A Blueprint Towards an Integrated Healthcare Information System Through Blockchain Technology

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***Abstract*— Since the advent of the Internet, software development has continuously transformed the healthcare industry. Electronic medical or health records are prominent examples of healthcare data digitization. However, these records are vulnerable to cyber-attacks and data loss. Careful attention must be paid to data integrity, patient privacy, data management, and storage concerns. Blockchain technology is proposed in the literature to integrate healthcare information systems through a decentralized and unified network. Conceptual configurations of blockchain-based healthcare information systems are conquering the literature. Nevertheless, these studies lack empirical evidence. In response, we employ the design science research methodology and target the healthcare information system in Montreal, Canada. This paper presents an empirical research blueprint that proposes an integrated healthcare information system through blockchain technology.**

Keywords-blockchain; decentralized information system; healthcare supply chain; data management.

I. INTRODUCTION

Building an efficient and trusted healthcare information system is arduous, given the direct impact on patients and global health [1][2]. In addition, the very primitive tools in some medical supply chains continue to challenge healthcare data management. Counterfeit medicinal drugs are another consistent and growing challenge that impacts recipients and the costs associated. According to a joint study carried out by the European Union Intellectual Property Office (EUIPO) and the Organization for Economic Co-operation and Development (OECD), the total expenditure on trade in counterfeit medicines was €4.03 billion between 2014 and 2016 [3].

The academic literature suggests using blockchain in healthcare to enhance the security and privacy of centralized information systems. In addition to the financial industry, blockchain as a distributed ledger technology attracts academia and various industries. Blockchain is defined as a decentralized database or distributed ledger of digital records or financial transactions that are immutably registered according to a precise consensus mechanism [4]–[6]. Blockchain's ledger consists of concatenated blocks of information or digital assets using powerful and unbreakable cryptographic techniques to ensure the integrity and security of the registered data. The consensus mechanism for validating data in the blockchain ledger is a key element that distinguishes blockchain from other enterprise resource planning systems [7][8].

Digital records need to be validated to be registered in the blockchain ledger indefinitely. Otherwise, it is rejected. Small, medium, and large companies have been tested blockchain in the supply chain to ensure better financial, physical, and information flows [9]–[11]. The healthcare industry is no exception [12]–[14].

Blockchain applications in healthcare span multiple aspects and focus on data management, traceability, transparency, privacy, and security [15]. For example, tracking medications through blockchain within an integrated health information system would drastically reduce tampering attempts. In addition, blockchain could provide a reliable and secure environment for data exchange between healthcare actors and the government in real-time [16][17].

This research is motivated by the need to develop an integrated healthcare information system through blockchain. This is because the integration of healthcare stakeholders' information systems remains out of reach, raising many problems concerning patients' privacy and poor treatment of medical data. This research aims to build and test a blockchain-based platform that connects different healthcare stakeholders in Montreal, Canada.

First, our study explores the possibility of using the private blockchain model (i.e., Hyperledger Fabric) to integrate different healthcare information systems and facilitate their access to a unified platform. Second, we propose hosting the blockchain ledger either on the cloud (i.e., Amazon Web Services or Microsoft Azure Cloud) or servers owned by the healthcare network. Third, we build application programming interfaces and secure access to the platform.

This paper is organized as follows. Section II reviews the literature on blockchain applications in healthcare. Section III describes our methodology represented in the design science research approach. Section IV presents our preliminary findings. To finish with, Section V concludes with remarks.

II. LITERATURE REVIEW

Blockchain can be divided into three main models: public, private, and consortium [4][5][18][19]. In a public blockchain system, access is open to all users where registered information is transparent. In addition, users can participate in the validation process of the network's transactions. The

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transactions in a private blockchain system may not be fully transparent. This is because one or more entities often control the network. Also, users who want to join the private blockchain network must get permission. A semi-decentralized blockchain, called a consortium blockchain, is managed by more than one entity, and all are involved in decision-making on the blockchain network [20]. It is worth noting that most studies in the literature do not recognize different blockchain models, nor do they consider the benefits associated with each model in practice.

McGhin et al. [21] highlight the need to secure electronic health and medical records by ensuring that only the authorized stakeholders have access to the records. Also, monitoring should be achieved to prevent the risks of possible tampering. The authors propose using blockchain to manage healthcare data better and mitigate the risk of data loss and cyber-attacks.

Benil and Jasper [22] propose a public auditing scheme for the healthcare industry called the Elliptical Curve Certificateless Aggregate Cryptography Signature-scheme (EC-ACS). The scheme suggests using blockchain to secure electronic healthcare records on the cloud.

In order to enhance patients' privacy and protect their medical records, Zhuang et al. [23] develop a private blockchain model that enables a patient-centric Health Information Exchange (HIE). The authors explain the strength of this technology in HIE and attempt to assess the feasibility of its adoption.

In a similar vein, Shi et al. [24] address the security and privacy policies of the Health Insurance Portability and Accountability Act (HIPAA). The authors show that blockchain can improve the healthcare supply chain's resilience and maintain its integrity.

III. METHODOLOGY

As previously mentioned, we explore blockchain in the Canadian healthcare system. We are in the process of building an integrated blockchain-based information system that facilitates and secures medical records and monitors COVID vaccination. To do so, we follow the design science research methodology [25][26]. Accordingly, we divide our study into five phases as shown in Figure *1*.

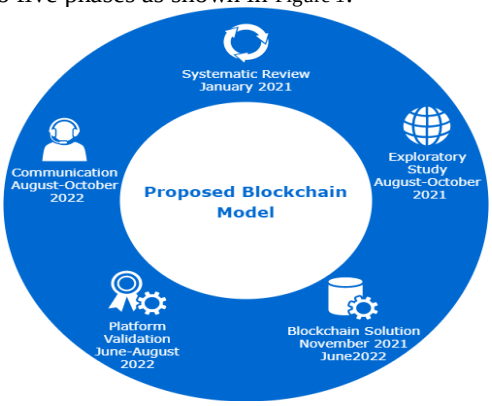

Figure 1. Progress of research phases.

In the first phase, we conduct a systematic review of the literature [27]–[29] to identify the problems that confront healthcare information systems. In the second phase, we conduct interviews with the McGill University Health Centre (MUHC) and its stakeholders to assess the literature claims. In the third phase, we build the technical solution: a blockchain-based healthcare information system to integrate different stakeholders' information systems and improve the integrity, privacy, and security of medical data. Other technologies (e.g., Internet of Things devices) will be considered to ensure data veracity. In the fourth phase, we test our system at the MUHC. In the fifth phase, we modify and approve the proposed system. Below is a brief explanation of the five phases.

A. *Phase 1: A systematic review of the literature (completed)*

In this phase, we review the literature on blockchain applications in the healthcare industry. We formulate the main propositions about the benefits that blockchain can bring to the healthcare industry and the challenges that it can resolve.

A set of inclusion and exclusion criteria was defined to collect and analyze the literature. First, we employed two academic search engines: Scopus and Business Source Ultimate. Many search strings were tested to assess the relevance and size of the literature. This procedure produced 277 academic papers. Second, we read each paper's title, abstract, keywords, and more text if needed to evaluate the eligibility of the collected studies. We only included papers that examined the use of blockchain in healthcare as a primary issue. This procedure minimized the number of articles to 142. Third, each article was coded to capture the blockchain's benefits and the challenges that it can resolve. Fourth, we carefully assessed the boundary conditions of each paper. Fifth, we highlighted the consensus algorithms proposed or studied in the literature for blockchain-based healthcare systems. Four main algorithms were identified: Proof-of-Work (PoW), Proof-of-Stake (PoS), Proof of Authority (PoA), and Practical Byzantine Fault Tolerance (PBFT).

B. *Phase 2: Exploratory study (occurring at the time of writing)*

After identifying blockchain benefits and the challenges that it can resolve in healthcare, we conduct several interviews with the MUHC to refine the literature's claims (questions are listed below). It is worth noting that we do not aim to identify the problems of the entire Canadian healthcare system. This is a daunting task that may take years. Our research is a step forward in this direction. More precisely, our unit of analysis is the MUHC and its stakeholders.

- What is the current design of the MUHC supply chain? Who are its main stakeholders?
- What type of communication systems are used by each stakeholder? What kind of data is exchanged? Where is the medical data hosted?
- Are there any supplementary technologies that need to be used with blockchain to ensure data veracity?

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- What are the most apparent issues challenging the current communication systems?

In addition, we conduct a market study to evaluate the most recent blockchain solutions proposed in the industry for healthcare (occurring at the time of writing). This study aims to answer several questions (listed below) that will help us refine our blockchain system.

- What model of blockchain is used?
- What is the consensus mechanism to validate and register information on the blockchain ledger?
- Where is the medical data hosted?
- Who controls the blockchain network (if any)?
- What is the added value of the blockchain solution in healthcare? Is it measured or quantified?

C. *Phase 3: Building the blockchain solution (occurring at the time of writing)*

In this phase, we build (code) the blockchain database. As previously mentioned, we develop a private blockchain system on Hyperledger Fabric. Hyperledger is an umbrella project of open-source blockchains. It offers a high degree of flexibility and multiple ordering services, making it suitable for private sector collaborations. After building the technical solution, we ensure better control over the stakeholders' access.

Overall, the proposed system enables healthcare stakeholders to exchange medical data in real time. According to the network designed during the exploratory study, the information registered on the blockchain ledger would be transparent to all or some stakeholders. Figure 2 shows a sketch of the technical solution. The proposed system and its components will be refined after the completion of the exploratory study, which is still ongoing at the time of writing.

After considering this sector's high confidentiality and authenticity, the system's apparent goal is to integrate the MUHC's stakeholders' information systems with a unified and secure blockchain database.

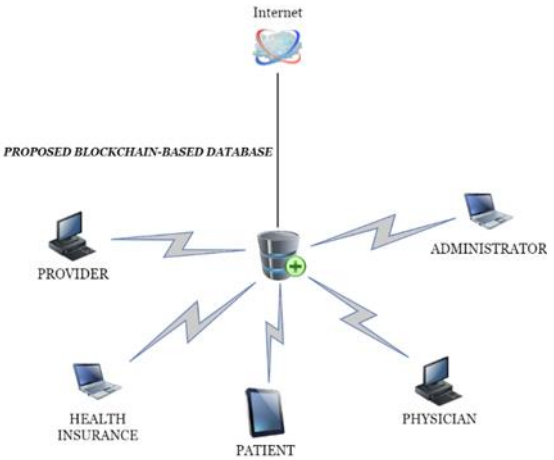

Figure 2. Blockchain unified database.

D. *Phase 4: Platform validation (to be completed during the first half of 2022)*

After building the system, another evaluation process will be conducted to assess and validate the proposed blockchain database. More precisely, the system will be subject to several test experiments at the MUHC. In addition, we interview experts, doctors, managers, information technology specialists working in the Canadian healthcare system.

E. *Phase 5: Communication and model evaluation (to be completed during the first half of 2022)*

In the fifth phase, if the results obtained are as expected, our system will be valid. Otherwise, we would take a step back to Phase 3 to make the necessary improvements. To proceed with this phase, we may need to conduct further interviews with the MUHC and its stakeholders to develop further or modify the system.

IV. PRELIMINARY FINDINGS

We have conducted a systematic review of the literature and analyzed the collected papers. Our exploratory study is occurring at the time of writing. Accordingly, we can report some of the preliminary findings.

Our review of blockchain applications in the healthcare industry revealed that many consensus algorithms are not suitable for healthcare. Many blockchain architectures and new supply chain configurations can emerge by changing the blockchain consensus mechanism.

Proof-of-Authority (PoA) and Practical Byzantine Fault Tolerance (PBFT) are examples of suitable mechanisms. PoW consumes an enormous amount of energy to validate and register information. Although the PoS is considered a solution for the energy problem associated with PoW, this algorithm does not allow healthcare stakeholders to register medical data flexibly. In addition, we categorized tens of blockchain benefits that blockchain can offer to healthcare, such as traceability, transparency, security, privacy, anonymity, interoperability, etcetera.

Our preliminary findings from the exploratory study highlight that current healthcare systems are highly fragmented. In other words, each stakeholder has its own information system. Accordingly, information is poorly communicated with the different stakeholders, which causes significant delays. In addition, medical data is not secure and vulnerable to data loss and cyber-attacks. These factors negatively impact data management and patients' satisfaction.

Although blockchain is proposed to solve these problems, this potential seems to be still conceptual. We found that many companies today (e.g., IBM) offer easy-to-use blockchain solutions for the healthcare industry. However, these solutions are standard and difficult to customize to fulfill specific needs.

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V. CONCLUDING REMARKS

Research investigating the potential of blockchain in healthcare continues to grow, particularly concerning security, privacy, integrity, and interoperability. Most articles in the literature discuss the capacity of this technology to secure medical records. While this cannot be entirely dismissed, we believe that this has yet to be proven in practice.

Blockchain technology has proven successful and attracted the attention of several industries. However, there is still a considerable need to develop and test customized blockchain solutions in practice. In response, our proposed system is a step forward toward building a decentralized healthcare supply chain. Our system solves the integration problem highlighted in the healthcare industry through a design science research approach.

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