LISBON SCHOOL OF ECONOMICS & MANAGEMENT
UNIVERSIDADE DE LISBOA

MESTRADO EM
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TRABALHO FINAL DE MESTRADO

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IMPLEMENTATION MODEL OF AN INTEGRATED BLOCKCHAIN AND IOT SYSTEM TO HEALTHCARE ECOSYSTEM

MARÍLIA CLAUDINO MOREIRA CUNHA

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ORIENTAÇÃO:

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"Gratitude is the memory of the heart".

And my eternal memory to my parents and friends who always made me see that giving up is not a solution and that I am always able to achieve my goals.

Thanks to Professor Palma dos Reis for his help, contributing his experience and knowledge.

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My sincere thanks!

Marília Claudino Cunha

Resumo

No cenário de transformação digital em que estão inseridos todos os setores de atividade, para melhorar a eficiência, a produtividade e reduzir o tempo e os custos, é necessário investir em novas tecnologias.

Novas tecnologias como *Internet of Things (IoT)* e *Blockchain* são desenvolvidas para melhorar a eficiência de processamento, a criação de oportunidades de negócios, a regulamentação de requisitos, a segurança e transparência e descentralização de informações, e provavelmente serão as próximas tecnologias disruptivas que transformaram os diversos setores de atividade.

Por sua vez, o setor saúde tem enfrentado dificuldades com o surgimento de novas doenças e precisa se transformar e se reinventar para manter sua legitimidade e continuar cumprindo suas obrigações para com os cidadãos. A implementação de novas tecnologias acaba sendo uma das abordagens mais eficazes para aumentar a eficiência, segurança, gerenciamento, análise de *big data* e performance dos dados.

Devido a isso, este projeto propõe um modelo de *framework Blockchain* e IOT aplicada a saúde.

A implementação engloba a criação de um aplicativo (i.e., pacientes) e um site (i.e., médicos, hospitais, farmácias, saúde publica), os dados partilhados pelos usuários são armazenados no blockchain conectado ao aplicativo e o acesso ao Blockchain é liberado por *smartcontracts*.

O objetivo do modelo proposto é que os dados sejam descentralizados e possibilita o acesso a todos os conectados ao blockchain. E para não infringir a proteção dos dados pessoais dos pacientes, foi tomado o cuidado de que o usuário paciente seja o “proprietário” de todos os seus dados e compartilhe-os com qualquer entidade de saúde que deseja.

Para atingir os objetivos mencionados, foi definida uma metodologia de validação por conceito do modelo proposto. A validação do conceito do modelo foi dividida em cinco etapas, seguida da análise qualitativa das entrevistas semiestruturadas realizadas com pacientes, médicos e gestores de saúde.

Como resultado da validação por conceito foi observado que a opinião de todos os entrevistados é que a implementação do modelo proposto é vantajosa e poderá contribuir com avanços no setor saúde.
Portanto, uma vez que médicos e hospitais tenham acesso a mais dados de saúde dos pacientes, esses dados podem colaborar para um diagnóstico mais preciso e o ecossistema da saúde obtém avanços tecnológicos que contribuem para uma melhor gestão dos dados e combate as novas doenças.

Palavras – chave: Blockchain, IOT, saúde.

Abstract

In the digital transformation scenario in which all sectors of activity are inserted, to improve efficiency, productivity and reduce time and costs, it is necessary to invest in new technologies.

New technologies such as Internet of Things (IoT) and Blockchain are being developed to improve processing efficiency, the creation of business opportunities, requirements regulation, security and transparency and information decentralization, and are likely to be the next disruptive technologies that have transformed the various sectors of activity.

In turn, the health sector has confronted difficulties with the emergence of new diseases and needs to transform and reinvent itself in order to maintain its legitimacy and continue to fulfill its obligations to citizens. The implementation of new technologies is one of the most effective approaches to increase efficiency, security, management, big data analysis and data performance.

Because of this, this project proposes a Blockchain and IOT framework model applied to health.

The implementation includes the creation of an application (ie, patients) and a website (ie, doctors, hospitals, pharmacies, public health), the data shared by users is stored on the blockchain connected to the application and access to the Blockchain is released by smartcontracts.

The aim of the suggested model is that the data is decentralized and allows access to all those connected to the blockchain. And in order not to infringe on the protection of patients' personal data, care has been taken that the patient user is the “owner” of all his data and shares it with any health entity he wishes.

To achieve the objectives was applied a validation methodology by concept of the proposed model. The validation of the model concept was divided into five stages, followed by a qualitative analysis of the semi-structured interviews conducted with patients, doctors and health managers.

As a result of the concept validation, it was observed that the opinion of all interviewees is that the implementation of the proposed model is advantageous and may contribute to advances in the health ecosystem.

Therefore, once doctors and hospitals have access to more patients health data, these data can collaborate for a more accurate diagnosis and the health ecosystem obtains technological advances that contribute to better data management and to fight new diseases.

Keywords: Blockchain, IOT, Healthcare.

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Abbreviations

BC – Blockchain

IOT – Internet of Things

PHD - healthcare devices

AL - Assisted Living

AI - Artificial Intelligence

POC – Proof of conecpt

COVID-19 - Orthocoronavirinae

APP – Mobile application

OSI - Open System Interconnection

IWF - IoT World Forum

SMS – Short Message Service

SHA – Secure Hash Algorithms

H2H - Human to Human

M2M - Machine to Machine

PHI - Protected Health Information

RPM - Remote Patient Monitoring

IoHT - Internet of Healthcare Things

RC - Register Contract

PPR - Patient–Provider Relationship Contract

SC - Summary Contract

MEMS – Micro Electro Mechanical Systems

GIS - Geographic Information System

mHealth - Mobile Health

eHealth – Electronic Health

HIV – Human immunodeficiency virus

TB – Tuberculosis

Dapps - Decentralized Applications

EVM - Ethereum Virtual Machine

GSM – GSM Module

1. Introduction

1.1. The Motivation for the Research

Today, the digital revolution is causing substantial increases in efficiency and productivity, while also transforming the business environment. The pace of change is only increasing with each advancement or new technology (McCracken, 2019).

New technologies like the Artificial Intelligence, Internet of Things (IoT) and Blockchain are likely to be the next disruptive technologies that transform the world as we know it and the primary concern with the adoption of these new technologies is security (Saunders, 2017).

Blockchain's potential for resolving security vulnerabilities is the reason it is viewed as a transformational technology.

Nevertheless, further development of blockchain is warranted, because its advancement could prove more applicable and valuable for other uses. The key aspect of blockchain is its ability to provide trust between participants who may not know each other, allowing them to transact in a more secure and transparent way (McCracken, 2019).

Blockchain is developing rapidly and could be used in many ways. For example, it could enable a person's digital identity management, allowing storage and control of personal information in one location. (Baars, 2018).

Instead having every person's personal information stored by various entities, personal information would be stored in one location like a personal computer. Then, entities requesting information or receive more detailed information if given permission. This would increase personal privacy and security, decrease identity fraud, and reduce transaction times.

Further, blockchain could even be used in this way to enable a universal medical record system shared by all hospitals. (Baars, 2018).

Data that are present inside the Blockchain databases are in an encrypted state. All the private keys must be kept safe and the data range of private keys are of few kilobytes of data. Personal healthcare devices (PHD), Assisted Living (AL), wearable devices can all benefit by the security provided by BC technology. (Yang, 2018).

Medical product supply chains could utilize blockchain for product information or conditions. For example, many medical and pharmaceutical products require specific environmental or storage conditions to maintain product integrity and quality. A test case was performed where sensors were used to track temperature and humidity conditions throughout the supply chain, and these records were stored on a blockchain network. The use of blockchain in the way would increase the trust of a products' integrity and reliability of records for all parties involved. (Bocek et al., 2017).

There are many definitions of IoT. One of them is networked connections of people, data, process, and things. Internet of Things (IoT) is a sort of "universal global neural network" in the cloud which connects various things. (Sharma lei al., 2016).

A vision for how IOT could change the world in the distant future. Now in this era the iot may be used in various research field in this literature those may classified as: massive scaling, creating knowledge and big data, architecture and dependencies, robustness, openness, security, privacy, and human-in-the-loop (Ray, 2018).

IoT has the potential to enable extensions and enhancements to fundamental services in transportation, logistics, security, utilities, education, healthcare, and other areas, while providing a new ecosystem for application development (Connected Living, 2014).

Applications are developed based on IoT enabled devices for monitoring and control.

In Health field is used to: 1. All Detection: Assistance for elderly or disabled people living independent;2. Medical Fridges: Monitoring and Control of conditions inside freezers storing medicines ,vaccines, and organic elements; 3. Sportsmen Care: Vital signs monitoring in high performance centers and field; 4. Patients Surveillance: Monitoring of conditions of patients inside hospitals and in old people's home; 5. Ultraviolet Radiation: Measurement of UV sun rays to warn people not to be exposed in certain hours (Sharma1 et al., 2016).

Internet of Things applications have a future market potential for electronic health services and connected telecommunication industry. In this context, the telecommunications can foster the evolution of ecosystems in different application areas. Medical expenditures are in the range of 10% of the European gross domestic product (Vermesan et al., 2013).

The IoT solutions outcome is promote economic growth and able to move large numbers of people out of poverty. All countries in the world will sooner or later, lead to the digital technology development together. The challenge is whether quickly and correctly they start the appropriate development. (Satar et al., 2018).

Blockchain technology has shown adaptability in recent years leading to its incorporation in a wide range of applications including biomedical and healthcare systems (Zhang,2018). The use of blockchain and AI in healthcare is evident in the following areas: management of electronic medical records; drugs and pharmaceutical supply chain management; biomedical: research; education; remote patient monitoring;and health data analytics (Agbo,2019).

Blockchain can unlock a new era of technological advancement, where IoT devices communicate and transact with one another. Where blockchain is the source of validation, consistency, recordkeeping of the transaction, and smart contracts within blockchain govern execution and validation of IoT devices

activity through their sensors. If this is type of seamless automated network is achieved, it will change business is conducted forever. (McCracken, 2019).

Emerging health innovations such as blockchain and artificial intelligence (AI) technology can be coupled with POC diagnostics to enable self-testing of patients in isolation as a result of exposure to COVID-19. Blockchain is a digital, public ledger that records online transactions. It involves the digital distribution of ledger and consensus algorithms and eliminates all the threats of intermediaries (Yaqoob,2019).

1.2. Research Aim and Objectives

Observing the whole context, the main aim of this dissertation is to identify positive changes in the health sector, with the implementation of technologies (i.e., Blockchain and IoT) to improve the management, analysis and communication of information, in a secure way and preserving privacy patient data.

The objectives of this dissertation are:

1. Understand the technological needs of the health sector.

2. Understand the Blockchain and IoT implementation in the health sector.

3. Check the advantages and positive changes with the implementation of these technologies.

4. Propose an implementation model for the health sector using new technologies (Blockchain and IOT).

5. Verify the advantages for the health ecosystem with the implementation of the proposed model.

1.3. Aim and Objectives Relevance

Considering the information mentioned and the objectives, the relevance of the study is to understand the impact of new technologies in the health sector, observing the efficiency in the processing of information and the creation of business opportunities in a safe and transparent way.

In addition, to list the advantages with the implementation of Blockchain-IoT proposed model and considering the high security and confidentiality of medical data and that all this data should be accessed by only authorised person.

1.4. Research Questions

According to the objectives and relevance of this theme, it is expected throughout the dissertation to answer the research questions:

Q1. How does the implementation of Blockchain and IoT occur in the health sector?

Q2. What are the main challenges faced with the implementation of these technologies?

Q3. How to ensure that data will be treated in a secure and transparent manner?

Q4. What are the advantages for health services with the implementation of Blockchain and IoT?

Q5. How could it be the implementation of a system in the health sector using blockchain and the benefits for patients?

Q6. What are the advantages with the implementation of a proposed new model?

2. Literature Review

2.1. New Technologies

2.1.1. Blockchain

2.1.1.1.1. Definition

The blockchain framework can be defined as software solutions that simplifies the development and deployment of blockchain applications with little customization. (Quasim, M. T., et al., 2020).

Blockchain has defined by many organizations from different perspectives. For instance, Coinbase, the world's largest cryptocurrency exchange, defined blockchain as a distributed, public ledger that contains the history of every bitcoin transaction. (Coinbase, 2107).

Sultan et al., 2018, provides a general definition for the blockchain. It stated a decentralized database containing sequential, cryptographically linked blocks of digitally signed asset transactions, governed by a consensus model.

Richard Bradley explains what Blockchain is in Deloitte's broadcast in under 100 words, you (a "node") have a file of transactions on your computer (a "ledger"). Two government accountants (let's call them "miners") have the same file on theirs (so it's "distributed"). As you make a transaction, your computer sends an e-mail to each accountant to inform them. Each accountant rushes to be the first to check whether you can afford it (and be paid their salary "Bitcoins"). The first to check and validate hits "REPLY ALL", attaching their logic for verifying the transaction ("proof of work"). If the other accountant agrees, everyone updates their file. This concept is enabled by "Blockchain" technology.

In addition, a generic definition for the blockchain is provided by Wikipedia. A blockchain, originally block chain, is a growing list of records, called blocks, that are linked using cryptography. Each block contains a cryptographic hash of

the previous block, a timestamp, and transaction data (generally represented as a Merkle tree).

2.1.1.1.2. Characteristics

Blockchain technology provides the means for safe and secure transactions without having to trust a third party. This concept in blockchain is known as ‘‘trustlessness’’ — as long as each participant in a transaction can trust in the accuracy and integrity of the ledger, there is no additional requirement for trust between the parties (Zheng, Z., et, al., 2018).

According to the site Gartner (2020), one thing that needs to be understood is BC is still in its nascent stages and it is not under any legal, government body or traditional institutions. Its completely decentralized, distributed and highly secure. So, what does the combination of BC and IoT brings to the table? Listed below are few of the advantages of combining these two cutting-edge technologies.

1. Records created in BC are transparent which makes tracking and analysis of any activity possible by authorised network users. This is highly useful to track outages, failures, possible data leaks, identification of weak links and take the necessary countermeasures.
2. Since all the records are encrypted, anyone involved in a transaction can trust the data and all transaction will be recorded by machines which avoids the human oversight.
3. BC provides options for creating “smart contracts” that allows for executing agreements when specific conditions are met. This is highly useful in case of delivery-based services.
4. BC improves the overall security of the IoT network which primarily constitutes highly sensitive personal data.

Even though financial sector was the first targeted sector for realizing the full potential of BC, its is now found that it can be extended across multiple sectors that includes manufacturing, supply chain, healthcare, government, supply chain, education and energy (Heng, J., 2017).

According to the author Bragadeesh SA (2018), the various strengths of BC technology can be listed: Distributed resilience and control, Decentralized Network Architecture, Fully Open Source, Security and modern cryptography, Asset tracking and maintenance, Dynamic and fluid value exchange. The potential weaknesses exhibited by BC may include the following factors: Lack of ledger interoperability, Customer unfamiliarity and poor user experience, Lack of governmental, tested technology, Key management, Skills scarcity and skill building costs, Immature scalability.

Blockchain is more secure compared to the traditional database since if the data is hacked,changed, or corrupted, we lose what the truth was. Blockchain has a high degree of security and an extensive permission set to verify and control who can access data in what circumstances. It also improves quality assurance services by tracking the origins of all supply chain components to mitigate the cost and control any damaged elements. An example is, food origin and/or safety recall using a smart contract as a replacement for middlemen operators (Niranjanamurthy, M. et al., 2019).

Blockchain ensures consistent business processes across different organizations and automates the business process by employing a smart contract. Finally, blockchain removes intermediaries, which reduces cost and increases the efficiency of business operations. It allows the organizations to operate faster and reacts to changes in the business landscape much quicker than they could otherwise. (Gatteschi, V. et al., 2018).

Blockchain can also be used as an event tracking system where announcements mark the occurrence of significant events, and those events can be made actionable through the use of smart contracts/chaincode; software programmed to respond to certain types of these events (Sankar, 2017).

Summing up, the characteristics of blockchain is:

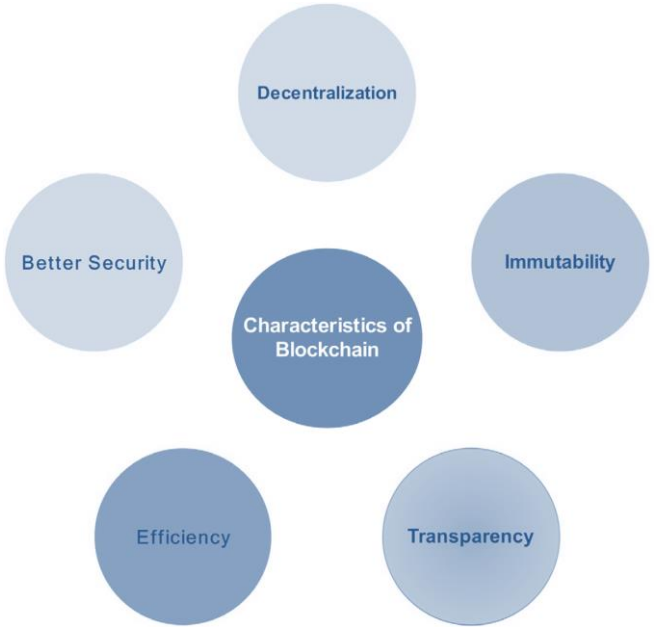

Figure 1- Characteristics of Blockchain.

(Source: Adapted from Bragadeesh,2018).

The one major benefit of employing BC was the cost savings that could achieved for performing interoffice transactions and asset tracking. (Bragadeesh, 2018).

2.1.1.1.3. Architeture

Blockchain creates sequences of transactions, known as blocks, and records them in an ongoing chain of events that can be shared among members of a network. Because the blocks are protected using advanced cryptographic technology, the records are virtually impossible to change (Mougayar, 2016).

Blocks are typically divided into two segments, header, and a group of transactions. The header contains the block metadata which is used to contain all details about the block in the ledger (Ahmad et al., 2018)

The figure two shows the structure of a block and illustrates how blocks chained together with the block header information described as follows:

1. Version number: 4bytes to indicate the version number of the block.

2. Previous block hash: 32 bytes to describe the hash of the previous block of the blockchain. It acts as a pointer between the current block and the previous block in the ledger.
3. Timestamp: 4bytes to record the time at which the block has been created.
4. Merkle tree: 32 bytes which are a hash (SHA-256) of all transactions that are related to this block.
5. Difficulty target: 4bytes to identify the difficulty target of the block.
6. Nonce: 4bytes to create the block and compute different hashes.

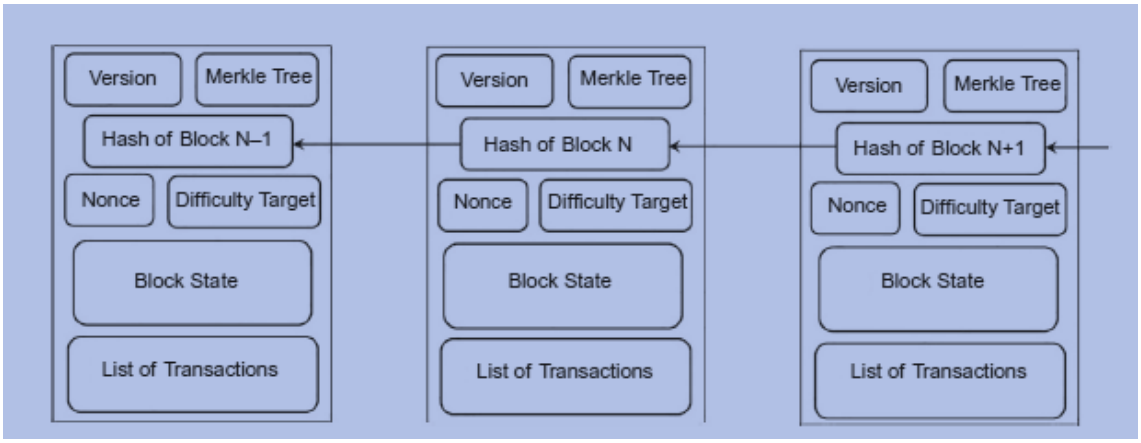

Figure 2- Structure of block showing how blocks chained together with header information.

(Source: Adapted from Ahmad et al. (2018).

According to Farouk, et al. (2020), in many business scenarios, the anonymity and full-transparency that define public platforms are wholly undesirable, but some sort of permanente append-only ledger is still required.

For now, think of blockchain as the following simple process (See figure 3):

1. An announcement is made before multiple witnesses (nodes, miners, validators, etc.).

2. Each participant documents the details of the announcement in their own personal copy of the ledger.

3. Announcements are grouped together in ‘‘blocks’’. Each participant regularly attempts to compare their current block with the current block of all the other participants on the network.

4. If there is a version of the current block which the majority of participants have in common, this version is considered to be the truth. Any participant that does not have the same data as the majority will discard their copy, obtain a copy from another participant, and move on.

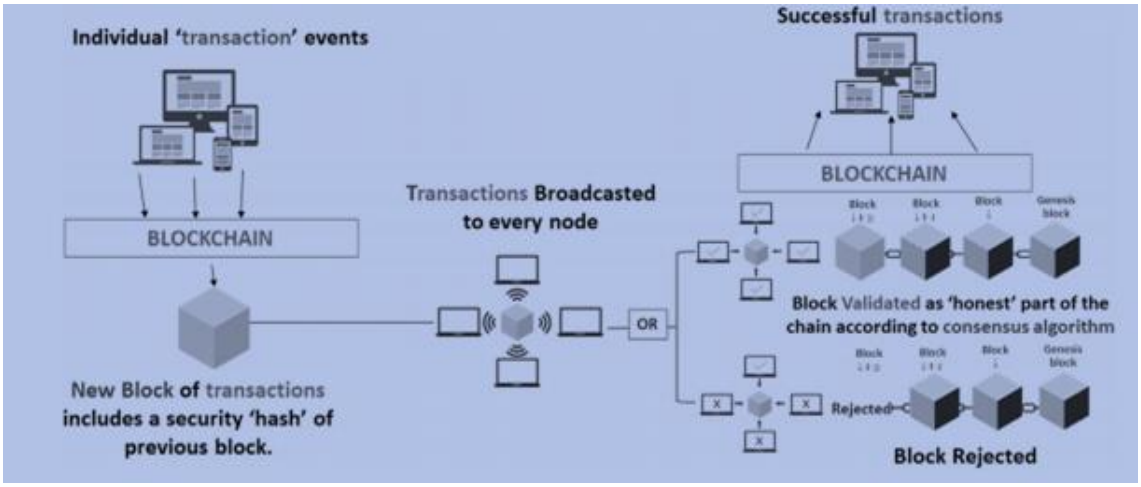

Figure 3- The process of blockchain.

(Source: Adapted from Farouk et al.,2020).

This wallet contains the account’s private key which is used to sign all transactions from that account. Any transactions presented by that account will be verified by the network using the cor- responding public key for the account (Motohashi et al., 2019).

2.1.2. IoT

2.1.2.1.1. Definition

The fundamental idea of the Internet of things (IoT) is to connect existing and future physical objects to the Internet, always serviceable at anywhere, anytime, with anything and anyone, through any path/network and any-service. IoT is based on smart infrastructures revolution, connecting companies, machineries,

transports and so on under a unique system characterized by logistic mechanisms, energy resources and means of communication (Del Giudice, 2016).

Experts describe the Internet of Things as ‘‘Things’’ or smart devices (e.g., sensors, surveillance, drones, etc.) that have the capabilities of sensing, collecting, processing, and exchanging information with other interlinked devices (Ray et al., 2017).

The IoT promises to deliver a step change in individuals‟ quality of life and enterprises‟ productivity. Through a widely distributed, locally intelligent network of smart devices, the IoT has the potential to enable extensions and enhancements to fundamental services in transportation, logistics, security, utilities, education, healthcare and other areas, while providing a new ecosystem for application development (Sharma et al., 2018).

The Internet of Things (IoT) is a key element of global digital transformation, where network of physical objects—devices, vehicles, buildings and other items embedded with electronics, software, sensors, and network connectivity—that enables these objects to collect and exchange data (Byrne, 2017). In a technological context, industrial IoT have two linked terms called Human to Human (H2H) and Machine to Machine (M2M), these contributes to the future of Internet (Trilles et al., 2017).

2.1.2.1.2. Characteristics

According to Sharma1 and Tiwari (2016), now in this era the IOT may be used in various research field in this literature those may classified as: massive scaling, creating knowledge and big data, architecture and dependencies, , robustness, openness, security, privacy, and human-in-the-loop.

Advantages:

1. Students or employee easily get important notice or information by message any time 24x7.

2. Within a second organization can change notice or information by sending SMS only.
3. Admin can change the display message or notice from any place or anywhere.

Disadvantage:

1. If anybody wants information, they have to do message and for every new information they have to send message again and again to the system**.**

As solution that are developed and emerging opportunities that serve people. Domain application works as Tactile Internet in markets (e.g.,mobility, manufacturing, event-organization, education with entertainment (edutainment), (health) care, smart grid and further emerging markets like agriculture, drones, constructions, etc) (Simsek, 2016).

IoT application sits in the cloud and typically accessed by mobile application-based (apps) in smartphone, tablet or desktop. According to figure 4, opportunities are offered through appropriate exertion of IoT use cases (Markit, 2018).

Figure 4 - IoT Integrated Application.

(Source: Adapted from Markit, 2018).

By collecting and combining data from various IoT devices and using big data analytics, decision-makers can take appropriate actions with important economic, social, and environmental implications (Sadiku, 2017).

Furthermore, with the sheer volumes of information produced by IoT applications, data security and protection are of utmost importance. In the era of connectivity, it is vital that personal privacy be cherished, given that it is so hard earned. IoT is set to revolutionize how the world operates. Not only the homes, but even whole cities of the future and the vast majority of our consumer products and functional materials will be influenced by IoT. However, like all disruptive technology it is not without controversy (Ley, 2015).

2.1.2.1.3. Architeture

There are different architectures for the IoT system that represent various perspectives about the IoT and its functions. However, the most common architecture for the IoT is the one made by IoT World Forum (IWF) architecture committee in October 2014 (Stallings,2015). This reference model provides a common framework to allow deploying the IoT easily and quickly in the industry. Similar to Open System Interconnection (OSI) reference model of the network, the IoT reference model is divided into seven layers to promote the association and expansion of IoT deployment models, as shown in figure 5. It identifies where various kinds of processing are operated through different layers of the IoT reference model and enables various manufacturers to produce compatible IoT products working with each other smoothly and efficiently. Also, this architecture model converts the IoT from a conceptual model into a real and approachable system (Shah, 2016).

Layer 1 is the physical layer. It is the hardware layer which collects data from the physical world and transfers it to the upper layer. This layer involves physical objects and sensors. Essentially, the purpose of this layer is to identify different objects and collect information about the surrounding environment such as temperature, humidity, pressure, water quality, motion detection, amount of dust in the air, etc (Cisco, 2014).

Layer 2 is connectivity. This layer is used to interconnect different IoT things with each other using interconnection devices such as switches, gateway and router. It also transfers gathered data securely from sensors to the upper layer for processing. Layer 3 is edge computing. This layer takes data coming from the connectivity layer and converts it into information appropriate for storage and higher-level processing. At this layer, the processing components work with a huge amount of data which could execute some data transformation to reduce the size of data.

Data accumulation occurs in layer 4. The main function of this layer is to store data coming from layer 3. It absorbs a huge amount of data and places them in storages to be accessible by upper layers. So, it simply changes event-based data to query-based processing information for upper layers. Layer 5 is data abstraction. This layer combines data coming from different sources and converts stored data into the appropriate format for applications in a manageable and efficient manner (Atlam et al., 2017).

Layer 6 is the application layer. This layer is concerned with the information interpretation of various IoT applications. It includes various IoT applications such as healthcare, smart city, smart grid, smart home, connected car, smart agriculture, etc (Stallings,2015). Layer 7 is collaboration and processes. This layer identifies individuals who can communicate and collaborate to make use of the IoT data efficiently. It provides other functionalities like creating graphs and business models and other based on data retrieved from the application layer. It also assists managers to make precise choices about their business based on their data analysis (Muntjir et al., 2017).

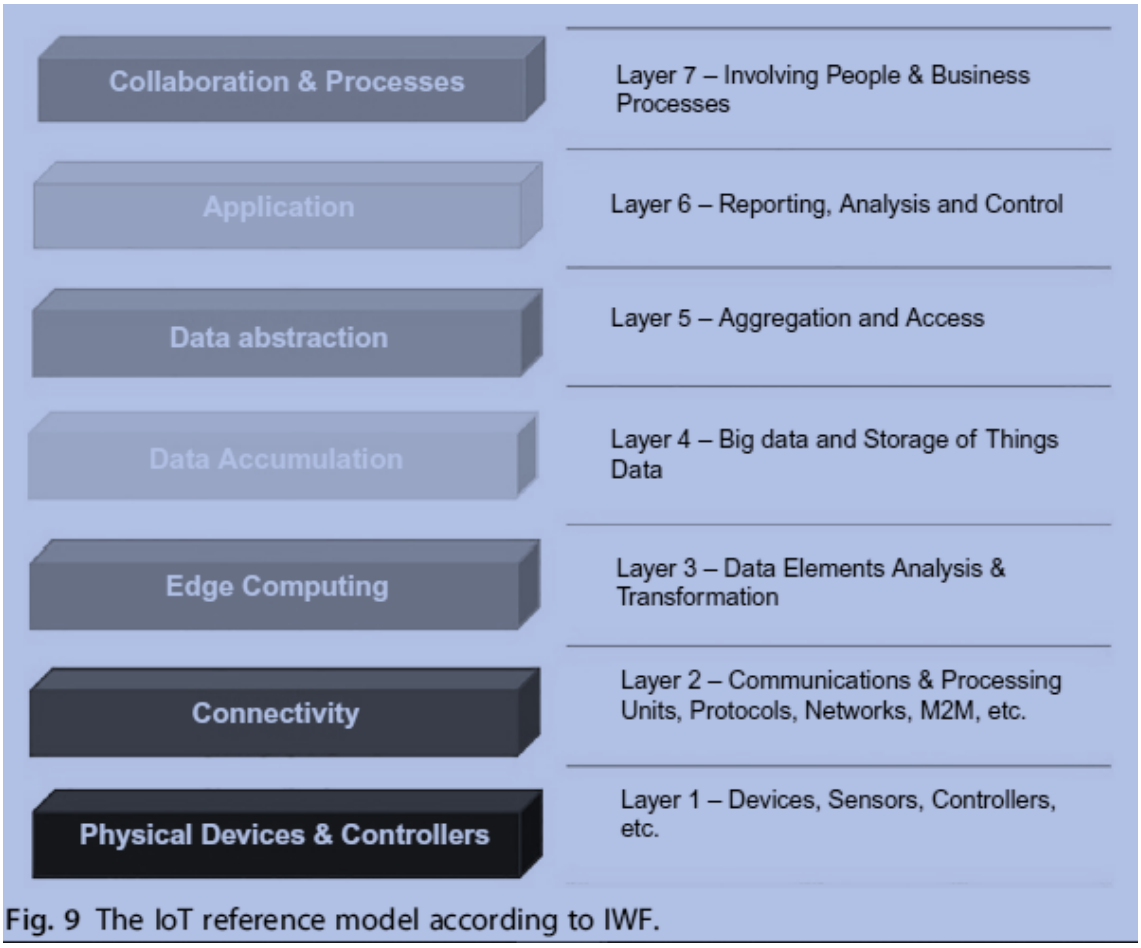

Figure 5- The IoT reference model according to IWF.

(Source: Adapted from Atlam et al., 2017).

2.2. Health Sector

2.2.1. Need to adopt new technologies

The current healthcare industry is shifting from volume-based to value-based care that promotes patient-centered services with a high level of control the challenges of cross-institutional sharing of medical data within the healthcare domain are significant (Chen, 2020).

Blockchain applications for healthcare data management create utilities for patient, doctors and healthcare institutes in the directions of patient record access

and control, claims and payments management, management of medical IoT security (Liang, et al., 2017) and research data verification and exchange for financial auditing (Zhang, et al., 2017) and transparency. In these applications, real-time updates to an encrypted, decentralized blockchain ledger are done to understand, monitor, and control medical information (Witchey, 2019).

Other blockchain opportunities include faster and more-efficient credentialing of employees.

Blockchain technology has emerged as a key technology recently in the digital revolution of

the healthcare sector and several research studies (Linn, et al., 2016). According to the author Bocek (2017), have identified blockchain potential for the healthcare ecosystem.

Blockchain are key enabling technologies for the decentralization and digitalization of healthcare institutions and provides modern and digitalized healthcare ecosystem to patients as well as service providers (Puthal et al., 2018).

The patient centric mechanisms of the healthcare industry make it suitable for blockchain and IoHT technologies. The combination of the two technologies enables the secure, unalterable transmission of medical data (Mettler,2016).

A blockchain combined with IoT technologies that enables the healthcare facilities to have eficiente and accurate record management, which is critical. The entire process with the various components from the time of collecting real-time data of patients using IoT until providing a suitable drug that ensures the satisfaction of the patient is described (Farouk et al., 2020).

2.3. Implementation of new technologies in healthcare

2.3.1. Blockchain implementation

Blockchain offers transformational opportunities in healthcare processes, including the ability to establish self-sovereign identity and a consente audit trail for the patient's digital identity. These identity systems are used primarily for authentication and authorization (Bhargav-Spantzel, 2019).

The fundamental promise of blockchain is to provide a seamless method for multiple entities to share data without a single entity fully controlling all of the information (Randall et al., 2019). Provider to control the identity that 35% of executives at health and life sciences companies are planning to implement blockchain within the next 12 months (Che net al., 2019).

Globally, blockchain technology could help with reliability, security, transparency of self-sovereign data, and consent management to inform the exchange of information across approved entities. As patients gain more control of their data and permissions for exchanging of that data, robust privacy and security considerations will be critical to maintain appropriate protections for protected health information (PHI) (Nichol, 2019).

According to the author Der et al., 2017, when using self-sovereign identities, every person has authority over his or her own digital identities. Self-sovereign identity can be characterized as the:

1. Existence of a person's identity independente of identity administrators.
2. Control of their digital identity.
3. Full access to their own data.
4. Interoperable digital identities.
5. Protection of individual rights.

Remote healthcare monitoring and analysis requires cloud storage for resilience and easy access of the data retrieved. Even though cloud is the best platform for privacy and sharing of data among various subjects involved in healthcare monitoring analysis such as patients, doctors, data analyst etc, it does not

supports interoperability among the above mentioned stakeholders and also it does not guarantee the integrity and authenticity of medical data (Rifi et al., 2017).

According to the author Ekblaw et al., (2016), the blockchain is utilized as a structure to manage the electronic medical records of the patients (see Fig. 6). The structure is divided into three categories of contracts, which are Register Contract (RC), Patient–Provider Relationship Contract (PPR), and Summary Contract (SC). RC is used to transform the identification of participants to their associated Ethereum address identity, and PPR is generated between two nodes in the system for storing and managing the medical records of patients. SC is responsible for retrieving the history of medical records for patients and indicating all the participant's previous and existing activities with other nodes in the system. A unique framework to maintain the exchange of health information that combines the health organizations, institutions and patients is illustrated in Krawiec et al., (2016). Furthermore, the structure envolves universal, and secure network infrastructure, provable identification and authentication of every participant, compatible representation of authorization to access electronic health information, and numerous other benefits (see Fig. 7).

There are many start-up companies that use blockchain for various healthcare solutions including managing patients' identity, supporting patient-centric healthcare, recording and tracking personalized medicine, building policies where patients could share their perspective on medical records and information with different stakeholders securely, and so on blockchain technology can be incorporated in this model which ensures and enhance integrity, consistency and also authenticity of the medical records stored (Deloitte, 2016).

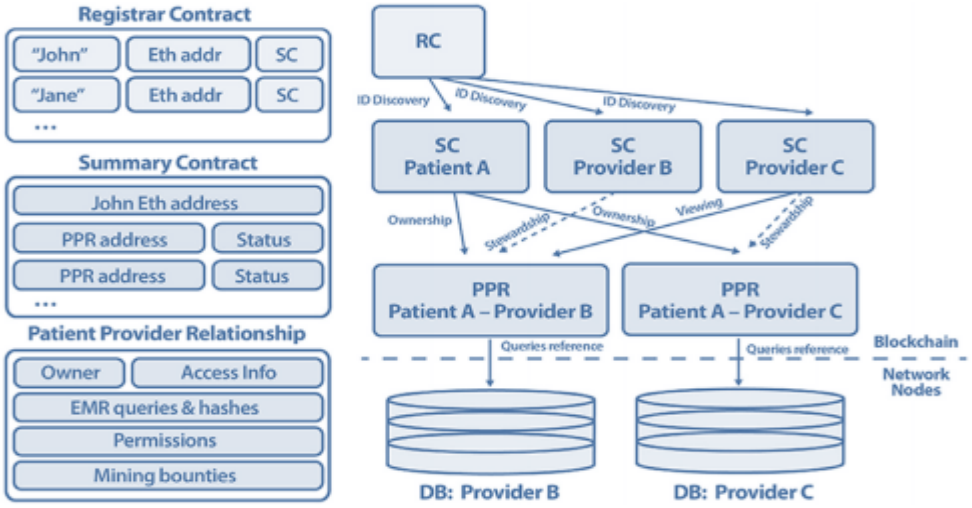

Figure 6- Blockchain as structure for electronic medical records.

(Source: Adapted from Ekblaw et al., 2016).

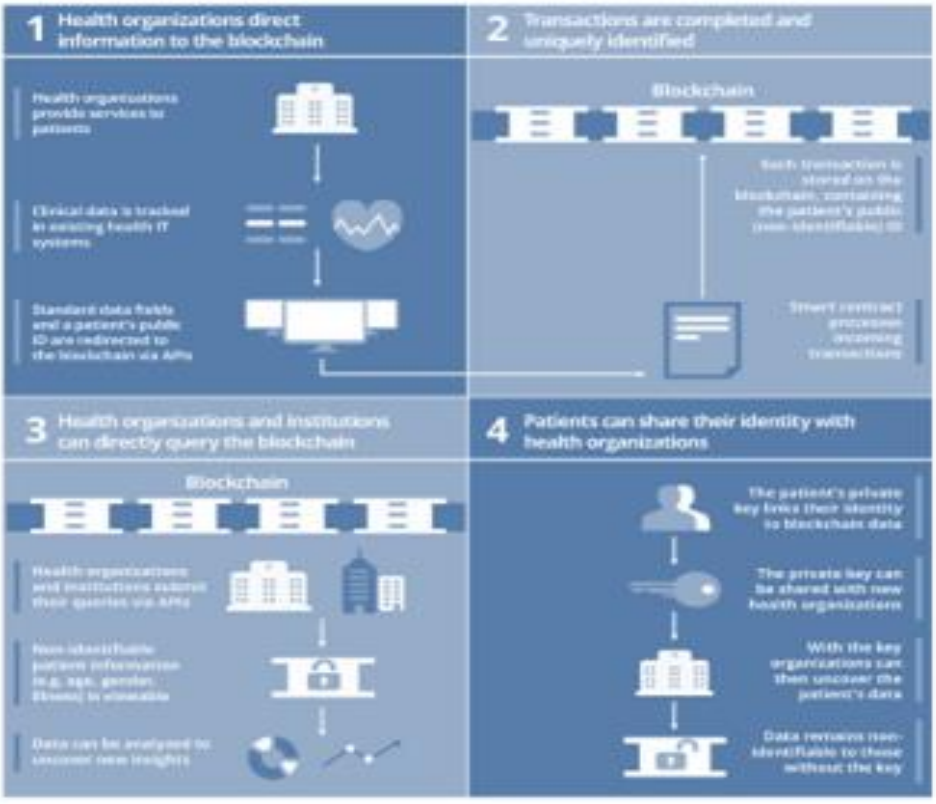

Figure 7- Healthcare blockchain framework.

(Source: Adapted from Krawiec et al., 2016).

Blockchain which is based on the distributed ledger technology can be implemented to IOT networks which themselves are distributed in nature. Therefore these networks can be secured and shielded from any kind of data tampering at any point (Das, 2015).

According to the author Trung et al., (2020), conceptually, blockchain technology will need a move from an information focus to a value and trust focus. It is necessary to consider how information can be utilized and transmitted in the blockchain.

Introduced a blockchain smart contract solution that can play a fundamental role in ensuring data privacy. The proposed smart-care framework has made several improvements in the healthcare system by:

1. Addressing information security and privacy
2. Solving the lack of trust between providers
3. Encouraging scalability of healthcare interoperability. Our proposed healthcare system consists of 5 groups of the user: patients, doctors, medical men, nurses, and insurance men. Each user is identified by a user id and collection of their user's group. The overview of our proposed healthcare system is illustrated in Figure (8).

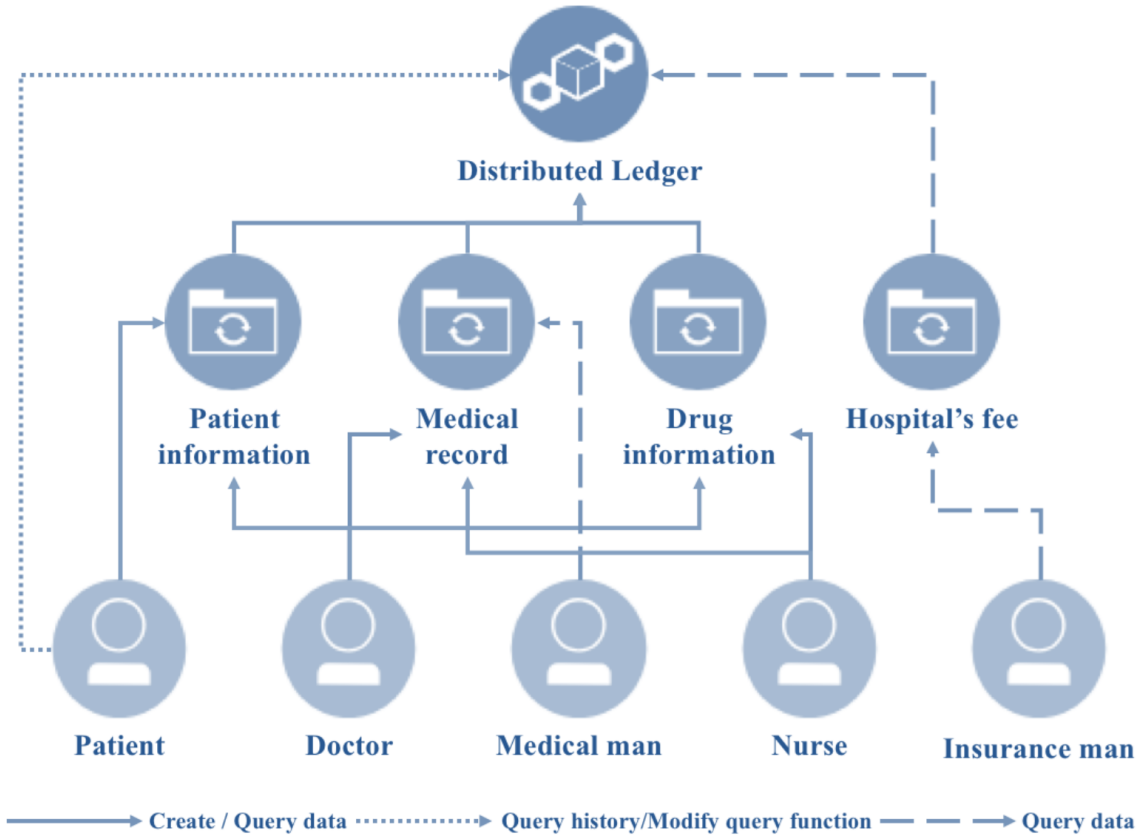

Figure 8- The overview of our proposed healthcare system.

(Source: Adapted from Trung et al., 2020).

2.3.2. IoT implementation

Many healthcare organizations are already using the Internet of Healthcare Things (IoHT), from monitoring newborns to tracking inventory, and maintaining assets (Islam, et al., 2015). There are two distinct categories of use cases — one for clinical services and the other for support operations. In clinical settings, IoHT improves patient-centric activities with remote patient monitoring (RPM). This extends to clinical trials where IoHT closely tracks vital signs and any other indicators importante to the study, such as blood-sugar levels and weight trends. IoHT benefits support operations by enabling improved utilization of mobile medical assets, which will additionally reduce overall operational costs. This improvement is facilitated by equipment-centric sensors and data-collection

capabilities that can reduce costs and give the staff real-time information about the usage rates and location of digital X-ray equipment, ventilators, and other movable resources (Farouk, et al., 2020).

Healthcare decision-makers are also evaluating the combination of IoHT and augmented-reality (AR) technology to create digital twins of the technology (Kranz, 2016).

One concern in implementing IoHT is the security and reliability of the servers used to connect the IoT devices and exchange critical medical data (Atzori et al., 2010). There is an obvious solution: a blockchain which is able to fully protect the process through decentralization and encryption (Zyskind et al., 2015).

IOT is making huge advancement in wireless communication, sensor based technology a and if we combine it with the technologies like Big data and Artificial Intelligence it makes the system more intelligent while not exceeding the cost. But taking into the consideration the limited maintenance cost and management cost there is restricted privacy of data and also insecure exchange of data among the personal computers. There comes concept of Blockchain into play (Hashemi et al., 2016).

According to the authors Vermesan, and Friess (2013), new and innovative technologies are needed to cope with the trends on wired, wireless, high-speed interfaces, miniaturization and modular design approaches for products having multiple technologies integrated. The communication technologies are addressing different levels and layers in the smart health platforms, as shown in Figure 9.

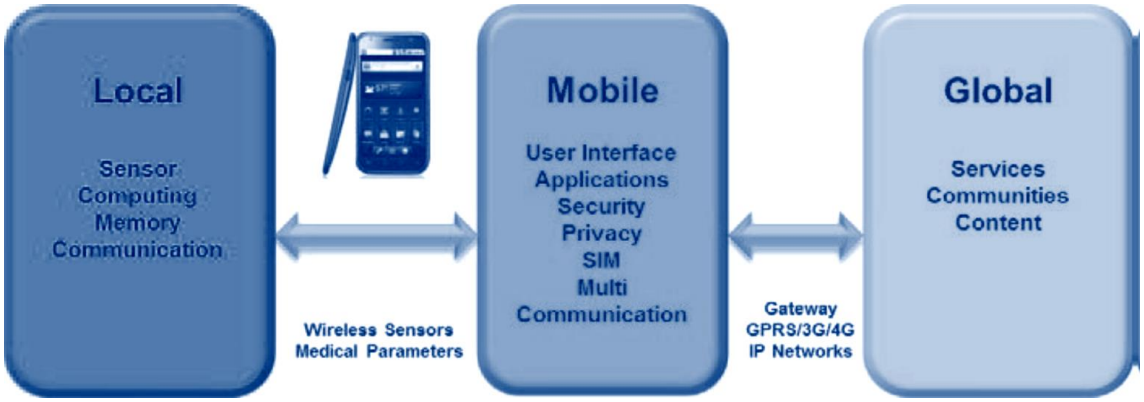

Figure 9- Communication layers in smart health platform.

(Source: Adapter from Vermesan and Friess, 2013).

The market segment of telemedicine, one of lead markets of the future will have growth rates of more than 19%. Convergence of bio parameter sensing, communication technologies and engineering is turning health care into a new type of information industry.

In this context the progress beyond state of the art for IoT applications for healthcare is envisaged as follows:

1. Standardization of interface from sensors and MEMS for an open platform to create a broad and open market for bio-chemical innovators.
2. Providing a high degree of automation in the taking and processing of information.
3. Real-time data over networks (streaming and regular single measurements) to be available to clinicians anywhere on the web with appropriate software and privileges; data travelling over trusted web.
4. Reuse of components over smooth progression between low-cost “home health” devices and higher cost “professional” devices.
5. Data needs to be interchangeable between all authorized devices in use within the clinical care pathway, from home, ambulance, clinic, GP, hospital, without manual transfer of data.

2.4. Case studies: implementation of Blockchain and IoT in the health sector

There is limited evidence on the use of blockchain and IOT technology for disease diagnosis. Bearing in mind the era of COVID-19 and the evidence on the overburdened healthcare systems and poor disease surveillance systems in resource-limited settings, and taking advantage of the available mobile Health (mHealth) systems, we recommend, a rapid development and deployment of low cost blockchain and AI-coupled mHealth connected self-testing and tracking systems as one of the strategic response strategies for COVID-19 and other immerging infectious diseases. Blockchain and AI system will enable the transfer of the test result to alert the outbreak surveillance authorities of all tests performed as well as the number of positive and negative test results. This will help ensure that all positive cases are referred to a quarantine site for treatment and monitoring. The in-built geographic information system (GIS) in mobile devices will enable the tracking of the people who tested positive. This system will also be connected to the local and international databases to ensure appropriate surveillance and control of the outbreak.

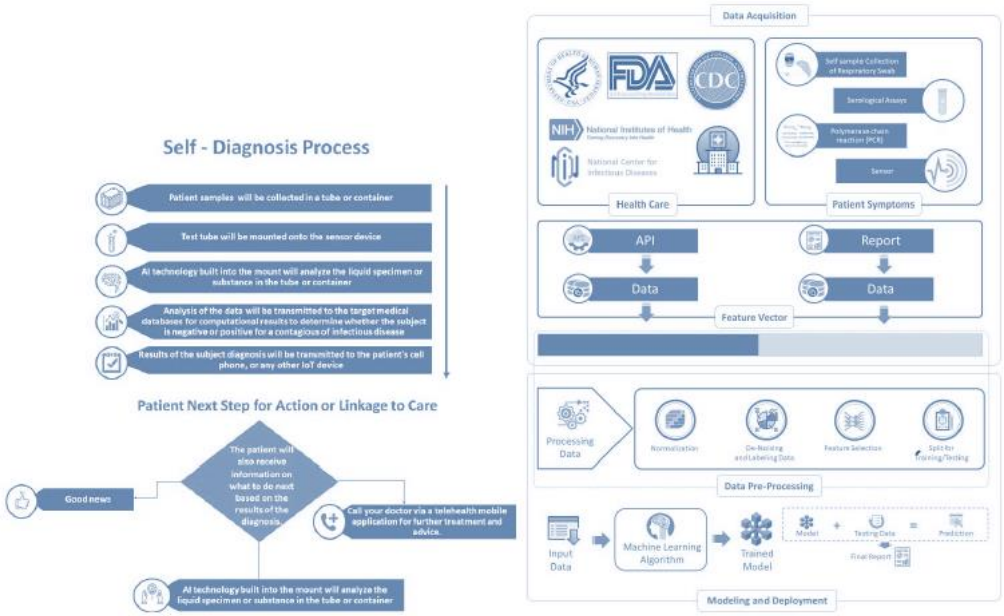

Figure 10- Proposed community-based blockchain and artificial intelligence-coupled mobile-linked self-testing and tracking system for emerging infectious diseases.

(Source: Apadted from Mashamba-Thompson and Crayton (2020).

According to the author Kuupiel et al., (2017), the local development of these diagnostics can help overcome the supply chain challenges and the cost which can limit accessibility of POC diagnostics in resource-limited settings. This technology can be adapted for use in community-based case finding of other infectious diseases such as HIV, TB and Malaria, which may be exacerbated by the current COVID-19 outbreak. Relevant stakeholders' involvement will be crucial to ensure the client development and sustainable implementation of the proposed technology, particularly in underserved populations.

According to the author Bervell (2019), mobile connected point-of-care diagnostics and self-testing has been successfully implemented in resource-limited settings. The results of the study showed that m-health was prevalent in usage for promoting information for treatment and prevention of diseases as well as serving as an effective technology for reminders towards adherence. For e-health, the uniqueness lay in data acquisition and patients' records management; diagnosis; training and recruitment. While m-health was never used for monitoring or training and recruitment, e-health on the other hand could not serve the purpose of reminders or for reporting cases from the field. Both technologies were however useful for adherence, diagnosis, disease control mechanisms, information provision, and decision-making/referrals. HIV/AIDS, malaria, and maternal (postnatal and antenatal) healthcare were important in both m-health and e-health interventions mostly concentrated in the rural settings of South Africa and Kenya. ICT infrastructure, trained personnel, illiteracy, lack of multilingual text and voice messages were major challenges hindering the effective usage of both m-health and e-health technologies.

3. Proposed Model

This work proposed an integration system involved in the healthcare ecosystem using blockchain and IOT technology for better patient experience and data management.

Blockchain is the decentralized distributed ledger which is based on the peer to peer network method and so its main purpose is clear that is security.

Blockchain technology can be applied to the information sharing component of IoT. It provides a secure method for sharing vital information captured by IoT devices.

Healthcare ecosystem using blockchain technology for better data management. Different medical workflows have been designed and implemented using the Ethereum blockchain platform which involves complex medical procedures like surgery and clinical trials. This also includes accessing and managing a large amount of medical data. Within the implementation of the workflows of the medical smart contract system for healthcare management.

The workflow has been designed and implemented using the technology and software Ethereum, DApp, Smart contracts and Phyton.

This also includes accessing and managing a large amount of medical data. Within the implementation of the workflows of the medical smart contract system for healthcare management.

This work would facilitate multiple stakeholders who are involved within the medical system to deliver better healthcare data service and facilitates the healthcare institution to restrict the unauthorized person to access sensitive information and the patient allow who access your data.

3.1 Concept Design

The proposed implementation model includes:

1. App implementation (i.e. for patients) and website (i.e. for health care entities).

The functionalities available to the patient are:

I. Synchronize data (i.e. Synchronize IOT data (smartwatch, mobile phone, healthcare devices)).

II. Update data (i.e. Update IOT data).
III. Show data (i.e. View the data that is stored on the blockchain).
IV. Show shared data (i.e. See the data that was shared and for which health care entity).
V. Pending permission (i.e. View and accept the permissions requested by the entities to access your data).
VI. Show permissions (i.e. View the entities that are allowed to access your data).
VII. Notification (i.e. Receive to notification of permission requests and shared data from entities).

The functionalities available to the health care entities:

I. Requests permissions (i.e. Send to patient request for access to data).
II. Show data (i.e. View patient health data that is stored on the blockchain).
III. Import data (i.e. Import patient data to be stored in Blockchain).
IV. Notification (i.e. Receive to notification when permission is accepted or denied).

2. Data shared by users is stored on the blockchain connected to the app.
3. Blockchain access is released by smartcontracts.

Our purpose is that the data is decentralized and with possible access to everyone connected to the blockchain.

Due to data protection, care was taken for the patient user to be the “owner” of all his data and to share the data with any health entity he wants (doctor, hospital, health care entities). Once doctors and hospitals have access to more patient health data, these data can collaborate for more accurate diagnosis.

The figure 11 depicts the concept of the implementation proposal.

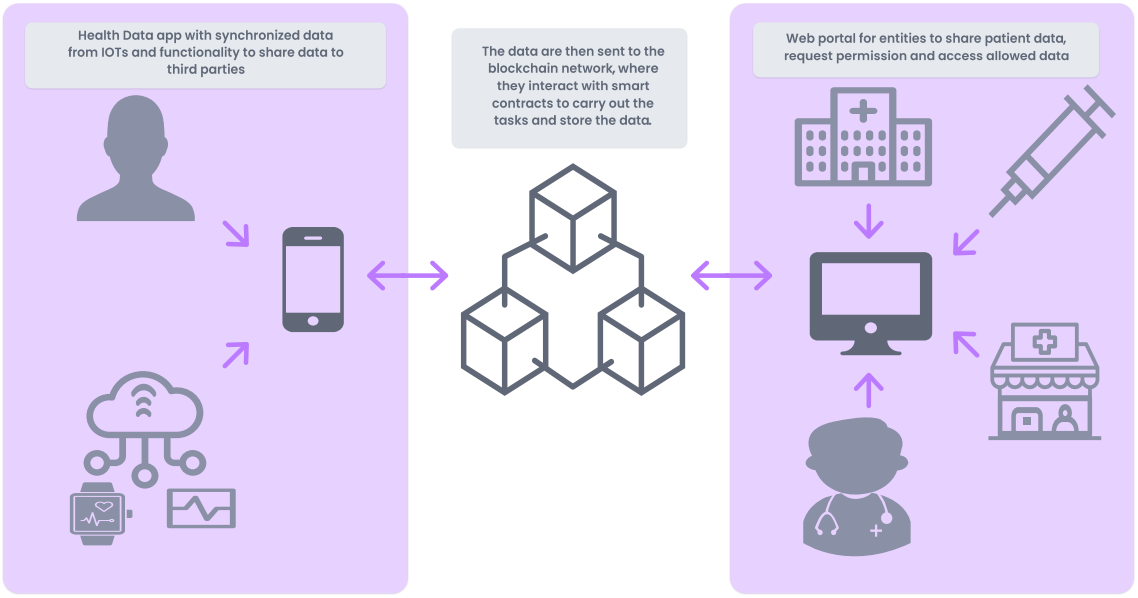

Figure 11 - Concept of the implementation proposal.

3.2 Model Drawing and Flowchart

By examining in details the operating procedures of the features, the interaction of users with the app and integration of app / web portal with blockchain was designed the flowcharts of implementing the proposal.

The account creation flowchart details how the patient and health entities create your accounts to access Health Data. Account creation occurs according to the steps:

1. User insert email and password.
2. Insert verification code has been send to email.
3. Health data generates ID number for the user.
4. Account created.

The figure 12 illustrate the account creation flowchart.

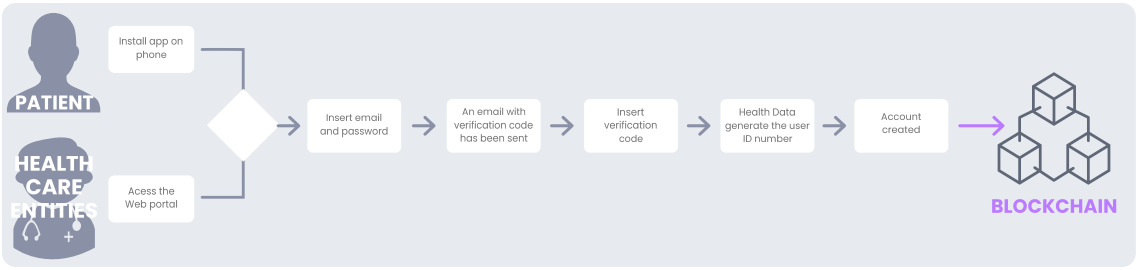

Figure 12- The account creation flowchart.

After account created. The patient synchronizes the IOTs with the Health Data app (i.e. they are connected by smartcontract to the blockchain that stores the shared data) according to the steps:

1. Select “Synchronizes data” in the Menu.
2. Select the option “Set up my devices” and start paring.
3. Select “Allow access data” to synchronize the data.

The figure 13 illustrate the synchronize the IOTs with the Health Data flowchart.

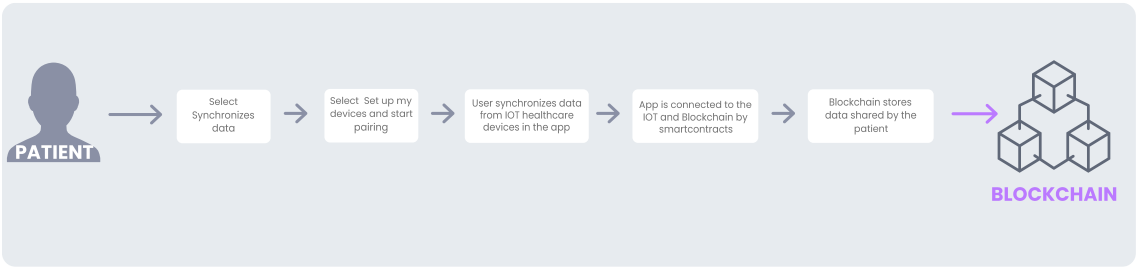

Figure 13- Synchronize the IOTs with the Health Data flowchart.

The patient to update his data:

1. Select “Synchronizes data” in the Menu.
2. Select the option “Update my data”.
3. Select which data want to update.
4. Update Blockchain data.

The figure 14 illustrate feature Update data.

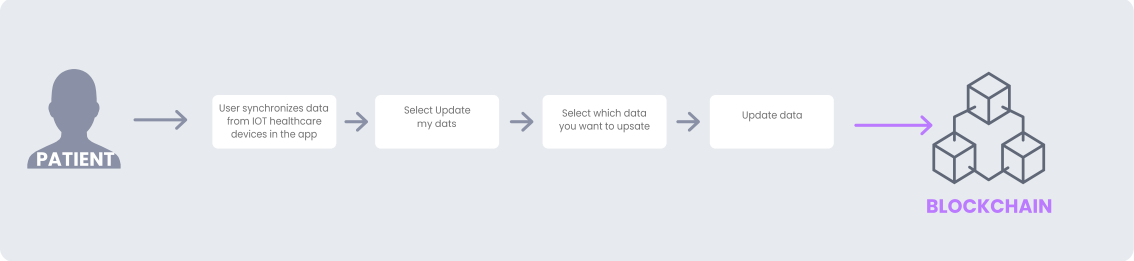

Figure 14- Update data flowchart.

The patient to view his data, the data that was shared with the entities and the accepted permissions:

1. Select the desired option in the Menu.
2. App conecta to the Blockchain by smartcontracts.
3. Access the data stored in the block.
4. App show the data.

The figure 15 illustrate the features Show data, Show shared date and Show permissions.

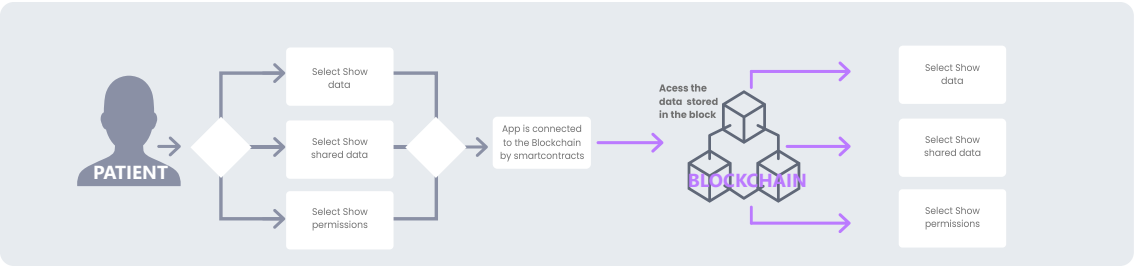

Figure 15- View data, shared data and accepted permissions flowchart.

Health care entities to access patient data must request permission. The entity to request permission:

1. Select “Request permissions” in the Menu.
2. Insert Name and patient ID.
3. Select Health Data that want access.
4. Request Permission.

The patient receive permission if denied, permission denied notification is sent to the entity. If data access is allowed:

1. Notification of allowed access is sent to entity.
2. App/portal is connected to the blockchain by smartcontrats.
3. Entities access patient data.

The figure 16 illustrate the feature Request permissions.

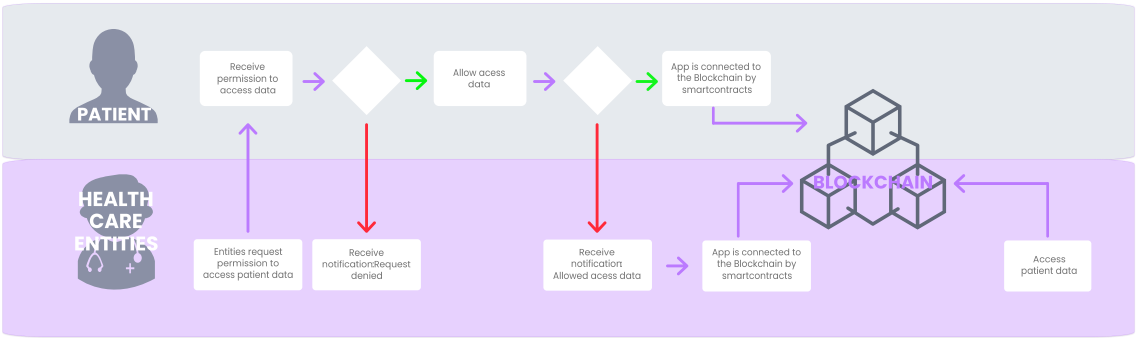

Figure 16 - Request permissions flowchart.

Entities select "Import data" in the menu to import patient data:

1. Insert Name and patient ID
2. Select Health Data that to import
3. Share patient data to the blockchain by smartcontracts

The patient receive notification of shared by entities and can check the data in the app.

The figure 17 illustrate the feature Import data.

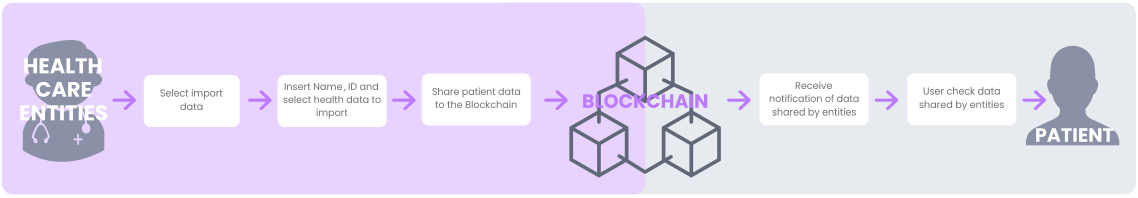

Figure 17- Import data flowchart.

3.3 Technologies and software

The technologies chosen to be used in the development of the prototype were;

1. Decentralized Applications (Dapps): Dapp has a frontend similar to the normal app but the backend is a peer-to-peer network, that is, it does not need a centralized server as in normal apps. The choice to create Dapp is due to the security advantage and data privacy provided by the technology.
2. Python: Python is also very easy to implement as compared to the other programming languages. It is well equipped with the huge amount of inbuilt libraries which can be directly implemented in the Blockchain through a GSM module.
3. Ethereum: Ethereum is a distributed computing platform which is based on blockchain and is open source and public. It also features smart contract functionality. Thousands of different applications can be created using the Ethereum platform. Its core innovation, the Ethereum Virtual Machine (EVM), helps in creating blockchain applications easier. Developers do not have to start coding from scratch, instead, they can use the Ethereum platform and can create their transaction formats, rules and state transition functions (Wood, 2014).
4. Smart Contracts: A Smartcontract is a piece of code that contains a set of terms governing the transactions over the blockchain network and executes these terms without any third-party intervention. A smart contract can be accessed by all its users using a contract's address generated by the blockchain platform during its deployment stage. The combination of blockchain and smart contracts has revolutionized the current business scenarios and this combination is termed by developers blockchain 2.0. Healthcare smart contract system for medical data management and to sharing IOT patients data.

4. Methodology

In order to achieve the mentioned objectives, a validation methodology was defined by concept of the proposed model. In order to validate whether the prototype is prospective for all stakeholders involved in the scope of the prototype implementation in the health sector.

The model's concept validation was divided into five stages, followed by a qualitative analysis of semi-structured interviews with patients, doctors and health managers.

The initial stage was the construction of mock up and research questions. In this mock up stage of the app / web portal and open questions were created to compose the semi-structured interviews conducted with the interviewees. The intention of this step is to obtain new ideas that will be useful to validate the prototype by concept and to see if the implementation is satisfactory and has advantages for all users. The mock up outline can be found in Annex I and the research questions to be asked in the interviews can be found in Annex II.

The second stage was the selection of respondents and the establishment of protocols for the interviews. Interviewees were selected who play different roles in the use of the suggested model (i.e., patients, doctors, pharmacists, health managers, representatives of public health agencies).

The third step was data collection. Data were collected in semi-structured interviews. The interviews were conducted via the web and the proposed model for implementing the solution for the health sector was presented. The opinions and responses obtained were subsequently analyzed qualitatively.

The fourth step was data analysis. Qualitative analysis was chosen because it is a proof of concept that aims to extract from the respondents subjective answers based on the research questions and experience with the proposed model.

The last stage was the results obtained according to the opinion of the interviewees, in this stage validations were made about the implementation of the solution in the health sector. The validations were made based on the qualitative analysis obtained from the responses collected in the semi-structured interviews.

5. Results And Discussions

For a validation of the model were interviewing 17 people, in which six were patients, five were doctors, one were dentist, two were managers of hospitals, two were managers of clinical analyzes, one were manager of the public health system.

The responses and opinions collected from interviewees were qualitatively analyzed and it was observed that the patients, doctors, dentists interviewed had no or little knowledge about IOT and blockchain. The managers of hospitals, analysis clinics and the public health system were aware, however, they associate blockchain with Bitcons and a technology applied to the financial sector.

It was also observed that all 17 respondents were curious and interested in learning more about how blockchain can be applied to the health sector. And because of this interest, everyone had a positive opinion and thought the concept of the model of the proposed implementation to be successful.

The interviewed after interacting with the app / web portal mockups thought it easy to use but had different impressions. Of the 5 patients 2 complained that the app could be more user friend and without much technical terms so that it can be easier to use. This was considered the greatest challenge on the part of the patients. In addition, the doctors, dentist and managers interviewed had thought the web / portal objective and easy to use and did not observe any challenge in the use of the web / portal.

Interviewees from health organizations considered an application that would facilitate your daily life and that you would use daily to analyze patient data to have more accurate diagnosis.

The patients thought it interesting to be able to store all their IOTs data, medical exams, medication prescriptions, the result of clinical analyzes and which they would use frequently to have a better management of their data.

In the patients' opinion, the benefits associated with the implementation of the proposed model are that they have total control of their data and can share with which health entity they want. Besides achieving manage all your health data, whether provided with IOTs or shared by doctors, hospitals, clinics in one place.

For doctors, the only perceived benefit was being able to access more data and that this will contribute to obtain more accurate diagnosis. For now, the managers of hospitals, clinics and public health, it is beneficial to have decentralized data, thus eliminating the repeated data of patients who occupy a large part of the store data.

It was the opinion of all respondents that the implementation of the proposed model is advantageous for the health sector. Since it was observed that the health sector may have progress in studies according to the analysis of patient data that will facilitate the fight against epidemics, pandemics and diseases that are incidents in a given region.

6. Conclusion

Based upon the results obtained from the interviews conducted with stakeholders (ie patients, doctors, hospital managers, clinical analyzes and public health entities), it was concluded that the proposed model for the implementation of the system that integrates IOTs and blockchain is prosperous and bring positively impacts the health sector.

It was also concluded that the proposed model is advantageous since it decentralizes the data, automates the patient's interaction with the health entities, allows the patients to “own” their data, contributing to a better management of your data and allows the health entities have access to more patient data.

Therefore, with the implementation of the proposed model, it was concluded that the health sector will obtain technological advances that will contribute to better data management.

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APPENDIX

Annex I- Questions for semi-structured interviews with selected interviewers

Q1. What is your knowledge about IOT and blockchain?

Q2. What was the opinion about the concept of the proposed implementation model?

Q3What impression after seeing the mock ups of app / web portal?

Q4What challenges in using the app / web portal were observed?

Q5. Considers an application easy to use?

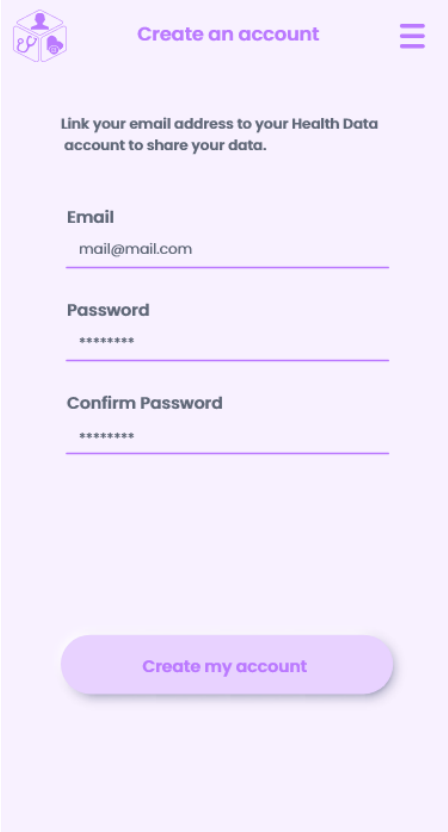
Q6. Would the application be useful in your daily life?

Q7. As a user which benefits are observed with the implementation of the proposed model?

Q8. What advantages for the health sector are observed with the implementation of the proposed model?

ANNEX II – Imagens App Mock up

Figure 18- Login screen



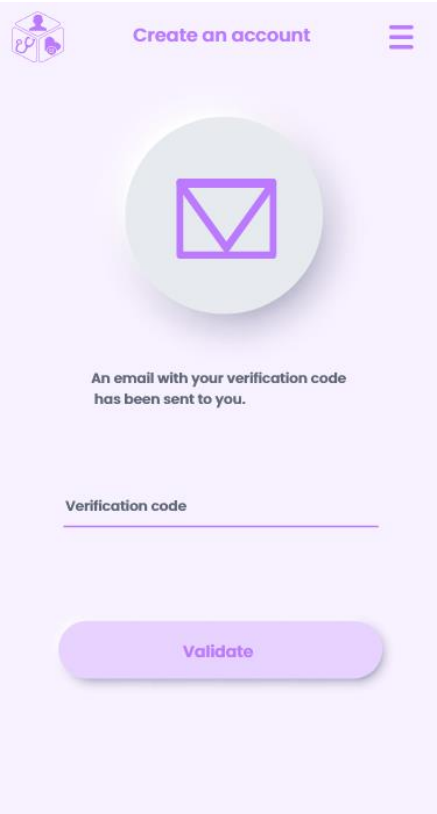


Figure 19- Create an accont sceen

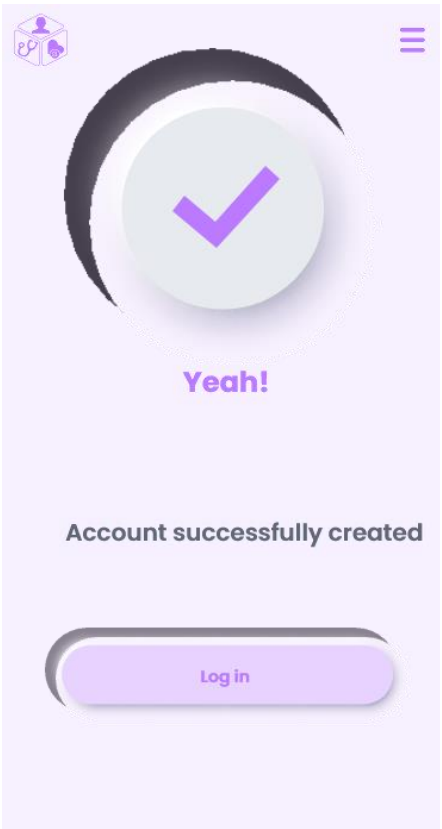


Figure 21- Account successfully created sceen

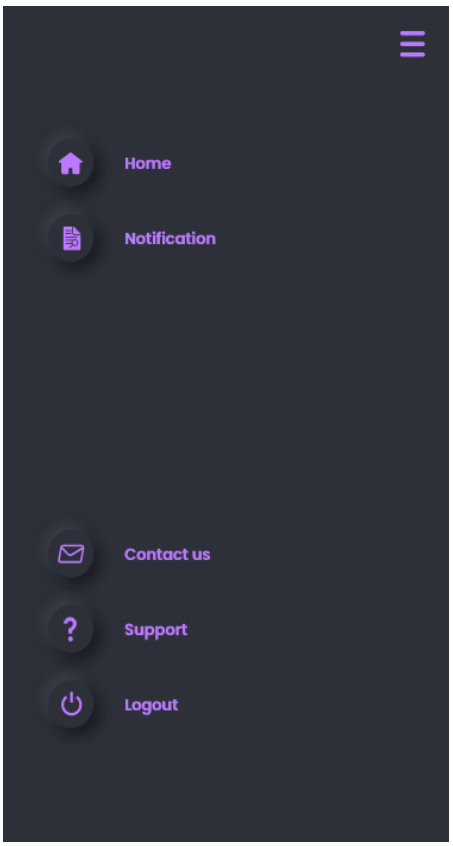


Figure 20- Menu screen

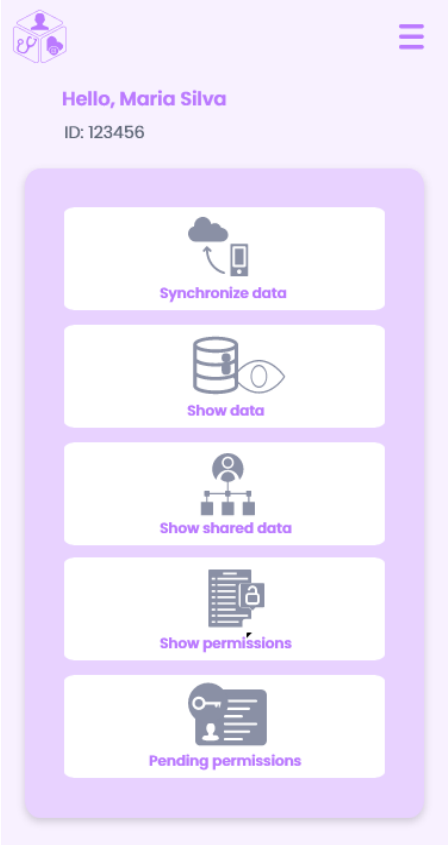


Figure 24- Home screen for patient

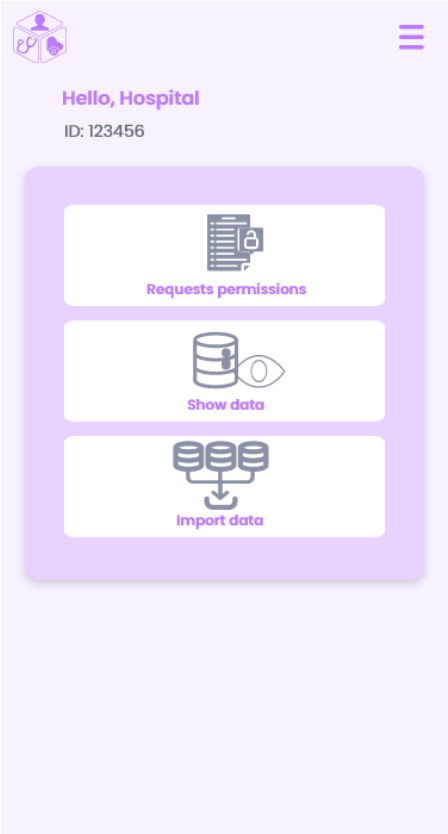


Figure 22 - Home screen for entities

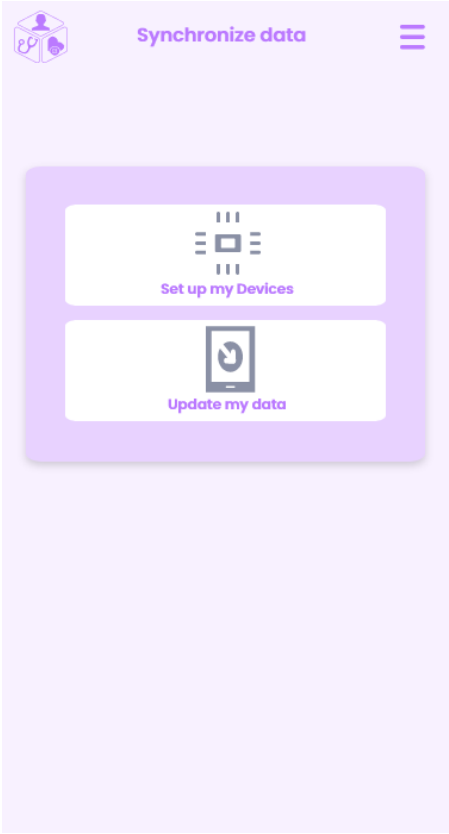


Figure 23 - Synchronize data screen

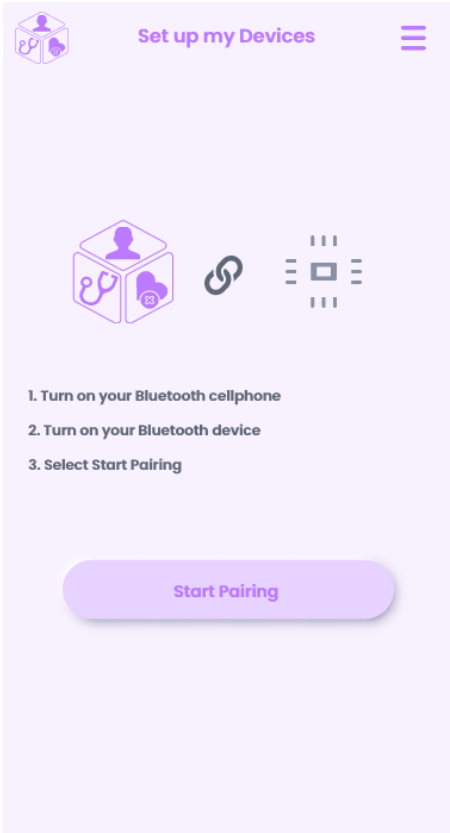


Figure 25- Set up my devices screen

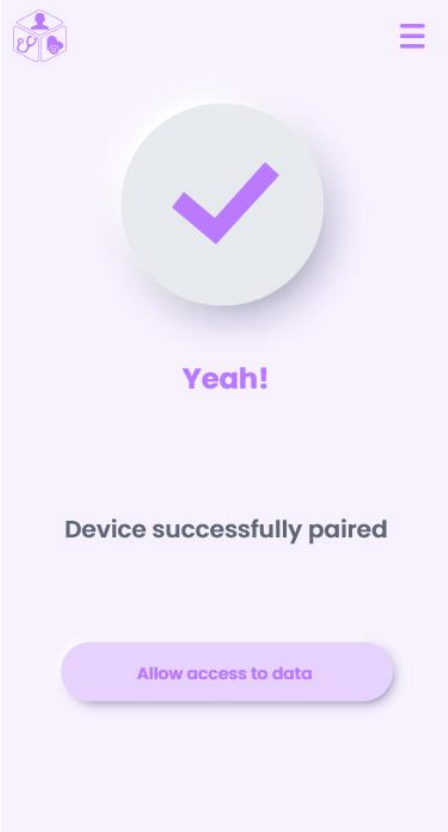


Figure 27 - Device successfully paired screen

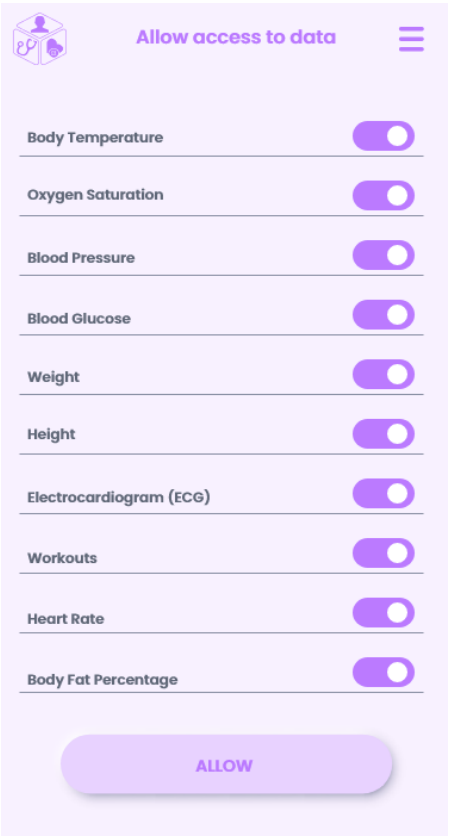


Figure 26- Allow access to data screen

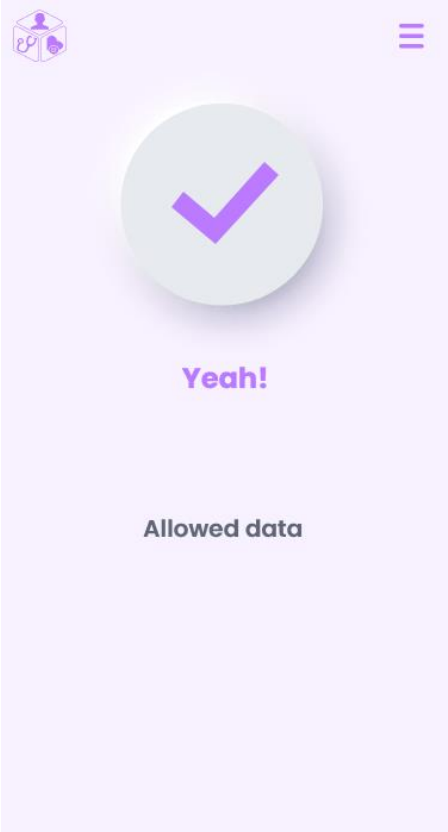


Figure 28 - Allowed data screen

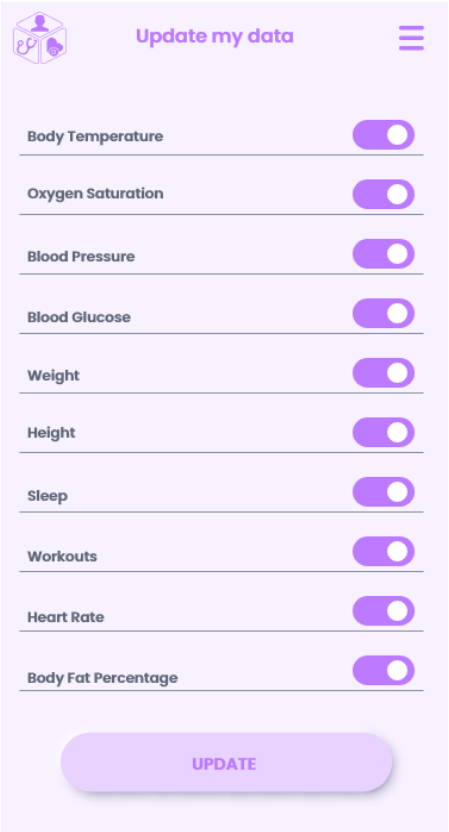


Figure 29 - Update my data screen

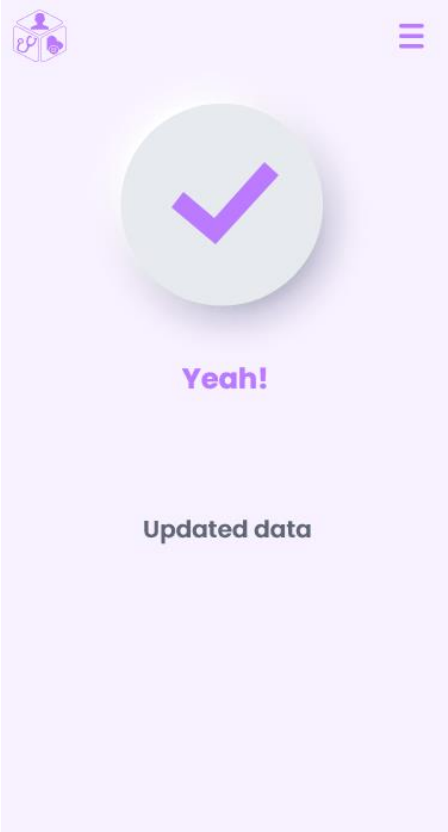


Figure 31- Update data screen

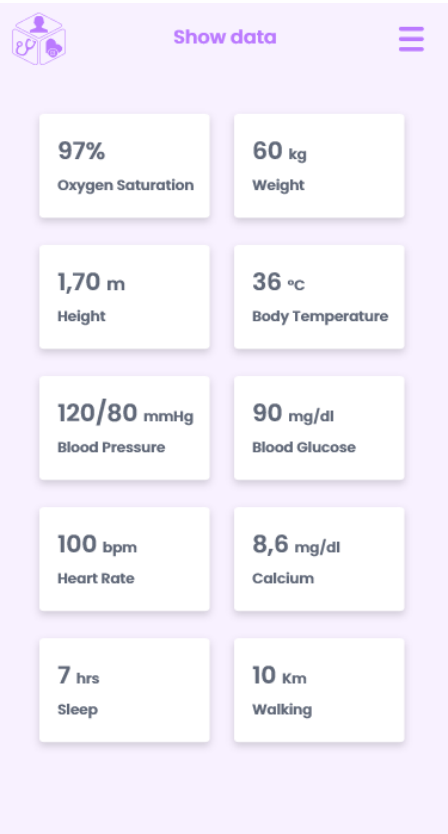


Figure 30- Show data screen

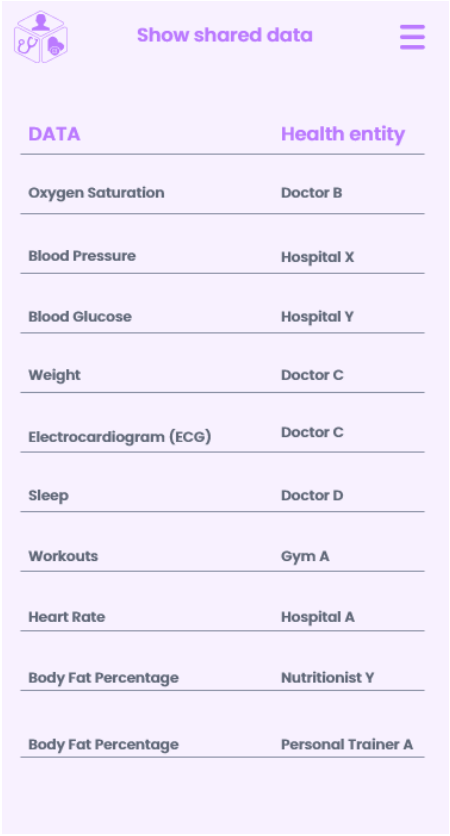


Figure 32- Show shared data screen

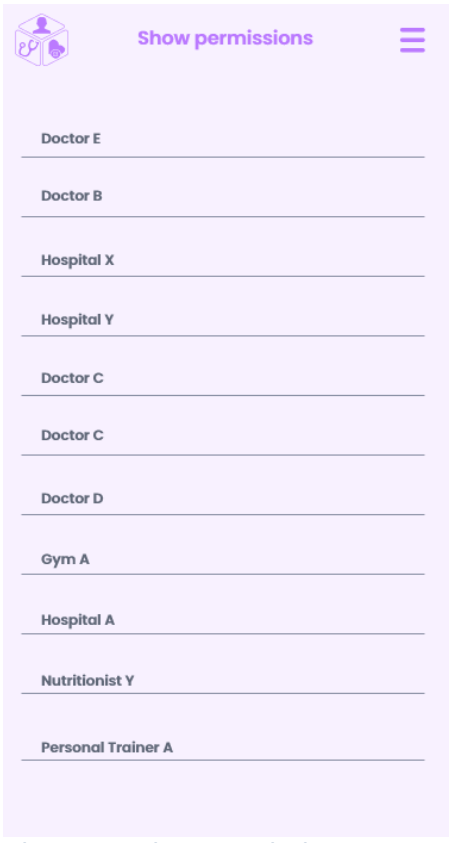


Figure 33- Show permissions screen

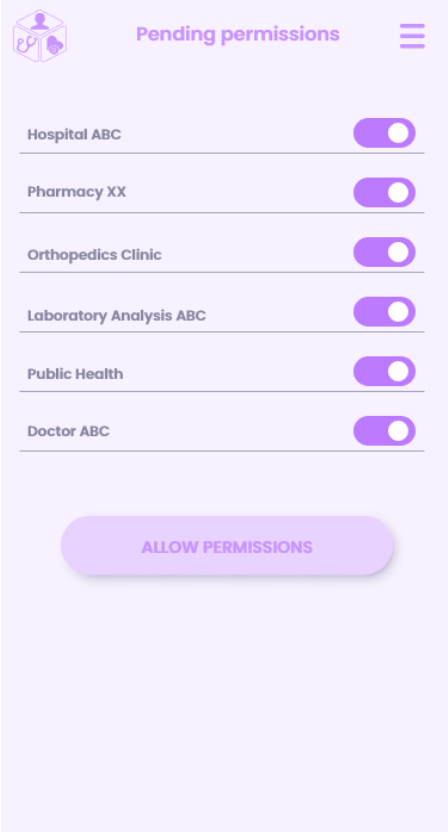


Figure 35- Pending permissions screen

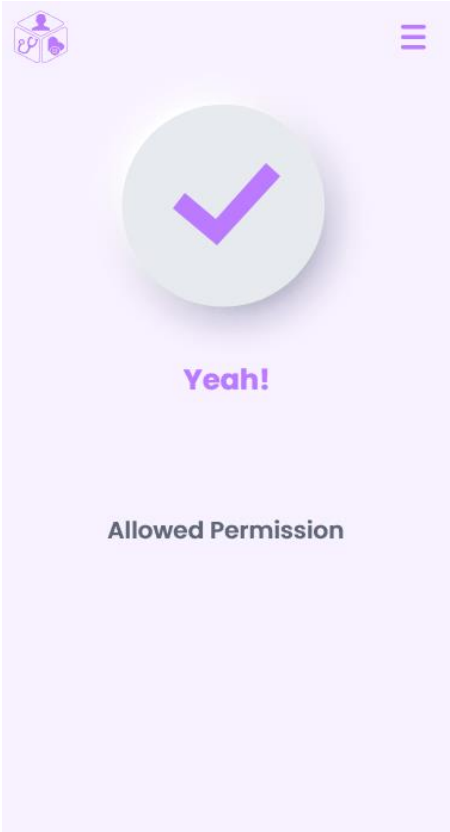


Figure 34- Allowed Permission screen

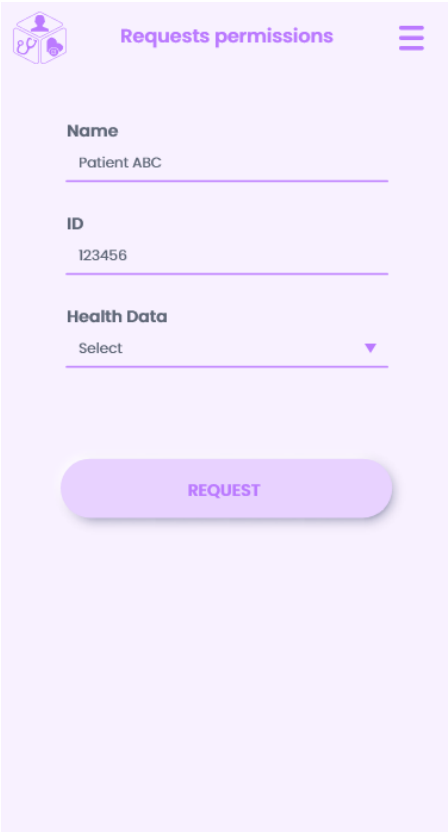


Figure 37- Requests permissions screen

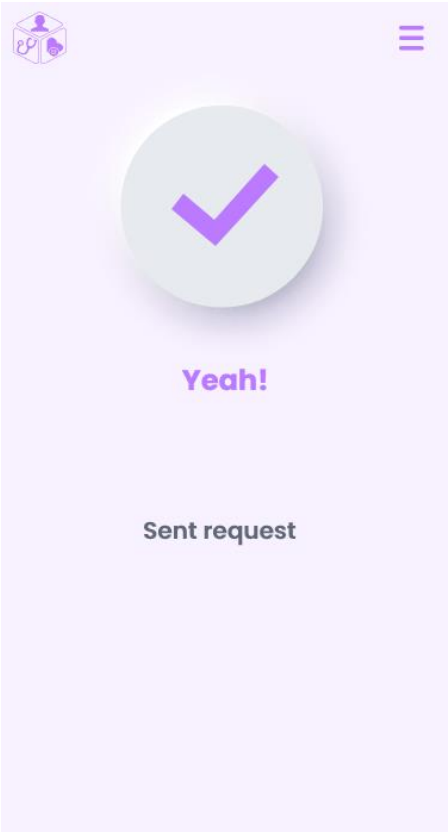


Figure 36- Sent request screen

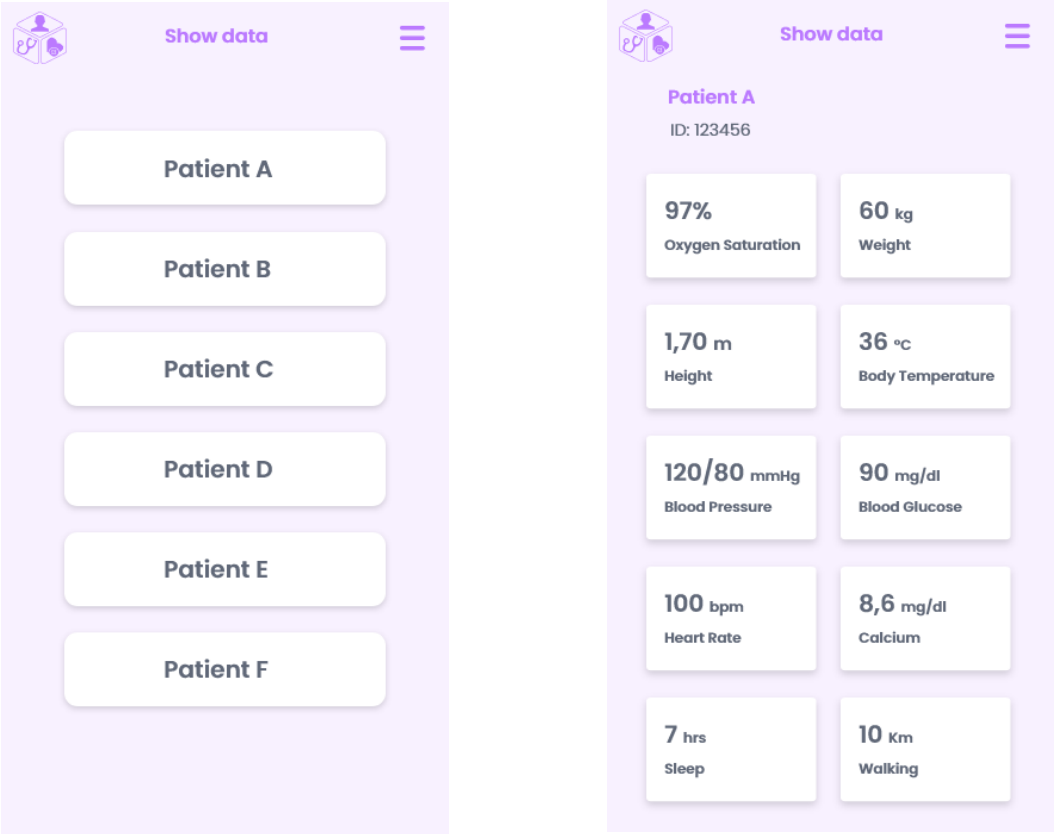


Figure 38- Show patient data screns

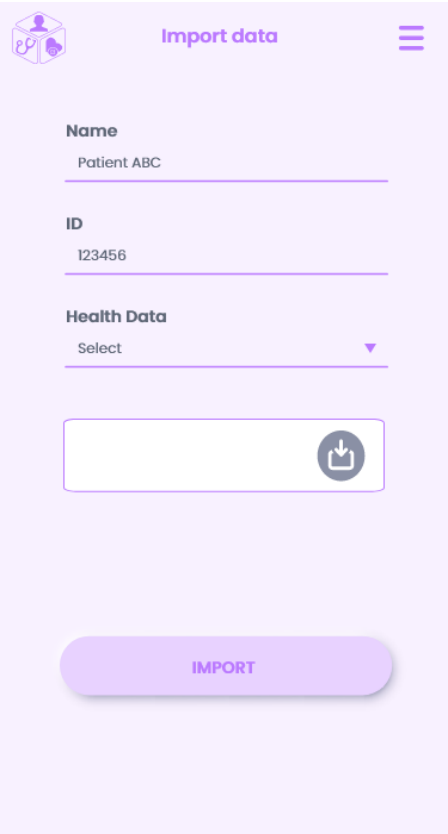


Figure 39- Import data scren

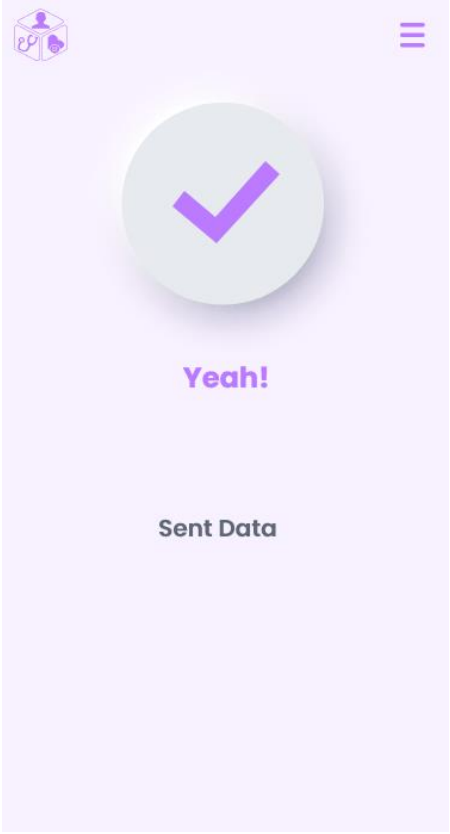


Figure 39- Sent data screen

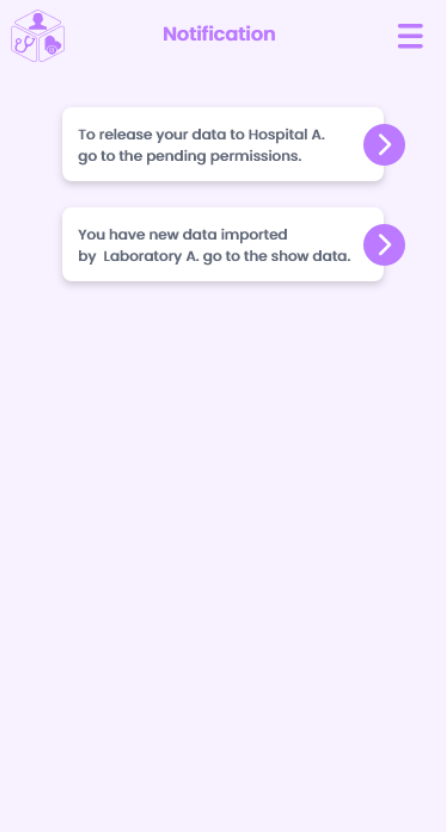


Figure 40- Notification screen