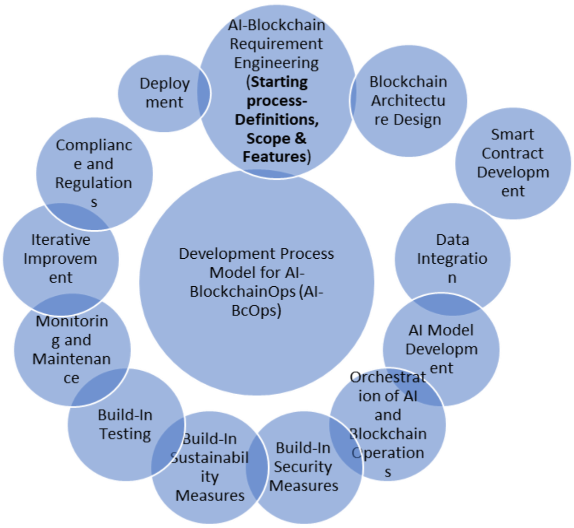

Fig. 2 Development Process Model for AI-BlockchainOps (AI-BcOps)

AI-Blockchain Requirement Engineering: Identify the specific business requirements that can benefit from the integration of AI and blockchain. Determine the goals, functionalities, and expected outcomes. Model use cases and Business process modeling and simulation to study and validate performance, cost, and complexity metrics for chosen AI algorithms. Conduct complete data cleaning and transformation process during this stage.

Blockchain Architecture Design: Design the blockchain architecture that aligns with the identified requirements. Determine the consensus mechanism, data structure, and governance model for the blockchain. For this purpose, this article proposes references architecture with a concept of an AI-Blockchain Service Bus for making the orchestration elegant.

Smart Contract Development: Develop smart contracts that encapsulate the logic required for executing AI-related operations on the blockchain. Ensure security and auditability of smart contracts.

Data Integration: Establish mechanisms for integrating relevant data into the blockchain. Explore methods for securing and validating data on the blockchain using AI-based verification.

AI Model Development: Develop and train AI models that will interact with the blockchain. Ensure that AI models align with the goals of the blockchain operations.

Orchestration of AI and Blockchain Operations: Define workflows for how AI and blockchain operations will interact. Implement the integration points between AI and blockchain components.

Build-In Security Measures: Implement security measures for both AI and blockchain components from requirements, design, implementation & testing. Consider cryptographic techniques and consensus algorithms to secure the system.

Build-In Sustainability Measures: Identify and implement sustainability requirements and develop a list of smart contracts for compliance based on sustainability development goals (SDG).

Build-In Testing: Conduct thorough testing of the integrated system from requirements, design for testability. Perform unit testing, integration testing, and security testing for both AI and blockchain components.

Deployment: Deploy the integrated AI-BlockchainOps system into the production environment. Monitor for any issues during the initial deployment phase.

Monitoring and Maintenance: Implement monitoring tools to oversee the performance of AI and blockchain components. Establish a maintenance plan for updates, patches, and improvements.

Iterative Improvement: Collect feedback and data from the live system to identify areas for improvement. Iterate on the system to enhance performance, security, and functionality.

Compliance and Regulations: Ensure compliance with relevant regulations, especially when dealing with sensitive data or industries with specific requirements. Please note that the integration of AI and blockchain operations is a dynamic and evolving field, and organizations may tailor their process models based on their specific use cases and industry requirements. It's advisable to stay updated with the latest developments in both AI and blockchain technologies for the most effective implementation.

4. AI-BlockchainOps in Healthcare: An EHR Case Study

EHR stands for Electronic Health Record, which is a digitalized and comprehensive longitudinal record of an individual's health and medical history. Its benefits include streamlined healthcare processes, improved care quality, enhanced patient safety, seamless information sharing among healthcare providers, and secure and efficient access to patient records. A longitudinal record in an Electronic Health Record (EHR) typically consists of various types of information that span a patient's entire healthcare journey. This can include:

- Medical History: Details about past illnesses, surgeries, injuries, and medical procedures.
- Medications: A list of current and past medications prescribed to the patient, including dosage and frequency.
- Allergies: Information about any known allergies or adverse reactions to medications or substances.
- Laboratory Results: Test results from blood tests, urine tests, imaging studies, and other diagnostic procedures.
- Imaging Studies: Records of X-rays, MRIs, CT scans, ultrasounds, and other imaging tests.
- Diagnoses: Formal diagnoses of medical conditions or diseases made by healthcare professionals.
- Treatment Plans: Plans for managing and treating medical conditions, including medications, therapies, and procedures.
- Progress Notes: Healthcare providers' notes documenting patient encounters, assessments, and treatment plans over time.
- Vital Signs: Records of vital signs such as blood pressure, heart rate, temperature, and respiratory rate.
- Immunizations: Documentation of vaccines received by the patient, including dates and types of vaccines.
- Family History: Information about the patient's family medical history, including any hereditary conditions or diseases.
- Social History: Details about the patient's lifestyle, habits, occupation, and social support network.

These components collectively provide a comprehensive overview of a patient's health status and medical history, facilitating better-informed healthcare decision-making and continuity of care. Electronic Health Records (EHRs) represent a cornerstone application in modern healthcare, benefiting greatly from the integration of AI and Blockchain technologies, which substantially enhance patient health on a global scale. EHRs serve as digitized, comprehensive archives detailing a patient's medical history, encompassing vital data such as medical conditions, treatments, medications, allergies, and diagnostic results. These records are meticulously designed to streamline healthcare processes, elevate care quality, bolster patient safety, and facilitate seamless information sharing among healthcare providers. They have evolved into indispensable components of contemporary healthcare frameworks, enabling practitioners to securely and efficiently access and update patient information.

The benefits and features of EHRs are elaborated by EHR [33] and Ekblaw et al. [34]. Leveraging the Ethereum programming language, a variety of smart contracts can be employed to construct EHR systems, including but not limited to:

- Patient Registry Smart Contract: Housing patient demographic data and medical history.
- Electronic Health Record Smart Contract: Storing health-related information like diagnoses, medications, and test results.
- Consent Smart Contract: Managing patient consent for data utilization and access.

- Identity Smart Contract: Verifying patient identity and ensuring authorized access.
- Payment Smart Contract: Handling healthcare service payments and dispute resolution.
- Prescription Smart Contract: Overseeing medication prescriptions and adherence.
- Medical Device Smart Contract: Managing usage and maintenance of medical devices.

These smart contracts serve as foundational elements, customizable and combinable to cater to the diverse needs of healthcare organizations and patients alike. By adopting AI-BlockchainOps development process, we can standardize the applications in healthcare for safety, security & sustainability as follows, and the process is shown in Figure 3.

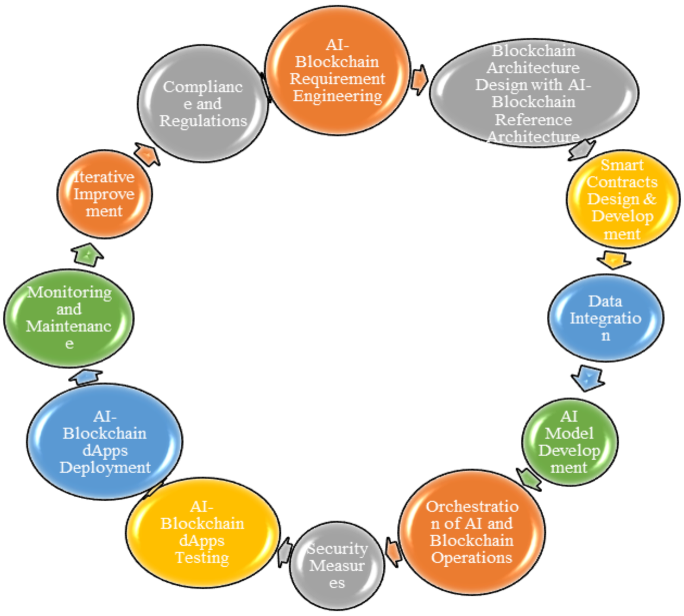

Fig. 3 AI-BlockchainOps Development Process

1. AI-Blockchain Requirement Engineering:

AI-Blockchain Requirement Engineering within the AI-BlockchainOps Development Process involves a dual approach. Firstly, it entails identifying and defining the specific requirements for integrating artificial intelligence (AI) technologies into blockchain systems, encompassing aspects such as AI algorithms, data processing needs, and cognitive capabilities. Secondly, it involves delineating the requirements for implementing blockchain technology, including consensus mechanisms, smart contracts, data immutability, and decentralized governance structures. This holistic process ensures that both AI and blockchain components are seamlessly integrated to achieve the desired functionalities, performance, and outcomes within the overarching AI-BlockchainOps framework.

Objective: Improve the security, transparency, and interoperability of patient data in healthcare systems.

Requirements: Secure sharing of patient records, traceability of data access, interoperability between healthcare providers, and AI-driven analytics for personalized treatment plans.

2. Blockchain Architecture Design with AI-Blockchain Reference Architecture:

In the context of AI-BlockchainOps Development Process, the steps involved in Blockchain Architecture Design with AI-Blockchain Reference Architecture are as follows:

Requirement Analysis: This initial step involves gathering and analyzing requirements for both AI and blockchain components. This includes understanding business objectives, user needs, data sources, security requirements, and regulatory constraints.

Define Use Cases: Identify specific use cases where AI and blockchain integration can bring significant value. These use cases should align with the overall business goals and objectives.

Select AI Algorithms: Choose appropriate AI algorithms and techniques based on the use cases identified. Consider factors such as data complexity, volume, and the desired outcomes.

Define Blockchain Components: Determine the necessary blockchain components such as consensus mechanism, smart contracts, data storage, and access controls. Select the appropriate blockchain platform based on factors like scalability, security, and interoperability.

Design Data Architecture: Develop a data architecture that supports the integration of AI and blockchain technologies. This includes defining data schemas, data flows, and data storage mechanisms for both AI and blockchain components.

Integration Strategy: Define how AI and blockchain components will interact and communicate with each other. This involves designing APIs, protocols, and interfaces for seamless integration.

Security and Privacy Considerations: Address security and privacy concerns associated with AI and blockchain technologies. Implement encryption, access controls, and data anonymization techniques to protect sensitive information.

Scalability and Performance Optimization: Design the architecture to ensure scalability and optimize performance. Consider factors such as transaction throughput, latency, and resource utilization.

Testing and Validation: Test the architecture thoroughly to ensure that it meets the specified requirements and performs as expected. This includes functional testing, performance testing, and security testing.

Deployment and Monitoring: Deploy the AI-Blockchain architecture in a production environment and monitor its performance and reliability. Implement monitoring tools and processes to detect and address any issues that arise.

By following these steps, organizations can design and implement a robust AI-Blockchain architecture that supports the integration of AI and blockchain technologies within the AI-BlockchainOps Development Process. For example,

Blockchain Type: Permissioned blockchain for healthcare consortium.

Consensus Mechanism: Practical Byzantine Fault Tolerance (PBFT) for fast and secure transactions.

AI Model: Deep Learning with 80% training data, etc.

Governance Model: Consortium of healthcare providers governing the network.

Standardizations: using reference architecture will help standardize the dApps development.

3. Smart Contracts Design & Development: Smart contract development in the context of AI-BlockchainOps development process refers to the creation and implementation of self-executing contracts encoded on a blockchain network, leveraging both artificial intelligence (AI) technologies and blockchain operations (BlockchainOps). These contracts automatically

execute and enforce agreed-upon terms and conditions, using predefined rules and logic encoded into the blockchain, while also integrating AI capabilities for enhanced automation, decision-making, and intelligence within the contract execution process. Develop smart contracts for patient consent management, data access control, and incentive mechanisms for data contributors.

Security Measures: Implement cryptographic techniques for secure storage and sharing of medical records.

4. Data Integration:

Data integration in the context of AI and blockchain integration involves the seamless merging and synchronization of data from disparate sources, such as AI algorithms and blockchain networks, to enable cohesive and efficient analysis, decision-making, and operation within interconnected systems.

Data Sources: Data sources may include Electronic Health Records (EHRs), wearable devices, and medical imaging systems.

Integration: Use AI algorithms for data normalization and integration into the blockchain. Ensure privacy-preserving techniques like homomorphic encryption.

5. AI Model Development:

Objective: Develop AI models for predictive analytics, disease diagnosis, and treatment recommendation.

Training Data: Utilize blockchain-stored and verified data for training AI models.

Interoperability: Ensure AI models can seamlessly interact with the blockchain to access updated patient data.

6. Orchestration of AI and Blockchain Operations:

Workflow: Create workflows for AI-driven data analytics, with smart contracts triggering AI processes based on predefined conditions.

Integration Points: Establish secure APIs for communication between AI models and the blockchain.

7. Security Measures:

Blockchain Security: Implement measures like consensus algorithms and decentralized storage to prevent unauthorized access.

AI Model Security: Employ techniques like federated learning to train models without exposing raw patient data.

8. AI-Blockchain dApps Testing:

Testing Scenarios: Conduct testing scenarios for data integrity, access controls, and the performance of AI algorithms.

Security Testing: Perform rigorous security testing, including vulnerability assessments and penetration testing.

9. AI-Blockchain dApps Deployment:

Rollout Plan: Deploy the integrated system in a phased manner, starting with a pilot program.

Training: Train healthcare professionals on using the new system and understanding AI-driven insights.

10. Monitoring and Maintenance:

Monitoring Tools: Implement real-time monitoring tools for blockchain transactions, AI model performance, and system health.

Maintenance Plan: Establish regular maintenance schedules for updates and improvements.

11. Iterative Improvement:

Feedback Loop: Collect feedback from healthcare providers, patients, and AI models' performance.

Continuous Improvement: Iterate on the system to enhance AI model accuracy, system efficiency, and user experience.

12. Compliance and Regulations:

Compliance Checks: Regularly audit the system to ensure compliance with healthcare regulations (e.g., HIPAA).

Regulatory Updates: Stay informed about changes in regulations and update the system accordingly.

Outcome:

Patient Empowerment: Patients have secure access to their medical records and can control data sharing with healthcare providers.

Interoperability: Healthcare providers can seamlessly share and access patient data across the network.

Personalized Treatment: AI-driven analytics enable healthcare professionals to provide more personalized and effective treatment plans.

Security and Transparency: The blockchain ensures the security and transparency of medical records, building trust among stakeholders.

4.1. BPMN Simulation Using Reference Architecture

BPMN stands for Business Process Model and Notation. It is a standardized graphical notation used for modeling business processes in a visual manner, allowing organizations to depict complex processes in a clear and understandable format. The benefits of BPMN for validating and simulating key performance requirements include:

- Clarity and Understanding: BPMN provides a common language and visual representation for stakeholders to understand business processes, facilitating communication and collaboration.
- Process Optimization: By modeling processes with BPMN, organizations can identify inefficiencies, redundancies, and bottlenecks, enabling them to optimize workflows for improved efficiency and productivity.
- Validation of Requirements: BPMN allows stakeholders to validate requirements by visually representing how processes should function, ensuring that all stakeholders have a clear understanding of the desired outcomes.
- Simulation and Analysis: BPMN models can be used for simulation and analysis, enabling organizations to predict process outcomes, analyze performance metrics, and identify potential risks or areas for improvement.
- The BPMN process typically involves the following steps:

- Identifying Processes: The first step is to identify the business processes that need to be modeled, including their scope, objectives, and key stakeholders.
- Modeling Processes: Using BPMN notation, modelers create graphical representations of the identified processes, capturing the sequence of activities, decisions, and interactions involved.
- Defining Notations: BPMN provides a set of standardized symbols and notations to represent different elements of a business process, including tasks, gateways, events, and flows.
- Validating Requirements: Stakeholders review and validate the BPMN models to ensure that they accurately represent the desired processes and requirements.
- Simulating Processes: BPMN models can be used for simulation and analysis, allowing organizations to test different scenarios, predict outcomes, and optimize processes for key performance requirements.

Overall, BPMN provides organizations with a powerful tool for modeling, validating, and simulating business processes, enabling them to improve efficiency, productivity, and performance. Utilizing Business Process Modeling Notation (BPMN), Simulation, and Evaluation techniques can significantly enhance the development of blockchain applications (dApps). By constructing model scenarios that represent business processes or systems, organizations can gain insights into their operations. BPMN enables visualization and documentation of various process steps, activities, and decisions, laying the groundwork for creating blockchain scenarios that mirror physical systems or processes.

Through modeling, simulation, and evaluation, blockchain application requirements can be scrutinized to analyze performance, pinpoint bottlenecks, and optimize resource allocation and business workflows. A plethora of BPMN modeling and simulation tools, such as BonitaSoft and Bizagi, are available, each offering unique capabilities. Additionally, studies like Chang et al. [35] provide valuable evaluations of BPMN tools, while Goa et al. [36] have demonstrated BPMN applicability in implementing enterprise resource planning (ERP) systems in manufacturing.

By leveraging BPMN, organizations can deepen their understanding of processes and systems, enabling them to simulate different scenarios, test changes, and evaluate their impact on resource utilization and business performance. This approach facilitates the identification of inefficiencies, the optimization of resource allocation, and the enhancement of overall productivity.

For instance, in a manufacturing setting, dApps developed using BPMN can simulate production line scenarios to determine the most effective allocation of resources, such as machinery, manpower, and materials. Analysis of process modifications' effects on productivity, throughput, and quality enables organizations to optimize resources, trim costs, and streamline operations. Figures 4 and 5 exemplify BPMN's application in modeling and simulating the reference architecture for blockchain, as depicted in Ramachandran [37]. Figures 4 & 5 show the simulations of EHR for 100 real-time requests, and it shows at each stage in the simulation time taken to complete the tasks, waiting time, resources utilization, and the cost requirements. This is an efficient way of evaluating initial requirements for performance and resources efficiently.

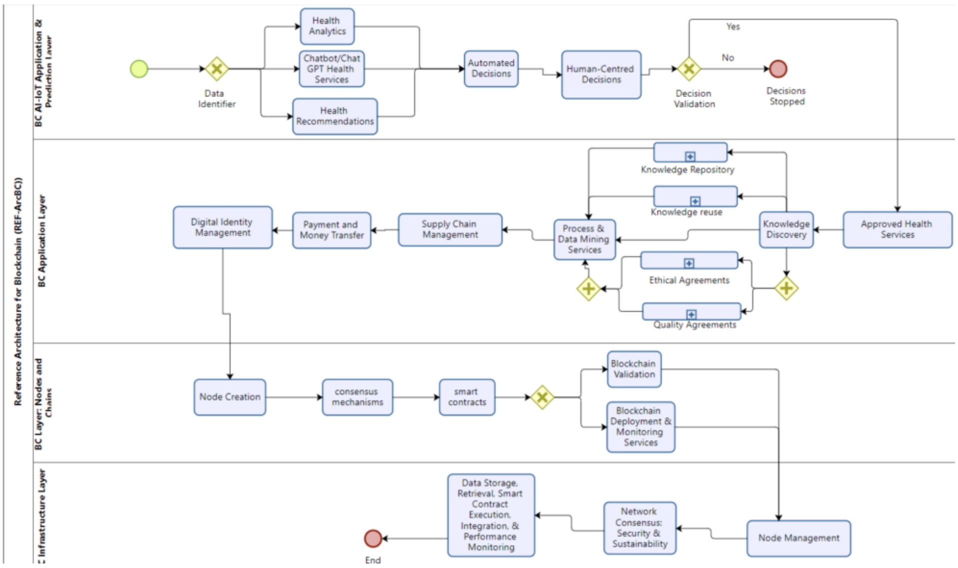

Fig. 4 REF-Arc BPMN Model for Electronic Health Record (EHR) (Bizagi Modeller)

Simulation Results

Resources

Reference Architecture for Blockchain (REF-ArcBC))

Scenario information

Name	Scenario 1
Time unit	Minutes
Duration	030,00:00:00

Resource	Utilization	Total fixed cost	Total unit cost	Total cost
Cloud Resources	97.09 %	0	0	0
Knowledge Discovery	76.33 %	0	0	0
Blockchain & AI Scientists	93.20 %	0	0	0
Blockchain Security & Sustainability	95.92 %	0	0	0
Chatbots & chatGPT	98.06 %	0	0	0
Blockchain Analytics	94.97 %	0	0	0
Blockchain Nodes & Network	97.09 %	0	0	0
	Total	0	0	0

Fig. 5 Simulation Results

Business Process Model and Notation (BPMN) serves as a widely embraced standard for visually representing and designing business processes. It offers a standardized format for depicting complex workflows, facilitating comprehension and analysis. Below is an overview of BPMN notation, modeling, processes, and simulation steps:

- BPMN Notation: BPMN encompasses a collection of symbols and conventions for visually illustrating business processes. These symbols include tasks, gateways, events, flows, and pools, each carrying specific meanings and functions. By leveraging these symbols, businesses can craft diagrams that elucidate the flow and structure of their processes.

- Modeling: BPMN empowers organizations to construct visual models of their processes, streamlining understanding, documentation, and analysis of intricate workflows. BPMN diagrams typically consist of start and end events, activities (tasks), gateways (decision points), and connecting flows, encapsulating the sequence of actions.
- Processes: A BPMN process embodies a series of interconnected tasks and activities constituting a holistic business process. These processes may range from straightforward, linear workflows to sophisticated, branching, and parallel structures, capturing an organization's operational dynamics.
- Simulation Steps: Simulation stands as a pivotal facet of BPMN modeling, enabling businesses to evaluate and enhance their processes preemptively. The steps for simulating a BPMN process usually involve:
- Model Creation: Commence by crafting a BPMN diagram illustrating the intended process, delineating tasks, decision points, and activity flows.
- Data and Resource Allocation: Specify data inputs and outputs for each activity and allocate resources (such as personnel or equipment) as necessary.
- Parameterization: Assign values to process parameters to explore diverse scenarios and assess their impact on the process.
- Simulation Execution: Employ BPMN simulation tools to execute the model, simulating the actual process execution while considering factors like task durations, resource availability, and decision outcomes.
- Analysis and Optimization: Evaluate simulation results to pinpoint bottlenecks, inefficiencies, or areas ripe for improvement. Adjust the model and parameters accordingly to optimize the process.
- Documentation and Reporting: Document simulation results and insights, facilitating informed decisions regarding process enhancement or automation.

Moreover, BPMN simulation validates and verifies blockchain application requirements and reference architecture. Architectural layers and subsystems can be replicated as swim lanes and pools. Various tools, including Bizagi Modeler, support BPMN modeling, with Chang et al. [35] offering a critical evaluation of BPMN tools.

4.2. Simulation Results & Analysis

Simulating a BPMN (Business Process Model and Notation) model for a blockchain reference architecture ash shown in Figure 3, where swim lanes represent different layers, can be a valuable exercise for understanding and optimizing interactions and processes within the architecture. In this context, swim lanes depict various layers such as blockchain AI, IoT, prediction layer, blockchain application layer, blockchain layer, and infrastructure layer, with a blockchain service layer coordinating communication among them. Here's a breakdown of how to approach simulating this architecture using BPMN:

- Identify Key Processes: Determine the essential processes within each layer and their interactions. For instance, the blockchain AI layer might involve data analysis and decision-making, while the IoT layer may focus on data collection and transmission.
- Layer Swim Lanes: Create swim lanes for each layer in the BPMN diagram, illustrating the hierarchy from the prediction layer at the top to the infrastructure layer at the bottom. The blockchain service layer coordinates communication among these layers.
- Activities and Tasks: Populate each swim lane with activities and tasks representing processes and interactions within that layer. For example, tasks in the prediction layer might

include data analysis and prediction, while the blockchain application layer could involve smart contract deployment.

- Gateways and Events: Use gateways and events to model decision points and triggers in the processes. Gateways depict conditional flows or splits, while events signify occurrences initiating or completing processes.
- Message Flows: Depict communication and data exchange between layers using message flows. The blockchain service layer facilitates communication and event handling between different layers, illustrating the flow of information.
- Exclusive and Inclusive Gateways: Model decision points with exclusive and inclusive gateways, representing mutually exclusive or multiple paths based on conditions.
- External Events: Incorporate external events or triggers using BPMN events, showing how they are received and processed within the blockchain service layer before being distributed to other layers.
- Data Objects: Represent data objects, stores, and flows using BPMN symbols to visualize data collection, storage, and usage across layers.
- Simulation Tools: Utilize BPMN simulation tools to run simulations of the model, analyzing architecture performance under various scenarios and conditions.
- Optimization: Analyze simulation results to identify bottlenecks or inefficiencies, adjusting processes as needed to optimize flow and performance.

Simulating the BPMN model provides insights into the behavior and performance of the blockchain reference architecture, enabling informed decisions about enhancements and adjustments. Real-time scenarios, as shown in Figure 3, can demonstrate processing times and resource utilization, aiding in optimizing energy efficiency and sustainability, as depicted in Figure 4. This approach facilitates a comprehensive understanding and optimization of the blockchain architecture's operations. This case study demonstrates the potential benefits of AI-BlockchainOps in healthcare, emphasizing improved data management, patient outcomes, and overall system efficiency. It also highlights the importance of considering security, compliance, and continuous improvement in the deployment and maintenance phases.

5. Conclusions

AI and Blockchain integration in healthcare will provide security, sustainability, and privacy which include record keeping, clinical trials, medical supply chains, patient monitoring, etc. The combined power of AI and blockchain has the potential to revolutionize healthcare delivery, ensuring improved security, transparency, and efficiency. It is also important to address the societal and ethical challenges that are underpinning the widespread use of AI and Blockchain. The revolutionary impact of Blockchain on the Global Economy, Societal Change, and Healthcare were also presented. Therefore, this paper also presented best practices and guidelines on societal impact on both technologies. This paper also presented one of the key findings, a systematic framework for a secure and sustainable software engineering framework for healthcare blockchain applications, and a systematic development framework for AI-Blockchain integration, known as AI-BlockchainOps.

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REFERENCES

[1] S. Porru, A. Pinna, M. Marchesi and R. Tonelli, "Blockchain-Oriented Software Engineering: Challenges and New Directions", In Proceedings of the 39th International IEEE/ACM Conference on Software Engineering Companion (ICSE-C), Buenos Aires, Argentina, 2017, pp. 169-171.
[2] T. N. Dinh and M. T. Thai, "AI and Blockchain: A Disruptive Integration", *Computer*, vol. 51, pp. 48-53, 2018.
[3] C. C. Agbo, Q. H. Mahmoud and J. M. Eklund, "Blockchain Technology in Healthcare: A Systematic Review", *Healthcare*, vol. 7, no. 2, p. 56, April 2019.
[4] A. Banafa, *Blockchain Technology and Applications*, River Publishers, 2020.
[5] M. Beller and J. Hejderup, *Blockchain-based Software Engineering*, Delft University of Technology, Technical Report, 2018.
[6] M. Christidis and M. Devetsikiotis, "Blockchains and Smart Contracts for the Internet of Things", *IEEE Access*, vol. 4, pp. 2292-2303, 2016.
[7] V. Chang, et. al. "Evaluation and comparison of various business process management tools", *Int. J. Bus. Inf. Syst.*, vol. 43, no. 3, pp. 281-308, July 2023.
[8] L. Chung and J. C. S. do Prado Leite, *On non-functional requirements in software engineering* In: *Conceptual modeling: Foundations and applications*, Springer, Berlin, Heidelberg, 2009, pp 363–379.
[9] Coindesk, State of blockchain q1: blockchain funding overtakes bitcoin, 2016. Available at: http://www.coindesk.com/state-of-blockchain-q1-2016/
[10] CompTIA, Blockchain Terminology: A Glossary For Beginners, 2023. Available at: https://connect.comptia.org/content/articles/blockchain-terminology, Accessed [24/09/2023]
[11] J. S. Czepluch, N. Z. Lollike and S. O. Malone, *The use of block chain technology in different application domains*, The IT University of Copenhagen, Copenhagen, 2015.
[12] P. De Filippi and A. Wright, *Blockchains, Bitcoin, and Decentralized Computing Platforms*. In *Blockchain and the Law: The Rule of Code*, Harvard University Press, 2018, pp. 13–32.
[13] G. Destefanis, et al., "Smart Contracts Vulnerabilities: A Call for Blockchain Software Engineering?", In Proceedings of the International Workshop on Blockchain Oriented Software Engineering (IWBOSE), Campobasso, Italy, 2018, pp. 19-25.
[14] D. Dzhalila, D. Siahaan, R. Fauzan, R. Asyrofi and M. I. Karimi, "A systematic review on blockchain technology in software engineering", *J. ELTIKOM: J. Teknik Elektro*, vol. 7, no. 1, pp. 38-49. 2023.
[15] A. Ekblaw, A. Azaria, J. D. Halamka, A. Lippman, "A case study for blockchain in healthcare: "medrec" prototype for electronic health records and medical research data", whitepaper, 2016. Available at: https://www.media.mit.edu/publications/medrec-whitepaper/
[16] HER, The Office of the National Coordinator for Health Information Technology (ONC), "What is an Electronic Health Record (EHR)?, 2023. Available at: https://www.healthit.gov/faq/what-electronic-health-record-ehr, [accessed on 11/10/23]
[17] J. Feist, et al., "Slither: A Static Analysis Framework For Smart Contracts", In Proceedings of the 2nd International IEEE/ACM Workshop on Emerging Trends in Software Engineering for Blockchain (WETSEB), 2019, pp. 8-15.
[18] P. K. Ghosh, "Blockchain Application in Healthcare Systems: A Review", *Systems*, vol. 11, no. 1, p. 38; 2023.
[19] P. Giungato, R. Rana, A. Tarabella and C. Tricase, "Current Trends in Sustainability of Bitcoins and Related Blockchain Technology", *Sustainability*, vol. 9, no. 12, p. 2214, 2017.
[20] Quantstamp, Securing the future of web3. Available at: https://quantstamp.com/
[21] PwC, PwC's Global Artificial Intelligence Study: Exploiting the AI Revolution. Available at: https://www.pwc.com/gx/en/issues/data-and-analytics/publications/artificial-intelligence-study.html
[22] MedRec, a modern way to track your health with blockchain. Available at: https://medrec-m.com/
[23] Medicalchain. Available at: https://medicalchain.com/en/
[24] S. Wang, W. Ding, J. Li, Y. Yuan, L. Ouyang and F. -Y. Wang, "Decentralized Autonomous Organizations: Concept, Model, and Applications", *IEEE Trans. Comput. Soc. Syst.*, vol. 6, no. 5, pp. 870-878, Oct. 2019.
[25] D. Bron, The Role of AI in Decentralized Autonomous Organizations (DAOs): From Governance to Decision-Making, 2023. Available at: https://www.linkedin.com/pulse/role-ai-decentralized-autonomous-organizations-daos-from-daniel-bron/
[26] Zcash, Zcash is cash for the new age. Available at: https://z.cash/
[27] SingularityNET, Integrating AI, AGI (Artificial General Intelligence), and Blockchain. Available at: https://singularitynet.io/
[28] Oasis Labs, The Future of Responsible AI, Building Cutting-Edge Technologies in Decentralization, Privacy and AI. Available at: https://www.oasislabs.com/
[29] NeuroChain, Future of Blockchain, More secure, more reliable and much faster than blockchain. Available at: https://www.neurochaintech.io/

[30] NeuroChain AI, The Ultimate Web3 + AI Infrastructure. Available at: https://www.neurochain.ai/
[31] IOTA — The Backbone of the Internet of Things. Available at: https://medium.com/coinmonks/all-about-iota-870526773e1c#:~:text=Unlike%20traditional%20blockchain%2Dbased%20technologies,of%20IOTA%20is%20its%20scalability.
[32] IOTA, IOTA's Tangle is an open, feeless and scalable distributed ledger, designed to support frictionless data and value transfer. Available at: https://www.iota.org/get-started/what-is-iota
[33] A. Ekblaw, A. Azaria, J. D. Halamka and A. Lippman, "A case study for blockchain in healthcare: "medrec" prototype for electronic health records and medical research data", whitepaper, 2016. Available at: https://www.media.mit.edu/publications/medrec-whitepaper/
[34] HER, The Office of the National Coordinator for Health Information Technology (ONC), "What is an Electronic Health Record (EHR)?, 2023. Available at: https://www.healthit.gov/faq/what-electronic-health-record-ehr, [accessed on 11/10/23]
[35] V. Chang, et. al., "Evaluation and comparison of various business process management tools", *Int. J. Bus. Inf. Syst.*, vol. 43, no. 3, pp. 281-308, July 2023.
[36] L. F. Gao, et al. "The measurement impact of ERP system implementation on the automotive industry business process efficiency", *Int. J. Bus. Inf. Syst.*, vol. 43, no. 3, pp.429–442, 2023.
[37] M. Ramachandran, "S3EF-HBCAs: Secure and Sustainable Software Engineering Framework for Healthcare Blockchain Applications", *Int. J. Blockchain Healthcare Today* (BHTY), vol. 6, no. 2, Sept. 2023.
[38] M. Ramachandran, *Quality Framework for Explainable Artificial Intelligence (XAI) and Machine Learning Applications* in *Explainable Artificial Intelligence (XAI) Concepts, Tools, Technologies, & Use Cases*, Editors P. Raj et al., IET Press, 2023.