Blockchain Applications in Healthcare

Blockchain-based solution for the medical prescription system in Portugal

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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 Prescription; Transparency

1. Introduction

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)

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). 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. 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.

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). 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: Medicine Supply Chain; Patient Data; Clinical Trials Research; Insurance Claim; 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. The United States of America declared the opioids crisis a national problem, people are getting access to all type of drugs through pharmacies. 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 current medical prescription system in Portugal was analyzed, and flaws were detected. The capacity of blockchain technology to solve those detected flaws is further analyzed.

3. Literature Review

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).

3.1.1 Consensus Mechanism

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).

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).

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).

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.

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).

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.

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.

3.2 Healthcare

3.2.1 Medical 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.

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). 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).

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.

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).

3.2.5 Medical Prescriptions

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). 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.

4. Methodology

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.

4.1 Mapping the current system

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. 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.

4.2 Flaws Analyzes

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). 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.

4.3 Blockchain-based solution

This step can be divided into three parts:

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.

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.

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 system

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. 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.

5.2 System Flaws Analyzes

The Delphi method was applied. From the first survey, 10 flaws could be identified. From the second survey, it was possible to confirm 8 of the 10 detected flaws:

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

2.Unclear or invalid prescriptions (EMP and MMP)

3.EMP may be contradictory due to misleading information - nonexistent package

4.Lack of control over the patient treatment

5.Multiple prescriptions for the same medication

6.User's data restrictions

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

8.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

5.3.1 Experts Analysis

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 Implementation Barriers

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 Solution

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.

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 that permits the creation of smart contracts. Blockchain technology promises to disrupt multiple sectors, mainly the healthcare. Blockchain technology is evolving and holding a prominent position in health. 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, it was applied the Delphi method where ten pharmacists answered to it according to a scale of discordance and, where 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 ten flaws detected 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 that 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 blockchain-based 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, that is, 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 present 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. In the highly digitized world so reliant on a data-driven economy, blockchain can help make lives easier. By adopting for 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.

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