Blockchain Applications in Healthcare

Blockchain-based solution for the medical prescription system in Portugal

Rodrigo Varela Alves da Silva Salgueiro

Thesis to obtain the Master of Science Degree in

Industrial Engineering and Management

Supervisor: Prof. António Miguel Areias Dias Amaral

Examination Committee

Chairperson: Prof. Paulo Vasconcelos Dias Correia

Supervisor: Prof. António Miguel Areias Dias Amaral

Member of the Committee: Prof. António Sérgio Constantino Folgado Ribeiro

January 2021

Declaration

I declare that this document is an original work of my own authorship and that it fulfills all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

DECLARAÇÃO

Declaro que o presente documento é um trabalho original da minha autoria e que cumpre todos os requisitos do Código de Conduta e boas Práticas da Universidade de Lisboa.

Acknowledgements

First, I would like to express my thankfulness to my Professor and Supervisor António Miguel Areias Dias Amaral, for the opportunity to explore a field of study of my interest, and for all the support that the Professor gave me throughout the dissertation.

I want to acknowledge all the people involved, from Dra. Candida and Technical Director Manuela Jesus who helped me to map the current Portuguese medical prescription system; to the ten pharmacists who took some time to respond to the surveys; and, to the blockchain experts Paulo Rodrigues and Nuno Cortesão who embraced the final chapter of this dissertation. A special thanks to my sister, Dra. Mariana Salgueiro, for all the availability and to easily connect me with the pharmacy industry.

This thesis represents the conclusion of a two-year program, where I had the opportunity to meet new colleagues, today I may call them friends. We did spend a lot of nights working on projects but also, we got to learn so much from each one as individuals.

Finally, to my parents, António Salgueiro and Cristina Salgueiro, for all the support and for all the opportunities that enriched my knowledge.

Abstract

Bitcoin was the first real world blockchain application. Blockchain is a decentralized network that rules out the need for a central authority, it is a distributed ledger system. This peer-to-peer network allows to manage transactions through time stamped blocks. Blockchain-based solutions have been increasingly useful in multiple domains throughout industries. One of the most prominent sectors in the use of this technology is Healthcare. Proposals based on this technology are beginning to appear offering a solution to the health system current problems. This thesis starts by approaching, in an exploratory way, five health domains where blockchain solutions can have significant impact, namely: Medicines Supply-chain, Patient data, Clinical research, Health insurance and Medical prescriptions. After understanding the impact that blockchain technology has on the aforementioned areas, one focused the analysis on the case of medical prescriptions. In fact, medical prescription, stood out as the domain and problem that needs urgent solution. In order to narrow down the analysis to a specific case, this thesis focus on the opioid crisis to understand the interplay between blockchain and medical prescription tracking system in Portugal, hence bringing new insight on technological change in this specific field at the national level. After mapping the current system, eight flaws where identified. The potential of blockchain technology to improve the detected flaws was analyzed by blockchain experts. A blockchain-based solution architecture was presented to them and also analyzed. It was clear to conclude that blockchain technology can improve the medical prescription system.

Keywords: Blockchain; Healthcare; Medical Prescriptions; Transparency

Resumo

Bitcoin foi a primeira aplicação real de uma *blockchain*. É uma rede descentralizada que exclui a necessidade de uma autoridade central e é usada como um sistema de contabilidade distribuído. Esta rede permite gerenciar informações e, respetivas transações através de blocos com registo de data e hora. Soluções baseadas em *blockchain* têm sido cada vez mais apresentadas em vários domínios por todos os setores. Um dos mais importantes a beneficiar dessa tecnologia é o setor de saúde. Durante o projeto foram abordados cinco domínios da saúde nos quais soluções baseadas em *blockchain* podem ter um impacto significativo. Estes foram: cadeia de abastecimento de medicamentos, dados dos pacientes, pesquisa clínica, seguro de saúde e receita médica. Com o desenrolar da revisão de literatura, foi possível averiguar o impacto que esta tecnologia pode ter nos casos abordados. No entanto, a crise de opioides, que foi o caso de estudo utilizado para analisar o domínio da receita médica, destacou-se como um problema que precisa de uma solução urgente. Esta dissertação foca-se no sistema de prescrição médica em Portugal. A metodologia apresentada visa melhorar o sistema atual. Após o mapeamento do sistema, oito falhas foram detetadas com a ajuda de profissionais de saúde. A capacidade desta tecnologia para corrigir as falhas detetadas foi comentada por peritos. Uma proposta de arquitetura foi apresentada de forma a melhor perceber como esta tecnologia seria implementada, também sido analisada pelos peritos. Foi possível concluir que a tecnologia blockchain apresenta grande potencial para melhor o sistema de receita médica.

Palavras-chave: *Blockchain*; Sistema de Saúde; Receita Médica; Transparência

Table of Contents

List of Tables

List of Figures

List of Abbreviations

AHHS – American Health and Human Services

API – Application Programming Interface

ARS - Regional Health Administrations

BDNP - Portuguese National Prescription Database

EHR – Electronic Health Record

GDPR – General Data Protection Regulation

EMP – Electronic Medical prescription

HCEG – HealthCare Executive Group

HIPAA – Health Insurance Portability and Accountability Act

L&SCM – Logistics and Supply Chain Management

MMP - Manual Medical Prescription

NFC – Near Field Communication

NISS - Social Secure Identification Number

ONC - Office of the National Coordinator for Health Information Technology

PDMP – Prescription Drug Monitoring Programs

PHR – Personal Health Record

PoA – Proof of Activity

PoS – Proof of Stake

PoW – Proof of Work

PRVR - Vignettes and Recipes Request Portal

QR – Quick Response

RNU – (Registo Nacional de Utentes) - National Registry of Users

SAPA - Support Products Assignment System

SNS – National Health Service

SPMS - Shared Services of the Ministry of Health

USA – United States of America

1 Introduction

The present chapter aims to contextualize the reader about what is approach in this work (Section 1.1), discussing the scientific motivation and key research objectives (Section 1.2) and, finally, outlining the project's structure (Section 1.3).

1.1 Problem Context

The following work focus on blockchain technology applications within the healthcare sector. Further on, the work was centered on the Portuguese medical prescriptions tracking system.

Blockchain technology concept was first introduced in the early 90´s by Haber & Scott (1991), but it was just conceptualized in 2008 by the creation of Bitcoin by the pseudonymous Satoshi Nakamoto (Lin & Liao, 2017). According to the Bitcoin whitepaper (2008), Bitcoin emerged to solve the digital currency double-spending problem that happens when the same coins are used more than once. Conforming to Theodouli (2018), blockchain technology can be described as a lineup of recorded transactions in blocks that is continuously expending. Lansiti & Lakhani (2017) define blockchain technology as an open distributed ledger that records all the transactions efficiently and in a verifiable permanent way.

Recent researches show that the USA are facing an opioid epidemic crisis (Thatcher & Acharya, 2019; Zhang et al., 2018). This problem has gained volume from early 90's, leading to more than 200,000 overdose deaths, it was mainly caused by medicines based on opioids (Thatcher & Acharya, 2019). Conforming to Thatcher & Acharya (2019), the main cause of this problem originated from the excess use of opioids, mainly from medical pain relievers.

Blockchain technology can be used to impact the use of medical prescription fraud, it can help monitor prescriptions, making the system safer (Zhang et al., 2018)

1.2 Dissertation Motivation and Goals

The key motivations for developing the present dissertation relate, on one hand, with the rapid development and application of blockchain technology, which is traversal to several goods, services, processes and industries; on the other hand, the health industry is developing at a fast pace and it faces many challenges that – as proposed, based on the literature and empirical evidence – may be addressed with blockchain. There is still a clear scarcity of research exploring blockchain technology in the health industry, which constitutes a clear research opportunity. Finally, the fact that blockchain technology is an extremely emergent technology, it brings an additional relevance and research interest of the topic and on potential applications of blockchain within the health system. The present work intends to develop a preliminary structured framework to the topic and provide a solid basis for approaching the specific empirical analysis that will be developed at further chapters. Therefore, the main goals to be achieved with the literature review chapter were to discuss the key definitions and conceptual issues connected to blockchain technology (“What is Blockchain?”) and, to analyze blockchain applications within the healthcare sector while understanding the key processes associated with its implementation and use (“How can blockchain technology improve the health industry?”).

The literature review contributed to conclude that there is a lack of security and transparency in medical prescription systems (Thatcher & Acharya, 2019). Although some efforts were made the problem was not mitigated (Zhang et al., 2018). Blockchain technology can be used to impact the use of medical prescription fraud, it can help monitor prescriptions, making the system safer (Zhang et al., 2018).

Further on this dissertation, the focus will be on the current medical prescription system in Portugal. To be able to link an immersive technology, such as blockchain technology, with one of the most important sectors of society, added extra motivation for the development of this work. The expected results of this work are based on defining the current medical prescription system in Portugal; find flaws in the current system; and study the capacity of blockchain technology in this field.

1.3 Dissertation Structure

The dissertation structure is presented:

1 - Introduction

The first chapter presents a succinct description about the dissertation context and its motivational aspects. Expected goals to be achieved by the end are presented.

2 - Problem Definition

Blockchain technology is a transparent and decentralized network where transactions are recorded and shared with all the participants among the network, an open book of recorded transactions. This technology has the potential to transform industries and sectors. Healthcare system is one of the most important sectors of our society, it faces multiple challenges mainly regarding data management. Blockchain technology can be the solution to many of these challenges faced by the health sector, especially regarding the medical prescription tracking systems.

3 - Literature Review

This chapter is divided into two main topics, it envisions to clarify blockchain technology and how the healthcare sector can benefit from it. The first section goes throughout blockchain, from its concept definition to a more detailed technical explanation, Bitcoin is presented as the first real world Blockchain application to a better understanding of how this technology works. The second main section go towards the healthcare sector by approaching five examples where blockchain technology can be used to improve the health system. The literature review led the work towards five case studies (Medicines Supply-chain, Patient data, Clinical research, Health insurance and Medical prescriptions.) where it was concluded that there are a lot to be improved in the medical prescription systems. It was determined that the work from that point on would be focused on the medical prescription system in Portugal.

4 - Methodology

The methodology chapter summarizes what was done in the thesis. Three main steps are described:

- Step 1 – Mapping the system
- Step 2 – Flaws Analysis
- Step 3 – Experts analysis; Proposed Architecture; Implementation Barriers

The system was mapped by conducting two descriptive/interpretative interviews to a doctor and a technical pharmacist director. To identify the flaws, the Delphi method was applied. Ten pharmacists answered two surveys. Two blockchain experts were interviewed in order to explore the capacity of blockchain technology to overcome the identified flaws. A blockchain based solution architecture was presented to the experts. This part aims to clarify how blockchain technology could be implemented as a solution for the prescription system in Portugal. It is also analyzed by the experts. The proposal does not go much into technical detail, it tries to create an image of how the implementation of a blockchain-based solution would manifest. The solution takes into account the projects approached in the literature review and other information collected throughout this dissertation.

5 – Results

The results refer to the development of what was proposed in the methodology chapter.

6 - Conclusions

In this last chapter, the main conclusions are summarized.

2 Problem Definition

Blockchain technology concept was first introduced in the early 90´s by Haber & Scott (1991), but it was just conceptualized in 2008 by the creation of Bitcoin by the pseudonymous (person or group) Satoshi Nakamoto (Lin & Liao, 2017). According to the Bitcoin whitepaper (2008), Bitcoin emerged to solve the digital currency double-spending problem that happens when the same coins are used more than once. Conforming to Theodouli (2018), blockchain technology can be described as a lineup of recorded transactions in blocks that is continuously expending. Additionally, according to McGhin (2019), all the information is recorded and shared with the entire network of nodes. All the participants can have access to those records anytime and anywhere (Alharby & Moorsel, 2017). The decentralized network will be secure while the majority of the nodes are honest (Satoshi Nakamoto, 2008). Blockchain also simplifies the use of decentralized platforms that exchange data and/or that keep records (Crosby et al., 2016). Blockchain is a distributed public ledger that records transactions, and immutability is guaranteed by a peer-to-peer network and not by a centralized authority (Moinet et al., 2017; Satoshi Nakamoto, 2008).

Blockchain technology can have significant impact in multiple industries and sectors (Giungato et al,. 2017; Tijan et al., 2019), either financial or non-financial (Crosby et al,. 2016) and, in different domains of our societies (Stenum et al., 2015). Blockchain is a revolutionary technology that establishes new advanced features in banking, manufacturing, finance, supply chain and even healthcare, enlarging operational and managerial industrial processes that allows new business models (Al-Jaroodi & Mohamed, 2019; Ramani, 2018). It has the potential to contribute at technical and economic level of innovation (Alharby & Moorsel, 2017) and to reshape and improve society costumes (Ramani et al., 2018; Vyas et al,. 2019). Researchers belief that blockchain technology will have as much impact in our society as the invention of the Internet (Shah et al., 2019), it offers a distributed consensus model that can be applied in multiple contexts (Crosby et al., 2016).

In agreement with Novikok et al. (2018), and as initially stated, the first generation of blockchains were just related to cryptocurrency. However, the unfolding of knowledge due to additional research, enabled a clearer understanding of additional applications that go beyond cryptographic digital assets (Tijan et al., 2019). In the second generation of blockchains (Blockchain 2.0), smart contracts and smart properties concepts were introduced (Agbo et al,. 2019; Novikov et al., 2018). In consonance with Agbo et al. (2019), smart properties are digital assets managed within the blockchain. Smart contracts are coding programs that establish the rules by which, those digital assets are managed (2019). In addition, according to Pham et al. (2019), smart contracts enable the execution of previous established agreements with no third party involvement. These contracts occur in a private and secure manner with zero chances of tampering (Pham et al,. 2019). That said, decentralization may be the most distinguished property of blockchain technology, allowing to overcome the need for a central authority (Agbo et al., 2019). For new electronic payment systems, trust must be overcome by cryptographic proof, where transactions can be processed directly without the need for “trusted” parties (Satoshi Nakamoto, 2008). As argued by Crosby et al. (2016), society is emerged in the digital world while relying always on third parties to secure the network, ignoring the possibility to be compromised.

While Blockchain has become a main discussion topic across multiple industries, it is getting special attention within the healthcare community (Kassab et al,. 2019). According to Vyas et al. (2019), Healthcare is the most impactful sector of society, its infrastructure lays out the foundation for people's quality of life (Engelhardt, 2017). In agreement with Prokofieva & Miah (2019), privacy, service quality and data security are some of the issues concerning the healthcare sector. But there are also other critical issues connected to the sector which can generate new opportunities, for example, according to Medtronic (2018) the sector is losing around $300B per year in data integration.

As stated by Advisor (2019), during the 2019 HealthCare Executive Group annual forum, the most critical challenges, issues, and opportunities healthcare is expected to face in 2020 were outlined:

1. Costs and Transparency
2. Consumer Experience
3. Delivery System Transformation
4. Data and Analytics
5. Interoperability and Data Access
6. Holistic Individual Health
7. Payment Methods
8. Accessible Points of Care
9. Healthcare Policy
10. Privacy and Security

In line with Kassab et al. (2019), the sector produces enormous quantity of data by monitoring patients, managing health records and, by creating medical insurance claims. Engelhardt (2017) also reinforced the importance of managing health information accurately. According to Medtronic (2018), the investment on the healthcare industry, is reaching trillions of dollars worldwide, and it is increasing by 5.6% every year. In consonance with Ramani et al. (2018), it is essential that the medical management procedures are processed with accuracy and timely, without compromising the patient safety. In consonance with Shah et al. (2019), the healthcare industry has been facing sophisticated improvements due to emerging technologies. Yet, the last major improvement regarding data management was the digitalization of health records, which cannot solve the interoperability challenge (Shah et al., 2019). As reported by Ramani et al. (2018), currently most of the healthcare systems are controlled by a central authority, the access to the patient information is difficult and it can be compromised, thus leading to a lack of accuracy and more frequent errors.

Blockchain technology has been identified as a data distribution management tool (Prokofieva & Miah, 2019), and it has been extended to healthcare (Kassab et al., 2019). As stated by Dah (2019), healthcare will face some disrupt challenges in 2020, mainly regarding systems interoperability, and by the next ten years, blockchain technology will be the foundation of personal health data management.

Additionally, conforming to Down et al. (2018), in five years, 55% of healthcare applications will embrace blockchain technology. The decentralized and distributed properties of this technology enables to support the system needs (Prokofieva & Miah, 2019). It features new ways to secure and manage patient data, a most efficient and flexible way to share data, and installs interoperability in the system as well as facilitates the billing methods (Ramani et al., 2018). The core characteristics of blockchain technology can contribute in a unique way to improve the healthcare sector (Prokofieva & Miah, 2019), it brings advantages to the overall health ecosystem with a demonstrated higher interest regarding information sharing between multiple entities (Mettler, 2016). Managing health data requires special attention due to privacy and compliance concerns associated with patient rights (Medtronic, 2018).

As claimed by Zhang et al. (2018), some of the health domains where blockchain can be beneficial are:

- Prescription Tracking
- Data Sharing Between Telemedicine and Traditional Care
- Patient-Controlled Cancer Data Sharing
- Cancer Registry Sharing
- Patient Digital Identity
- Personal Health Records
- Health Insurance Claim Adjudication

Mari Greenberger, the director of informatics at Healthcare Information and Management Systems Society, a non-profit American organization dedicated to Healthcare improvement, remarked (Mertz, 2018) - “Because of multisystem platforms and an often-fragmented environment within Healthcare, I think this distributed-ledger technology has immense potential to help with some critical component”.

As stated by Matthews (2018), blockchain can have huge impact in the health sector, enabling better health results. According to P. Zhang el al. (2018), the healthcare sector can benefit from blockchain technology in multiple domains, as described in Chapter 2. Nevertheless, for the purpose of this project, only five domains are going to be approached, these are:

1. Medicine Supply Chain
2. Patient Data
3. Clinical Trials Research
4. Insurance Claim
5. Medical Prescription

The unfold of these five cases, where blockchain technology is already being studied, determined what would be the follow-up of this thesis. Even knowing that all these five cases are relevant, the medical prescriptions case stood out due to the current problems it is facing.

There is lack of transparency within the system and this problem got even more serious when it started to put people’s lives in danger as happened in the USA with the opioids crisis (Thatcher & Acharya, 2019; Zhang et al., 2018). This problem has gained volume from early 90's, leading to more than 200,000 overdose deaths, it was mainly caused by medicines based on opioids (Thatcher & Acharya, 2019). In 2017 more than 70,000 Americans died due to drug overdose, where over 60% involved opioids use (Hill et al., 2019), it was declared a public health emergency (Thatcher & Acharya, 2019).

Since there are medicines based on opioids (e.g., painkillers), anyone just needs to have access to a medical prescription to get access to those medicines. Although the opioids crisis in the USA gave dimension to the lack of security and transparency on the medical prescription system, the problem involves all types of medications. These problems are reaching other countries, such as Portugal where recently was detected fraud activity within the medical prescription system.

The capacity of blockchain technology to solve this problem is further analyzed.

3 Literature Review

This chapter is divided into two main topics, blockchain technology (Section 3.1) and blockchain within the healthcare (Section 3.2). Across Section 3.1 a generic definition of blockchain technology will be presented. Section 3.1.1 explains the consensus mechanism protocols that run blockchains. By Section 3.1.2 different permission types of blockchains are clarified, furthermore to a better understanding of what was presented until that point, in Section 3.1.3, Bitcoin will serve as a practical example, the section goes into a general overview about it. New projects emerged after Bitcoin especially in consonance with Blockchain 2.0 where smart contracts were introduced, Ethereum Blockchain and Hyperledger Platform are described in Section 3.1.4. Finally, Section 3.1.5 goes through some blockchain applications.

The analysis of five real world applications of blockchain technology within the healthcare, intends to give a better understanding of how this technology can improve the health system. The choice of these applications aims to demonstrate the differences among different scenarios rather than, to indicate the relevance of one topic versus another. The healthcare chapter is composed by the following sections:

- Section 3.2.1 – Medicine Supply Chain
- Section 3.2.2 - Patient Data
- Section 3.2.3 – Clinical Research
- Section 3.2.4 – Health Insurance
- Section 3.2.5 – Prescription Tracking

Section 3.2.6 describes potential blockchain implementation challenges within the healthcare industry. To finish this chapter, a conclusion is presented in Section 3.3.

3.1 Blockchain

According to Lansiti & Lakhani (2017), blockchain technology can be viewed as an open distributed ledger that records all the transactions efficiently and in a verifiable permanent way. In consonance with Dinh et al (2017), blockchain as a distributed ledger totally open to everyone that records and shares all the transactions that arise within the network. Additionally, it combines a peer-to-peer network that uses distributed consensus algorithms to solve traditional distributed database synchronize problems (Lin & Liao, 2017). As stated by Thatcher & Acharya (2019), blockchain is a decentralized database that works on cryptographic behaver, in particular by hashing algorithms and digital signatures. Blockchain is a transaction keeper, all the network nodes have an actualized copy of the ledger where all the transactions are described, it proves the system has not been modified (Pierro, 2017).

Conforming to Lin & Liao (2017) and Mark A. Engelhardt (2017), blockchain technology is:

- **Decentralized**: Blockchain works as a peer-to-peer network, it means that it does not relies on a central point of control, each node represents part of the network. This technology records, stores and shares the information through the network. Meaning that the network is controlled by all the participants.

- **Transparent**: All the information recorded into the blockchain is visible by all the participants bringing trust to the network.
- **Immutable**: All the data that is stored in the blockchain cannot be deleted or changed. Any change within the chain would have to be approved by the majority of the network.
- **Open Source**: Blockchain is an open-source network, it allows anyone to create decentralized applications.
- **Autonomy**: The consensus mechanism protocol lets a single node to transfer and upload information into the network and it maintains the trust and security.
- **Anonymity**: Transfers within the blockchain are made between addresses that doesn't link to anyone directly, it hides the IP addresses and, it keeps all the networks participants anonymous. Information is encrypted inside each block and, to have access to it, only with the correct cryptographic key.

In addition to the properties already stated, Wust & Gervais (2017) added:

- **Redundancy**: Recorded information is shared through all the network participants, while in centralized systems it requires backups on physical servers that can led to replicated documents.

Lin & Liao (2017) describe the working process of a blockchain as follows:

1. A sending node records new data and broadcasts it to the entire network.
2. A receiver node verifies if information is correct.
3. A block is created when has enough information stored and with a minimum of transactions.
4. Nodes execute the consensus mechanism protocol over the created block.
5. If consensus is achieved, the block is added to the chain.

3.1.1 Consensus Mechanism

Consensus means agreement, unanimity throughout the blockchain network nodes (Sankar et al., 2017). The mechanism protocol makes the network nodes reach group consensus (Zhang et al., 2019). Consensus mechanism ensures that the last created block was added to the blockchain accurately, with the right information stored in it and protected from possible tamper attempts (Lin & Liao, 2017). Blockchain consensus mechanism is based on byzantine general problem, the Byzantine Generals Problem tries to discover a solution to meet agreement between loyal Generals (Khan et al., 2019; Lamport et al., 1982).

There are some consensus protocol mechanisms, such as Proof of Work (Nakamoto, 2008), Proof of Stake (Zhang et al., 2019) and Proof of Activity (Bentov, 2014). The three referred consensus mechanism are explained below:

- **Proof of Work**: A chosen node, also called "miner", must find the block hash value in order to add the new block into the chain, this procedure is called the "mining" process (Vangulick et al., 2019). The execution of PoW just depends on the miner work capacity, due to the difficulty of this process it is possible to create "mining pools", where a group of nodes emerge together to achieve higher computational power (Lin & Liao, 2017). As reported by R. Zhang et al. (2019), the validation process must pass this challenging process, taking into account that a block can only be added to the chain through the mining process. Also according to R. Zhang et al. (2019), PoW is referred as having two main assumptions: (1) it should be difficult and time-consuming for any prover to produce a proof that meets certain requirements; (2) it should be easy and fast for others to verify the proof in terms of its correctness. The low success probability of this process, makes uncertain who is the miner that will have the capacity to generate the next new block (Lin & Liao, 2017), it depends on the first to achieve the PoW (Xu et al., 2016). As explained in the white paper of Bitcoin (2008), Bitcoin relies on PoW, the miner who successfully adds the next block to the chain is rewarded with new bitcoins.

- **Proof of Stake**: While PoW requires high CPU power and electricity, PoS is a less complex consensus mechanism, the main resource is the amount of coins the validator holds, it gives him voting power (Lin & Liao, 2017). Mining ability is proportional to the stake of the respective blockchain currency that the miner holds (Xu et al., 2016). In order to tamper the network, the validator would need to hold more than 50% of the network stake (Lin & Liao, 2017), which is quite costly (Xu et al., 2016). The creator of the next block can be chosen in a random selection, depending for example on his stake (Cong et al., 2017) after they have proved that they are in the possession of the required amount of coins (Xu et al., 2016).

- **Proof of Activity**: PoA combines PoW and PoS properties, this protocol begins with various miners trying to find a new block and the next step is to validate the block trough PoS protocol, the chosen miner signs the block (Bentov et al., 2014).

Table 1 presents the advantages and drawbacks of the three consensus mechanisms just presented, based on the work of Zubaydi et al. (2019):

Table 1 – PoW, PoS and PoA advantages and drawbacks (adapted from: Zubaydi et al., 2019).

Algorithm	Advantages	Drawbacks
Proof of Work	* Provides comprehensive decentralization of power and control in the network * More secure network	*High processing power (expensive) *High electricity consumption *Small networks can be compromised
Proof of Stake	* More energy efficient * Better rewards with bigger stakes * Provides faster processing of transactions	* Less decentralized network than PoW * Less security than PoW
Proof of Activity	* High security * Eliminates 51% attack in blockchain network * Improve network topology *Low transaction fees	* Requires large amount of resources in mining phase * Stakeholders have the ability to double sign transactions * Difficult to implement

According to Lin & Liao (2017), if a node would have the majority of the network stake (PoS) or CPU power (PoW), it could: (1) Modify the transaction data, it may cause double-spending attack; (2) To stop the block verifying transaction; (3) To Stop miner mining any available block. As reported by Yermack (2017), a blockchain cannot be compromised. In order to alter a transaction inside a block, all the following computational blocks would have to be changed and interlinked before any new block is added (Yermack, 2017).

Blockchain is a continuously growing chain of blocks that are linked and secured by cryptography (Iansiti & Lakhani, 2017). Each block is given its own hash once it is created, it is always unique and, if the information inside the block is changed, the hash of the block will also change making it no longer the same block (Iansiti & Lakhani, 2017; Nakamoto, 2008). The hash of the previous block is what connects the following block, establishing the chain (Haber & Stornetta, 1991; Iansiti & Lakhani, 2017; Nakamoto, 2008), it is an output of a computational transformation of a given input information (Pilkington, 2016). Tampering one single block will compromise the chain, making it invalid (Iansiti & Lakhani, 2017; Nakamoto, 2008).

3.1.2 Types of Blockchain

Blockchains can be characterized as permissionless or permissioned, where the last one divides into private and consortium blockchains (Alhadhrami et al., 2018). Both types of blockchains are presented below in agreement with Alhadhrami et al. (2018):

A. **Permissionless Blockchains**: Referred to as public blockchains, these are opened to everyone who wants to be part of it. A public blockchain allows any participant to be part of the transactional validation process, by setting themselves as validation nodes. Since this type of blockchains do not have access restrictions, they are considered public, every transaction is public, and users can maintain individual anonymity.

B. **Permissioned Blockchains**: The storage of sensible information in a public blockchain can compromise individuals or organizations and so, some proper precautions are needed to provide the required confidentiality. Permissioned blockchains appeared to provide more confidentiality and privacy, it is driven by two different concepts, private and consortium, both run on a private network and can only be accessed preauthorized entities.

B1. **Private Blockchains**: Private blockchains are permission-based networks. In this type of blockchain rules can be adjusted and even revert recorded transactions. The validation of the transactions is verified only by the network creator, making the network fully centralized on one entity. Users are granted permission to access certain type of information, they are able to perform just specific and preauthorized functions.

B2. **Consortium Blockchains**: Ideology is the same as private blockchains, but rather of having the power over one party, trust is given to more than one entity. When a block is added to the chain, it means that more than 50% of chosen entities validates the transaction. Unlike private blockchains, consortium blockchains can be viewed as almost decentralized.

Permissionless (public) blockchains are affected by unwanted characteristics, mainly the data replication, while permissioned (private and consortium) can be more practical but at the same time more risky (Abdullah & Jones, 2019). Permissioned blockchains have faster operation process and more energy efficient since it can use consortium protocols, which requires less CPU power (Sankar et al., 2017). Instead of having a competition between miners to solve an algorithm (PoW), a less competitive method can be applied such as PoA, where trust is maintained by acceptance of the transaction through voting process (Leeming et al., 2019). Both permissioned and permissionless blockchains have advantages, it depends on the need, service or place this technology is being used (Lin & Liao, 2017). Figure 1 represents a visual architecture of public, consortium and private blockchains.

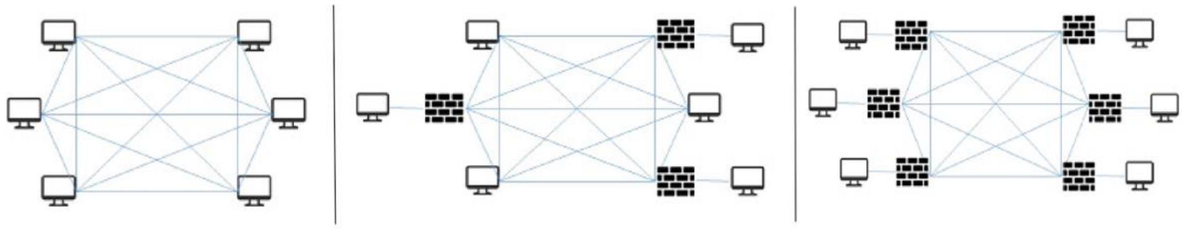


Figure 1 – Public, Consortium and Private Blockchain (Lin & Liao, 2017).

To solidify the explanation about public, consortium and private blockchains, Table 2 describes their concepts; the quantity of authorities that rules the network; the consensus process speed; and, the scenario where each type of blockchain would be more appropriate.

Table 2 - Blockchain Types (adapted from: Zhang et al., 2019).

Blockchain Types	Describe	Authorities	Consensus Speed	Scenarios
Public	Anyone can participate and is accessible worldwide	0	Slow	Global decentralized scenarios
Consortium	Controlled by pre-selected nodes within the consortium	≥ 1	Slightly Fast	Businesses among selected organizations
Private	Write rights are controlled by an organization	1	Fast	Information sharing and management in an organization

3.1.3 Bitcoin

Bitcoin was the first real use case of a Blockchain application (Lin & Liao, 2017), and remains the main application using blockchain technology (Yli-Huumo et al., 2016). Bitcoin is a digital currency that runs on an open source peer-to-peer payment system (Giungato et al., 2017), that relies on the PoW consensus protocol (Androulaki et al., 2013). Bitcoin is not controlled, or emitted, by any centralized authority, the entire coins supply distribution and transaction authentication is maintain by the Bitcoin network (Decker & Wattenhofer, 2013). As stated at Crosby et al. (2016), once a bitcoin transaction is recorded into a block, it cannot be erased or changed.

According to the Bitcoin white paper (2008), Bitcoin emerged to solve the double-spending cryptocurrencies problem, it means using the same coin more than once (Androulaki et al., 2013). As reported by Yli-Huumo et al. (2016), Bitcoin benefits from the use of public key infrastructure mechanism, and it runs over two types of keys. The public key, that is associated with the user Bitcoin wallet address, and the private key, that is used as the user authentication (Yli-Huumo et al., 2016). The public key identifies senders account, then, the private key signs the transaction from the sender (Decker

& Wattenhofer, 2013), the keys make part of the transaction authorization process between users (Androulaki et al., 2013). Bitcoin holders are identified between them by their Bitcoin addresses, while keeping their real identity anonymous (Androulaki et al., 2013). Each transaction has its own hash value identity (Decker & Wattenhofer, 2013). Bitcoin is a chain of digital signatures, when a transaction from the initial holder (sender) to the next one (receiver) happens, the sender is digitally signing the hash of the previous transaction and the public key of the receiver into the coin (Androulaki et al., 2013; Nakamoto, 2008), as follows the example in Figure 4 presented in the Bitcoin whitepaper by Nakamoto (2008):

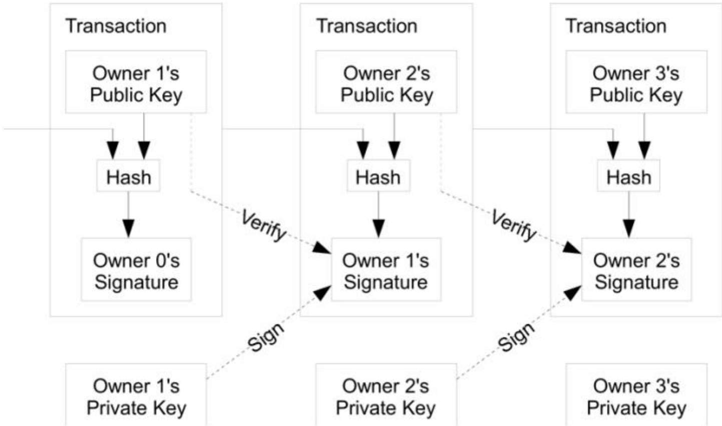


Figure 2 - Bitcoin Transaction Example (Nakamoto, 2008).

In conformation to Androulaki et al. (2013), the follow formulation represents a transaction T from sender address $\mathrm{a_S}$, to receiver address $\mathrm{a_R}$:

$$\mathrm{T}(\mathrm{a_S} \rightarrow \mathrm{a_R}) = \left\{\mathrm{source}, \mathrm{B}, \mathrm{a_{R,}}\mathrm{SIG}_{\mathrm{sk_{a_S}}}(\mathrm{sorce}, \mathrm{B}, \mathrm{a_R})\right\}$$

Where, $\mathrm{SIG}_{\mathrm{sk_{a_S}}}$ is the private key and, $\mathrm{sk_{a_S}}$ is the signature associated with the public key $\mathrm{a_S}$. B, is the quantity of coins to be sent. Source , is the reference from where the sender received the coins that he wants to send to the receiver $\mathrm{a_R}$.

Transactions are recorded in the Blockchain and a copy of the ledger is shared among all the network users, it maintains consistency between nodes (Decker & Wattenhofer, 2013; Nakamoto, 2008).

As exactly described in the original paper of Bitcoin (2008), the steps to run the Bitcoin network are:
1) New transactions are broadcast to all nodes.
2) Each node collects new transactions into a block.
3) Each node works on finding a difficult proof-of-work for its block.
4) When a node finds a proof-of-work, it broadcasts the block to all nodes.
5) Nodes accept the block only if all transactions in it are valid and not already spent.
6) Nodes express their acceptance of the block by working on creating the next block in the chain, using the hash of the accepted block as the previous hash.

The process starts by certifying that the transaction is correct, which means, it verifies if the sender really has the amount of coins he wants to send (2008). A block is created with a group of transactions recorded in it and then it is broadcasted to the network and waits to be verified by the miner nodes (Decker & Wattenhofer, 2013). The nodes will compete to verify through PoW (Decker & Wattenhofer, 2013), any node can try to verify it (Androulaki et al., 2013). When the PoW is completed, and a hash is given to the block, it waits to be checked by the network, and if the transactions inside the block are correct it is accepted and added to the longest chain (Androulaki et al., 2013). As mentioned in the Bitcoin white paper (2008), the rule enounces that - "the longest chain is the correct one, and nodes will work on extending it". The ledger is updated and all the nodes have access to the last version of the chain, that will be used to confirm the veracity of future transactions (Yli-Huumo et al., 2016). Network nodes can leave and reenter the network anytime, they just have to accept the last chain version (2008). The node that finds the new block is rewarded (Decker & Wattenhofer, 2013), it incentivize them to be supportive and honest (Androulaki et al., 2013; Satoshi Nakamoto, 2008). When the new block is created the miner is rewarded with new bitcoins and that's how new bitcoins enter the network, these new bitcoins are recorded as the first transaction of the new block (Nakamoto, 2008). A transaction fee also exists to the ones who validates the transaction (Nakamoto, 2008), when a transaction is checked as correct, the validator node is rewarded (Yli-Huumo et al., 2016). If a transaction is in the public ledger, the mining node can confirm that transition is valid (Crosby et al., 2016; Nakamoto, 2008).

The following figure shows an example of a Bitcoin transaction:

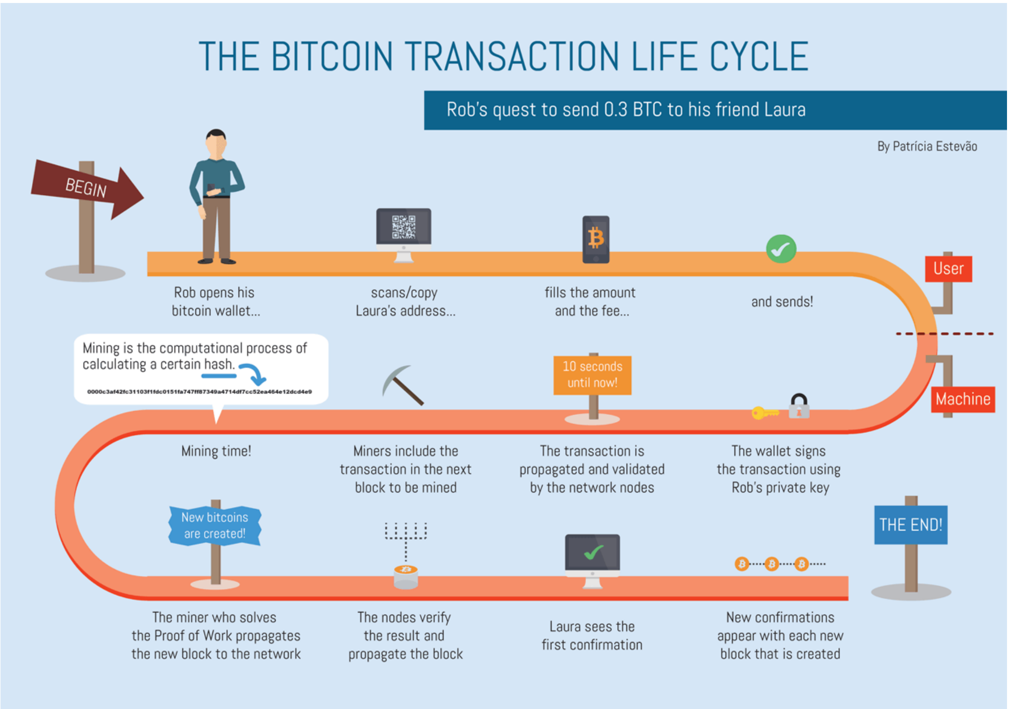


Figure 3 - Bitcoin Transaction, by Patrícia Estevão..

3.1.4 Smart Contracts

According to Kumar et al. (2018), smart contracts are an integral part of the blockchain based applications acting as agreements created between multiple parties, it is a computer protocol that runs on specific and pre-defined rules, codes and constraints.

Blockchain technology enables the creation of decentralized applications such as smart contracts (Cong et al., 2017). These intelligent contracts are coded programs that enforce agreements that must be fulfilled based on the agreement that was previously stablished between two or more entities, these contracts are enforced by a legal organization (Macrinici et al., 2018). It facilitates, execute and enforce, the agreement terms once the previous agreed conditions are met (Alharby & Moorsel, 2017). Since the contract is implemented and executed on the blockchain network, the involved entities must fulfil their previous stablished obligations in order to the contract be valid (Xu et al., 2016).

According to Macrinici et al. (2018), different blockchains can run smart contracts being Ethereum the most used and the most common to build decentralized applications. As well as stated by Alharby & Moorsel (2017), Ethereum blockchain is a public platform where it is possible to personalize and execute smart contracts in the Ethereum Virtual Machine, these contracts can be programmed by more than one code language.

As exactly described by Novikov et. al (2018), besides the possibility of performing transactions with smart contract technology, Ethereum blockchain also:

- Allows you to maintain an optimal level of security due to a large deployment and its irreversibility.
- Ensures transparency of the public blockchain, especially through open-source franchising contracts.
- Has many improvements, especially with regard to scalability.

There are some blockchains such as Ethereum, Ethereum classic, NEO, QTUM, Hyperledger Fabric platform and J.P. Morgan's Quorum, that allow to build projects (Agbo et al., 2019; Zhang et al., 2018).

According to Cachin (2016), the Hyperledger project is an open source project hosted by Linux Foundation that is developing an open source tool that enables the creation of code based distributed ledgers for businesses. In line with what was said, Hyperledger Fabric is a Hyperledger developed project, that runs smart contracts. It is an open source permissioned platform where users form a consortium to decide who can participate in the validation and consensus process (Cachin, 2016).

Table 3 comparers Ethereum and Hyperledger Fabric blockchains.

Table 3 - Ethereum VS Hyperledger Fabric (adapted from: Valenta & Sandner, 2017).

Characteristic	Ethereum	Hyperledger Fabric
Description of platform	- Generic blockchain platform	- Modular blockchain platform
Governance	- Ethereum developers	- Linux Foundation
Mode of operation	- Permissionless, consortium or private	- Permissioned, private
Consensus	- PoW	- Broad understanding of consensus that allows multiple approaches - Transaction level
Smart contracts	- Smart contract code (e.g., Solidity)	- Smart contract code (e.g., Go, Java)
Currency	- Ether - Tokens via smart contract	- None - Currency and Tokens

In consonance with Table 3, the main difference between Ethereum and Hyperledger Fabric is the type of blockchain, while projects build on Ethereum can be permissionless or permissioned (private or consortium), Hyperledger Fabric projects are private. Another relevant difference is the consensus mechanism protocol, at the moment Ethereum consensus protocol is PoW and for Hyperledger Fabric there are multiple approaches.

3.1.5 Blockchain Applications

As stated in Crosby et al. (2016), blockchain technology is earning place between financial, and non-financial areas. Abou Jaoude & George Saade (2019) reinforce that, this technology is built on properties that make it an important and helpful tool for industrial applications and a possible source of disruption for existing industries. In line with Swan (2015) and Novikov et al. (2018), there are three conditional blockchain generations with different applications:

- **Blockchain 1.0** – crypto-currency transactions (crypto- currencies are used in various applications related to financial transactions, for example, the system of transfers and digital payments).
- **Blockchain 2.0** – smart contracts (applications in the field of economy, markets and finance working with various types of instruments - shares, bonds, futures, mortgages, titles, assets and contracts).
- **Blockchain 3.0** – applications, the scope of which goes beyond financial transactions and markets (e.g., public administration, health, science). It will revolutionize the throughput of blockchain technology, which is currently one of the most important challenges of blockchain technology.

As reported by reporter Marr (2018), blockchain technology can be applied in multiple industries such as:

- **Entertainment**: Spotify company implements Blockchain technology to improve the connection between artists and their music tracks licensing agreements.
- **Retail**: Companies using this technology have their products registered into a blockchain, enabling everyone to confirm their quality.
- **Logistics and Supply Chain:** Consumers can easily track the products they are buying since their manufacture point; every move is shown with total transparency. This technology can be found in companies operating in the food industry or even in the diamonds (De Beers).
- **Insurance:** Accenture company creates Blockchain solutions to support their insurance clients.
- **Real State:** The real state sector is benefiting from this technology by cutting out the need for third parties. Through smart contract technology it is possible to negotiate houses and land anywhere in the world at any time. Companies that use this technology offer lower commission fees since they don't need a broker. These companies are able to arrange better deals with total transparency and security as it is with companies like BitProperty and Deedcoin.
- **Charity:** Some platforms, like BitGive or AidCoin, are using Blockchain technology to increase the trust people have on charities since almost 50% of people nowadays don't trust on them. Through distributed ledgers and smart contract technology, these platforms are completely transparent, every donated money that is spent is clearly shown.
- **Financial Services:** Ripple is a cryptocurrency project that intends to become a global payment solution used by financial organizations like banks.
- **Healthcare:** MedicalChain, MedRec, Nano Vision, Gem and SimplyVital Health, are some examples of companies operating in the Healthcare sector that already implement Blockchain technologies in their Health solutions. Management of medical records and improvement of medical research are some projects developed by these companies.

Abou Jaoude & George Saade (2019), in an attempt to identify the major blockchain fields between more than twenty industries, they identified healthcare as one of the main areas where blockchain can have crucial impact just after IoT, Energy and Finance. Abou Jaoude & George Saade (2019), presented a systematic review literature about blockchain technology where they identified three advantages regarding blockchain in the healthcare sector:

1. **Easier access to medical data** – Blockchain can be a solution that facilitates patients access to their information, with privacy.
2. **Medical data sharing** – At the same time, blockchain will allow patients to manage their own data, it will permit them to share medical data with other entities, without losing the track of it and always with security.
3. **Unifying medical records** – By using a distributed ledger to store medical records, it helps standardize and uniformize all that sensitive information.

3.2 Healthcare

For the purpose of this project, only five domains are going to be approached, these are:

1. Medicine Supply Chain
2. Patient Data
3. Clinical Trials Research
4. Insurance Claim
5. Medical Prescription

These five health domains are presented and sustained by recent and relevant published works.

3.2.1 Medicine Supply Chain

As referred by Howells (2019), by taking advantage of blockchain technology it is possible to provide a secure and reliable verification routing system that can detect counterfeit drugs. According to the World Health Organization (2010), 10% of supply worldwide drugs are counterfeit and for developing countries that number increases up to 30%. Counterfeits drugs are usually based on the correct active ingredient, but with impartial components dosage, higher or lower doses compromising the drug effect (WorldHealthOrganization, 2010). The lack of control is just not covering lifestyle products (e.g. supplements, slimming products), it's affecting more critical drugs such like antibiotics, contraceptives, painkillers and even cardiovascular disorders and cancer treatment drugs, among other prescription drugs, putting peoples life in extremely dangerous situations (WorldHealthOrganization, 2010).

In consonance with Tijan et al. (2019) and Yli-Huumo (2016), current supply chains remain complex and with a major failure of transparency. It would be a distinct advantage for the stakeholders to implement blockchain technology, enhancing the logistics processes into the supply chain (Tijan et al., 2019; Yli-Huumo et al., 2016). Conforming to Lambert (2008), globalization has been impacting the way supply chains are structured. Until the final product reaches the customer's hands it goes through several intermediaries (Lambert, 2008). According to Azzi et al. (2019), the primary supply chain challenge is to improve traceability and data management. In addition, Petersen et al. (2018) declares that one of the most complex and relevant problems of L&SCM is transparency. Blockchain technology creates a reliable connection, making it more transparent (Pilkington, 2016), authentic and trustworthy (Laaper et al., 2017). L&SCM features significant advancements from blockchain technology, essentially when dealing with shared information (Petersen et al., 2018). This technology allows to a better control over cargo's time, location, and guaranty of who is performing what actions with it (Kshetri, 2018). According to Kshetri (2018), by using blockchain technology, it is possible to reduce the amount of intermediaries involved in the supply process, increasing efficiency, and consequently, costs reduction.

Regarding medical supply chain, R. Kumar & Tripathi (2019) proposed already some approaches to trace counterfeit drugs such as Smart-Track, Data-Matrix and NFC, respectively in concordance to Paik et al. (2009), Ur et al. (2011) and Wazid et al. (2017):

- **Smart-Track** – implementation of radio frequency identification (RFID) code in the medicines in order to confirm its veracity.
- **Data-Matrix** – gives each medicine a matrix with specific information about the manufacture, product and package identification, authentication code and optional meta-data.
- **Near Field Communication** – validates the medicines by tags through three stages: product registration, product authentication by key value and NFC tag.

Medical centers' Chief Information Officer and, Healthcare Innovation Professor at Harvard Medical School, John Halamka (2018), gave an example of how blockchain technology could be used to track drugs: "Suppose that Pfizer produces a batch of Tylenol – maybe a million bottles – and writes into the blockchain that it introduced this lot number into the marketplace on this date. That would prevent someone else from making fake Tylenol, because you´d always be able to trace back every shipment to the fact that Pfizer created it."

Figure 4 shows an example of drug traceability:

Figure 4 - Drug Traceability (IBM, 2018).

By analyzing Figure 4, every medicine movement in the supply chain since the manufacture is recorded in the blockchain. The medicine is recorded as a transaction. By the moment that the wholesaler receives the medicine, a new transaction will be created and stored in the network, as well as, when it is passed to the pharmacist. Patients can have access to the ledger and verify if the medicine is legit.

Kumar and Tripathi (2019), proposed a framework to track counterfeit drugs. This framework is presented in three sections, **A**, **B** and **C**:

A. Medical Chain Data Storage in Blockchain

This part regards transactions storage, very similar to Bitcoin. The participants will share among the network their public key, the last transaction hash and encrypted Quick Response code (QR) by producer. This code allows the access to all the information about the medicine. Each medicine will have its own QR code and, it is associated as transaction in the Blockchain. Illegal medicines will not be able to enter the medicine supply chain, since each participant has its own public key associated to a digital signature of the operator.

B. Drug Safety using blockchain

Assure the connection between manufacture, distributor and consumer is secure. The manufacture creates an encrypted QR code to each drug with the respective informative information e.g., name, location, timestamp, ingredients. This process uses smart contract technology to guarantee that the required information is given.

C. Methodology for Proposed Work

The proposed solution works on a private blockchain. The drugs transaction follows the presented steps as exactly described by Kumar & Tripathi (2019):

1- Transaction between participants will consist sender public key and digital signature, receiver public key and the information which is sent by sender.
2- The shared information between the participants will be in encrypted QR code format, which can be only accessed by receiver public key.
3- Sender public key will be verified by all the participants of medical chain supply.
4- Once the transaction gets committed then it will be distributed to all the participants.

3.2.2 Patient Data

Some projects already attempt to improve the management of patient information. For instance, Ronanki (2019) project is based on a permission-based blockchain which enables the patients to control and own their personal health information while controlling who gets access to it. According to IBM Company (2018), dealing with patients information requires a certain level of responsibility, it has high value and there are two main problems when managing it: (1) medical information is very exclusive for each patient (2) sharing it with other medical entities is a considerable threat. According to Harvard School of Public Health (2008), an EHR is a digital record that is created and managed by entities like doctors, while the PHR can be created by different entities like hospitals or pharmacies, but it is managed by the patient. These PHR's are applications where data owners can easily control their health data, by managing how it is used and shared (Leeming et al., 2019;Zhang et al., 2018).

EHR's consist of an individual medical history, and as reviewed by Dasaklis et al. (2019), by managing these documents some challenges can appear:

- Health data lives in silos with ultimately disjoint integration to other data sources.
- Various regulations, while valuable and necessary, make it extremely hard to efficiently combine and share data between people and various stakeholders.
- Patients often have limited access to their own data and their management.

As stated by Zhang et al. (2018), Apple and Microsoft already have projects that aim to give a solution to manage patients health records, through Apple Health and Microsoft HealthVault respectively. However, it does not take into account the sharing problem since all this solutions are based on a centralized system (Zhang et al., 2018). According to Shah et al. (2019), these centralized health systems, do not have the capacity to communicate in a transparent way, they present weak interoperability between them.

Kumar et al. (2018), states that blockchain technology gives patients the power to access their health data securely and with total control over who accesses it. This system can be managed over an Application Programming Interface, where the patient has its own profile with personal stablished access conditions, supported by smart contract technology (IBM, 2018). Blockchain technology connects existing health systems into a protected and useful data service, enabling the aggregation of individual health records without the need to, reach every health provider (Zhang et al., 2018). As reported by Mertz (2018), an EHR allows to better manage patient data, but in a centralized way. However, when it comes to access those documents from another facility, it is inaccessible (Mertz, 2018). Tech experts believe blockchain has the capacity to solve this problem, centralizing all the data stored in one place, but accessible where and, when the most needed by the owner and authorized entities (Mertz, 2018; Zhang et al., 2018).

The discussion above can be illustrated with two real cases of projects where blockchain technology is used as a solution in healthcare patient data: “MedicalChain” (2017) and “A Blockchain for Health systems Case” by Wu & Tsai (2018).

MedicalChain

According to the MedicalChain Whitepaper 2.1 (2017), the project offers a decentralized platform, that intends to improve the exchange and management of health information, while keeping just one authentic version of patient data in the server. This platform was built through Hyperledger Fabric architecture, a permissioned (private) blockchain, each user can define access rules through smart contract technology. Profile access can be authorized to hospitals, doctors, pharmacists or clinical labs. Every interaction such as information access view and changes, will be recorded as a transaction in the MedicalChain distributed ledger, while keeping the patient privacy. EHR are standardized and all the medical documents are encrypted while kept on a single cloud server. By giving access permission, the user is allowing access to the documents stored in the server from anywhere. In this context, a grant access transaction between Patient A and Practitioner A will be as follows, as exactly described in MedicalChain Whitepaper 2.1 (2017):

- Patient A grants access to EHR to Practitioner A.
- Practitioner A’s ID is added to Patient A’s authorized asset on the ledger.
- Patient A’s ID is added to Practitioner A’s authorized asset on the ledger.
- The Symmetric key for the EHR is decrypted with Patient A’s private key.
- Symmetric key is then encrypted with Practitioner A’s public key.

The relationship between practitioner, patient and a research institution, read and write permission is presented in Table 4:

Table 4 - Read and write permission, (adapted from: Ammbr, 2017).

Participant	***Permission***
Practitioner	- Read/Write on permissioned EHRs - Request permission for other Practitioner/Institutions to gain Read/Write access
Patient	- Read their EHR - Permission a Practitioner/Institution to Read/Write EHR or a portion of their EHR - Revoke permission from Practitioners/Institutions - Permission next of kin/emergency contact to Read/Grant permission - Write certain attributes to EHR - Ability to integrate IoT data into EHR
Research institution	- Read permissioned EHRs

A Blockchain for Health systems Case

Wu & Tsai (2018), presented a health systems architecture with data transmission purposes. The project architecture is defined through an example by the following three steps where, U_x represents the data owner and N_y, the node that requests information:

- Step 1: User U_x has a wearable device or sensor to conduct identity verification against node N_y; when the verification is successful, privacy protection is triggered to protect user U_x's data.

- Step 2: When node N_y demands more medical information from user U_x, node N_y will broadcast a request message to the other nodes in the same blockchain to collect the medical records from these different hospitals.

- Step 3: After the node has received the request message from node N_y, and if it has the medical record of user U_x, it will send this information back to node N_y. Then node N_y will have the complete medical record of user U_x which will help the doctor make a diagnosis and administer treatment.

The presented architecture allows a better control of personal information and it gives the ability to share data with different entities.

3.2.3 Clinical Research

As stated by Shae & Tsai (2017), blockchains can restore trust in science by capturing the lifetime of clinical trials. Also, according to Kumar et al. (2018), clinical trials are an essential part of the healthcare system, an important step that needs special attention. The purpose of a clinical trial is to experiment the resilience and efficiency of a test drug in order to analyze if it can be used as a medicine, this process can take years depending on the efficacy of available data, usually inaccuracy can happen along the way accidentally or not (IBM, 2018). In agreement with Agbo et al. (2019), blockchain technology can improve precision medicine by providing health data analytics, it can have huge impact in biomedical research and education too by minimizing forgery data and enhancing more accurate results. In addition, according to Benchoufi & Ravaud (2017), blockchain stands out as a key support for clinical research.

In order to gain more insight on the discussion above, two real projects are presented, these are MedicalChain (2017) and FHIRChain Dapp (2018).

MedicalChain

Health Data Marketplace is another application field approached by the MedicalChain project. The platform allows patients to negotiate with medical researchers the use of their medical information to researches and for other purposes. Patients have an opportunity to benefit from their health data by sharing it with research institutions, there is also the possibility to be rewarded with MedTokens, it is the MedicalChain's cryptocurrency.

FHIRChain Dapp

In consonance with the FHIRChain project (2018), they proposed a blockchain-based architecture that intends to create a decentralized app. This Dapp aims to share clinical data in a secure and scalable manner. It meets the five technical requests defined in the "Shared Nationwide Interoperability Roadmap" by the ONC (2015), as presented below:

- Requirement 1: Verifying Identity and Authenticating all Participants
- Requirement 2: Storing and Exchanging Data Securely
- Requirement 3: Consistent Permissioned Access to Data Sources
- Requirement 4: Applying Consistent Data Formats
- Requirement 5: Maintaining Modularity

According to Zhang et al. (2018), the FHIRChain Dapp interacts on a private test net on the Ethereum blockchain, and it uses three smart contracts coded with Solidity (a smart contract programming language). It offers a method that, efficiently shares patient cancer data into a tumor board. Then, it collectively helps to systemize treatment plans for other patients with cancer. Additionally, the application has a system alert that gives a signal when new data is ready to be reviewed (Zhang et al., 2018). The Dapp used on the project takes advantage of smart contract technology, as stated by Zhang et al. (2018). Each user has a digital health identity associated to its public encryption key and to access those profiles, providers have to be authorized (Zhang et al., 2018). The authorization access is stablished by smart contracts and providers can then have access to the information by using the digital tokens that are assigned to them (Zhang et al., 2018).

3.2.4 Health Insurance

As reported by Kassab et al. (2019), the immutable property of blockchain technology constitutes a crucial characteristic included as an advantage to insurance companies. Health insurance is an insurance that covers medical expenses, protecting individuals from having large expenses when medical treatment is needed (Zhang et al., 2018). It benefits from the transparency, immutability and decentralized properties of Blockchain technology (Agbo et al., 2019). Insurance claims are not always accepted, where 22% of them get rejected due to errors or because the insurer doesn't receive it (Zhang et al., 2018). Smart contract technology, allows to better automate the adjudication process by making it more transparent and by disclosing possible errors or frauds (Zhang et al., 2018). It also ensures that all the participants are actualized with administration and regulation rules (Zhang et al., 2018).

In order to gain more insight on the discussion above, we present the following real cases of projects where blockchain technology is used as a solution in healthcare clinical research, "MedicalChain" (2017) and "MIStore" (2018).

<u>MedicalChain</u>

MedicalChain has a potential insurance blockchain integration within their platform as referred in their Whitepaper (2017). If patients give insurers direct access to their health information, the insurance companies will have reliable information to work on. By doing that, patients will be rewarded with lower upfront insurance payment and MedTokens, the project cryptocurrency.

<u>MIStore</u>

Zhou et al. (2018), proposed an Ethereum Blockchain based medical insurance storage system where, the tamperproof characteristic of blockchain provides trust between patients, hospitals and insurers. The system works as presented in Figure 5, entities like hospitals and clinics record the medical processes in the blockchain, the insurance companies can verify the patient activity directly while being sure those activities are legit.

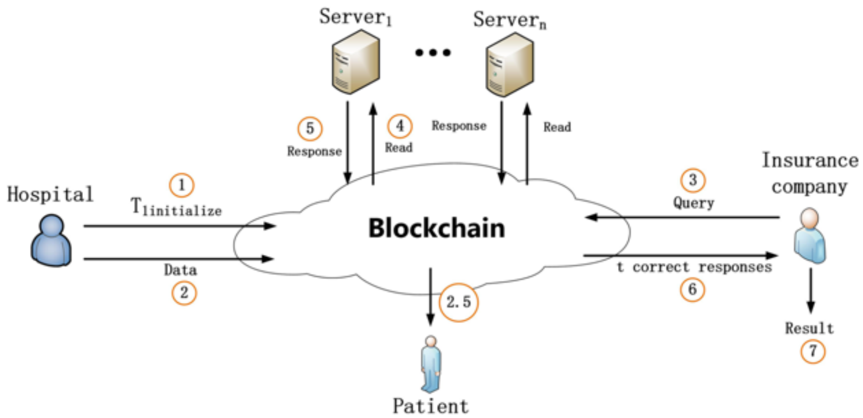


Figure 5 - MIStore Proposed System (Zhou et al., 2018).

As exactly described by Zhou et al. (2018), the system process works in eight steps:

1. Hospital sends a initialize transaction to blockchain network.
2. Hospital sends record transactions to blockchain network.
3. The patient can verify whether his spending records are correctly computed by the hospital.
4. Insurance company sends a query transaction to query some result.
5. Servers read the query transaction and related record transactions from blockchain.
6. After locally computing, servers generate their responses and then send respond transactions to blockchain network.
7. Insurance company collects respond transactions and obtains *t* correct responses.
8. Insurance company recovers the result with the t correct responses.

Insurance companies would benefit from less labor and resources since the information used is legit (Ammbr, 2017).

3.2.5 Medical Prescription

According to the USA government (2018), opioids are classified as a type of drug, may be of natural (opium plant) or synthetic origin. Taking heroin as an example of an illegal drug, it is considered an opioid, but this psychoactive chemical compound is also found on some pain relievers drugs prescribed by doctors, such as fentanyl and oxycodone (USA Governement, 2018). Recent researches show that the USA are facing an opioid epidemic crisis (Thatcher & Acharya, 2019; Zhang et al., 2018). This problem has gained volume from early 90's, leading to more than 200,000 overdose deaths, it was mainly caused by medicines based on opioids (Thatcher & Acharya, 2019). In 2017 more than 70,000 Americans died due to drug overdose, where over 60% involved opioids use (Hill et al., 2019), it was declared a public health emergency (Thatcher & Acharya, 2019). Conforming to Thatcher & Acharya (2019), the main cause of this problem originated from the excess use of opioids, mainly from medical pain relievers. This situation is boosted by the pharmaceutical companies, these companied do not control the use of opioids drug prescriptions and non-prescription (illegal) opioids (Thatcher & Acharya, 2019). Many efforts are being addressed to face this problem, for example, the prescription awareness campaigns which do not control the use of doctor shopping (Zhang et al., 2018). Blockchain technology can be used to impact the use of medical prescription fraud, it can help monitor prescriptions, making the system safer (Zhang et al., 2018). Due to its decentralization characteristic, it can incentivize to reduce the number of prescriptions (Zhang et al., 2018). In order to solve the opium crisis in the USA, the American Health and Human Services implemented a six points strategy (Thatcher & Acharya, 2019):

- better prevention
- treatment and recovery services
- better data
- better pain management
- better availability of overdose-reversing drugs
- better research

The Prescription Drug Monitoring Programs is a state-run database that stores patient's prescription data, it is used to manage and check the opioids drugs prescription. Forty nine USA states decided to take advantage of PDMP's, revealing an evident crisis decreases (Thatcher & Acharya, 2019). However, share PDMP's between states is a problem since the results seem to be inconsistent. At a certain time, the USA government was pushing to an e-Prescription trend, but then the overall results were not as expected, the need for a private server to run the program became a lack of security to the system (Thatcher & Acharya, 2019). Camden Thatcher & Acharya (2019) proposed the Blockchain Solution Integration project to solve the opioids crisis in the USA.

Blockchain Solution Integration

Camden Thatcher and Subrata Acharya (2019), came up with the idea to integrate e-Prescription and blockchain technology, reinforcing the potentiality of the six point strategy plan from the AHHS, and install an interoperable PDMP. Blockchain is a network, interconnected by nodes, and in this solution, the nodes can be pharmacies, hospitals or clinics. Always that a doctor prescribes medication, it would be recorded as a transaction. They created their own cryptocurrency, the *RxCoin* token based on the Ethereum blockchain that allows the use of smart contracts, it is used to manage patient's medication refills. The token uses specific information to manage the prescription, such as:

- patient and prescriber identification
- drug name
- drug strength
- quantity prescribed and how many refills is the patient authorized to get

This information determines how many *RxCoins* are transferred. The process begins when a prescription is launched and new tokens are created, which means that a new contract is assigned into the blockchain. Since this information is recorded on the ledger, all nodes have access to it and then fill the prescription where the process is finished by transacting the tokens from the prescriber.

According to Engelhardt (2017), another project that tries to bust the prescription fraud was developed by Nuco company.

Nuco Company

This project adresses three methods that bypasses the system in order to commit prescription fraud, they are:

1. "modifying numbers to change the prescription itself"
2. "duplication of prescriptions (e.g., photocopying)"
3. "doctor shopping, visit many doctors to collect as many original prescriptions as possible"

The company names this as the "open-ended loop" problem, there is no connection between prescribers and fillers. Nuco's blockchain based solution: After a prescription is created, a "machine-readable code" is associated to it as an identifier, it is recorded with drug name, prescribed quantity, patient identity (anonymous) and, the digital record of the occurrence time, the timestamp (Engelhardt, 2017). Stakeholder's identity is maintain secure within blockchain encryption, each authorized stakeholder just have access to certain information if they have the respective correct cryptography key, this project is based on a permissioned blockchain (Engelhardt, 2017).

In line with Katuwal et al. (2018), there are many other blockchain based solutions projects that have been proposed in order to improve medical prescription management:

BlockMedx

BlockMedx is a startup that already offers a service that prevents the incorrect use of prescriptions with a next generation of smart e-prescribing and analytics software compliant with HIPAA. This startup aims to offer a platform that allows to have real time worldwide access, send and receive electronic prescriptions, track prescriptions and predict at risk patients. The project uses an Ethereum based platform to manage the prescriptions, the entire history of transactions is recorded in the blockchain, it makes the prescription management process more efficient (BlockMedx, 2019; Katuwal et al., 2018).

Project Heisenberg

This project also aims to manage prescriptions through smart contract technology on top of the Ethereum based platform. It is a decentralized identity management and pharmaceutical ERP system built on top of a permissioned Ethereum consortium network. The main functionality is also to track the drugs, each user has access to the platform (Heisenberg, 2019; Katuwal et al., 2018; Leffew, 2018).

ScriptDrop

ScriptDrop's project aims to deliver the drugs directly to the patients without the need to be present at the pharmacy. This platform also controls the usage of medicine, to make sure that patients are tanking it correctly through a virtual assistant. All the delivery and control processes are tracked through the blockchain (Katuwal et al., 2018; ScriptDrop, 2019).

ScalaMed

The main goal of ScalaMed's project is to provide patients with a history of medication taken. Some taken medication can affect future treatments and so it's important to have that history (ScalaMed, 2019; Katuwal et al., 2018).

3.2.6 Blockchain Implementation Challenges

Despite all the studies in the field of blockchain technology this topic still is an unknown subject, difficult to understand and to visualize its applications, at this point it is more an educational than a technical barrier (Voas, 2018). According to Kassab et al. (2019), in terms of adoption, blockchain cryptographic concepts still unknown for most people. Regarding the healthcare sector, the main barrier is the lack of awareness about blockchain technology (Voas, 2018).

As stated by Kumar et al. (2018), there are seven topic challenges to be addressed previously to blockchain implementation as described below:

1. **Scalability Restrictions:** The blockchain network would need to keep up with the demand technical requirements, the computing capacity versus the volume of medical transactions.
2. **High Development Cost:** Blockchain technology implementation may have high initial operation costs to the healthcare systems, such as systems development.
3. **Standardization Challenges:** What is stored in the blockchain needs to be clarified, installing a uniform size and format of the documents, and also defining what is stored in the chain and off-chain.
4. **Cultural Resistance:** Share personal medical data does not take part of societies current culture, it will require some change in society costumes.
5. **Regulatory Uncertainty:** Regulatory entities such as HIPAA, need to establish policies regarding the use of Blockchain technology to public health services.
6. **Security and Privacy Concerns:** Healthcare deals with sensitive data, sharing it with other entities must be secure. The network transparency can compromise patient's privacy.
7. **Unwillingness to Share:** Hospitals and insurance companies keep some information just for themselves to have advantage over others. Medical information has value, and who if access is restricted, they can profit from it.

3.3 Literature Review Conclusions

Blockchain is one of the most promising technologies that promises to change the World. Blockchain is a shared and immutable ledger that records transactions. The decentralization property makes unnecessary the need for a central authority strengthening the system against security breaches. This technology reduces the errors when validating information which improves accuracy. Transactions are recorded and stored inside blocks as soon as they are validated by the nodes. The process of creating new blocks can require high computing power, depending on the consensus mechanism. Blockchains can be permissionless or permissioned, depending on the purpose where this technology is applied, it can be public where anyone can participate, or it can provide a more private system. Alternative coins to Bitcoin emerged with innovative projects, Ethereum project stands out with its ability to run smart contracts, just like Hyperledger Fabric, a more recent project, that also allows the use of that technology through a more private network. These smart contracts are computer protocols that intend to perform contracts without the need of a third party.

Currently, several blockchain-based applications are being implemented in the most diverse industries, however, one of the most prominent sectors to benefit from this disruptive technology is Healthcare.

Current supply chain cannot keep counterfeit drugs under control leading to huge losses. Counterfeit drugs reach the final consumer by entering in the supply network without any registration control. A blockchain-based solution can solve this problem by providing an immutable and timestamp identity for each drug. All the intermediaries through which the drug passed until it reaches the final consumer is recorded in the ledger, the patient can confirm the legitimacy of the medicine.

Another challenge faced by the health sector is the lack of information available and the management of patient medical data. It includes the storage, access and share of sensitive information, and these health entities use unsafe platforms to manage that data. Blockchain can be used to safely manage and store patient information, while the patient can control all his medical information and if necessary, share it in a safe and controlled manner.

Clinical research depends on tons of trial data, the main challenge is to take care of collected data appropriately. Blockchain improves the monitoring and effectiveness of clinical trials by eliminating fraud and data manipulation, further improving healthcare. It provides data integrity and can act as proof of authenticity when documents have to be verified. Patients can also share their data without revealing their identity and also be rewarded. This is extremely favorable for health institutes, where anonymous data can be used to improve health research. Patients always control their data and decide who can access it.

Medical insurance companies do not always have detailed access to patient expenses. By recording information such as medical treatment bills into the blockchain, medical insurance companies may have direct access to information that is legit, improving the service quality.

The opioid crisis in the USA has become a serious national health problem. One of the causes of this problem has been found to be the misuse of medical prescriptions, which is easily falsified or even purchased from doctors who allow it. Blockchain-based solutions have been proposed in order to implement a more effective prescription drug tracking system. The possibility to identify excessive use of opioid based drugs and control the number of created prescriptions, are some of the possibilities these proposed systems are able to perform.

Although medical prescription fraud has had started to have huge impact in the United States of America, this problem has been identified in other countries. This year, the opioids crisis faced by the USA, has become a mediatic affair for some European countries such as Portugal (Bento & Gonçalves, 2019; Publico, 2019; Tomé, 2019). Portugal also has a prescription fraud problem to be faced, where corruption and other criminal activities regarding medical prescriptions occur (Expresso, 2019; Marcelino, 2019). Based on the literature review and, taking into account what was concluded about the impact that medical prescription fraud can have on society, the main focus of this thesis from now on, will be around the Portuguese medical prescription tracking system.

4 Methodology

This chapter provides a detailed description of the methodology to be followed throughout the dissertation. This chapter is divided into three sections, which correspond to the three major methodological steps to be employed. The application and triangulation of different methods allows for a better model validation, theory testing and a better gathering of important information to consider.

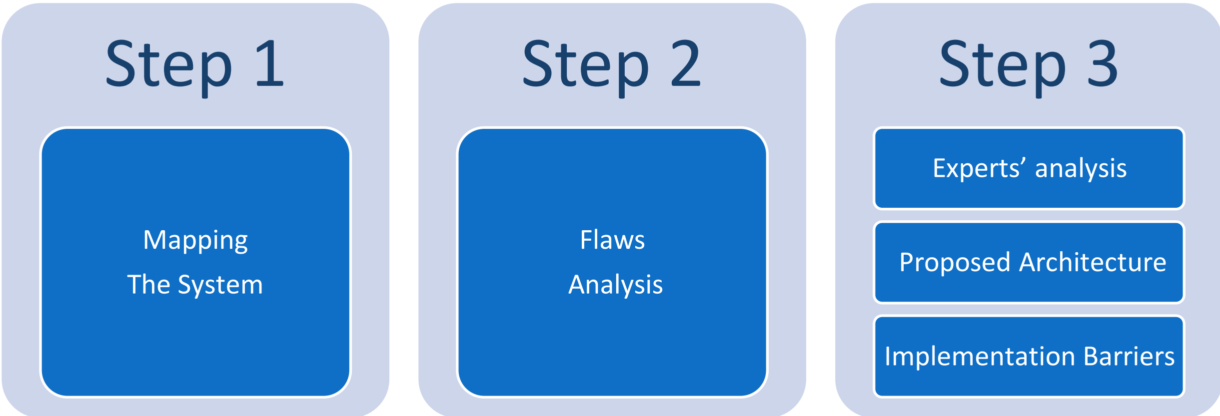


Figure 6 - Methodology Steps.

The first step is be conducted by two interviews; in the second step the Delphi method is applied where ten pharmacists responded to two surveys; and in the third step is defined by the interview a two blockchain experts. Each step of the methodology is explained in detail below.

4.1 Mapping the Medical Prescription System in Portugal

This first step aims to map the full "lifetime" of a medical prescription, from the moment it is created by an authorized professional, till it is used by the patient at an authorized pharmacy. It represents an essential step that shed some light on the entire process of prescriptions management. This first step also explains how a medical prescription works technically.

This process is an inductive research with a more exploratory purpose that begins with a research question. It collects empirical data to then reach a conclusion (Gioia et al., 2013; Jebb et al., 2017). For a best practice of this inductive research, there will be followed five points proposed by Woo et al. (2017):

- **Point 1:** Start with a clear purpose
- **Point 2:** Exploit your data
- **Point 3:** Replicate and cross-validate your findings
- **Point 4:** Be transparent in reporting
- **Point 5:** Moving forward

In order to track and follow with accuracy the medical prescription trajectory in Portugal, this step takes into account an exploratory semi-structured interview with two health professionals that are key players regarding the validation of a medical prescription. The first one was Doctor Cândida – a Portuguese doctor who works in CUF and that has her own medical office — Dra. Cândida helped to track the management of a prescription since it is created until the moment it reaches the system. The second professional that was interviewed is the pharmacy technical director Dra. Manuela Jesus, who contributed to map the process since the patient reaches the pharmacy with the prescription and consequently used. Both professionals also contributed to highlight information for the second step – flaws analysis.

As stablished by McIntosh & Morse (2015), there are four types of interviews regarding heuristic typology of semi-structured interviews, as one can observe in Table 5.

Table 5 - Heuristic Typology of Semi-Structured Interviews, McIntosh & Morse (2015).

Interview Type	Purpose	Epistemological Privilege	Role of Participant	Outcome
Descriptive/confirmative	Assessment	Known	Respondent	Confirmation of fit
Descriptive/corrective	Evaluation	Knower and the known	Collaborator	Refutation, elaboration, correction
Descriptive/interpretative	Discovery	Knower	Informant	Understanding
Descriptive/divergent	Contrast	Groups of knowers	Informants	Discernment

Since the purpose of these interviews was to discover the management and tracking system of a medical prescription and, the expected outcome was to understand the current system, it was conducted as a descriptive/interpretative semi-structured interview. As stated by McIntosh & Morse (2015), a descriptive/interpretative semi-structured interview aims to discover the experiential world and view epistemologically privileges the participant as knower.

The main question for both interviews was:

- “Can you lead me through the prescription process?”

Then, for each professional there was more specific questions:

- For Doctor Cândida – Pediatrician in Portugal:

I. “What do you need to prescribe a medical prescription?”
II. “How do you prescribe a medical prescription?”

- Pharmacy Technical Director Manuela Jesus

I. “How do you receive and validate a prescription?”

II. “What difficulties do you face?”

To better understand how prescriptions work, the results of the interviews were triangulated with the analysis of a document from INFARMED (2014) and Shared Services of the Ministry of Health (2019). The route of the medical prescription in Portugal is presented schematically to get a clearer and simpler view of the process.

4.2 Flaws analysis

After mapping the tracking system in Step 1, an analysis about the possible weaknesses takes place. The main goal of Step 2 was to clearly define and understand the need in order to focus (later) on blockchain technology as a potential part of the solution.

To better analyze the results, the Delphi method was applied as proposed by Steurer (2011). This method has been used to select healthcare quality indicators (Boulkedid et al., 2011) and health research within multiple fields such as health technology assessment, health education, diagnostic criteria development and indicator selection for quantifying medical care quality (Steurer, 2011). As reported by Garatti et al. (2002), the Delphi method tries to collect and distill data from anonymous judgments of experts with feedbacks. This method is particularly successful when applied to improve the understanding of problems and solutions (Garatti et al., 2002). The Delphi method proposed by Steurer (2011) is defined by having three main phases:

1. Defining and describing the topic
2. Select the experts
3. Run the survey (two or more rounds)

The topic is the medical prescription system in Portugal, it identifies the system flaws. A panel of ten knowledgeable pharmacists, with years of work experience, were selected as the experts. These are who have the ultimate responsibility to verify the medical prescription and, to deliver the medicines and other health products to the user.

In a previous informal conversation with several pharmacists before the start of this chapter, it was explicit that the system has indeed some points to improve. The majority of them immediately highlighted the issue of manual vs. electronic prescription. Initially, a first survey would be sent with only one statement that would try to understand if the system has flaws. But since the experts had already pointed out that the system has flaws and, by understanding the work situation that these pharmacists were in, the first statement on the first survey is just a confirmation since the outcome would be the expected, that the indeed, the system has flaws. The supposed first survey and the second survey were sent as one.

The survey intended to receive points of view and judgements. The Delphi method focus on group consensus where each person will give individual feedback on the survey (Steurer, 2011). The idea behind the method is to unfold the potential problems that are recognized by industry professionals, they agreed or disagreed with each sentence based on the scale of disagreement. And on top of that, in order to obtain a more robust analysis, they had the possibility to justify their answers. The sentences presented on the survey were based on the open conversation that happened before and, on the problems, already detected by other studies that were mentioned in the literature review.

The pharmacists were asked to respond to it according to the following scale of disagreement:

Table 6 - Scale of disagreement.

1	Strongly Agree
2	Agree
3	Uncertain / Not Applicable
4	Disagree
5	Strongly Disagree

The first survey was composed by the first statement and seven more as shown in Table 7. By the end of the survey an open question divided into two parts was presented to the professionals. This last question helped to uncover and identify any other specs and upgrades that industry professionals identify as potential benefits to the system.

Table 7 - First Survey.

I – The current medical prescription system in Portugal is completely reliable and flawless.
II - The current medical prescription system prevents substance abuse.
III - Manual medical prescriptions are never misleading.
IV - Medical prescriptions by electronic means never mislead.
V - The current medical prescription system avoids fraud such as "doctor shopping" (the practice of visiting several doctors to obtain various prescriptions for prescription drugs, or the medical opinion you want to hear).
VI - The current medical prescription system helps to monitor the patient's health.
VII - The current medical prescription system is completely transparent, which allows you to clearly control the number of medical prescriptions issued / raised by each health professional / patient.
What would you add / change to improve the current medical prescription system? Is there any other system that you know even at an international level that you consider a better option?

The professionals answered to the statements according to a scale of disagreement and some of them also justified their answers. It was answered by 10 professionals, as expected, 8 pharmacists and 2 technical directors, but also pharmacists. After the first survey a second survey was structured in order to confirm the potential flaws detected. The same ten professionals were asked to agree or disagree to each flaw based on the same scale of disagreement used before.

4.3 Blockchain-based solutions

The main objective of Step 3 was to approach the blockchain technology as a solution to the current system. At first, the results obtained from the last step were presented to two blockchain experts:

1. Paulo Rodrigues – CEO at *Public mint*
2. Nuno Cortesão - Growth Strategy Lead for Blockchain Center of Excellence at *Celfocus*

The experts were approached through a semi-structured interview as an attempt to elicit information where the potential of blockchain technology can mitigate the problems in the current Portuguese medical prescription system. These semi-structured interviews were conducted through a list of predetermined questions. Since the expected outcome of these interviews is to refute, elaborate and correct, it will be conducted as a descriptive/corrective semi-structured interview as shown in Table 5.

This step can be divided into three parts:

i. Initially, the experts were asked to give their opinion about the capacity of blockchain technology to improve the flaws detected by the professionals on step 2. And what barriers and challenges could be faced when implementing a blockchain-based solution.

ii. Secondly, implementing a blockchain base solution brings some challenges and barriers, as already approached in the literature review chapter. The experts gave their opinion on what could be faced when implementing a blockchain solution.

iii. Finally, to clarify how blockchain technology can be implemented as a solution. A blockchain based solution architecture that takes into account projects approached in the literature review (e.g., Blockchain Solution Integration, ScriptDrop, ScalaMed, Nuco, BlockMedx, Heisenberg) and other information collected throughout this thesis was presented. Although the majority of this projects are yet pilot, this part aimed to present a possible architecture that could be implemented in Portugal. Otherwise, this part serves to substantiate and validate the ability of blockchain technology to solve the problems identified in the current system. There is briefly an explanation on how this architecture would overcome the detected flaws in Step 2. The same two experts were asked to give their opinion on the proposed architecture, as well as what would they change on it. Is important to emphasize that the proposed solution was just a way to create a better vision under a possible implementation and that the solution presented does not go deeply into the technical details. Although the proposed solution is analyzed by the experts, it is just a perspective emerged from what was approached throughout the dissertation.

5 Results

5.1 Mapping the current prescription system

The semi-structured descriptive/Interpretative interview with Doctor Cândida began with the understanding of the system. There are two possibilities to prescribe a medical prescription, through a manual medical prescription (MMP) or an electronic medical prescription (EMP). This is also stated by the National Authority for Medicament and Health Products in Portugal (INFARMED, 2014). Although some prescribers still use MMP, it should only be used in case of an exceptional situation. The prescriber must justify by informing the exceptional reason by crossing one of the following reasons (INFARMED, 2014):

- Computer failure
- Reasoned inadequacy of the prescriber, previously confirmed and validated annually by the respective Professional Order
- Prescription at home (cannot be used in the case of prescriptions made in nursing homes)
- Up to 40 recipes / month

But many prescribers use it regularly as before, and the pharmacists cannot refuse to accept it.

As Dra. Candida explained in the course of the interview, the use of a MMP requires a printed format and the respective prescriber's vignette. The entity responsible for the MMP format model is *Casa da Moeda* (INFARMED, 2014). A prescriber who wants to use those prescriptions must get them through the Vignettes and Recipes Requisition Portal where he/she are registered as authorized professionals (INFARMED, 2014). The use of vignettes allows to identify the prescriber, if needed, through a bar code. The vignettes are also purchased through the Vignette and Recipe Requisition Portal (INFARMED, 2014).

As exactly informed by Infarmed (2014), the specifics of a MMP are:

- The recipes cannot contain erasures, different handwriting and cannot be prescribed with different pens or pencils.
- The number of prescribed packages must appear in cardinal and in full.
- No more than one copy of the manual recipe is allowed.

To a MMP be valid, the prescriber must include the following elements:

- Identification of the prescription site or respective sticker, if applicable. In SNS units, if the prescription is intended for a sick pensioner covered by the special regime, the green unit identification sticker must be affixed. In private offices and/or doctors, the place must also be identified, with the number of the prescription site registered in the PRVR, by means of a sticker or the apposition of the respective code.
- Vignette identifying the prescriber.
- Medical specialty, if applicable, telephone contact and email address.

- Identification of the exception that justifies the use of the manual recipe, marking the corresponding item with a cross.
- Name and number of the user's SNS and, where applicable, the beneficiary number.
- Responsible financial entity taking into account the specifics of the user.
- Special regime for the reimbursement of medicines.
- Drug identification.
- Technical justification, if applicable.
- Identification of the order that establishes the special medication reimbursement regime, if applicable.
- Prescription’s date
- Prescriber’s signature.

As Dra. Cândida does, and the majority of the authorized entities, the most used prescriptions are EMP. This type of prescription can be used to prescribe any type of medication. Some medications can just be prescribed through EMP, such as medicines based on opioids. According to the latest update by INFARMED (2014), prescriptions for manipulated drugs and drugs that contain narcotic and psychotropics, must be carried out electronically. It must also be executed through systems that are recognized by the Shared Services of the Ministry of Health (INFARMED, 2014). EMP brings more safety into the prescription and dispensation process, making the communications between health professionals from different institutions and streamline processes easier (INFARMED, 2014). EMP can also be printed, it’s called, materialized electronic medical prescription. An authorized software validates and record the EMP into the Portuguese National Prescription Database (BDNP) before being issued (INFARMED, 2014). The regular EMP is dematerialized and it is accessed via computer and validated by an authorized software that records it in the BDNP. The entire network of authorized pharmacies can access the EMP. All prescribers must be registered on the PRVR, so the EMP can be accepted by the BDNP (INFARMED, 2014). The prescriber’s software used in this process must be accepted by the SPMS (2016).

According to Infarmed (INFARMED, 2014), an electronic medical prescription must have the following information:

- Numbering

The BDNP assign a number based on a code.

- Prescription Location

The Regional Health Administrations (ARS) and the SPMS assign the codification of prescription sites (INFARMED, 2014). Only locations registered in the PRVR can issue prescriptions and this information is automatically field by the software (INFARMED, 2014).

- Identification of the prescribing physician

To identify the prescriber the software automatically has access to data such as: clinical name; specialty; contact information; email address; professional ID.

- User Identification

- Financial Entity
- Prescription Type

Dematerialized or materialized.

- Drug identification
- Technical Justification
- Special Reimbursement Regime
- Prescription date and time
- Signature of the Prescriber

If the EMP services software identifies inconsistencies, it should inform the prescriber to allow the prescription to be modified and, thus, proceed with the registration of it in the BDNP again. EMP can be canceled by the prescriber if:

- Prescribed by the prescriber.
- Prescriptions that have not yet been canceled.
- Prescriptions that are still valid.
- Prescriptions that have not yet been dispensed.

As stated by Dra. Candida and Infarmed (INFARMED, 2014), EMP require authorized and certified software. There are multiple choices of software, such as:

- iMED software (IMED, 2020) - used in multiple private and public hospitals and in clinics;
- Glintt software (Glintt, 2020) – the one used in hospitals and clinics from CUF;

The option to choose the software depends on each user since these software have monthly/annual fees. For example, Dra. Candida in her own office has the iMED software, but in CUF, she works with Glintt's software. Although the choice of which software to use depends on the user, all the prescriptions software for medicines and health products have to comply with technical specifications stablished by SPMS (2019). According to SPMS (2019) most recent rules, the technical specifications for the support software are:

- Communication with the SPMS Interoperability platform.
  EMP software must be connected online with the SPMS database.
- Universe of medicines and health products.

Medicines and other health products database must be provided by Infarmed. EMP software providers cannot limit the options of drugs that can be prescribed by brand, price or other spec. It can be seen as distorting competition, as well as limiting prescriber's choice.

- Publicity.

It is not allowed publicity in any EMP software.

- Updates to the drug database.

EMP software providers must ensure that the drug database for their application is daily updated.

- Interface with the National Registry of Users (RNU).

EMP software must be connect to the database provided by RNU in order to have access to all user's identification. This information also allows the system to know user's special benefits for the reimbursement of medicines.

- Interface with the Central Prescription System.

To validate the prescription the software must be integrated with the central prescription system that will check user's existence in the RNU. If the validation and registration of the prescription by the central prescription system is approved, the following information is returned:

  - Prescription identification number
  - Date / Time
  - Codes for use in the pharmacies
  - Matrix code to use offline

- Interface with Clinical Process Software.

As explained by Dra. Candida, as soon as the prescription is approved by the Central Prescription System, the prescriber can notify the patient with the returned information, which can be sent as an electronic file, with extension to the patient and pharmacies, by phone message or even by paper to the patient residence address.

Half of the process is now completed, from the moment when the prescription for medications or other health products is created and validated by the national health service. This part of process is simplified in Figure 7.

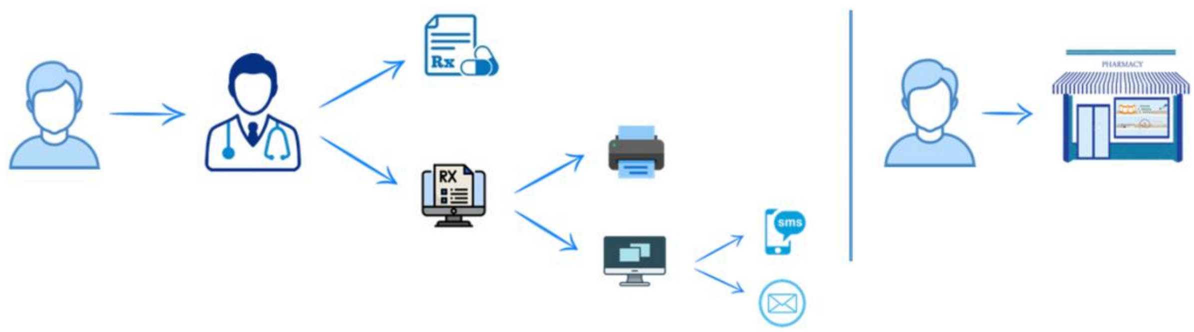


Figure 7 - Patient, doctor interaction.

The patient visits his/her doctor. The doctor decides to prescribe a medication or other health product. The doctor has two options available to prescribe the medical prescription. Through a MMP by using the paper format and the vignette both purchased in Casa da Moeda, or, through an EMP by using an authorized software and that can be printed (materialized) or sent in digital format (dematerialized) to the patient via email or SMS. The patient must now go to an authorized pharmacy.

Reaching the pharmacy

By reaching an authorized pharmacy to buy the medicines, the patient only needs to carry the prescription, if manual or electronic materialized, or to inform the pharmacist with the respective codes if it is a dematerialized EMP.

As explained by the pharmacy technical director Manuela Jesus, if the patient carries a MMP the pharmacist will verify it by how it looks. Although the MMP has the prescriber's vignette, a pharmacist cannot verify if it is authentic, it can be verified later by the National Pharmacy Association or the Portuguese Pharmacy Association. So, by the moment the prescription is identified as not valid, the patient already has the medicine. The prescription model and prescriber's vignette can be authentic but stolen, and it is not traceable. On top of that, pharmacists have to insert manually the reimbursement plan and any other required information if needed.

For EMP, the pharmacist just needs the prescription's number and the respective access code to verify it, and it works exactly the same if it is dematerialized or materialized. When dealing with a materialized prescription, the identification number and respective access code are shown on the paper, if dematerialized, the patient has to give the respective information. As soon as the pharmacist inserts the prescriptions identification number and the access code in the system, the pharmacist can confirm user's identity as the prescriber's information. The prescription is entirely shown on the system, including the type of treatment.

Each pharmacy uses an authorized software to verify the EMP and to insert the MMP. It is also used to manage pharmacy's stock, orders, services and management. There a few software such as SIFARMA from Glintt, which is used by 90% of the pharmacies (2477) in Portugal (Glintt, 2016) including the pharmacy where technical director Manuela Jesus is responsible.

Figure 8 shows the entire process.

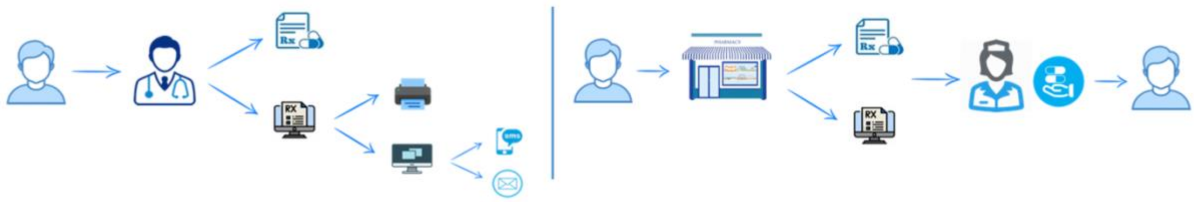


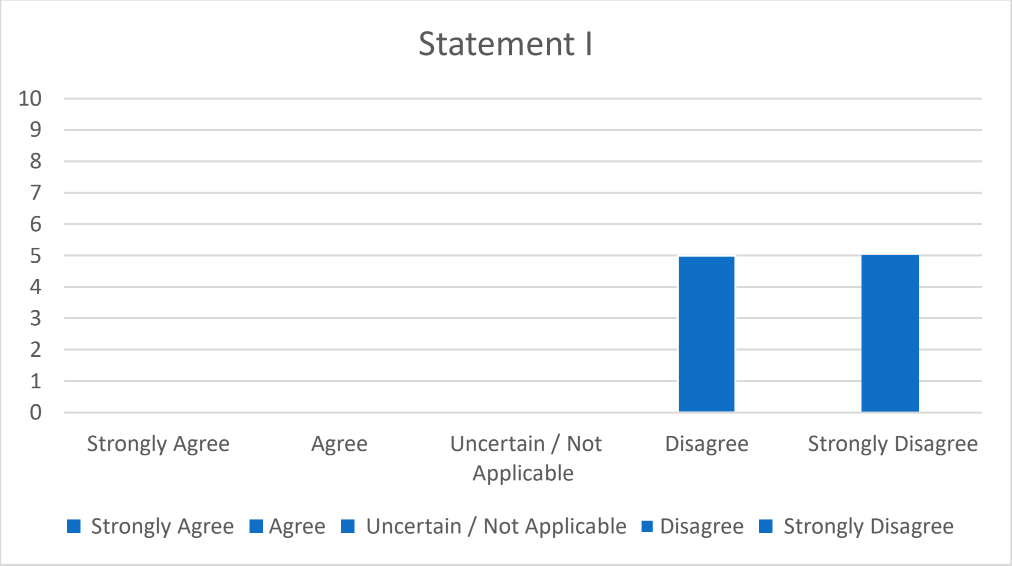
Figure 8 - Actual prescription system process.

5.2 System flaws analysis

The results obtained on the first survey are as follow:

I - The current medical prescription system in Portugal is completely reliable and flawless.

From the 10 responses, the first statement received 10 answers based on the scale of disagreement and 5 justifications. The data collected from the first statement is analyzed below. In Graph 1, shown below, the vertical axis represents the number of responses and, the horizontal axis the scale of disagreement, it is clear that professionals identify the system as being not totally reliable and maybe with some flaws.



Graph 1 - Statement I.

This statement becomes more substantiated when analyzing the justifications given by five of the professionals:

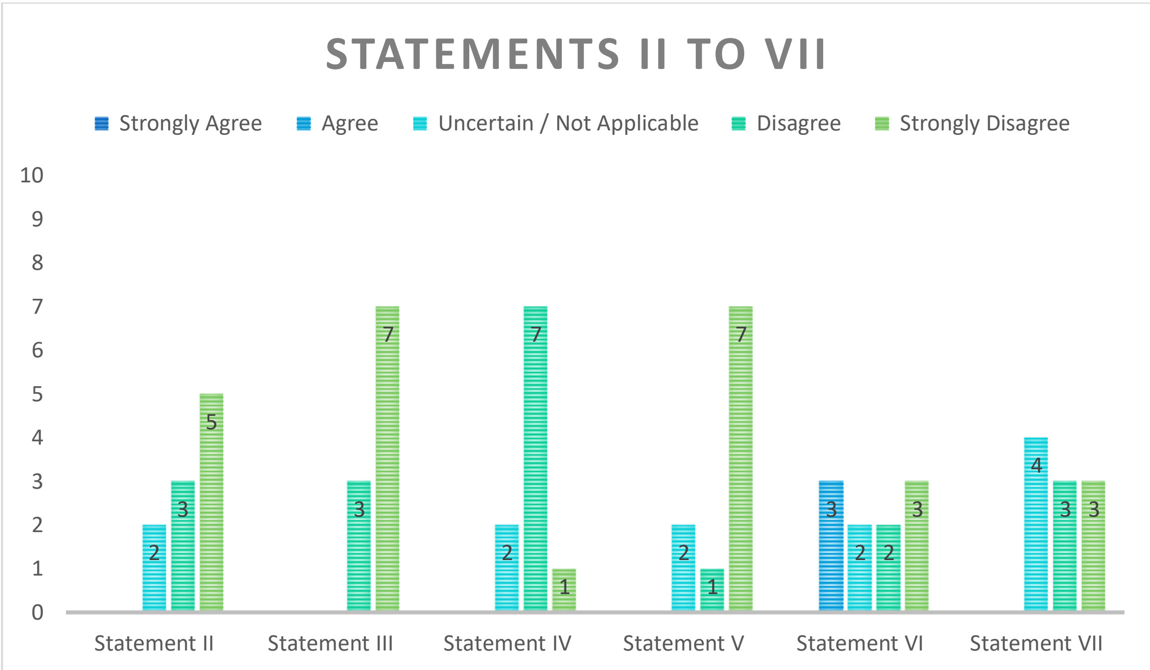
- "4 - As a general rule the medical prescription is reliable, but there are several cases in which failures can occur."
- "5 - The current medical prescription system is not entirely reliable and has many flaws, because several forms of prescription coexist - manual written by the doctor's wrist, manual issued electronically, electronically said, and each one can present, due to its specific flaws in different order without 'double checking' or alerts for medication errors."
- "5 – The system allows prescriptions with nonexistent drugs, dictionary posologist not suitable for the treatment in question, and flaws in the estimated price for reimbursement."
- "4 - Any medical prescription can be flawed, especially manual prescriptions that are more likely to fail."
- "4 – It is not perfect, there are always improvements to be made."

The responses from the pharmacists have shown obvious detection of lack in security, mainly regarding the type of prescription (MMP vs EMP) and, the systems transparency that can lead to mislead information such as patient's treatment.

With an expected result from the first statement, the statements that followed had the following results:

Table 8 - Survey I, Statements II to VII.

II - The current medical prescription system prevents from substance abuse.
III - Manual medical prescriptions never misleading.
IV - Medical prescriptions by electronic means never mislead.
V - The current medical prescription system avoids fraud such as "doctor shopping" (the practice of visiting several doctors to obtain various prescriptions for prescription drugs, or the medical opinion you want to hear).
VI - The current medical prescription system helps to monitor the patient's health.
VII - The current medical prescription system is completely transparent, which allows you to clearly control the number of medical prescriptions issued / raised by each health professional / patient.



Graph 2 - Statements II to VII.

At first glance, without analyzing the justifications, it is notable that none of the pharmaceutics strongly agreed or agreed with any of the positive statements with the exception of statement VI, where there are three pharmacist that agreed based in the scale of disagreement.

Justifications and results from statement II to statement VII are shown below:

II- The current medical prescription system prevents from substance abuse:

- "3 - The current system allows only the prescription of 2 packages of certain drugs controlled by each prescription. The problem also lies in the non-prescription dispensing of such substances by pharmacies."

- “5 - The current medical prescription system contributes to substance abuse because there is no way to control all the prescriptions issued and dispensed to a user in a given period of time.”
- “5 - Allows prescription of large packages for short treatments.”
- “5 - Each medical prescription is prescribed for a certain time; however, it is not possible to control whether the patient takes the same medication in a shorter period of time.”
- “5 - There is not much control over the quantities purchased, a person can have access to more prescriptions, even the same prescription through different doctors.”

The given justifications are indeed interesting. It’s difficult to control the use of certain medical substances since the patient can get different prescriptions from different doctors for the same medicine. Some responses already approached statement V. Although some treatments do not require a higher dose of medication, the patient ends up getting the full pack, which can lead to substance abuse. There is also an alert for drugs that are available in pharmacies and that don’t require a prescription.

III - Manual medical prescriptions never misleading:

- “4 - Handwritten recipes sometimes have drugs written in an inconspicuous way, which can lead to errors.”
- “5 - Manual medical prescriptions can easily be misleading, namely those written by the doctor's hand, normally with handwriting that is difficult to decipher.”
- “5 - Misunderstanding the doctor's handwriting can be misleading.”
- “5 - Manual medical prescriptions are the most likely to be wrong as they can suffer possible manipulation.”
- “5 - Although they are used less frequently these are the easiest to manipulate.”

All the five responses gotten from statement III clearly specify that MMP are the most likely to commit errors since it is handwritten, and it’s easier to be manipulated. As stated before, and again in one of the justifications, this type of prescription is still used but with less frequency.

IV - Medical prescriptions by electronic means never mislead:

- “4 - Decrease the reading error but not another type of error (dispensing error, dose error, etc.).”
- “4 - Because there are obsolete codes for medicines that are still active (for example, the medicine is sold in packs of 20 and 60, and there is a code corresponding to the pack of 30 which does not exist), packaging that does not exist is prescribed; the user receives the access codes to the prescription via SMS without knowing which medication is prescribed, knowing only when exposing the codes at the pharmacy.”
- “5 - Medical prescriptions by electronic means can be misleading and the doctor can select the wrong medication or the wrong combination of them without subsequent verification and alert mechanisms.”
- “4 - Significantly reduce the risk of misleading but allow manual alteration by the doctor of medications and dosages, which in these situations may be misleading.”

- “4 - Electronic prescriptions can also have computer errors or even errors in the selection of the correct medication (example: correct dosage, pharmaceutical form).”
- “4 - Although the system is more controlled, the system is unable to assess the veracity of the need for the medication.”

EMP are indeed more accurate than the MMP, meanwhile, misleading still occur in this type of prescriptions. Information such as dosage and the type of medication, is sometimes contradictory. Medication’s package that does not exist or the wrong medicine for the wrong patient’s treatment. The system presents lack of transparency.

V - The current medical prescription system avoids fraud such as "doctor shopping":

- “5 - A user can visit several doctors to obtain different prescriptions.”
- “5 - The doctor does not have access to the prescriptions issued in the name of a patient, thus not knowing, reliably, which medication was prescribed in a certain period of time.”
- “5 - There is no control between different doctors or between pharmacies about the prescriptions raised by the same user.”
- “5 - Any doctor with a prescription system can issue prescriptions and therefore if the user visits several doctors, he can get several guides for the same medication.”
- “5 - The truth is that it happens more than we think, easier with manual recipe but possible with electronic prescription too. It may also happen that the doctor prescribes medications that suit him (sales premiums).”

Although medications are sold in pre-determined quantities the user can easily get access to multiple prescriptions from different means. The system does not control the number of prescriptions issued. The user’s access to medicines will not be tracked.

VI - The current medical prescription system helps to monitor the patient's health:

- “3 - Although monitoring which prescriptions is provided by the user is possible… it is impossible to verify adherence to therapy with the current system.”
- “5 - The current system does not help to monitor the patient's health because prescriptions are often issued at the request of the patient for medications they usually take, but without regular concrete analysis of the need to maintain a particular medication or dosage.”
- “5 - Does not allow access to the user's history to assess their health.”
- “4 - It is not possible to control the attendance with which the patient takes the medication, nor does it comply with the doctor's orders.”

User’s health information is sensitive data, the restrictions on user’s data are comprehensive, but in some situations, it could be useful for the pharmacists. Although such information could help improve user’s health, the current system complies on security/privacy rules.

VII - The current medical prescription system is completely transparent, which allows you to clearly control the number of medical prescriptions issued / raised by each health professional / patient:

- "3 - It is possible to verify which prescriptions are issued and from which they are actually filled, however there is no effective control if there is a high number of medicines collected by the user."
- "5 - There is no transparency or control over the number of prescriptions issued or when dispensing medicines from a prescription. The prescriber can issue prescriptions in his own name or issue prescriptions to another person without any justification or control."
- "3 - The system only allows to control the medical prescriptions issued if they are electronic, likewise, the lifting of these prescriptions is only controlled in electronic prescriptions. There is no control over the collection of prescriptions by the same user between different doctors."
- "4 - The system is not fully transparent, not least because data privacy does not allow it."

This last statement supports all the previous ones. Lack of transparency in the system is the primary lack identified.

Open question responses:

What would you add / change to improve the current medical prescription system? Is there any other system that you know even at an international level that you consider a better option?

- "Cross Data."
- "Cross Data, hospital / pharmacy / USF; CNPD problem. Ex. In the United States, a person cannot purchase multiple boxes of a drug because the purchase is associated with his ID."
- "I don't know anyone else, but I would change the fact that the user's medication is not visible to all health professionals and also the fact that there is no control in the prescriptions, since, even without a history, there are doctors to prescribe just because the user asks."
- "It should be possible to trace medical prescriptions issued and dispensed by the user. Although the current system may allow such screening, as long as there are doctors who prescribe manual prescriptions, there is always a way to avoid it. Regarding the monitoring of the therapy and, consequently, the health of the user, there have been new tools that can be very useful in the future, such as the Dr. Box application, which allows the user or caregiver to control adherence to therapy."
- "There could be a database at national level with updated information for each user regarding pathologies, prescriptions, medication dispensation dates for each prescription and others considered relevant and to which health professionals could have access, namely prescribing doctors and even others health professionals for more effective and safer therapy."
- "Use of unit dose; access to a patient's medical history by all health professionals; quick communication channel between doctor and pharmacist; I am not aware of the operation of other international prescription models."

- “Eliminated the need for printed receipts because they are more likely to be fraudulent and are sometimes invalid.”

During the interview with Dra. Candida and technical director Manuela Jesus, they also highlighted some wanted features:

- “Make the system more up-to-date - Patients change personal information such as their address and the system does not update, which at the time of approving the prescription fails. It would make the system more targeted at detecting errors such as prescribing the wrong dosage for a child.”
- “It would be interesting to be able to communicate directly with the prescriber in case of having any doubt about the prescription.”

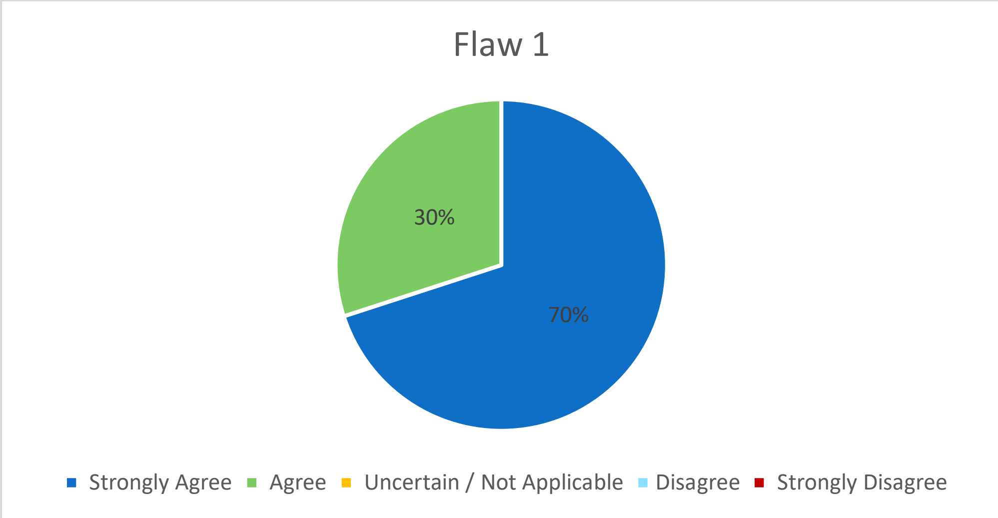
From the first survey, 10 flaws could be identified:

1. MMP vs EMP – MMP is most likely to have flaws / to be manipulated
2. Medication error - nonexistent drugs
3. Unclear or invalid prescriptions
4. EMP may be contradictory due to misleading information - nonexistent package
5. Lack of control over the patient treatment
6. Multiple prescriptions for the same medication
7. Users’ data restrictions
8. Lack of consistency and up-to-date user’s data
9. Duplicated prescriptions
10. System transparency

The highlighted flaws were returned to the same ten professionals as a second survey. They were asked to assign a value to each of the detected flaws in order to determine its weight. The same scale of discordance from the last survey was used.

The results obtained were as follow:

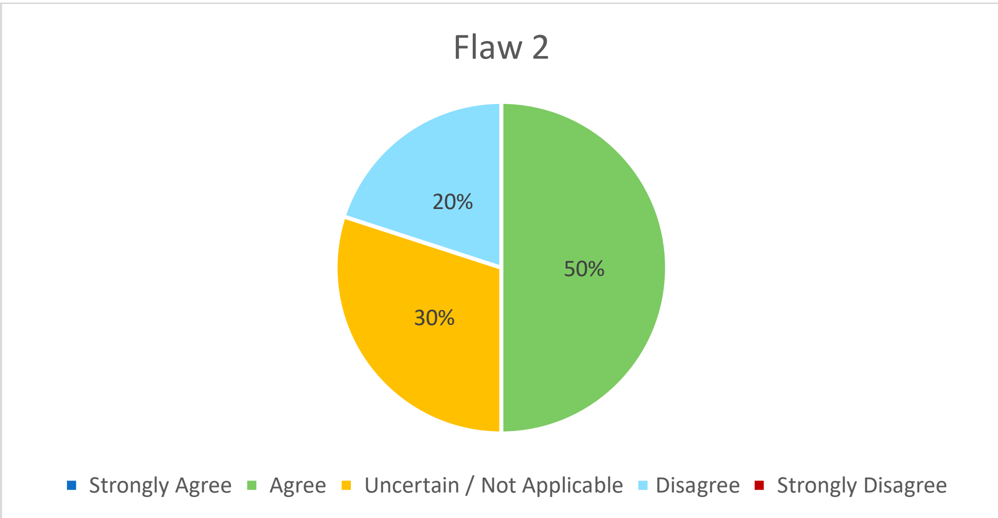
- **MMP vs EMP – MMP is most likely to have flaws / to be manipulated**



Graph 3 – Flaw 1.

This first statement clearly proves the impact that MMP still has on the system. As previously discussed, this type of prescription creates a gap in the system and although is less used, it still exists. MMP is confirmed by prescriber's vignette, but it can be easily manipulated since it is handwritten and not inserted in the system like the EMP. Another negative aspect of this type of prescription is the potential easy access.

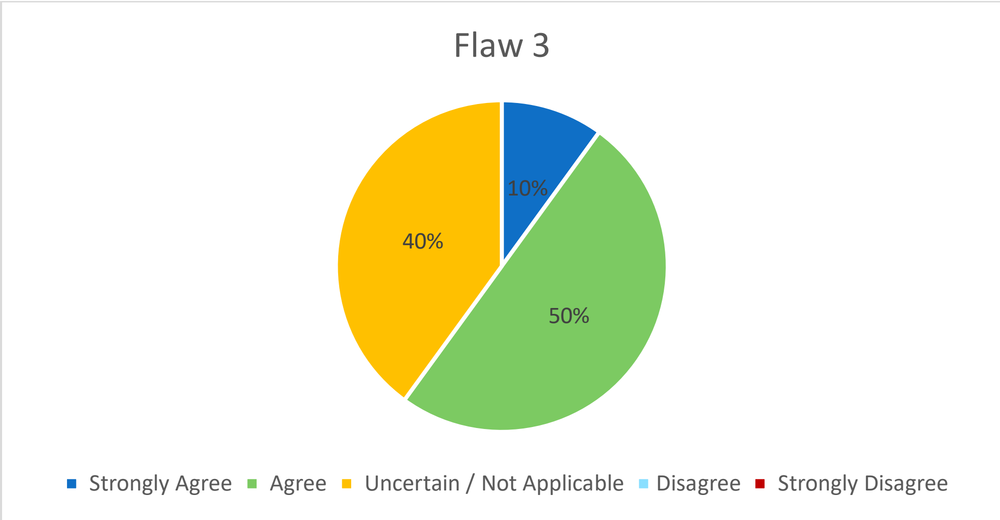
- **Medication error - nonexistent drugs**



Graph 4 - Flaw 2.

This flaw was pointed out to confirm that drugs identified by the prescriber are in the system. According to the data collected it may not be a problem in the current system.

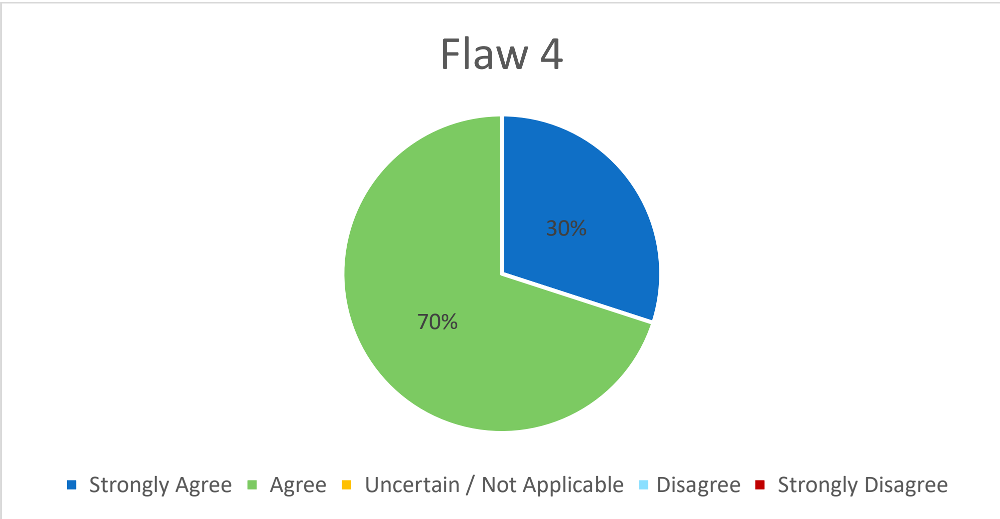
- **Unclear or invalid prescriptions**



Graph 5 - Flaw 3.

This statement refers whether to MMP or EMP that end up being invalid, perhaps due to incorrect information or even because the recipe is no longer valid. Regardless of the specific reason, there are still prescriptions that are not valid. Although 40% are uncertain about this as a flaw, the possibility to invalid prescriptions is possible.

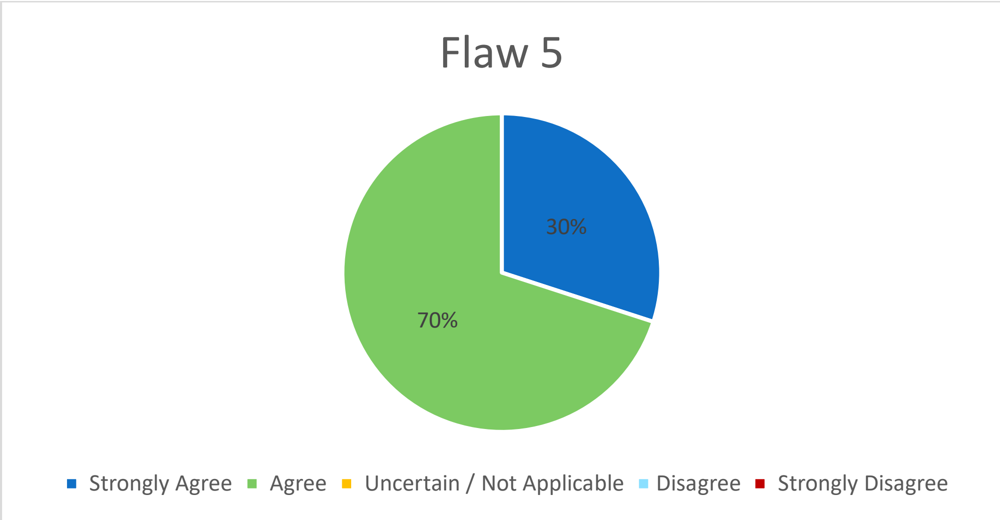
- **EMP may be contradictory due to misleading information - nonexistent package**



Graph 6 - Flaw 4.

This statement was originated by professionals' justifications when they mentioned that sometimes the prescription indicates a package for a specific medicine that do not exist, for example, a prescription for a medicine in a package of 30 but the medicine only exists in a package of 20 or 40. This flaw can be correlated to the system's accuracy or the system transparency that will be analysed further, but it was already agreed by the professionals.

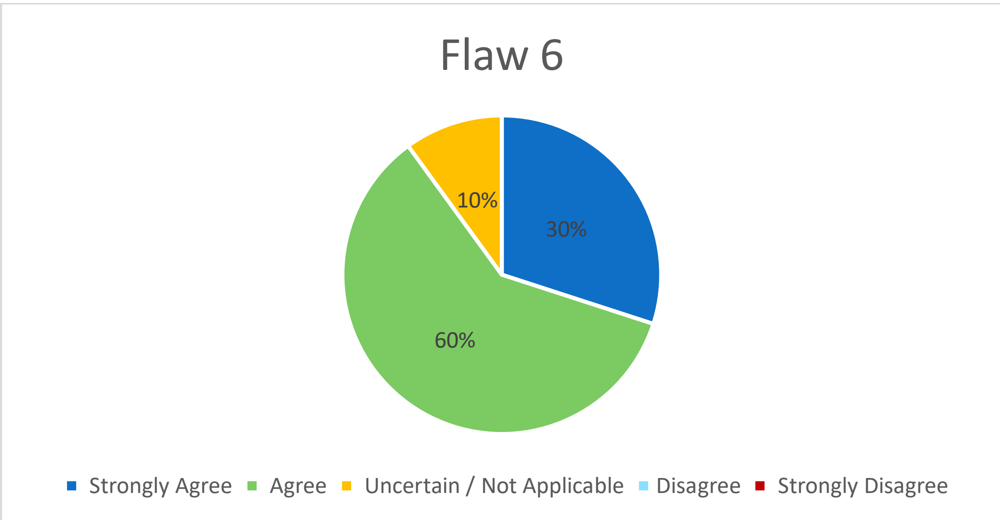
- **Lack of control over the patient treatment**



Graph 7 - Flaw 5.

The patient must be responsible, however certain treatments require supervision; all the asked professionals identify that there is a lack of control over patient treatment. This lack of control could be overcome if there was more access to patient’s information.

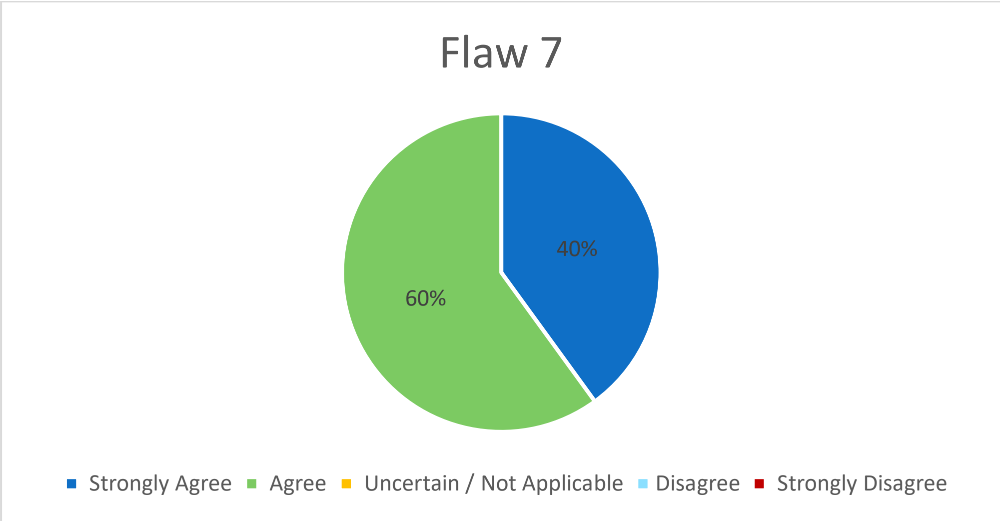
- **Multiple prescriptions for the same medication**



Graph 8 - Flaw 6.

This statement got relevant due to the claims that a patient can purchase as many prescriptions as he/she wants for a certain drug. Users can have access to multiple prescriptions through multiple doctors.

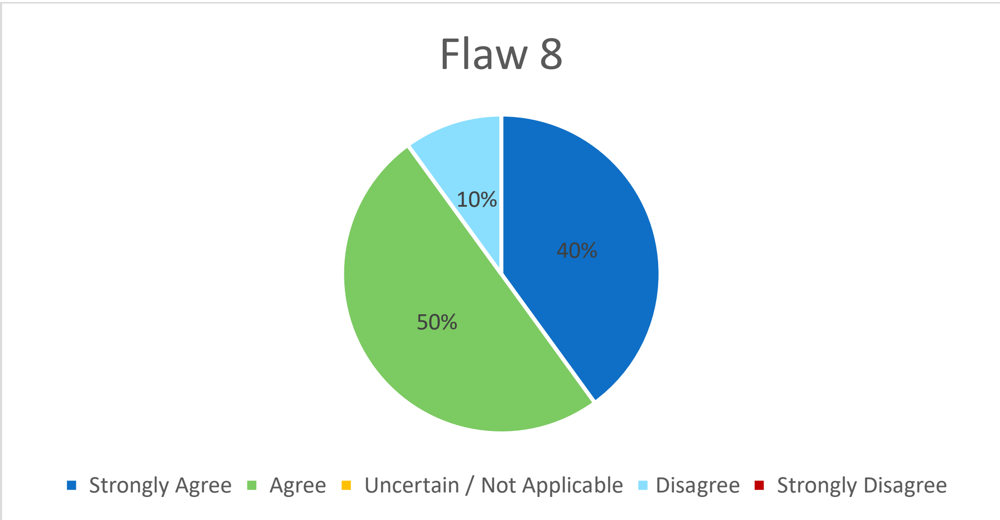
- **User's data restrictions**



Graph 9 - Flaw 7.

User's personal and medical information could help control their health. Pharmacists have the medical knowledge to identify and advise medical treatments. By accessing user's health history, they can have a more accurate opinion and take action if needed. A lot of times the patient goes directly to a pharmacy even before visit a doctor.

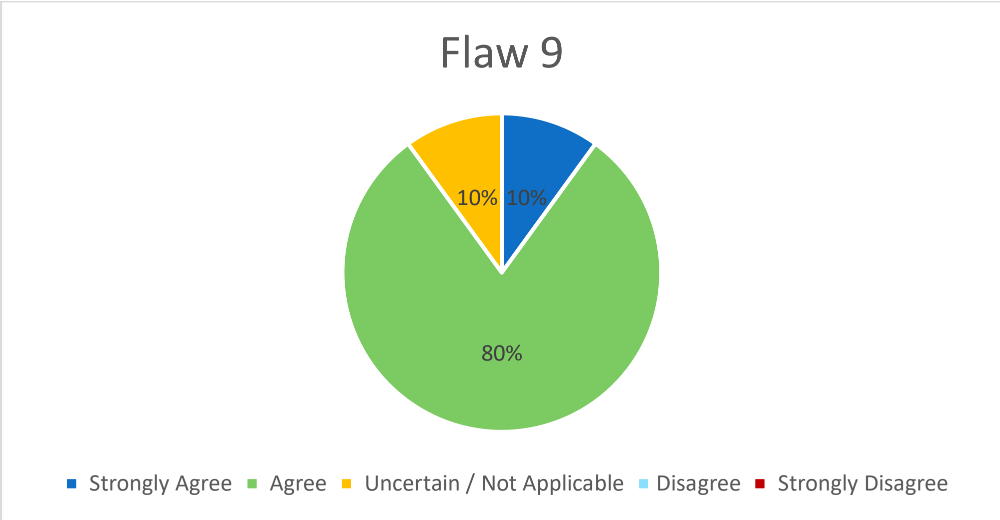
- **Lack of consistency and up-to-date user's data**



Graph 10 - Flaw 8.

EMP requires patient's basic information (e.g., name, age, address) and yet it can be not actualized, creating confusion and problems within the prescription validation. This type of data can also be important to then facilitate the medical insurance.

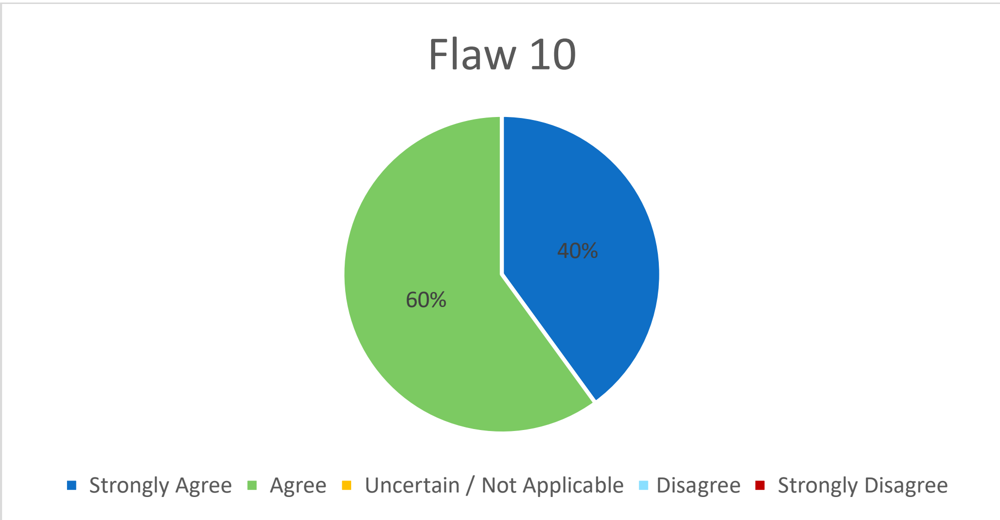
- **Duplicated Prescriptions**



Graph 11 - Flaw 9.

This flaw supports the access to multiple prescriptions flaw as already approached.

- **System transparency**



Graph 12 - Flaw 10.

The overall flaw can be identified as the system transparency.

There are no perfect systems and as result, processes have to be established to identify gaps and flaws that have to be constantly assessed and solved. The current system for medical prescriptions in Portugal is no exception.

5.2.1 Summary of Key Results

From the second survey, it was possible to confirm 8 of the 10 detected flaws. The confirmed flaws are identified in Table 9.

Table 9 - Detected flaws.

MMP vs EMP – MMP is most likely to have flaws / to be manipulated
Unclear or invalid prescriptions (EMP and MMP)
EMP may be contradictory due to misleading information - nonexistent package
Lack of control over the patient treatment
Multiple prescriptions for the same medication
User's data restrictions
Lack of consistency and up-to-date user's data
System transparency

Beyond the enounced flaws, prescription fraud is a problem detected. The medical prescription system is vulnerable to crimes of fraud, document forgery, active and passive corruption as shown in recent news (Pinto, 2020). The system does not control who get hands on the prescriptions. The lack of connection between pharmacist and prescriber illustrates the deficiency in trust and verifiability associated with the current system.

5.3 Blockchain-based solution for the current system analysis

The power of blockchain technology to mitigate the detected flaws will be addressed in this last chapter.

5.3.1 Can blockchain technology help overcome the detected flaws?

Both experts agreed that blockchain technology has the capacity to overcome the detected flaws, presenting itself as a solution for the Portuguese medical prescription system.

According to Paulo Rodrigues, COO at Public mint, blockchain technology can definitely solve the fraud issues and the lack of trust bringing more transparency to the system. He also stated that, nevertheless, blockchain is not a "panacea", and in this particular case it should be properly designed in a way that complies with GDPR. The system needs to guarantee the important confidentiality requisite of health users' data. As it was referred before, patients' personal information is considered sensitive data which needs to be secure.

The growth strategy leader for blockchain Center of Excelence at Celfocus, recognizes the capability of this technology to improve the current system – "Blockchain can be a good answer because you have several players (pharmacies, clinics, hospitals, users, SPMS, etc.)". Nuno Cortesão considers that it can advance users' identification and ensure data visibility/permissibility through the use of smart contract technology. Improving user's data access while keeping it safe and guarantee actualized users' personal data.

The last expert also highlighted the improvements that can be made at the level of creating unique prescriptions, which cannot be forged without the consent of the prescriber, since blockchain wallets, together with good cybersecurity policies, make "impersonate" much more complicated. The problem of MMP vs EMP would be overtaken by creating these unique prescriptions standard. Prescriptions can be tokenized, becoming unique and can be consumed in whole or in part and can be easily confirmed as authentic or not. Multiple prescriptions for the same medication would be traced. The smart contracts would be used to define medication withdrawal rules and use or withdrawal, it can also be used for general optimization of processes and removal of many manual activities. A set of certified data can be used for data analysis and provide bases for identification of active fraud (authorized by doctors) or for system and stock management. The system would reduce the amount of unclear and invalid prescriptions.

Nuno Cortesão finished by saying that IOT's integration models for usage control and similar ideas can be implemented. More control could be given over patients' treatment.

5.3.2 What barriers could be faced when implementing a blockchain solution?

As discussed in the literature review, blockchain technology faces major implementation challenges. The experts emphasized the difficulty to adopt cryptocurrencies, it may not be feasible for mass adoptions. As referred by Kumar et al. (2018), scalability is a major barrier where CPU capacity and the amount of medical transactions must be compensated.

The experts showed signs of concern regarding crypto's volatility, therefore it can be a problem to sustain enterprise use cases. Another factor to take into account is the transactions fee. Someone has to pay for the transaction, and as Paulo Rodrigues mentioned – Who is willing to do that?

Blockchain technology implementation requires high investments. Another barrier identified is the non-user-friendly interface that can emerge from this technology. It must be easily to handle and operate, otherwise, it will face enormous rejection. Blockchain transparency can compromise users' information, it can still be a gap to deal yet. It would be necessary cooperation from regulatory entities in order to make the system work.

The biggest barrier is the society mentality, since this is a new technology that is unknown for the majority, it will easily create an implementation barrier. It is important to recognize that at the end of the day every sector deal as a business and information is a key player, for a successful implementation information hold by entities must be shared.

5.3.3 Proposed blockchain-based solution

The proposed architecture is presented.

Proposed Architecture

The proposed architecture is explained through six main stages:

1- **Type of blockchain**
2- **What blockchain**
3- **Defining nodes**
4- **Token**
5- **System connectivity**
6- **System working flow**

1- Type of blockchain:

Starting from the bottom, the type of Blockchain is essentially important. As it has been mentioned, all data ingested and processed on healthcare systems is considered sensitive. Indeed, the basis of blockchain technology is decentralization, but as explained in chapter 3.1.2 – Types of Blockchain – there are two main types of blockchain, permissionless and permissioned. The last one is also divided into private and consortium blockchain. Permissioned blockchains allow to have confidentiality when storing sensible information without compromising user's privacy, which for this type of system seems to be the most adequate option. The medical prescription system should be implemented on a permissioned consortium blockchain controlled by pre-selected nodes within the consortium, with more than one authority and with slightly fast transactions.

2- What blockchain:

Smart contract technology (detailed in chapter 3.1.4) is the main resource behind all the projects that act in the health sector (e.g., Blockchain Solution Integration, Nuco Company, BlockMedx, Project Heisenberg, ScriptDrop, ScalaMed). Medical prescriptions can be seen as an agreement between the prescriber and the patient that later will be affirmed by an authorized pharmacy.

The *Hyperledger Fabric* platform is an open-source permissioned platform where users form a consortium to decide who can participate in the validation and consensus process, a permissioned blockchain. Another possibility is the *Ethereum* network that also is used in the *Project Heisenberg* (Heisenberg, 2019; Katuwal et al., 2018; Leffew, 2018). The *Project Heisenberg* works as a decentralized identity management and pharmaceutical system that is on consortium permissioned *blockchain*. *Hyperledger* also has as big advantage the scale of transactions since it has less nodes than the Ethereum main net.

Both blockchains (*Hyperledger Fabric* and *Ethereum*) seem to be an adequate possibility for this type of process. A permissioned blockchain powering a consortium fits perfectly for medical prescriptions. When a block is added to the chain, it means that more than 50% of chosen entities did validate the transaction. Unlike private blockchains, consortium blockchains can be viewed as almost decentralized.

Summing up, a private blockchain would allow many trusted entities to share data in a secure and transparent way.

3- Token

A token can be used to track the prescription. In the case of blockchain *Solution Integration* by Camden Thatcher and Subrata Acharya (2019), a token called *RxCoin* (based on the *Ethereum* blockchain) is used to manage patient medication refills. Depending on the quantity prescribed, a certain number of tokens are created and then the patient can use it in a pharmacy to refill the medicines.

The *Heisenberg Project* also uses a token that effectively eliminates the risk and contained cost associated with pharmaceutical fraud by carrying information on it. The creation of a smart contract allows to define the ownership of a medical prescription, which results in:

1. Removing the possibility of counterfeit / forged prescriptions.

2. Enabling regulatory insight into the medicine's quantity, concentration and movement.

3. Creating an immutable record (ledger) of the movement (transactions), quantity, and type of medicine.

A token can be used as in the projects enounced. Each token would have information about the entities involved and the agreement. The data on each token could be:

- Prescriber name
- Prescriber professional number
- Prescriber office
- Patient name
- Patient national security number
- Patient's public key (allows to receive the tokens)
- Medicine name
- Medicine brand name
- Medicine quantity
- Medicine dosage
- Treatment information
- Prescription creation date
- Prescription expiry date
- Prescription date filled

The token could be a ERC20 token, a token based on the *Ethereum* blockchain.

4- Defining nodes

The nodes are the entities involved in the process. Starting from authorized professionals that can create a prescription, the pharmacies who can deliver the medicine, to the patient. Each node has different type of access and permissions in the network. The system allows the users (e.g., doctors, patients, pharmacists) to be connected between them through a decentralized application (dapp). As in the *Heisenberg Project* the nodes that rule the network are kept by authorized entities, it can be hospitals, a government agency or any other defined entities since the physical node location does not matter, it can be on a cloud service. A private consortium of trusted actors allows to feed the network.

For the Portuguese system, the national health service could run a node to have control over all the prescribers. The *Infarmed* could run another node to control the pharmacies. AN institution could work as node that control the patient's access to medicines, such as the SPMS.

5- System connectivity:

In terms of accessibility, the majority of the projects use a dapp that connects all entities. For example, in the *Heisenberg Project* there are three different portals for each doctor, pharmacy and patient. Patient's information can totally be controlled by them through the app, which allows users to upload and update personal information anytime. Simultaneously, hospitals and pharmacies can have access to that information if previously authorized by the data owner. Doctors manage their prescription system in the dapp, and pharmacists will also have access to that information.

Scalamed project accepts regular ePrescribing software in the system. The systems used by doctors to access the medicines and other health products database can be incorporated.

Some projects such as the *ScriptDrop*, are more ambitious and allow to deliver the medicines directly to the patients without the need to be present at the pharmacy. While controlling the usage of medicine it makes sure that patients are tanking it correctly through a virtual assistant.

For the purpose of the medical prescription system in Portugal, it could use the idea behind the *Heisenberg Project* while connecting the authorized software (e.g., iMED, Glintt). Another useful tool could be the virtual assistant as proposed by the ScriptDrop's project offering a better control over the patient's treatment.

6- Final system working flow:

During the process there are contact between the doctor, the patient and the pharmacy. The process could be described as follow:

1. **Doctor** - When the doctor creates a medical prescription a smart contract is executed by creating a token as valid prescription. The prescription is valid by the information on the token.

2. **Patient** – The patient receives the token issued by the doctor on the token wallet and uses it to fill the prescription by sending the token to the pharmacy's public address.

3. **Pharmacy** – Dispenses the medication when the transaction from the patient is completed and the respective medicine payment received. The prescription will be validated by the pharmacy by confirming the creation of the smart contract.

The figure below demonstrates this process.

Figure 9 - Blockchain-solution process.

After a patient visits the doctor, a smart contract is created on the blockchain and represented by a token. The token is sent to the patient digital wallet. When the patient visits the pharmacy, the token must be sent to the pharmacy digital wallet. As soon as the token is received, the pharmacist can verify the agreement on the blockchain. Basically, the pharmacist verifies that the token was created by an authorized prescriber and the prescribed medication.

The proposed solution would combat the detected flaws as explained below, it's important to clarify that this is just theoretical based.

MMP vs EMP – MMP is most likely to have flaws / to be manipulated

The proposed solution only offers one option. It is entirely digital.

Unclear or invalid prescriptions

The token would never be invalid since it was created and stored on the blockchain. What could happen is the medicine expire date, the token would be accepted but the information recorded on it would say that the prescription is not valid.

EMP may be contradictory due to misleading information - nonexistent package

Even if the prescriber wrongly prescribes something, the pharmacist would be able to stablish direct contact through the dapp and clarify the situation.

Lack of control over the patient treatment

With the possibility to incorporate a virtual assistant on the dapp, there would be more control over the patient treatment if needed.

Multiple prescriptions for the same medication

Since all the transactions are recorded on the blockchain, the pharmacist would have access to how many and with which frequency the patient gets access to the medicines.

User's data restrictions

The user owns the data and can give permission to other entities access his/her personal information.

Non actualized user's data

Again, since the user owns and control his/her personal data, it's their responsibility to actualize the system. The dapp would be able to send notifications if there would be missing important information (e.g., contact, address, personal info).

System transparency

Although the system would run on a private blockchain, the entire list of transactions is public. All the participants would have access to the creation and transaction history of *RSx* tokens.

5.3.4 Proposed solution analyzes

The proposed solution was simultaneously presented to the experts. They gave their opinion and suggestions.

The COO of Public Mint highlighted that blockchain systems are not all about tech - they are a mix of tech, governance, finance and human psychology. And it's something missing on the proposed solution, it does not approach token economics. This is an important gap which was also mentioned before when the experts talked about the implementation barriers. Every transaction as a fee, this fee is what keeps the network working and safe. The nodes keep the network honest, otherwise they would not be recompensated. Paulo Rodrigues suggests defining a model that provides financial incentives for different players to make sure the system is sustainable - a subsidized model by the state that will be imposed to users therefore falling into the same problem most other projects had which is to struggle to move beyond the proof-of-concept phase. Another topic mentioned by Paulo Rodrigues is governance - besides the token economics, it should be also dedicated some time to governance. As said by the COO of Public Mint - "Sustainability is key." A major factor that was also highlighted by the expert is the fact that not knowing the gas prices of each transaction on the network is a major blocking issue. The expert explained that it is the reason why Public Mint exists, to make sure everyone can rely on a fixed transaction fee and be able to operate in fiat currencies, not volatile cryptocurrencies.

Nuno Cortesão highlighted that using a wallet, the system only needs the user's wallet ID and the doctor's wallet ID, the references to private data can be in an external system. The same for the medicine underlying the invoice, which may contain the approved quantities and expiration dates. Regarding the type of token, he pointed out that drugs are not fungible, so instead of an ERC20 token an NFT-721 would be more appropriated because it makes a lot more sense since each recipe is unique and exclusive.

6 Conclusions

The literature review chapter allowed to conclude that the potential of blockchain technology goes beyond digital assets as Bitcoin. Different types of blockchain emerged with different capabilities, for instance, Ethereum blockchain with the creation of smart contracts.

Blockchain technology promises to disrupt multiple sectors, mainly the healthcare. This technology has the power to solve some of the problems yet to defeat within the healthcare industry, enabling the installation of trust among different health domains. The potential of blockchain was supported through examples of projects that proposed blockchain-based solutions. The healthcare industry is highly digitized nowadays, and by using blockchain technology all the stored information will be easily tracked allowing more security. The applications possibilities in the health sector are endless, however only five case studies were approached (Medicines Supply-chain, Patient data, Clinical research, Health insurance and Medical prescriptions), a more detailed conclusion about these case studies is found in chapter 3.3 - Literature Review Conclusions. The literature review directed the work to be done towards the Portuguese medical prescription system.

The methodological process was based on three mains steps, these were: map the current system; identify potential flaws in the current system; and experts analyzes.

With the help of two health professionals, it was possible to map the current system while understanding the prescriptions process, thus giving a better view over it.

In order to find flaws in the current system, the Delphi method was used, ten pharmacists answered to it according to a scale of disagreement and they had the possibility to justify their answers. The first survey had the expected result, it was highlighted ten potential flaws. In the second survey, the pharmacists helped confirming the detected ten flaws on the first survey by also using the same scale of discordance. The second survey confirmed eight out of the ten flaws.

With the intuition to understand if blockchain technology was able to correct the detected flaws, two blockchain experts gave their opinion. Both experts stated the technology presents the necessary requirements to combat the detected flaws and even more. They were also asked to help understand what barriers and challenges would be faced when implementing a blockchain based solution. There are multiple challenges, mainly scalability, implementation costs, adaptation and data security. To better understand how a blockchain-based solution would look like, a proposed solution architecture was presented to the experts so they could comment on it. The solution starts from a decentralized network where data is stored without the possibility to be changed or manipulated. The system works on a consortium level based on permissions. Blockchain technology enables to verify the ledger history, thus confirming the authenticity of the prescriptions, creating trust between entities such as doctors, pharmacists and patients. Since the experts did not pointed out major changes to be made, it means that the proposed solution fits within a possible solution. The proposed solution clearly represents how a system based on blockchain technology would be implemented within the medical prescription system. It certainly requires many improvements and changes in order to become a realistic solution, but for the presented work the objective has been accomplished, to propose a solution that facilitates the visualization of a system.

The three main methodological steps were accomplished.

Blockchain can be selected as one of the underlying technologies ready to disrupt the healthcare system as many other sectors. Some challenges are yet to be approached, but when overtaken, blockchain technology promises to change the health services. Knowledge is important when talking about implementing new trends and technologies. One of the main barriers on this subject is the lack of knowledge about it. Since It may seem a more technical topic to understand, people immediately create a psychologic barrier thus preventing from learning about it. A lot of the comments on this topic are inconsistent and without any foundation. The solution here is to educate people who are really interested in understanding what blockchain technology is and, how can it be used to improve sectors and industries.

In the highly digitized world so reliant on a data-driven economy, blockchain can help make lives easier. By adopting a blockchain-based medical prescriptions tracking system, there will be an improvement over the management of sensitive information. Conforming to Down et al. (2018), in five years, 55% of healthcare applications will embrace blockchain technology. With the exponential growth of studies in this area, it is expected that the fear of knowing the potentialities of this technology will fade and thus become a subject of easy approach.

References

Abdullah, T., & Jones, A. (2019). EHealth: Challenges Far Integrating BlockChain within Healthcare. *Proceedings of 12th International Conference on Global Security, Safety and Sustainability, ICGS3 2019*, 1–9. https://doi.org/10.1109/ICGS3.2019.8688184

Abou Jaoude, J., & George Saade, R. (2019). Blockchain applications - Usage in different domains. *IEEE Access*, *7*(c), 45360–45381. https://doi.org/10.1109/ACCESS.2019.2902501

Advisor, T. C. (2019). *Managed Healthcare*. *29*(12).

Agbo, C., Mahmoud, Q., & Eklund, J. (2019). Blockchain Technology in Healthcare: A Systematic Review. *Healthcare*, *7*(2), 56. https://doi.org/10.3390/healthcare7020056

Al-Jaroodi, J., & Mohamed, N. (2019). Industrial applications of blockchain. *2019 IEEE 9th Annual Computing and Communication Workshop and Conference, CCWC 2019*, 550–555. https://doi.org/10.1109/CCWC.2019.8666530

Alhadhrami, Z., Alghfeli, S., Alghfeli, M., Abedlla, J. A., & Shuaib, K. (2018). Introducing blockchains for healthcare. *2017 International Conference on Electrical and Computing Technologies and Applications, ICECTA 2017*, *2018-Janua*, 1–4. https://doi.org/10.1109/ICECTA.2017.8252043

Alharby, M., & Moorsel, A. van. (2017). *Blockchain Based Smart Contracts : A Systematic Mapping Study*. 125–140. https://doi.org/10.5121/csit.2017.71011

Ammbr. (2017). *Whitepaper 2.1 - MedicalChain*.

Androulaki, E., Karame, G. O., Roeschlin, M., Scherer, T., & Capkun, S. (2013). Evaluating user privacy in Bitcoin. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *7859 LNCS*, 34–51. https://doi.org/10.1007/978-3-642-39884-1_4

Ankalkoti, P., & Santhosh, S. G. (2017). A Relative Study on Bitcoin Mining. *Imperial Journal of Interdisciplinary Research (IJIR)*, *3*(5), 1757–1761. http://www.imperialjournals.com/index.php/IJIR/article/view/5024/4834

Azzi, R., Chamoun, R. K., & Sokhn, M. (2019). The power of a blockchain-based supply chain. *Computers and Industrial Engineering*, *135*(May), 582–592. https://doi.org/10.1016/j.cie.2019.06.042

Benchoufi, M., & Ravaud, P. (2017). Blockchain technology for improving clinical research quality. *Trials*, *18*(1), 1–5. https://doi.org/10.1186/s13063-017-2035-z

Bento, H., & Gonçalves, M. (2019). Expresso | Consumo de analgésicos com ópio em Portugal é “incomparável” ao dos EUA, mas há “prescrições menos adequadas.” *Expresso Journal*. https://expresso.pt/life_style/beleza/2019-11-07-Consumo-de-analgesicos-com-opio-em-Portugal-e-incomparavel-ao-dos-EUA-mas-ha-prescricoes-menos-adequadas

Bentov, I., Lee, C., Mizrahi, A., & Rosenfeld, M. (2014). Proof of Activity. *ACM SIGMETRICS Performance Evaluation Review*, *42*(3), 34–37. https://doi.org/10.1145/2695533.2695545

BlockMedx | Home. (2019). https://www.blockmedx.com/

Boulkedid, R., Abdoul, H., Loustau, M., Sibony, O., & Alberti, C. (2011). Using and reporting the Delphi method for selecting healthcare quality indicators: A systematic review. *PLoS ONE*, *6*(6). https://doi.org/10.1371/journal.pone.0020476

Cachin, C. (2016). Architecture of the Hyperledger Blockchain Fabric. *Leibniz International Proceedings in Informatics, LIPIcs*, *70*, 24.1-24.16. https://doi.org/10.4230/LIPIcs.OPODIS.2016.24

Cong, L. W., He, Z., & Zheng, J. (2017). Blockchain Disruption and Smart Contracts. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.2985764

Crosby, M., Pattanayak, P., Verma, S., & Kalyanaraman, V. (2016). Applied Innovation Review. *Applied Innovation Review*, *2*, 5–20.

Dasaklis, T. K., Casino, F., & Patsakis, C. (2019). Blockchain meets smart health: Towards next generation healthcare services. *2018 9th International Conference on Information, Intelligence, Systems and Applications, IISA 2018*, 1–8. https://doi.org/10.1109/IISA.2018.8633601

Decker, C., & Wattenhofer, R. (2013). Information propagation in the Bitcoin network. *13th IEEE International Conference on Peer-to-Peer Computing, IEEE P2P 2013 - Proceedings*. https://doi.org/10.1109/P2P.2013.6688704

DeSalvo, K. B. (2015). *Connecting Health and Care for the Nation: A Shared Nationwide Interoperability Roadmap (Draft Version 1.0)*.

Dinh, T. T. A., Wang, J., Chen, G., Liu, R., Ooi, B. C., & Tan, K. L. (2017). BLOCKBENCH: A framework for analyzing private blockchains. *Proceedings of the ACM SIGMOD International Conference on Management of Data*, *Part F1277*, 1085–1100. https://doi.org/10.1145/3035918.3064033

Engelhardt, M. A. (2017). Hitching Healthcare to the Chain: An Introduction to Blockchain Technology in the Healthcare Sector. *Technology Innovation Management Review*, *7*(10), 22–34. https://doi.org/10.22215/timreview/1111

Expresso. (2019). *Expresso | Operação Antídoto. Médicos e farmacêuticos detidos por fraude milionária no SNS*. https://expresso.pt/revista-de-imprensa/2019-07-02-Operacao-Antidoto.-Medicos-e-farmaceuticos-detidos-por-fraude-milionaria-no-SNS

Garatti, M., Costa, R., Reghizzi, S. C., & Rohou, E. (2002). The impact of alias analysis on VLIW scheduling. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *2327 LNCS*, 93–105. https://doi.org/10.1007/3-540-47847-7_10

Gioia, D. A., Corley, K. G., & Hamilton, A. L. (2013). Seeking Qualitative Rigor in Inductive Research: Notes on the Gioia Methodology. *Organizational Research Methods*, *16*(1), 15–31. https://doi.org/10.1177/1094428112452151

GitHub - tylerdiaz/Heisenberg: Solving prescription/pharmaceutical logistics using smart contracts. (2019). https://github.com/tylerdiaz/Heisenberg

Giungato, P., Rana, R., Tarabella, A., & Tricase, C. (2017). Current trends in sustainability of bitcoins and related blockchain technology. *Sustainability (Switzerland)*, *9*(12). https://doi.org/10.3390/su9122214

Glintt. (2016). *SIFARMA*. https://www.glintt.com/pt/o-que-fazemos/ofertas/SoftwareSolutions/Paginas/Sifarma.aspx

Glintt. (2020). *Software Solutions*. https://www.glintt.com/pt/o-que-fazemos/ofertas/SoftwareSolutions/Paginas/Software Solutions.aspx

Government, U. (2018). *Opioid Misuse and Addiction*. MedlinePlus.

Haber, S., & Scott Stornetta, W. (1991). How to time-stamp a digital document. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *537 LNCS*, 437–455.

Harvard. (2008). *Electronic vs. personal health record*. https://www.hsph.harvard.edu/news/magazine/fall08ehrpersonalvshealth/

Hill, L. G., Evoy, K. E., & Reveles, K. R. (2019). Pharmacists are missing an opportunity to save lives and advance the profession by embracing opioid harm reduction. *Journal of the American Pharmacists Association*, *59*(6), 779–782. https://doi.org/10.1016/j.japh.2019.06.019

Home - ScalaMed. (2019). https://scalamed.com/

Howells, R. (2019). *Counterfeit Drugs: A Bitter Pill To Swallow*. https://www.forbes.com/sites/sap/2019/10/03/counterfeit-drugs-a-bitter-pill-to-swallow/#72999fa07a68

Iansiti, M., & Lakhani, K. R. (2017). *The Truth About Blockchain*.

IBMb. (2018). *What are the use cases for blockchain tech in healthcare?* Blockchain in Healthcare. https://www.ibm.com/blogs/blockchain/2018/12/what-are-the-use-cases-for-blockchain-tech-in-healthcare/

IMED. (2020). *iMED software*. https://imed.pt/imed/

INFARMED. (2014). Normas relativas à prescrição de medicamentos e produtos de saúde. *3*, 1–23. http://www.infarmed.pt/portal/page/portal/INFARMED/MEDICAMENTOS_USO_HUMANO/PRESCRICAO_DISPENSA_E_UTILIZACAO/Normas_prescricao.pdf

Jebb, A. T., Parrigon, S., & Woo, S. E. (2017). Exploratory data analysis as a foundation of inductive research. *Human Resource Management Review*, *27*(2), 265–276. https://doi.org/10.1016/j.hrmr.2016.08.003

Kassab, M., DeFranco, J., Malas, T., Destefanis, G., & Graciano Neto, V. V. (2019). Investigating Quality Requirements for Blockchain-Based Healthcare Systems. *2019 IEEE/ACM 2nd International Workshop on Emerging Trends in Software Engineering for Blockchain (WETSEB)*, 52–55. https://doi.org/10.1109/wetseb.2019.00014

Kassab, M., DeFranco, J., Malas, T., Laplante, P., Destefanis, G., & Graciano Neto, V. V. (2019). Exploring Research in Blockchain for Healthcare and a Roadmap for the Future. *IEEE Transactions on Emerging Topics in Computing*, *6750*(c), 1–1. https://doi.org/10.1109/tetc.2019.2936881

Katuwal, G. J., Pandey, S., Hennessey, M., & Lamichhane, B. (2018). *Applications of Blockchain in Healthcare: Current Landscape & Challenges*. 1–17. http://arxiv.org/abs/1812.02776

Khan, F. A., Abubakar, A., Mahmoud, M., Al-Khasawneh, M. A., & Alarood, A. A. (2019). Rift: A high-performance consensus algorithm for consortium blockchain. *International Journal of Recent Technology and Engineering*, *7*(6), 989–997. https://doi.org/10.1109/compcomm.2018.8781067

Kshetri, N. (2018). 1 Blockchain's roles in meeting key supply chain management objectives. *International Journal of Information Management*, *39*(December 2017), 80–89. https://doi.org/10.1016/j.ijinfomgt.2017.12.005

Kumar, R., & Tripathi, R. (2019). Traceability of counterfeit medicine supply chain through Blockchain.

2019 11th International Conference on Communication Systems and Networks, COMSNETS 2019, *2061*(1), 568–570. https://doi.org/10.1109/COMSNETS.2019.8711418

Kumar, T., Ramani, V., Ahmad, I., Braeken, A., Harjula, E., & Ylianttila, M. (2018). Blockchain utilization in healthcare: Key requirements and challenges. *2018 IEEE 20th International Conference on E-Health Networking, Applications and Services, Healthcom 2018*, 1–7. https://doi.org/10.1109/HealthCom.2018.8531136

Laaper, S., Fitzgerald, J., Quasney, E., Yeh, W., & Basir, M. (2017). Using blockchain to drive supply chain innovation. *In Hamburg International Conference of Logistics, Hamburg.*

Lambert, D. M. (2008). *Supply Chain Management: Processes, Partnerships, Performance.* (3rd editio). Supply Chain Management Institute, Sarasota.

Lamport, L., Shostak, R., & Pease, M. (1982). The Byzantine Generals Problem. *ACM Transactions on Programming Languages and Systems (TOPLAS)*, *4*(3), 382–401. https://doi.org/10.1145/357172.357176

Leeming, G., Cunningham, J., & Ainsworth, J. (2019). A Ledger of Me: Personalizing Healthcare Using Blockchain Technology. *Frontiers in Medicine*, *6*(July), 1–10. https://doi.org/10.3389/fmed.2019.00171

Leffew, K. (2018). *Project Heisenberg*. https://medium.com/@kleffew/project-heisenberg-cacd0c329cf7

Lin, I. C., & Liao, T. C. (2017). A survey of blockchain security issues and challenges. *International Journal of Network Security*, *19*(5), 653–659. https://doi.org/10.6633/IJNS.201709.19(5).01

Macrinici, D., Cartofeanu, C., & Gao, S. (2018). Smart contract applications within blockchain technology: A systematic mapping study. *Telematics and Informatics*, *35*(8), 2337–2354. https://doi.org/10.1016/j.tele.2018.10.004

Marcelino, V. (2019). *Corrupção. Médicos e farmacêuticos detidos em todo o país - DN*. https://www.dn.pt/pais/medicos-e-farmaceuticos-detidos-em-todo-o-pais-11066415.html

Marr, B. (2018). *30+ Real Examples Of Blockchain Technology In Practice*. https://www.forbes.com/sites/bernardmarr/2018/05/14/30-real-examples-of-blockchain-technology-in-practice/

Matthews, G. (2018). *Will Blockchain Transform Healthcare?* https://www.forbes.com/sites/ciocentral/2018/08/05/will-blockchain-transform-healthcare/#14721dc2553d

McGhin, T., Choo, K. K. R., Liu, C. Z., & He, D. (2019). Blockchain in healthcare applications: Research challenges and opportunities. *Journal of Network and Computer Applications*, *135*, 62–75. https://doi.org/10.1016/j.jnca.2019.02.027

McIntosh, M. J., & Morse, J. M. (2015). Situating and constructing diversity in semi-structured interviews. *Global Qualitative Nursing Research*, *2*. https://doi.org/10.1177/2333393615597674

Medtronic. (2018). *Breaking Down Borders-What Blockchain Can Do for Healthcare*. https://www.statista.com/

Mertz, L. (2018). (Block) Chain Reaction: A Blockchain Revolution Sweeps into Health Care, Offering the Possibility for a Much-Needed Data Solution. *IEEE Pulse*, *9*(3), 4–7. https://doi.org/10.1109/MPUL.2018.2814879

Mettler, M. (2016). Blockchain technology in healthcare: The revolution starts here. *2016 IEEE 18th International Conference on E-Health Networking, Applications and Services, Healthcom 2016*, 16–18. https://doi.org/10.1109/HealthCom.2016.7749510

Moinet, A., Darties, B., & Baril, J.-L. (2017). *Blockchain based trust & authentication for decentralized sensor networks*. 1–6. http://arxiv.org/abs/1706.01730

Novikov, S. P., Kazakov, O. D., Kulagina, N. A., & Azarenko, N. Y. (2018). Blockchain and Smart Contracts in a Decentralized Health Infrastructure. *Proceedings of the 2018 International Conference "'Quality Management, Transport and Information Security, Information Technologies'", IT and QM and IS 2018*, 697–703. https://doi.org/10.1109/ITMQIS.2018.8524970

Paik, M., Sharma, A., Meacham, A., Quarta, G., Smith, P., Trahanas, J., Levine, B., Hopkins, M. A., Rapchak, B., & Subramanian, L. (2009). The case for SmartTrack. *2009 International Conference on Information and Communication Technologies and Development, ICTD 2009 - Proceedings*, 458–467. https://doi.org/10.1109/ICTD.2009.5426683

Petersen, M., Hackius, N., & von See, B. (2018). Mapping the sea of opportunities: Blockchain in supply chain and logistics. *It - Information Technology*, *60*(5–6), 263–271. https://doi.org/10.1515/itit-2017-0031

Pham, H. L., Tran, T. H., & Nakashima, Y. (2019). A Secure Remote Healthcare System for Hospital Using Blockchain Smart Contract. *2018 IEEE Globecom Workshops, GC Wkshps 2018 - Proceedings*, 1–6. https://doi.org/10.1109/GLOCOMW.2018.8644164

Pierro, M. DI. (2017). What Is the Blockchain? *Computing in Science and Engineering*, *19*(5), 92–95. https://doi.org/10.1109/MCSE.2017.3421554

Pilkington, M. (2016). Blockchain Technology: Principles and Applications. In I. F. X. O. and M. Zhegu (Ed.), *Blockchain Technology: Principles and Applications. In F. Xavier Olleros and Majlinda Zhegu, editors, Research Handbook on Digital Transformations* (Edward Elg, pp. 1–39). Edward Elgar Publishing.

Pinto, R. (2020). *Jornal de Notícias*. https://www.jn.pt/justica/farmaceutica-e-um-medico-condenados-a-prisao-efetiva-por-receitas-falsas-13064695.html

Prokofieva, M., & Miah, S. J. (2019). Blockchain in healthcare. *Australasian Journal of Information Systems*, *23*, 1–22. https://doi.org/10.3127/ajis.v23i0.2203

Publico. (2019). *Consumo de analgésicos opióides mais do que duplicou em oito anos | Saúde | PÚBLICO*. Publico. https://www.publico.pt/2019/09/04/sociedade/noticia/consumo-analgesicos-opioides-duplicou-decada-1885446

Rajeev Ronanki. (2019). *Anthem Will Use Blockchain To Secure Medical Data For Its 40 Million Members In Three Years*. https://www.forbes.com/sites/leahrosenbaum/2019/12/12/anthem-says-its-40-million-members-will-be-using-blockchain-to-secure-patient-data-in-three-years/#2b2ce2366837

Ramani, V., Kumar, T., Bracken, A., Liyanage, M., & Ylianttila, M. (2018). Secure and Efficient Data Accessibility in Blockchain Based Healthcare Systems. *2018 IEEE Global Communications Conference, GLOBECOM 2018 - Proceedings*. https://doi.org/10.1109/GLOCOM.2018.8647221

Sankar, L. S., Sindhu, M., & Sethumadhavan, M. (2017). Survey of consensus protocols on blockchain applications. *2017 4th International Conference on Advanced Computing and Communication Systems, ICACCS 2017*. https://doi.org/10.1109/ICACCS.2017.8014672

Satoshi Nakamoto. (2008). *Bitcoin: A Peer-to-Peer Electronic Cash System*. 1–9. https://doi.org/10.1007/s10838-008-9062-0

ScriptDrop - Integrated Prescription Delivery for Pharmacies. (2019). https://scriptdrop.co/

Shae, Z., & Tsai, J. J. P. (2017). On the Design of a Blockchain Platform for Clinical Trial and Precision Medicine. *Proceedings - International Conference on Distributed Computing Systems*, 1972–1980. https://doi.org/10.1109/ICDCS.2017.61

Shah, B., Shah, N., Shakhla, S., & Sawant, V. (2019). Remodeling the Healthcare Industry by employing Blockchain Technology. *2018 International Conference on Circuits and Systems in Digital Enterprise Technology (ICCSDET)*, 1–5. https://doi.org/10.1109/iccsdet.2018.8821113

SPMS. (2016). *Prescription Software*. https://pem.spms.min-saude.pt/category/fornecedores-de-software/

SPMS. (2019). *Especificações técnicas relativas aos softwares de prescrição de medicamentos e produtos de saúde*.

Stenum, J., Dk, C.-J., Zangenberg, N., Dk, L.-N., Oliver, S., & Dk, M.-S. (2015). *The Use of Block Chain Technology in Different Application Domains Bachelor Project in Software Development*. *May*.

Steurer, J. (2011). The Delphi method: An efficient procedure to generate knowledge. *Skeletal Radiology*, *40*(8), 959–961. https://doi.org/10.1007/s00256-011-1145-z

Swan, M. (2015). *Blockchain. Blueprint for a New Economy.* (1st Editio). O`REILLEY.

Thatcher, C., & Acharya, S. (2019). Pharmaceutical uses of Blockchain Technology. *International Symposium on Advanced Networks and Telecommunication Systems, ANTS*, *2018-Decem*, 1–6. https://doi.org/10.1109/ANTS.2018.8710154

Theodouli, A., Arakliotis, S., Moschou, K., Votis, K., & Tzovaras, D. (2018). On the Design of a Blockchain-Based System to Facilitate Healthcare Data Sharing. *Proceedings - 17th IEEE International Conference on Trust, Security and Privacy in Computing and Communications and 12th IEEE International Conference on Big Data Science and Engineering, Trustcom/BigDataSE 2018*, 1374–1379. https://doi.org/10.1109/TrustCom/BigDataSE.2018.00190

Tijan, E., Aksentijević, S., Ivanić, K., & Jardas, M. (2019). Blockchain technology implementation in logistics. *Sustainability (Switzerland)*, *11*(4). https://doi.org/10.3390/su11041185

Tomé, J. (2019). O historial de uma mentira que rendeu milhões mas mata pessoas. *Dinheiro Vivo Journal*. https://www.dinheirovivo.pt/geral/o-historial-de-uma-mentira-que-rendeu-milhoes-mas-mata-pessoas/

Ur, R. S., Rasool, R. U., Ayub, M. S., Ullah, S., Kamal, A., Rajpoot, Q. M., & Anwar, Z. (2011). *Reliable Identification of Counterfeit Medicine Using Camera Equipped Mobile Phones Saif ur Rehman, Raihan Ur Rasool, M. Sohaib Ayub, Saeed Ullah, Aatif Kamal, Qasim M. Rajpoot, and Zahid Anwar*. 273–279.

Valenta, M., & Sandner, P. (2017). Comparison of Ethereum, Hyperledger Fabric and Corda. *Frankfurt School Blockchain Center*, *June*, 8. www.fs-blockchain.decontact@fs-blockchain.dewww.twitter.com/fsblockchainwww.facebook.de/fsblockchain%0Ahttps://medium.co m/@philippsandner/comparison-of-ethereum-hyperledger-fabric-and-corda-21c1bb9442f6

Vangulick, D., Cornelusse, B., & Ernst, D. (2019). *Blockchain: A Novel Approach for the Consensus Algorithm Using Condorcet Voting Procedure*. 1–10. https://doi.org/10.1109/dappcon.2019.00011

Voas, J. (2018). Blockchain and Electronic Healthcare Records. *Imaging*, *83*(991), 569–577. https://doi.org/10.1259/bjr/21753020

Vyas, S., Gupta, M., & Yadav, R. (2019). Converging Blockchain and Machine Learning for Healthcare. *Proceedings - 2019 Amity International Conference on Artificial Intelligence, AICAI 2019*, 709–711. https://doi.org/10.1109/AICAI.2019.8701230

Wazid, M., Das, A. K., Khan, M. K., Al-Ghaiheb, A. A. D., Kumar, N., & Vasilakos, A. V. (2017). Secure Authentication Scheme for Medicine Anti-Counterfeiting System in IoT Environment. *IEEE Internet of Things Journal*, *4*(5), 1634–1646. https://doi.org/10.1109/JIOT.2017.2706752

Woo, S. E., O'Boyle, E. H., & Spector, P. E. (2017). Best practices in developing, conducting, and evaluating inductive research. *Human Resource Management Review*, *27*(2), 255–264. https://doi.org/10.1016/j.hrmr.2016.08.004

WorldHealthOrganazation. (2010). Growing threat from counterfeit medicines. *Bulletin of the World Health Organization*, *88*(4), 247–248. https://doi.org/10.2471/blt.10.020410

Wu, H. Te, & Tsai, C. W. (2018). TOWARD Blockchains for Health-Care Systems: Applying the Bilinear Pairing Technology to Ensure Privacy Protection and Accuracy in Data Sharing. *IEEE Consumer Electronics Magazine*, *7*(4), 65–71. https://doi.org/10.1109/MCE.2018.2816306

Wüst, K., & Gervais, A. (2017). Do you need a Blockchain? *IACR Cryptology EPrint Archive*, *i*, 375.

Xu, X., Pautasso, C., Zhu, L., Gramoli, V., Ponomarev, A., Tran, A. B., & Chen, S. (2016). The blockchain as a software connector. *Proceedings - 2016 13th Working IEEE/IFIP Conference on Software Architecture, WICSA 2016*, 182–191. https://doi.org/10.1109/WICSA.2016.21

Yermack, D. (2017). Corporate governance and blockchains. *Review of Finance*, *21*(1), 7–31. https://doi.org/10.1093/rof/rfw074

Yli-Huumo, J., Ko, D., Choi, S., Park, S., & Smolander, K. (2016). Where is current research on Blockchain technology? - A systematic review. *PLoS ONE*, *11*(10), 1–27. https://doi.org/10.1371/journal.pone.0163477

Zhang, P., Schmidt, D. C., White, J., & Lenz, G. (2018). Blockchain Technology Use Cases in Healthcare. In *Advances in Computers* (1st ed., Vol. 111). Elsevier Inc. https://doi.org/10.1016/bs.adcom.2018.03.006

Zhang, P., White, J., Schmidt, D. C., Lenz, G., & Rosenbloom, S. T. (2018). FHIRChain: Applying Blockchain to Securely and Scalably Share Clinical Data. *Computational and Structural Biotechnology Journal*, *16*, 267–278. https://doi.org/10.1016/j.csbj.2018.07.004

Zhang, R., Xue, R., & Liu, L. (2019). Security and Privacy on Blockchain. *ACM Computing Surveys*, *52*(3), 1–34. https://doi.org/10.1145/3316481

Zhou, L., Wang, L., & Sun, Y. (2018). MIStore: a Blockchain-Based Medical Insurance Storage System. *Journal of Medical Systems*, *42*(8). https://doi.org/10.1007/s10916-018-0996-4

Zubaydi, H. D., Chong, Y.-W., Ko, K., Hanshi, S. M., & Karuppayah, S. (2019). A Review on the Role of Blockchain Technology in the Healthcare Domain. *Electronics*, *8*(6), 679.

https://doi.org/10.3390/electronics8060679