TÉCNICO LISBOA

# Ambient Intelligent Model for Life Reinforcement


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Thesis to obtain the Master of Science Degree in

## Telecommunications and Informatics Engineering

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**January 2021**

This work was created using LaTeX typesetting language
in the Overleaf environment (www.overleaf.com).

# Acknowledgments

I would like to thank my parents for all they did so that I would have the opportunity to follow my dreams. I would also like to give a big thank you to my sister for being my role model, for always being my support and for never letting me give up. To my brother-in-law, for teaching me that difficulties will always be part of the path and that we should never choose the easiest way at the expense of our dreams. To my all colleagues, which were the best partners in this big adventure. I would also like to acknowledge my dissertation supervisor, Prof. Rui Cruz for all his patience, for all his availability, knowledge sharing and above all for always believing that I could do it.

To each and every one of you – Thank you.

# Abstract

The future of healthcare is an important issue involving several organizations, companies as well as research groups. As people live longer and acquire various chronic diseases, the burden on society will increase. While some serious situations require patients to be followed and monitored professionally, most patients with chronic illnesses can avoid disease worsening if they become more aware of their lifestyle choices and the impact those choices have on their well-being. Advances in technology enable us to design better, less intrusive, more user-friendly and less intimidating privacy systems. This work introduces a model for an intelligent Cyber-Physical System (CPS) environment that can notify the user about her/his well-being, interact with the environment to adjust the ambient comfort levels, and allow caregivers to monitor her/his health condition. The consistency of the model was evaluated through case studies, analysing how well it supports a solution to the problem, by comparing the obtained results with the objectives proposed.

# Keywords

Internet of Things (IoT); Cyber-Physical System (CPS); Healthcare; Ambient Assisted Living; Smart Wearables; Well-being;

# Resumo

O futuro da saúde é uma questão importante que envolve várias organizações, empresas e grupos de pesquisa. À medida que as pessoas vivem mais tempo e adquirem várias doenças crónicas, a carga sobre a sociedade aumentará. Embora algumas situações graves exijam que os pacientes sejam acompanhados e monitorizados profissionalmente, a maioria dos pacientes com doenças crónicas pode evitar o agravamento da doença se ficar mais consciente das suas escolhas de estilo de vida e do impacto que essas escolhas têm no seu bem-estar. Os avanços na tecnologia permitem-nos projetar sistemas de privacidade melhores, menos intrusivos, e de fácil utilização. Este trabalho apresenta um modelo de ambiente *Cyber-Physical System (CPS)* inteligente que pode notificar o utilizadoro sobre seu bem-estar, interagir com o ambiente para ajustar os níveis de conforto ambiental e permitir que os cuidadores possam monitorizar o seu estado de saúde. A consistência do modelo foi avaliada por meio de Casos de Estudos, analisando o quão bem ele suporta uma solução para o problema, comparando os resultados obtidos com os objetivos propostos.

# Palavras Chave

*Internet of Things (IoT)*; *Cyber-Physical System (CPS)*; Cuidados de Saúde; Ambiente de Vida Assistida; Smart Wearables; Bem-Estar;

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# Acronyms

**6LoWPAN** IPv6 over Low-Power Wireless Personal Area Networks

**AAL** Ambient Assisted Living

**AI** Artificial Intelligence

**ANN** Artificial Neural Network

**API** Application Program Interface

**ARIMA** Autoregressive Integrated Moving Average

**ASOMG** Actor Service Means Goal

**BAN** Body Area Network

**BLE** Bluetooth Low Energy

**CA** Central Authority

**CBOR** Concise Binary Object Representation

**CPS** Cyber-Physical System

**CoAP** Constrained Application Protocol

**CoRE** Constrained RESTful Environments

**DLM** Data Lifecycle Management

**DSRM** Design Science Research Methodology

**ECG** Electrocardiogram

**EHR** Electronic Health Record

**ELT** Extract-Load-Transform

| | |
|---|---|
| **ETL** | Extract-Transform-Load |
| **FHIR** | Fast Healthcare Interoperability Resource |
| **GUI** | Graphical User Interface |
| **HA** | Home Assistant |
| **HTTP** | Hypertext Transfer Protocol |
| **IP** | Internet Protocol |
| **IS** | Intelligence Systems |
| **IT** | Information Technology |
| **IoT** | Internet of Things |
| **JSON** | JavaScript Object Notation |
| **KSFs** | Key Success Factors |
| **LWM2M** | Lightweight M2M |
| **M2M** | Machine to Machine |
| **MQTT** | Message Queue Telemetry Transport |
| **OMA LWM2M** | Open Mobile Alliance Light Weight M2M |
| **PHI** | Protected Health Information |
| **PaaS** | Platform as a Service |
| **REST** | Representational State Transfer |
| **RFID** | Radio-frequency identification |
| **SLA** | Service Level Agreement |
| **SOA** | Service Oriented Architecture |
| **SaaS** | Software as a Service |
| **TOGAF** | The Open Group Architecture Framework |
| **URL** | Uniform Resource Locator |
| **Wi-Fi** | Wireless Fidelity |

**XML** Extensible Markup Language

**mPaaS** Mobile PaaS

**oneM2M** One Machine-to-Machine

# 1

# Introduction

## Contents

With the increase in life expectancy, the world population is projected to reach 9.7 billion by 2050 [2]. As people live longer and acquire various chronic diseases, the burden on society will increase. This burden will fall on health services, which, following their current format, will have no way to respond to so many requests; it will fall on the formal caregivers who will be instrumental in continuing care and also on the families who will have to provide more informal care. This weight can have serious consequences such as the overload of health services, this overload makes the time per patient limited and this can lead to errors in the diagnosis of the patient which can lead to very serious consequences. Every year, between 1300 and 2900 people die in Portugal, due to medical errors, much more than from road accidents [3]. To meet this challenge, the health sector is changing. The industry is moving from the reactive approach to health conditions to a more proactive approach in terms of early detection of conditions, prevention and management of health and long-term well-being. While some serious situations require patients to be followed and monitored professionally, most patients with chronic illnesses can avoid disease worsening if they become more aware of their lifestyle choices and the impact these choices have on their well-being.

The objectives of providing better health services and automatically improving the quality of life of citizens, lead us to consider those based on the Internet of Things (IoT) and Cyber-Physical System (CPS) concepts. IoT will play a key role in visualizing, developing, and maintaining intelligent, connected, and personalized healthcare services and solutions. This type of service can allow the continuous monitoring of physical conditions and their automatic processing.

Advances in technology enable us to design better, less intrusive, more user-friendly and less intimidating privacy systems. Daily monitoring allows, for example, the generation of processed events that can reveal important information about the person's condition, such as changes in heart rate, high blood pressure and stress, for example. The collection of this information leads to the need to think about adequate storage mechanisms to store the events processed, which eventually deal with the formation of Electronic Health Records (EHRs). This solution enables institutional users such as doctors or healthcare providers to consult, evaluate and detect earlier certain health conditions. These ideas have been envisioned in the concept of **eHealth** which includes the application of information and communications technologies across the whole range of functions that affect the health sector, from the doctor to the hospital manager, including nurses, data processing specialists, social security administrators and the patients, and also includes tools for health authorities and professionals as well as personalized health systems for patients (individuals) and citizens (community) [4–6].

As a result of this evolution, a new combination is being adopted where the IoT concept intertwines with the concept of an intelligent CPS environment to reform healthcare and well-being and to provide people with these services in their smart homes. This revolution then brings a new concept called Ambient Assisted Living (AAL) [7]. This concept covers all the technical systems that help the elderly and people with special needs in their daily routines. It's main objective is to promote and facilitate the autonomy of these people and thus increase safety in their lifestyle and domestic environment [8].

With those ideas in mind, I present in this work a model of an intelligent environment that can help users to better understand and observe their own behavior, and enable positive changes in their lifestyle. This Ambient Intelligent Model for Life Reinforcement involves IoT type components with both contact and proximity sensors and information treatment platforms/applications in the context of health and well-being. The architecture of the system considers portable sensors and environmental sensors at the home environment (but this ambient can be also considered in an hospital or in other caregiver environment), as well as a cloud-based platforms for data collection and processing. The model can be used to adapt the environment in order to provide well-being to the individual.

## 1.1 Motivation

Over the years several IoT platforms have been created for the most varied applications for the healthcare as will be described in Chapter 2. But these platforms are designed for a particular type of support, namely vital signs monitoring and intelligent systems designed to support the elderly people [9] or to help with chronic diseases [10]. In addition, those types of solutions are often not fully immersive, as the user notices that the platform is present. For example, many health care services require peripherals to make certain measurements and then either store those values on a specific platform or load them for other applications.

Given this scenario, one solution for this could be an intelligent environment for reinforcement of emergent, proactive life that takes into account the monitoring of the individual not only with the objective of detecting possible situations of health risk but also monitoring their well-being. Thus it's intended that this intelligent environment is also adaptive and can trigger actions that adapt the environmental conditions to a certain state of comfort for the individual. This kind of environment could be implemented at an individual's home or an hospital/caregiver environment.

Taking into account the future steps of health technology in a more preventive line, thus reducing hospital trips and health centers, a feature of such environment should also consider behavioral instructions, with notifications to the user advising/encouraging physical exercise, hydration among others, which would be very useful in the prevention and maintenance of health conditions.

## 1.2 Research and Design Methodology

In order to present a rigorous and scientifically justified model, the Design Science Research Methodology (DSRM) described in [1] was used. This problem-solving methodology describes how to create a "design artifact" of Information Technology (IT) to solve a problem in a given area. Those artifacts can be of different natures such as constructions, models, methods or instantiations. In order to evaluate and accurately describe the artifact, this methodology is composed by six phases:

- **Phase 1 - Problem Identification and Motivation:** This phase corresponds to the identification of the problem related to technological solutions in the health area which do not continue to be reliable for the future, due to the growing average life expectancy of people, and consequently, the increase in the number of years that an individual can live with one or more chronic diseases. It's the motivation to create a model that can help the health and well-being of the individual in a simple and immersive way.

- **Phase 2 - Definition of Objectives for a Solution:** This phase corresponds to the presentation of the objectives of the work, i.e., to present a model for an intelligent environment for life reinforcement. The objectives take in consideration a set of requirements in order to describe how a life reinforcement solution can act to help the individual in his daily decisions.

- **Phase 3 - Design and Development:** This phase will correspond to the model's design.

- **Phase 4 - Demonstration:** In the demonstration phase, a set of Case Studies will be defined with scenarios that allow to evaluate the model.

- **Phase 5 - Evaluation:** The evaluation phase will observe and analyse how the model behaves in the different scenarios. In this phase will be identified the limitations and how the model responds to different situations.

- **Phase 6 - Communication:** The communication phase corresponds to divulging and discussing the work performed through the thesis document and public defense, exposing the value of the problem, the model (the artefact), it's design and functionality, and it's design and effectiveness regarding the objectives.

Figure 1.1 illustrates the relation between the structure of this work and the DSRM methodology.

## 1.3 Objectives

This thesis aims to present an model to an intelligent environment for life reinforcement. Therefore, this work intends to:

- List the requirements that a platform like this has to have;

- Describe the essential components of the architecture of a platform that integrates several devices and services of data collection with communication with the user;

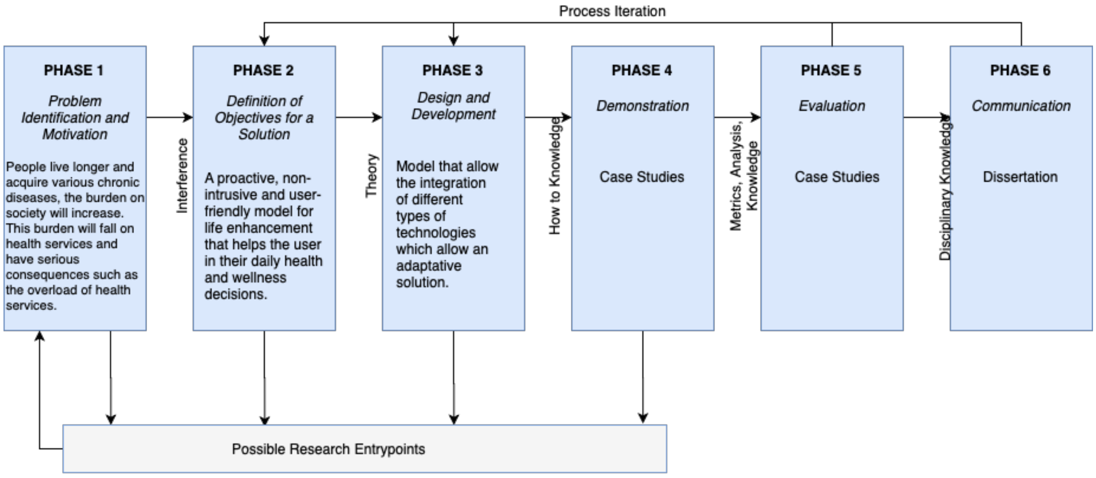


**Figure 1.1:** DSRM Process. Adapted from [1].

- Show how to measure physical and environmental signs that may influence the well-being of the individual;
- Analyze which external factors have the greatest influence on the individual's well-being by analyzing the results of a survey done on an arbitrary population sample.
- Describe how to combine vital signs and environmental measurements to trigger adaptive actions;
- Illustrate an example of environment model by demonstrating a test environment and case studies.

## 1.4 Organization of the Document

After this chapter, the dissertation is structured as follows:

- **Chapter 2:** Presents the fundamental concepts and the state of art with the aim to show the actual view about the theme and to construct a theoretical background with the most important concepts.
- **Chapter 3:**Describes the design of the model and its constituents.
- **Chapter 4:** Presents and discusses a survey about the impact of external factors in our well-being, deriving conclusions about how a model like the proposed could be important.
- **Chapter 5:** Describes the case studies designed to evaluate the model and its functionalities.
- **Chapter 6:** Through reflection on the case studies, an assessment is made based on what and how the model responds to the objectives, as well as its limitations.
- **Chapter 7:** Draws conclusions about the work developed and proposes future work.

# 2

# Fundamental Concepts And State of the Art

**Contents**

This chapter introduces and presents the main concepts related to the work, describing the topics and the information that was researched in order to design the model. Here are presented also the technologies and the actual view of the society and the key enterprises that have been developing new products in this area.

## 2.1 The Actual View

Frost and Sullivan predicted that the expansion of smart healthcare products will be 348.5 billion dollars market by 2025 [9]. At time of writing there are many researches and works ongoing in this area, and the ideas for improving healthcare and well-being systems are many. From smart syringes to Radio-frequency identification (RFID) cabinets, the smart healthcare domain is gaining the interest of all. The RFID technology, for example, has been used in many applications [11] like radiology and the control of infections (through the tracking of related objects). Some products and ideas have been developed in this present digital-health revolution. EHR is one of the most significant products of smart healthcare, as this product brought a different meaning for addressing big-data issues. Fields like inventory management, data storage and monitoring are some fields that use this type of product.

The largest enterprises in the market are also revolutionizing the digital health with their ideas. *Intel* is leading with its steady development of innovative technologies, from data analysis up to improving the home environment for the elderly population [9]. An artificially intelligent computer system was created by IBM, the *IBM's Watson*, that can study the content of the patient's EHR and relevant medical information to provide better healthcare models, more efficiently [9].

In the way to keep digital health research on a large scale, *IBM*, *Apple*, *Johnson & Johnson* and *Medtronic* have become partners [9] to improve the quality of the technological services for health, since the quality of data capture and data treatment will lead to better health apps [12].

For the development and research of new technologies in digital health *Google* has a life-sciences division [9] named *Verily* which creates tools that improves the data collection and organize health data, then creating interventions and platforms that put insights derived from that health data to be used for more holistic care management. This way *Verily* can make health data useful for people to enjoy healthier lives [13]. *Qualcomm* provides a platform—*Qualcomm Life*—that had a high range of system interoperability and security. The *Qualcomm Life* enables the delivery of medical devices data to the nearby database partner (because it can capture this type of data and make the delivery through a wireless medical device, securing the information) [9]. The connected health platform of *Microsoft* enables the provision of digital health services through desktop frameworks—for example, doctors use *Microsoft Lync* to provide medical services to patients in rural areas [9].

*Samsung* has a digital health initiative where they invested 50 million dollars. This initiative consists of open-source hardware and software platforms where there is a collaboration of smart sensors, algorithms, and data-processing techniques [9]. The *ResearchKit* of *Apple*, is another open-source framework that helps in the developments of apps and in medical research [9]. From a retail perspective, *Amazon* provides a unified healthcare platform that helps users to access information, health insurance, and on-demand related services [9].

Smartwatches or bands, are wearables that have been revolutionizing the market in this area. Examples of those products are *Fitbit*, *Pebble Time* and *Apple Watch*. Significant among the healthcare products are smartwatches, which are becoming more ubiquitous. It is expected for this type of devices to reach 70 million units at a growth rate of 18% by 2021, according to the projected annualized rate [9]. It is expected that *Apple* wins the participation in the market, but *Android* devices are also in constant growth in this area. *Apple's Watch* offers a package of built-in global positioning system and heart rate sensors with a fast dual-core processor [9].

Those were the more futuristic views presently in the companies' perspectives and investments in this area. But much has already been carried out over the last few years regarding the main constituents of this type of model, from the level of the sensors to the applications in the user's perspective.

### 2.1.1 Wearables, Sensors and Actuators

The first step in the direction of a smarter and personalized healthcare is undoubtedly the continuous monitoring of a person's physical parameters (and body signs) that allow precept the physical and mental person's conditions. Today, there already exist thousands of devices and gadgets on the healthcare wearable market that collect this type of data and can help their users to live a healthier and better life. For example, to help persons to sleep better therefore to getting rid of stress in their life [14]. Examples of these healthcare wearables for a healthy lifestyle are:

- *Pebble Time* family of smartwatches, that had one application named Pebble Health that measure sleep. Developed by *Pebble* in collaboration with researchers at Stanford University, Pebble Health automatically tracks when a person goes to bed, displaying sleep, deep-sleep, and the times when fall asleep and woke up. Currently Pebble watches have been discontinued and Pebble's intellectual property was purchased by Fitbit, the wearable technology company specializing in fitness tracking. Fitbit has several wearables to promote health and well-being [15].

- *PIP* is a small device that allows to give feedback about stress levels. This smartphone app helps a user to learn how to reduce stress by having the user to transform a depressing scene into a happy one by actively relaxing, and giving tips along the way. The user just holds the *PIP* device between the thumb and index fingers to measure skin conductivity for a few minutes, because skin pores on our fingerprints are extremely sensitive to changing levels of stress. *PIP* accurately captures these changes and through biofeedback, allows the user to visualize that condition [16].

Those two examples are one possible choice to connect to other smart objects that could actuate in accordance of device's information. At same time, sensors and actuators can be implemented in smart homes, hospitals, clinics, and other environments with the objective of understanding the environment context and, of course, facilitating the automation of this type of environment.

### 2.1.2 Protocols in M2M and IoT

Such as previously mentioned, the "Things" around us in an intelligent environment need to interact with each other. However, the real question is what language or protocol do all these devices need to have to communicate with the Internet. When the Internet was in development, all the stakeholders had the desire that all the computers connected to the Internet should be talking with the same language/protocol. Some of the results of this desire resulted in the TCP, IP and UDP protocols. However, Machine to Machine (M2M)/ Internet of Things (IoT) world still lacks a widely accepted and standard protocol, apart from a few proprietary/proposed protocols that are currently being used [17].

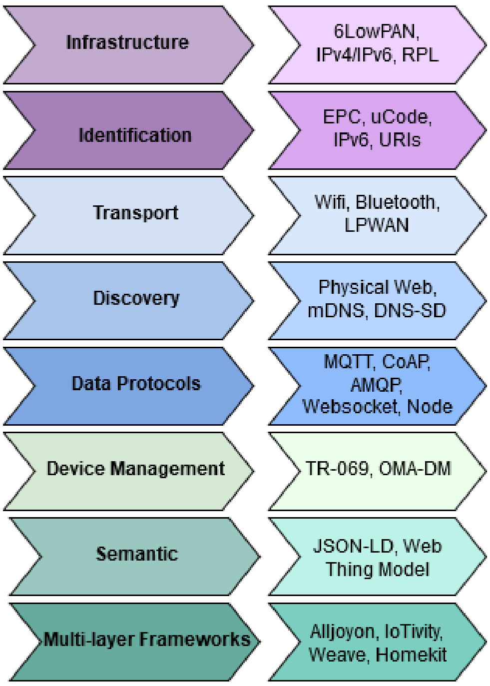


**Figure 2.1:** IoT Protocols on top of OSI Model

The communication challenges in IoT are due to the fact that in IoT and M2M, the interconnected devices are usually of short range, low power, wireless devices with their own predefined set of operations or purpose. The protocols that are currently used on the Internet cannot be directly used in these devices, because of those conditions. As such a new set of protocols which can be catered to the requirements of the M2M/ IoT world had to be created.

Some of the most widely used protocols in M2M/ IoT are Message Queue Telemetry Transport (MQTT), Constrained Application Protocol (CoAP) and Open Mobile Alliance Light Weight M2M (OMA LWM2M). These protocols specifically target low power devices which have to conserve power so that they can operate for a long time. Compared to the Internet protocols, where the payload is heavy along with big headers and footers, in M2M/ IoT protocols the payload is very small [17].

- **MQTT:** IT is a lightweight publish/subscribe messaging protocol, useful for power constrained devices and low-bandwidth, high-latency networks, applicable to many scenarios. MQTT with bandwidth efficiency, data agnostic nature, and continuous session awareness, helps in minimizing the resource requirements for IoT devices, ensuring reliability and assured delivery to a larger extent. The protocol is based on "topics" and hence the receivers of the messages can make sense of the data without even knowing who the sender is. This kind of behavior encourages usage of high-latency and low bandwidth networks which seems to be the norm of the M2M and IoT communication channels. Not designed for device-to-device transfer or for "multicasting" data to many receivers, MQTT is ideal for large networks of small devices that need to be monitored or controlled from a back-end server on the Internet [18].

- **CoAP**: This protocol is a specialized web transfer protocol that is suitable for constrained nodes and constrained networks in IoT. This protocol is described in the *RFC 7252* and is taken forward by *IETF* Constrained RESTful Environments (CoRE) working group. It is designed for M2M applications such as smart energy and building automation. Based on Representational State Transfer (REST) model like Hypertext Transfer Protocol (HTTP), in CoAP also the servers make resources available under a Uniform Resource Locator (URL), and clients can access these resources using methods such as GET, PUT, POST, and DELETE. The close resemblance of CoAP with HTTP makes it very user-friendly and also makes it easier for making them connected easily using application-agnostic cross-protocol proxies. Like HTTP, it can also carry different types of payloads and is able to integrate with Extensible Markup Language (XML), JavaScript Object Notation (JSON), Concise Binary Object Representation (CBOR), or any data format. The strong security capabilities of CoAP is another factor which makes it a desired choice among the available IoT protocols. Designed to use minimal resources, both on the device and on the network, it works on micro-controllers with as low as 10 KiB of RAM and 100 KiB of code space, as detailed in *RFC 7228* [17].

- **Lightweight M2M (LWM2M)**: It is a lightweight protocol developed by the *Open Mobile Alliance* specifically for device and service management. The device management includes device statistics, firmware update, access controls, and other powerful features. It helps in implementing an interface between M2M device and M2M Server and also provides a choice for the M2M Service Provider to deploy an M2M system to provide service to the M2M user. LWM2M helps to implement an interface between M2M device and M2M Server and also provides a choice for the M2M Service Provider to deploy an M2M system to offer service to the M2M user. The protocol was designed with performance constraints of M2M devices in mind, and build on CoAP, making it a preferred option among the IoT protocols [17].

With the purpose and goal of developing technical specifications, to address the need for a common M2M Service Layer that can be readily embedded within various hardware and software platforms, and to be relied for connecting the myriad of devices in the field with M2M application servers worldwide, there appeared the One Machine-to-Machine (oneM2M) initiative. A critical objective of oneM2M is to attract and actively involve organizations from M2M-related business domains such as telematics and intelligent transportation, healthcare, utilities, industrial automation and smart homes. Initially, the oneM2M strategy was to prepare, approve and maintain the necessary set of Technical Specifications and Technical Reports [19].

One of the most important parts in communications are wireless technologies that are the basis of smart healthcare networks, so they have been a great bet for development and improvement. Some technologies such as Wireless Fidelity (Wi-Fi), Bluetooth Low Energy (BLE) [20], IPv6 over Low-Power Wireless Personal Area Networks (6LoWPAN) [21] and RFID [22] have played key roles in the exchange of information between different devices. But other technologies have helped in this field, like the ones in Table 2.1 [23–26].

One way to have a general view the IoT protocols is try to fit all of them on top of existing architecture models like OSI Model. Figure 2.1 shows some examples of IoT protocols for each layer [27].

### 2.1.3 Data Storage and Data Processing

From the servers via heterogeneous networks, such as wireless Body Area Networks (BANs), *ad-hoc* networks or cellular mobile networks, each patient would require the servers to safely and reliably maintain their privacy, their sensitive and accumulative health data, and timely report the data to their family doctors or specialists. In this case, the amount of required data storage by users dramatically increases at every minute, and som an average person is able to generate 1 TB of information in just one day, and the access of these data must be real-time and efficient. These stringent requirements of e-health monitoring systems raise many research challenges among which, server resource allocation and data privacy preservation are the most important [28].

**Table 2.1:** Network Technologies used in Smart Healthcare

| Network Technologies | |
|---|---|
| MEMS | Micro-Electro-Mechanical Systems, or MEMS is a technology that use elements that are mechanical and electro-mechanical miniaturized with techniques of micro-fabrication. |
| WPAN/6WLoWPAN | A wireless personal area network where devices connect to each other around an individual person's workspace (the connections are wireless). |
| Wi-fi/WLAN | Wireless LANs is the term to refer any local area network that a mobile user can connect to through a wireless connection. Wi-fi is a term for certain types of WLANs that use 802.11 wireless protocol. |
| WSN | WSN, Wireless Sensor Network, consists in a wireless network wich a distributed autonomous devices that are devices sensors to monitor physical or environmental conditions. |
| RFID | RFID, is a term to refers technologies that use radio frequencies for data capture to identify objects with electronic devices RF Tags. |
| GPS | GPS, global positioning system, is a navigation system that use information of at least satellites. GPS works in any weather conditions. |
| BLE | Bluetooth, BLE , it's a simple system for making wireless connections over short distances. This version of Bluetooth consume less power and are optimized to run off a coin cell battery for a year or more. |

These requirements lead us to the concept of Big-Data, which was created to store, process and manage large volumes in the shortest time possible or even in real-time. This Big-Data technology allows to digitize large amounts of information and combine it with existing databases. In all the fields and applications where systems and solutions evolve towards the Internet of the Future, e-health might be the application sector where the technologies to be applied to the data may have a huge impact [28].

In smart healthcare it is necessary to manage more and better, patients and suppliers. The Big-Data with the concept of Health Cloud allows to change the data structure of the sector, staying more focused in individual patients and their history. The use of Big-Data can bring many advantages like [28]:

- **Detailed Information:** it is possible to have detailed information about treatments, and allow to determine which treatments are more effective for patients or patients groups;
- **Medical performance:** will be possible to know levels of performance of medical professionals, institutions of higher performance and optimal processes;
- **Patients Profile:** predictive models according to patient profiles;
- Transmission of information to the right people in the right time and manner to improve decision-making.

In fact, one of the biggest advantages of Big-Data technologies, oriented to the e-health, is the capability to store the data of all medical devices which are “associated” with patients and the medical team, to examine their values later, allowing to analyze the entire sector, the actions carried out, and make decisions subsequently or study their effect [28].

The Health Cloud, like the *Xiamen Healthcare Cloud*, is capable of storing data (into popular cloud vendor storage options such as *Windows Azure's* blob storage, or *Amazon Web Service's Simple Storage Service*, and can be readily extensible to support any cloud vendor) [29], making possible to save the health records and electronic medical records in Cloud data center. This allows storing a huge amount of data accessible anywhere at any time. The data stored is indexed so that retrieval is optimized. The configuring of the data backup and archival can be done easily and can be carried out during the configured intervals. As a contingency plan in case of disasters the service also provides options for geo-replication of the medical data. The service indexes the data that is stored in cloud and this helps in a faster retrieval of data. With the combinations of physiological monitoring data, health cloud provides chronic disease and risk assessment, which help the individuals to have a comprehensive understanding of health and disease type. There are many models which can be used in chronic disease forecasting in “Absolute risk”, such as Markov chain models, Grey models, general Regression Models, Autoregressive Integrated Moving Average (ARIMA) class models and Artificial Neural Network (ANN). However, these models typically require large numbers of observations and complicated input factors to make sensible predictions. Physiological monitoring data has the characteristics of random fluctuation. For better forecasting performance, hybrid models which combined two or more single models for communicable disease forecasting have also been explored, and previous findings indicate that hybrid models outperformed single models. A hybrid approach combines Grey Model and Markov Model to forecast the prevalence of Physiological monitoring data [29].

Currently, stand alone healthcare applications are used to process images. These images are acquired from a modality and processed systematically using different algorithms to diagnose the medical condition of a patient. These algorithms are compute intensive and are expected to return the results of processing in a very short time. Many healthcare providers have their own proprietary algorithms and the hospitals are charged heavily for the licenses, increasing the operational costs significantly. An essential solution is to have these compute intensive algorithms run on cloud as services. These services can then be used by any healthcare application and hospital on a pay-per-use basis. This also reduces the cost of procuring high-end healthcare hardware with good computational power and the needed infrastructure [29].

### 2.1.4 Security

The security is a theme very important in all fields but when we talk in health, security is the most important. So, in a cloud-based architecture, there exists a trusted cloud service provider or a Central Authority (CA). It makes use of the public, private and hybrid cloud infrastructures. In a cloud-based architectures, the patient's health information's are monitored through the BAN. The body sensors are projected in and around the patient's body through the wearable smart devices. The patient's health information is monitored through the body sensors and sent to the cloud server for storage purposes. The patients can also track their health information through the mobile devices. The Health service provider establishes the Service Level Agreement (SLA) with the patient and manages EHRs across the cloud server. The cloud service provider provides the healthcare services across the cloud computing environment. The provider stores and manages EHR over the cloud computing infrastructure. Once the data is stored into the cloud server, the provider imposes access policies and shares it with a trusted group of users. The user can gain access to the data only when the cloud provider has defined the access policy that matches with the user data access policy.

In this way it is possible to meet the requirements as defined in [30]:

- **Confidentiality:** verify that the IoT data flow is not intercepted and read; and check if someone is not corrupting the end system to steal data, credential or configuration parameters;

- **Integrity:** ascertaining that the IoT information received (or stored) has not been compromised and/or altered in an unauthorized manner. Infection caused by viruses and worms can be utilized by an inimical agent to alter the original data, thus impacting integrity (among other possible damage). Integrity can also be perceived in the context of authentication: making sure that entities/devices are who they claim to be, and that the identity of the systems or users is not compromised (misappropriated);

- **Availability:** ascertaining that IoT devices are not precluded from functioning and/or performing their function in an improper or compromised manner (because they might have been infected with viruses, worms, and other debilitating intrusions and/or have been exploited in terms of various Operating System, software utilities, packaged microcode, or applications).

In addition it is reasonable in the majority of cases to add other dimensions such as reliability and repeatably to the security term but such things are often outside the scope of technical standardization although there are a number of guides that address such issues, e.g. ISO/IEC 27001 [6].

### 2.1.5 User Interfaces

The development of health in our days turn on smart healthcare very important. This concept opens many doors at health services, from temperature monitoring for babies to tracking vital signs in the elderly [9]. The analysis of the raw data received from wireless network connected devices concludes that this data has contributed in managing and preventing chronic diseases and monitoring patients, so, products and services with this concept are increasingly being developed. Domains like Automation, Artificial Intelligence (AI) and Intelligence Systems (IS) for energy conservation, Green technology, and the likes, have been helping to increase these services [31]. So many applications, web sites, and others projects have been designed and thought to reach everyone. For this, the user interfaces have also been a challenge, for each time they have to be more intuitive, aesthetic and not conducive to error.

## 2.2 Examples of Healthcare Applications and Services

There are already some initiatives and solutions (some already commercial) that address the needs we have been exposing. The most significant are the *Cooey Smart Health* and the *Microsoft HealthVault*.

### 2.2.1 Cooey Preventive and Personalize Healthcare

*Cooey Smart Health* is a complete smart platform for connected and collaborative care which allows users to automatically log their medical data through bluetooth entitled devices [32]. *Cooey* is an smart and simple health vault that captures health vitals like Blood Pressure Log, Weight Loss Diary, Blood Sugar Diary that could be measured with Cooey devices, or users could insert the values manually, and even medicines list and lab reports. It takes note of the person's health by storing, analyzing and sharing their medical records. Through this data, the app can advice their users about smart tips and services. It gives notifications if some things are not right and enables users to follow remotely their health reports. Furthermore, this app has the option of connecting the user to various health services like pharmacies and homecare.

It consists of three different health monitoring systems: Smart Blood Pressure Monitor, Smart Body Analyzer, Smart Glucometer, as illustrated in Figure 2.2.

Cooey also provides some 3rd party Platform services:

- **Measure and Monitor:** the health monitoring systems like bluetooth enabled- *blood pressure monitor* and *weighing scal*e provide the users, automatically, records of the data and shares this data with their medical health experts, letting also them to access this data remotely.
- **Engage:** raw data about the patient is collect and after this, the system can send notifications to the user with health tips seconding the patient's profile, her/his health vitals, and others...


**Figure 2.2:** Cooey Health Monitoring Systems: Smart Bluetooth BP Monitor, Smart Body Fat Analyser and Alexa Smart Health, respectively

- **Fulfillment:** the app is able to create dynamic profile about the patient with data collected of patient health condition so this way it is possible, if necessary, to share this profile with other medical experts.

The main targets of *Cooey* services are chronic patients and antenatal care offering. The *Cooey* system uses the Smart Assist, M-assist and W-assist to record, analyze and share patients medical data. These devices have the following functions:

- **Smart Assist:** through smart algorithms the app can derive conclusions and provide personalized advises and recommendations.

- **M-Assist:** is responsible for health management, so this functionality provides the mobile Application Program Interface (API).

- **W-Assist:** web based portal which is connected to the internet and works on mobile devices.

### 2.2.2 Health Vault by Microsoft

*Microsoft HealthVault* helps users to gather, store, use, and share health information for them and their family members, putting the user in control of user health information [33]. In this way, *HealthVault* can:

- Organize user family's health information:
  - keep all user health records in one place;
  - be ready for school, sports teams, and summer camps by keeping track of user's kid's medical records in user family account;
  - keep track of all the details whether the user is managing complex health issues or just want to stay on top of her/his family wellness (medications, blood pressure, allergies, etc..);
- Be better prepared for doctor visits and unexpected emergencies;

  - be prepared for an emergency by making the user's most important health info available for emergency responses:
  - more out of doctor visits (up-to-date medication and allergy lists, blood pressure, user health history,...);
  - keep user information at the fingertips and access it using mobile devices, anywhere, connected at Internet;
- Create a more complete picture of users health, with patient at the center:
  - get patient lab results, prescription history, and visit records;
  - track user numbers to help monitor chronic conditions;
  - save and share users medical images with health professionals;
- Achieve User Fitness Goals:
  - reach user weight and fitness goals;
  - celebrate user's successes;

*Microsoft HealthVault* provides a place to the "patient" where the users can access all their health information online. Here the user can also, manage the health of a child, parent, or other family member. Web sites, computer software and mobile applications help user to put more out of *HealthVault*. These apps are able to keep the user motivated, analyze trends, and receive education and recommendations. *HealthVault* can integrate many devices, such as pedometers, blood pressure, blood glucose monitors, and even weight scales.

The user can share the own health records with anyone she/he chooses and where she/he wants.

## 2.3 Discussion and Requirements for the Model

From the analysis of the research carried out in this chapter I was able to understand the direction of the health-related technologies industry, the new ideas that are being developed and essentially the main requirements of an architecture for an "Ambient Intelligent" environment for "Life Reinforcement".

### 2.3.1 Discussion

This project aims to present an independent decision-support model that can work for any user (individual or institutional) and with the highest level of scalability possible. For this I will take into account all types of sensors, actuators and wearables, both environmental and physical, both around and centered on the user.

In terms of protocols, I will not specify any particular ones because complete environments with several types of sensors, actuators and wearables can use different protocols.

In terms of processing and storage I will assume that solutions/platforms based on the model would be cloud based and that the model abstracts from all the algorithms and related considerations.

Concerning safety, a possible solution is being developed in parallel, in the research work of Eduardo Delgado, a MSc student of the Master Degree in Information Systems and Computer Engineering of Instituto Superior Técnico, entitled “Trusted Ambient Intelligent for Life Reinforcement”, with the objective of developing the security algorithms and the security considerations of this type of system.

### 2.3.2 Main Requirements

So in order to designthe Model for an “Intelligent Ambient for life Reinforcement” we can divide its requirements into *Functional requirements* [7] and *Non-Functional requirements*.

- **Functional Requirements:**
  - **Data Generation:** integrated data generation subsystem (collection of physical parameters), where the environmental sensors data, and vital body signs are fundamental;
  - **Data Storage Subsystem:** subsystem with large data storage capacity, data handling support, both for raw data and of processed data.
  - **Data Processing Subsystem:** This subsystem must provide the generation of high level abstraction from raw data, making possible to have one smarter, personalized and connected healthcare. The higher level processing must have the capacity to make available both raw data and processed data;
  - **Consumer Subsystem:** where the user can receive recommendations from his particular doctor or caregiver.
  - **Devices Subsystem:** it tracks the registered devices and their settings; it must supports the discovery of resources to discover the M2M devices present and select the appropriate communication protocols;
  - **Security and Access Control Policies**: must be applied to allow authorized users to take advantage of customized healthcare solutions for both local users and institutional users;
  - **Notifications Service:** to allow the user to act on behavioral cues;
  - **Actuation Subsystem:** to allow interaction with the environment (e.g., smart home) based on the received notifications or on user preferences;

- **Interface Abstraction:** All interfacing with the system should be made through APIs, both Northbound (i.e., to or from the "User"/Application side) and Southbound (i.e., from and to the infrastructure/devices side).

- **Non-Functional Requirements:**
  - Modular in terms of components and services;
  - Resilient: tolerant to failure of individual components/services;
  - Cloud-Native: to enable loosely coupled subsystems/components that are resilient, manageable, and observable;
  - Scalable: to allow expansion and upgrading to newer versions and technologies;
  - Secure: higher level of security, namely to ensure the user's physical security;
  - Trusted: high level of protection of user's personal data.

# 3

# Platform Model

**Contents**

This chapter corresponds to the phase “Design and Development”, the third of DSRM methodology. Here is described the solution proposed to answer the research problem. In this way, this work aims to provide a contribution to address the following problem: People live longer and acquire various chronic diseases, the burden on society will increase. This burden will fall on health services and have serious consequences such as the overload of health services. The systems eventually developed based on the model can be limited from the point of view of combining software or hardware. Based on the analysis of the related work and on the research problem, the following objectives were established for the proposed solution: develop a model for an intelligent ambient for life reinforcement Platform with a preventive approach that allows the user to know their health status but also help with a decision-support system to make more conscious choices for their health and well-being. This model must also be sufficiently scalable and interoperable to be able to adapt as much as possible to the situation of each user.

## 3.1 Layered Model

Over the years numerous work has been done to study IoT architectures. An IoT architecture generally has a scheme like the one showed at Figure 3.1. In that scheme it is possible to identify four essential layers: Access Technology Layer; Access Mediation Layer; Middleware Layer; Application Layer.

**Access Technology Layer:** this layer is composed by various physical devices such as wearables, sensors, active RFID Tags, embedded systems and others. This layer realizes functions like communication with devices, collecting data from devices, or executing actions on devices.

**Access Mediation Layer:** the main function of this layer is cleaning, transforming, normalizing and optimized data.

**Middleware and Analytics Layer:** this layer is the connection between the technology layer and the application layer. Here is made the route to messages, the communication between platforms, by means of message brokering, such as publishing and subscribing mechanisms. The processing of the information is done at this layer. This layer also provides the core services of the system.

**Application Layer:** the applications at this layer, provide services, through APIs and Graphical User Interfaces (GUIs) to the end users users. like monitoring, alerting, analytics, visualisation, etc..

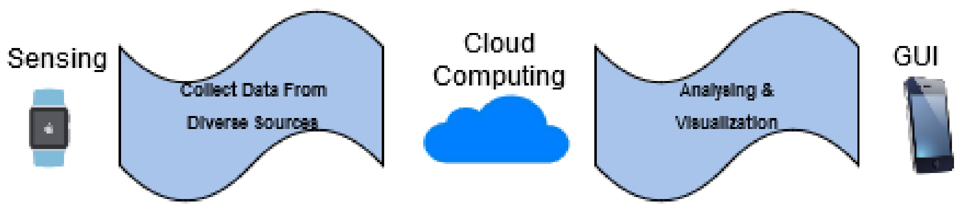


**Figure 3.1:** General Architecture for IoT

## 3.2 High-level Platform Architecture

In analyzing the requirements described in section 2.3, we can identify eight essential steps to tackle healthcare big data on our model, like described in [34]. They are the following:

- **Data Sources**
- **Data Acquisition**
- **Transformation Operations**
- **Data Storage**
- **Analytics**
- **Middleware**
- **Information Consumption**
- **Security and Privacy Management**

The design of the architecture of the proposed Platform is presented in Figure 3.2, showing its main components and interactions.

### 3.2.1 Data Sources

The responsible for data generation are the data sources which, in our model, could be **User Information**, **Mobile Apps**, **Health Signs** and **Environment Sensors**.

- **User Information** corresponds to information that the user puts manually in an mobile application, for example the quantity of salt consumed in certain day or the user height;
- **Mobile Apps** information represents the data that can be obtained through mobile applications like sleep data;
- **Health Signs** could be collected through many different devices like a wearable, a blood pressure meter, a thermometer, etc.;
- **Environment Sensors** which will be essential to collect data of external factors like environment temperature, luminosity and others that could have impact in the user well-being.

Healthcare data has multiple sources such as EHR and like previously said, different types of medical devices and environment sensors can be used to generate data. In this way, we can notice that data is collected with different formats such as *structured data* (e.g., Relational data), semi-structured data (e.g.,

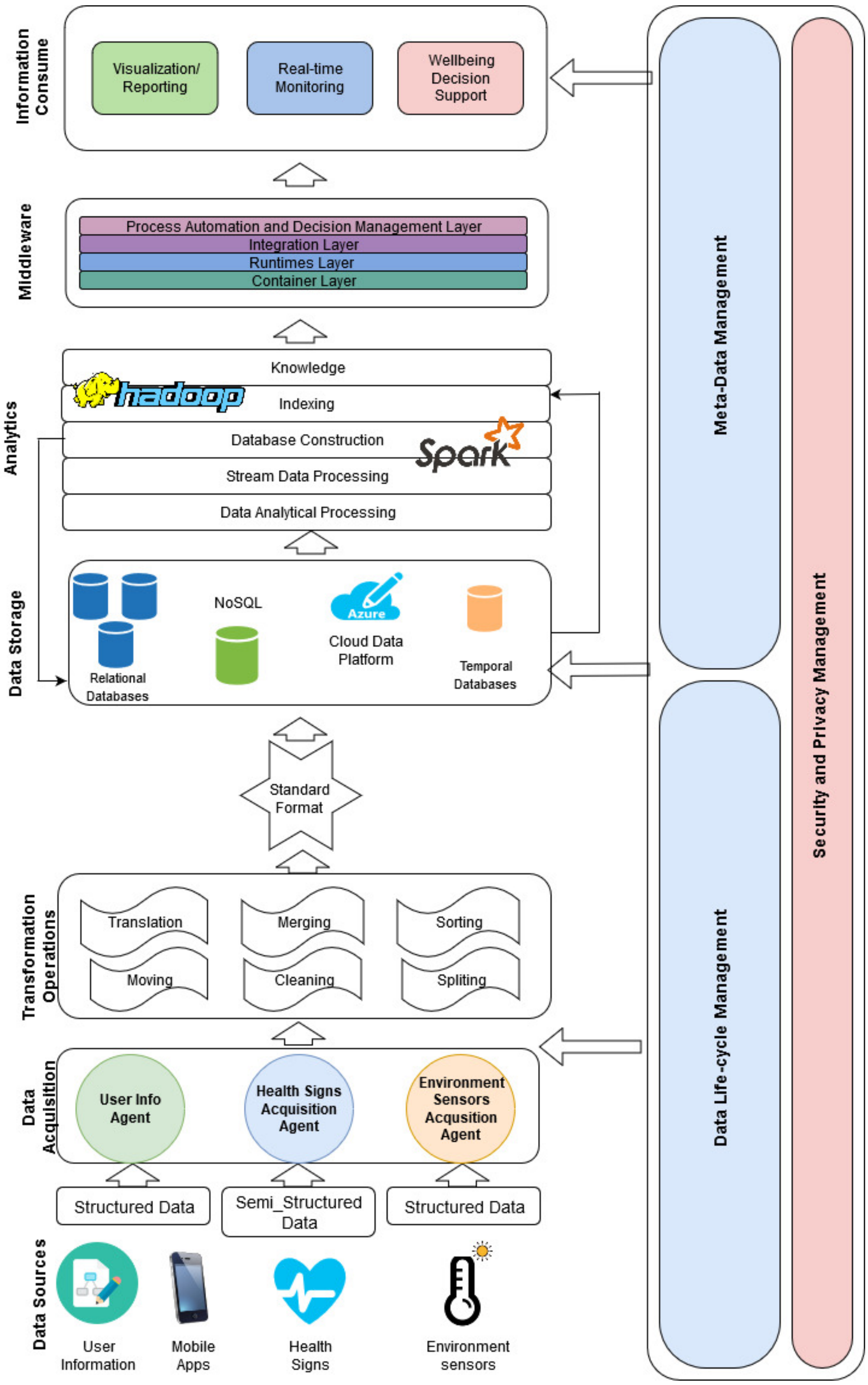


**Figure 3.2:** High-level Platform Architecture

XML, comma separated value, JSON) and *unstructured data* (e.g., Word Processing documents, PDF, unformatted Text, Images, Videos, Logs, etc.) [35]. The multitude of formats lead to the challenges of data acquisition and corresponding pre-processing and/transformation to normalized formats. The role of the Access Mediation Layer is therefore to provide that type of functionality and services facilitating data collection and pre-processing.

### 3.2.2 Data Acquisition

The process of data acquisition is performed through various **Agents** that are responsible for the adequate data extraction mechanisms. Data collection can be performed **automatically** or trigerred **manually**. Despite the manual term, the information recorded is electronic in nature and collected in real-time for both cases. In case of manual mode, the end user is responsible for the electronic data registration, while in the automatic mode data are registered automatically by the devices.

Figure 3.3 represents the interaction model with a user, from the acquisition of data to the answer from the actuator.

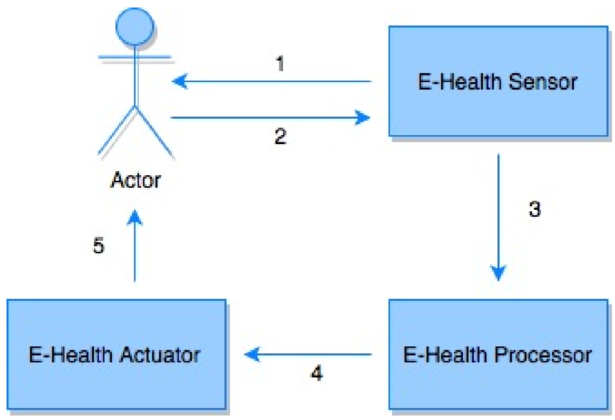


**Figure 3.3:** User interaction : 1 - Request for Acquisition; 2 - Acquired data; 3 - Data Process Request; 4 - Order to act; 5 - Action

### 3.2.3 Transformation Operations

It is in this module where the data is transformed, because, as previously discussed, the data sources generate different formats of data. Operations such as **moving**, **cleaning**, **splitting**, **translating**, **merging** and **sorting** are essentials to transform healthcare big data in an standard format that can then be loaded into storage subsystems.

### 3.2.4 Data Storage and Analytics

There are a number of different approaches of data systems storage available for facilitating rapid data access. Each of the available designs and technologies currently available, offer different strengths and weaknesses based on the structure of the data to be stored, such as:

- **Relational Databases** were designed for information that is replicated across multiple records, such as a billing database where a single person may have multiple bills. This type of storage system work best with data that can be subdivided across multiple tables. In security environments, they are usually best suited to maintaining event reports, personnel records, and other knowledge—things that are produced after processing data or that reflect an organization's structure. **Relational Databases** are good at maintaining integrity and concurrency; and as in this model we need to constantly update rows, they are the default choice;

- The major advance in big-data in the past decade has been the popularization of **NoSQL** big-data systems [36], particularly the *MapReduce* paradigm introduced by *Google*. *MapReduce* is based around two concepts from functional programming: *mapping*, which is the independent application of a function to all elements in a list, and *reducing*, which is the combination of consecutive elements in a list into a single element.

- **Temporal Databases** offer temporal data types and stores information relating to past, present and future this stores data relating to time instances. The temporal aspects usually include *valid time* (is the time period during which a fact is true in the real world), *transaction time* (is the time period during which a fact stored in the database is known) or *decision time* (is the time period during which a fact stored in the database was decided to be valid) [37];

- Data management in the open source Fast Healthcare Interoperability Resource (FHIR) standard is becoming turnkey for interoperability and machine learning on healthcare data. There is a growing need for healthcare partners to build and maintain FHIR services that exchange and manage data in the FHIR format. **Azure** API for FHIR offers exchange of data via a FHIR API and a managed Platform as a Service (PaaS) offering in **Azure**, designed for management and persistence of Protected Health Information (PHI) data in the native FHIR format. The FHIR API and data store enables us to securely connect and interact with any system that utilizes FHIR APIs, and **Microsoft** takes on the operations, maintenance, updates and compliance requirements in the PaaS offering, so we can free up our own operational and development resources;

- **Hadoop** is the underlying technology that is used in many healthcare analytics platforms [38]. This is because, **Apache Hadoop** is the right fit to handle the huge and complex healthcare data and effectively deal with the challenges plaguing the healthcare industry;

- **Spark** is a memory based computing framework which has a better ability of computing and fault tolerance, supports batch, interactive, iterative and flow calculations. **Spark** is a general distributed computing framework [39] which is based on **Hadoop** *Map Reduce* algorithms. It absorbs the advantages of **Hadoop** *Map Reduce*, but unlike *Map Reduce*, the intermediate and output results of the **Spark** jobs can be stored in memory, which is called *Memory Computing*.

The analytic part is focused on basic statistical analysis work. Here occurs the massive healthcare data analytical processing, the streaming data processing, where the databases are constructed and optimized, and indexing and other analytic operations performed.

### 3.2.5 Middleware

Middleware represents the software that provides services and capabilities which are common to internal or external applications. The middleware components generally handle the data management, messaging, application services, authentication and API management.

- The container layer of middleware manages the delivery aspect of application life-cycles in a uniform manner;
- The runtimes layer contains the execution environments for custom code. Middleware can provide lightweight runtimes and frameworks for highly distributed cloud environments such as microservices, in-memory caching for fast data access, and messaging for quick data transfer;
- The integration middleware provides services to connect customized and purchased apps, as well as Software as a Service (SaaS) assets through messaging, integration, and APIs to form functioning systems. It can also deliver in-memory database and data cache services, data/event streaming, and API management;
- The process automation and decision management layer of development middleware adds critical intelligence, optimization and automation, and decision management [40].

### 3.2.6 Information Consumption

The healthcare big-data could be massive and complex, which makes it difficult to understand and observe. So the information consumption component is responsible for the reporting/visualization, real-time monitoring and well-being decision support. In this way, great techniques are needed for efficiently visualizing and summarizing the healthcare big data related with vital signs. And for the users, the analysis of results is important not only for historical data but also for the current vital signs. For this purpose, real-time monitoring based on transient vital signs of users is needed and real-time monitoring of external factors too, for an accurate analysis of well-being status of the user. The recent development of big-data technologies, allows to enable real-time monitoring by utilizing streaming-like techniques. Some artificial intelligent algorithms such as *Byesian model*, *logistic regression*, *decision tree*, *support vector machine*, *random forest* and others can be integrated with domain knowledge for clinical decision purposes [41].

### 3.2.7 Data Life-Cycle Management

Lifecycle thinking and lifecycle assessment are scientific methods that support basic policies and data-driven decisions, and inhibit the transfer of problems from one phase of the lifecycle to the next or resolve the problems in one phase to prevent problems from recurring in other phases. Since the data are valuable assets beyond the immediate needs, data must be managed through-out the lifecycle. Data Lifecycle Management (DLM) is a policy-based approach for managing data flow in information systems throughout its lifecycle, from preliminary creation and storage until they become obsolete and deleted.

### 3.2.8 Meta-Data Management

The core goal of metadata management is to simplify the way people and programs find and use data. Metadata gives context, helps to organize and provide relevance to the data itself. Attributes like file location, file size, data type, and author are vital signposts that allow for faster querying and replication of insights. Without these markers, queries often fail to retrieve important data that might otherwise transform reports and findings. In a sense, effective metadata management prevents data from succumbing to chaos. Without proper metadata management to create an accurate data catalogue, it is next to impossible to establish data lineage. It is through continuous data lineage that healthcare maintain full awareness and accessibility of their data assets, no matter where it is moved in data warehouses or data lakes.

### 3.2.9 Security and Privacy Management

Users health information reside in multiple locations that must be accessed quickly. This information is also very sensitive, confidential and its integrity is fundamental. So, in healthcare, big-data security is vital. Security and privacy policies are essential to control who access the user information and how this information is used. Data protection regulations and high security measures are very important in systems like this.

## 3.3 Functional Architecture

Having defined all the essential components to handle the information collected and in order to arrive at the functional architecture of the platform, we used three classic The Open Group Architecture Framework (TOGAF) derived views to better model the system. This division supports a sufficient level of abstraction useful for the model with this level of heterogeneity. This heterogeneity makes this model a typical case of Service Oriented Architecture (SOA) where the architecture must be abstracted from the complexity characteristic-platform of underlying systems (loose coupling principle) [42]. The specific technical implementation of a service must be hidden from the consumer.

The main objective of these visualizations is to provide an appropriate view of the platform where functionalities, components, interfaces and infrastructures are detailed, so that each technical accomplishment results. So we can say that the platform architecture is the technical and conceptual translation of the requirements raised in Chapter 2 directed to the objective of the project

### 3.3.1 Methodology for the Architecture Design

As mentioned before, the architecture is portioned into three classical views, derived from TOGAF.

- **Business view (Business Architecture):** describes the model from a computationally independent point of view without technical considerations. In this architecture, the most relevant business actors, objects and processes are identified.
- **Information System Architecture (Information View):** in this view the model is analyzed in a complete computational form and is described as a platform independent model, but with some implementation details. Here are mainly identified platform services derived from processes. Here we can also see the components and the services interfaces described.
- **Technology View:** describes a general web-services stack, not specific to a programming language/technology i.e., describes a platform specific model that specifies and maps the information system view onto specific technology options for the platform.

### 3.3.2 Business View

The business view shows how the business processes, associated business units and individuals relate to each other. Here are shown the concepts that are supposed to be stable whatever the use cases or the implementations that are applied.

To construct a business view it is necessary to identify the key elements that are the *Actors*, *Services*, *Objects*, *Means* and *Key Success Factors (KSFs)*. The User is an example of Business Actor. Networks, servers and sensors are examples of Means.

In Figure 3.4 is shown a general meta-model of the Business model, where are specified the participants and the connections in general. The name *Goal* replaces KSFs for a better understanding.

To achieve the business view, an Actor Service Means Goal (ASOMG) analysis, like explained in [43] and summarized in Figure 3.5, recommends the business participants that should be present whatever the use cases or the implementations that are applied for the model.

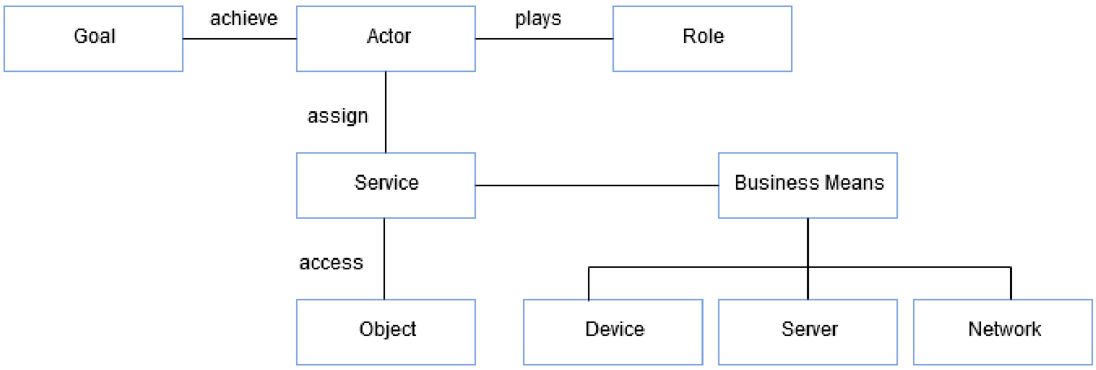


**Figure 3.4:** Meta-Model of the Business Model for the Platform

| Actor | Service | Object | Means | Goal |
|---|---|---|---|---|
| Patient | Health Signs Monitoring | Health | Health | Privacy, Low cost |
| Patient | Healthcare | Personal Healthcare Information | Smartphone/ Smartwatch | Privacy, Low cost |
| House | Environment Signs Monitoring | Environment | Environment | Low cost, Security |
| Telecom | Healthcare Information | Personal Healthcare Information | Network | Availability, inter-operability |
| Telecom | Healthcare Information Hosting | Personal Healthcare Information | Relational | Availability, interoperability |
| Telecom | Healthcare Information Analytics | Personal Healthcare Information | Cloud | Availability, interoperability |
| Healthcare Organization | Healthcare | Personal Healthcare Information | Smartphone/ Smartwatch | Security, availability |

**Figure 3.5:** ASOMG Participants in the Model's Business View

In this platform the main *actors* are the user, the user's house, the healthcare organization and the telecom operator. From a business standpoint, as Figure 3.6 shows, a user enjoys a constant monitoring service that acquires signals that can be vital signs or/and signs of the surrounding environment. This acquisition is made through health sensors or/and environmental sensors which are interconnected thought the house's network which in turn also connects the actuators. This signal containing real-time information is transformed into a standard format so that it can be analyzed and compared together with others in order to remove its context and meaning. For this to be possible, it is necessary to resort to the storage and cloud analysis features due to all the reasons previously discussed and also to relational and temporary databases where information from other patients will be stored and taking into account other previous contexts. Once this information has been analyzed it will then have a meaning from which information relevant to the user can be taken. This information will reach the users through (typically) a mobile application with an intuitive interface where they can consult and enter information, or through which they can receive notifications to advise on behavior or danger alert and in high risk cases dispatch a warning signal. This information can also trigger adaptive actions in the environment by sending simple commands to actuators in the surrounding environment to adapt and make the user feels better.

Through this description, accompanied by Figure 3.6, it is easier to understand the fundamental operation of the platform from a business point of view, as well as the key players that will remain in any use case.

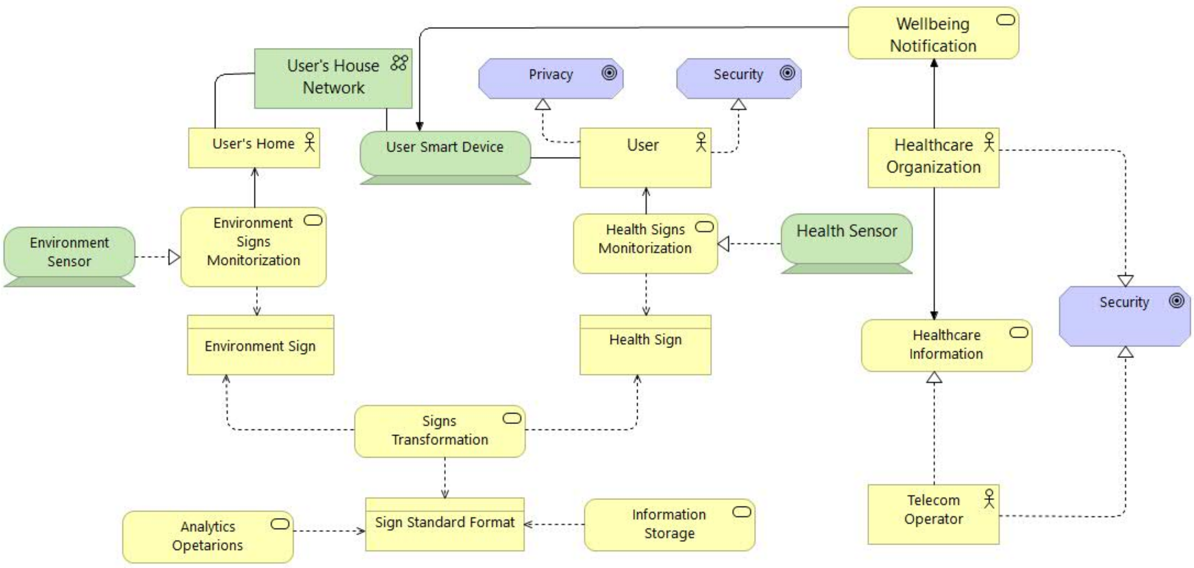


**Figure 3.6:** Business View (designed with ArchiMate)

**Signs Monitorization and Wellbeing Notification** are the core business activities of the platform. Two groups of processes have emerged to handle data exchange.

### 3.3.3 Information System View

The Information System View provides a blueprint for the individual application systems to be deployed, the interactions between the application systems, and their relationships to the core business processes of the organization with the frameworks for services to be exposed as business functions for integration. Because of the sensitive context of transmitting medical data, special attention is given to security and legal issues (e.g., levels of trust, operator access rights, and user consent). This section defines the structure and the high-level behaviour of the platform.

**Data Exchanges and Transformation:** The information view has, as main objective, to demonstrate the transformations that the data undergoes until they are considered information for the user's consumption.

Data starts to enter the system in three possible ways:

- The user inserts manually information through a smart device, for example directly in an APP;
- Health Signs directly measured by a Health Sensor;
- Environment Signs directly measured by Environment Sensors.

These data could be **structured**, **semi-structured** or **unstructured** like explained in Section 3.2.2. In order to be able to compare the data and get some information from them, they have to undergo a transformation operation that is carried out through various processes. This transformation operation consists of changing the format, structure or values of the data. Given the size of the data that is worked in a project like this, we can think of a solution that uses cloud-based data warehouses, which can scale computing and storage resources with latency measured in seconds or minutes. The scalability of the cloud platform allows to ignore transformations and pre-load and load raw data into the data warehouse and only then transform it at the time of consultation—a model called Extract-Load-Transform (ELT). Organizations that use local data warehouses often use an traditional Extract-Transform-Load (ETL) process, in which data transformation is the intermediate step.

Data transformation may be **constructive** (adding, copying, and replicating data), **destructive** (deleting fields and records), **aesthetic** (standardizing salutations or disease names), or **structural** (renaming, moving, and combining columns in a database).

The data transformation increase the efficiency of business processes and analytics and in this way enable a better data-driven decision making. The first transformation phase must go through shaping the data to increase compatibility with the analysis systems.

**Extraction and Parsing:** The data ingestion begins with extracting information from a data source (environment sensor, health sensor, smart device), followed by copying the data to its destination. Initial transformations are focused on shaping the format and structure of data to ensure itss compatibility with both the destination system and the data already there. Parsing fields out of comma-delimited log data for loading to a relational database is an example of this type of data transformation.

**Translation and Mapping:** Some of the most basic data transformations involve the mapping and translation of data. For example, a column containing integers representing the beat rate values can be mapped to the relevant values descriptions, making that column easier to understand and more useful for display in a customer-facing application.

Translation converts data from formats used in one system to formats appropriate for a different system. Even after parsing, web data might arrive in the form of hierarchical JSON or XML documents, but need to be translated into row and column data for inclusion in a relational database, for example like an temperature which was measured at a certain time on a given day.

**Filtering, Aggregation, and Summarization:** Data transformation is often concerned with whittling data down and making it more manageable. Data may be consolidated by filtering out unnecessary fields, columns, and records. Omitted data might include numerical indexes in data intended for graphs and dashboards or records that are not of interest in a particular situation.
The data can also be aggregated or summarized, transforming, for example, a time series of measurements of heart signals into an electrocardiogram.

**Enrichment and Imputation:** Data from different sources can be merged to create denormalized, enriched information. The daily measurements of the user's blood pressure can be accumulated in an overall total average and added to a user information table for easier consultation or for use by the analysis systems. Long or free-form fields may be split into multiple columns, and missing values can be imputed or corrupted data replaced as a result of these kinds of transformations.

**Indexing and Ordering:** After the transformation processes, we have an information on a standard format. This information has to be analysed so analytical operations are needed to give value to this info. Data can be transformed to be ordered logically or to suit a data storage scheme. For example, the creation of indexes in relational database management systems can improve the management of relationships between different tables or the performance.

**Anonymization and Encryption:** As this type of data contains personally identifiable information or confidential information and even information that could compromise the user's security, they must be anonymized before propagation. Encryption of private data is a requirement in this project and systems can perform encryption at multiple levels, from individual database cells to entire records or fields.

**Modeling, Typecasting, Formatting, and Renaming:** a whole set of transformations can reshape data without changing content. This includes casting and converting data types for compatibility, adjusting dates and times with offsets and format localization, and renaming schemes, tables, and columns for clarity.

**Visualization/Reporting, Real-time Monitoring and Well-being Decision Support:** After all transformation, analytical and security operations we have finally the well-being information ready to be consumed for the user. This information could be used: in a report to show the user for example a weekly report on the stress levels; in the real-time consulting of a arterial pressure; in the well-being decision support through a notification for the user to adapt behaviour. Finally, this information can trigger actions that will be performed by actuators, such as in the case of a high level of stress, the user can ask his home to reduce the light levels (the actuators can then decrease artificial light or lower blinds).

The diagram in Figure 3.7 shows the information view that illustrates the entire perspective of the information on the platform, from the data acquired raw to the useful information ready to be consumed by the user.

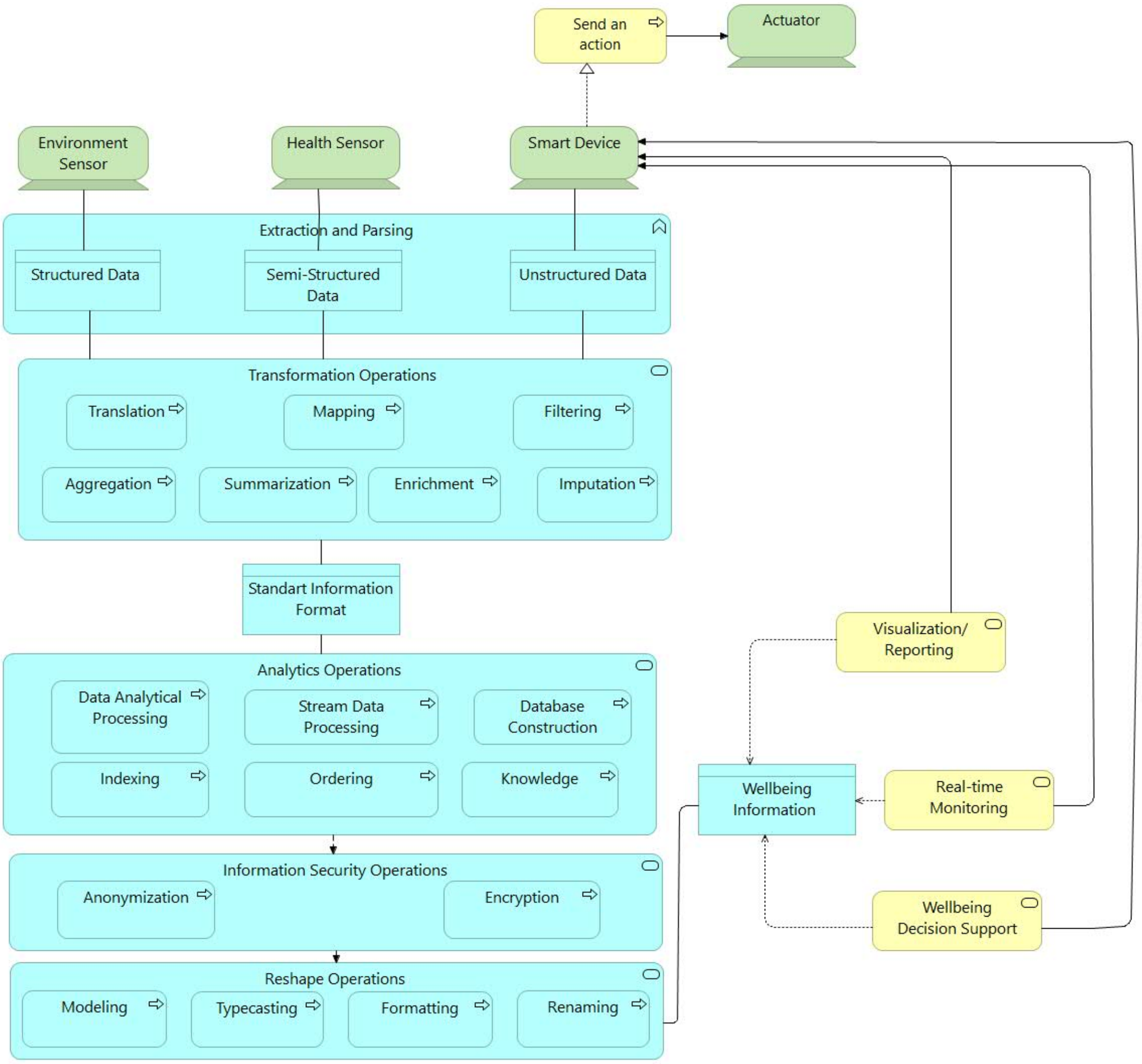


**Figure 3.7:** Information View (designed with Archimate)

### 3.3.4 Technology View

The Technology Layer elements are typically used to model the Technology View of the Architecture of the system, describing the structure and behavior of the technology infrastructure. Figure 3.8 shows the main interventions of hardware/software in the platform.

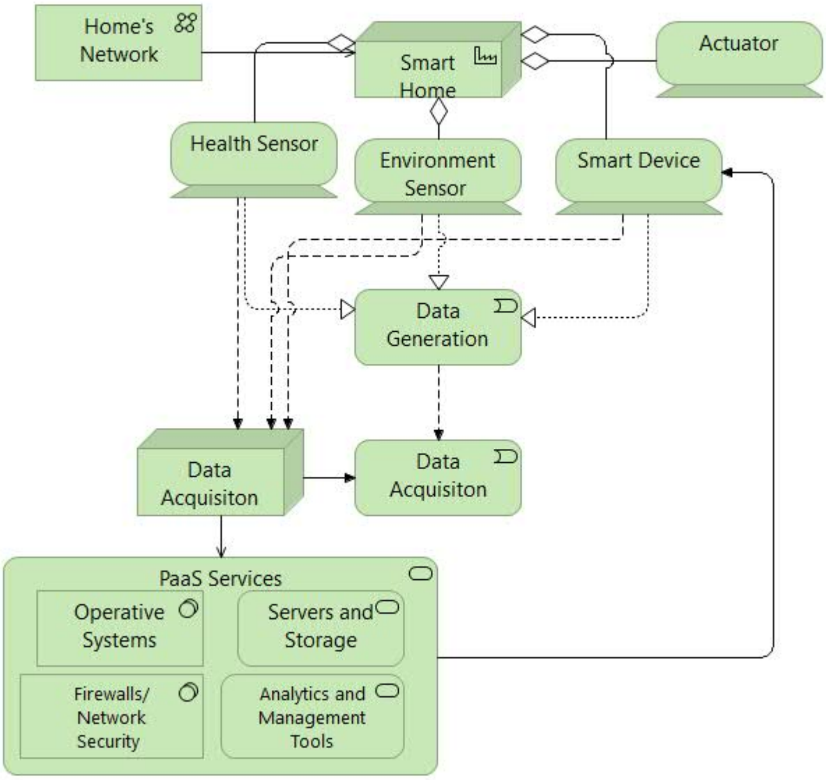


**Figure 3.8:** Technology View (designed with Archimate)

In that figure (Figure 3.8), it can be observed the interactions. The well-being notifications that trigger actions are based on the signals that are acquired by the different devices. These data are processed to create a specific context for that user. At an aggregate level, these data are also used to draw conclusions about other user states and to assess and adjust the user's health risk. To support this, there exists the data acquisition gateway that can connect to all kinds of smart devices that generate relevant data, so that, the data enter in the platform through the sensors that are aggregated to the Smart Home that works as facility. For all devices to be interconnected, the user's home network must be available.

The collected data then goes to the cloud in a PaaS model that is a cloud computing model in which a third-party provider delivers hardware and software tools to users over the internet.

PaaS does not typically replace a business's entire IT infrastructure. Instead, it tends to incorporate various underlying cloud infrastructure components, such as operating systems, servers, databases, middleware, networking equipment and storage services [44]. Each of these functions is owned, operated, configured and maintained by the service provider.

PaaS also provides additional resources, including database management systems, programming languages, libraries and various development tools.

Many PaaS products are geared toward software development. These platforms offer compute and storage infrastructures, as well as text editing, version management, compiling and testing services that help developers create new software more quickly and efficiently. A PaaS product can also enable development teams to collaborate and work together, regardless of their physical location.

PaaS architectures keep their underlying infrastructure hidden from developers and other users. As a result, the model is similar to serverless computing and function-as-a-service architectures where the cloud service provider manages and runs the server and controls the distribution of resources.

The deployments model for the PaaS can be of the following:

- **Public PaaS** is best fit for use in the public cloud. A public PaaS allows the user to control software deployment while the cloud provider manages the delivery of all other major IT components necessary to the hosting of applications, including operating systems, databases, servers and storage system networks;

- **Private PaaS** aims to deliver the agility of public PaaS while maintaining the security, compliance, benefits and potentially lower costs of the private data center. A private PaaS is usually delivered as an appliance or software within the user's firewall which is frequently maintained in the company's on-premises data center. A private PaaS can be developed on any type of infrastructure;

- **Hybrid PaaS** combines public PaaS and private PaaS to provide companies with the flexibility of infinite capacity provided by a public PaaS and the cost efficiencies of owning an internal infrastructure in private PaaS;

- **Communication PaaS** is a cloud-based platform that allows developers to add real-time communications to their apps without the need for back-end infrastructure and interfaces. Normally, real-time communications occur in apps that are built specifically for these functions. Examples include Skype, FaceTime, WhatsApp and the traditional phone;

- **Mobile PaaS** is the use of a paid integrated development environment for the configuration of mobile apps. In an Mobile PaaS (mPaaS), coding skills are not required. mPaaS is delivered through a web browser and typically supports public cloud, private cloud and on-premises storage. The service is usually leased with pricing per month, varying according to the number of included devices and supported features;

- **OpenPaaS** is a free, open source, business-oriented collaboration platform that is attractive on all devices and provides useful web apps, including calendar, contacts and mail applications. **OpenPaaS** was designed to allow users to quickly deploy new applications with the goal of developing a PaaS technology that is committed to enterprise collaborative applications, specifically those deployed on hybrid clouds.

# 4

# Demonstration

**Contents**

This chapter covers the 4th phase of the DSRM methodology. In order to demonstrate the feasibility of the solution, some use cases, but close to reality, were defined in order to understand the real application of the designed model and a simple test environment was created to understand the features. But firstly, I begin by showing the results of the survey carried out to a random sample of the population to help me be more objective in choosing scenarios for the demonstration.

## 4.1 Survey

In order to better structure my demonstration for the model, I launched a questionnaire on how external factors can affect the individual's well-being. This questionnaire aimed to find out if and which external factors (e.g., background noise, ambient light, ambient temperature) have influence on the individual well-being, from the point of view of the individuals themselves, since we scientifically know that there is a direct relationship between these stimuli and our way of being/acting.

This questionnaire, detailed in Appendix A, was discussed with the psychologist Dr. Isabel Botelho, who reviewed its content and form and also attested to the real influence of the mentioned factors on the individual.

The survey was published online, and collected answers from a population of 140 individuals. The individual's answers about the influencing factors allowed to know the importance of the adaptation of the environment to the user's well-being.

The survey was divided into four sections:

- **Background Noises:** set of questions to know how the user felt in different situations when exposed to background noises.

- **Ambient Light:** set of questions to know how the user felt in different situations with different levels of ambient light.

- **Ambient Temperature:** set of questions to know how the user felt in different situations with different ambient temperatures.

- **Identification Group:** set of questions to collect general data about the user, such as age and gender.

The survey was disseminated on social networks until obtaining 140 valid responses. The prevailing set of answers corresponded to users in the age ranges of 14 to 69 years.

In order to carefully analyze the results, let's look at the responses for each external factor.

### 4.1.1 Background Noises

By analyzing the answers, we could conclude that the majority of the respondents feel bad in the presence of very loud background noises and that this makes it impossible for them to work (maintain concentration) and may even leave them disturbed. The answers of the respondents are presented in Figure 4.1 and Figure 4.2.

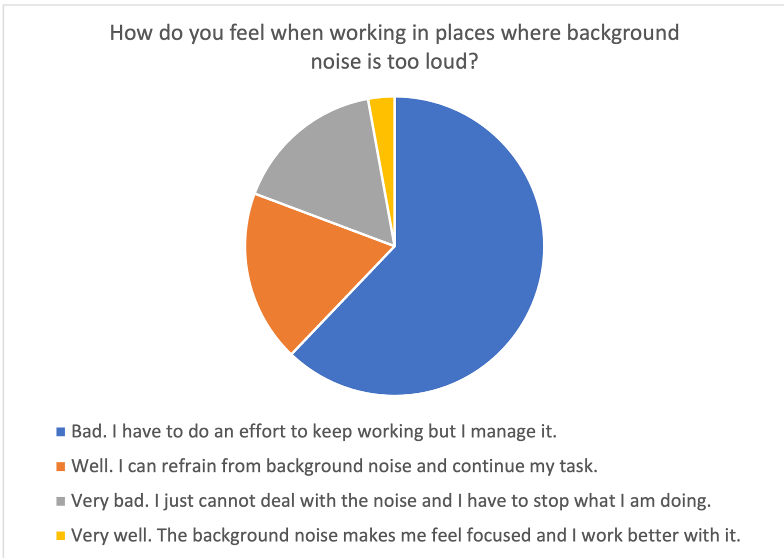


**Figure 4.1:** Results obtained for the question: *How do you feel when working in places where background noise is too loud?*

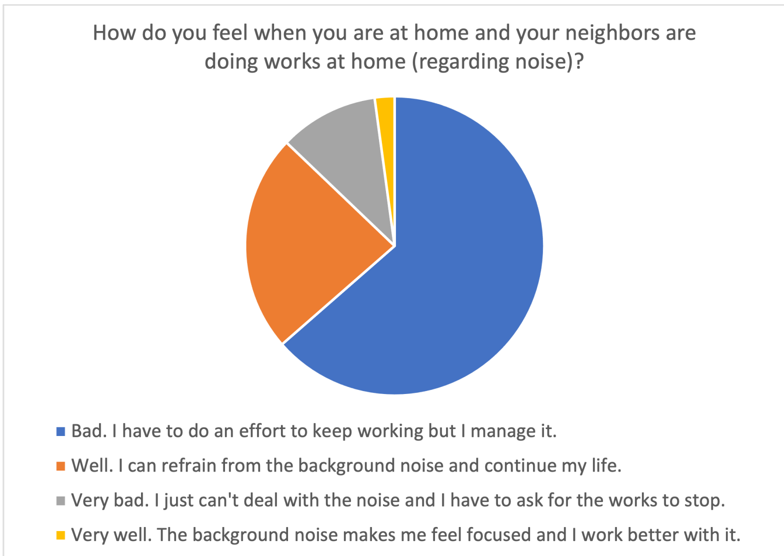


**Figure 4.2:** Results obtained for the question: *How do you feel when you are at home and your neighbors are doing works at home (regarding noise)?*

Regarding feeling relaxed with noise, **50 percent** of respondents said they feel good but never totally relaxed. When asked what kind of sensations they had already experienced when exposed to background noise, respondents inserted most of the answers in: **Loss of Attention** with **99** answers, **Irritability** with **92** answers and **Difficulty Communicating Verbally** with with **54** answers.

We can conclude that background noise has a strong negative impact and that it can disturb the individual.

### 4.1.2 Ambient Light

Analyzing the answers presented in Figure 4.3 and Figure 4.4 we can conclude that the intensity of the ambient light has impact in the spirit state of the individual, as when the light intensity is lower, in spite of some respondents feeling better than others, all agreed that they feel in general, drowsier. But on the contrary, when the intensity of the light is higher, people feel more excited and noisy, and although a large percentage feel good in this environment (35.7 percent) in general, respondents say that it is difficult to maintain concentration.

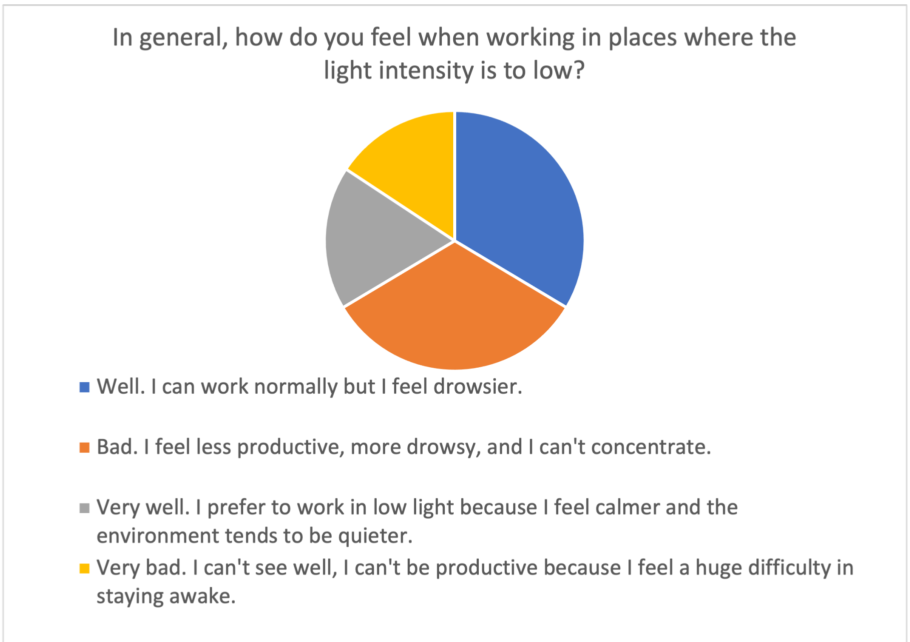


**Figure 4.3:** The graph presents the results obtained for the question: *In general, how do you feel when working in places where the light intensity is too low?*

Regarding feeling relaxed with high intensity light, **43.6 percent** of respondents said they feel bad, tense, and they cannot sleep. When asked what kind of sensations they had already experienced when exposed to low intensity light, respondents inserted most of the answers in: **Ocular sensitivity** with **77** answers, **Sleepiness** with **64** answers and **Relaxed** with **50** answers.

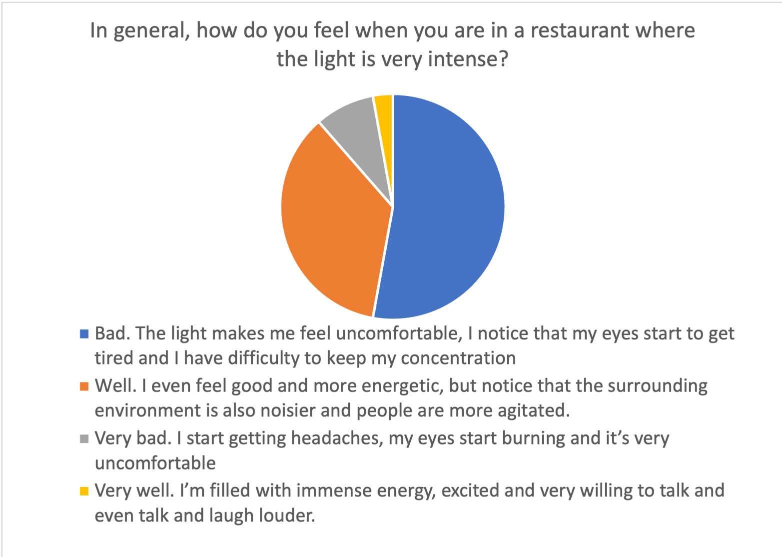


**Figure 4.4:** Results obtained for the question: *In general, how do you feel when you are in a restaurant where the light is very intense?*

### 4.1.3 Ambient Temperature

Figure 4.6 and Figure 4.5 show the results from the important role that temperature plays on the well-being of the individual. The extreme temperatures (too low or too high), in general, lead the individual to feel bad or very bad.

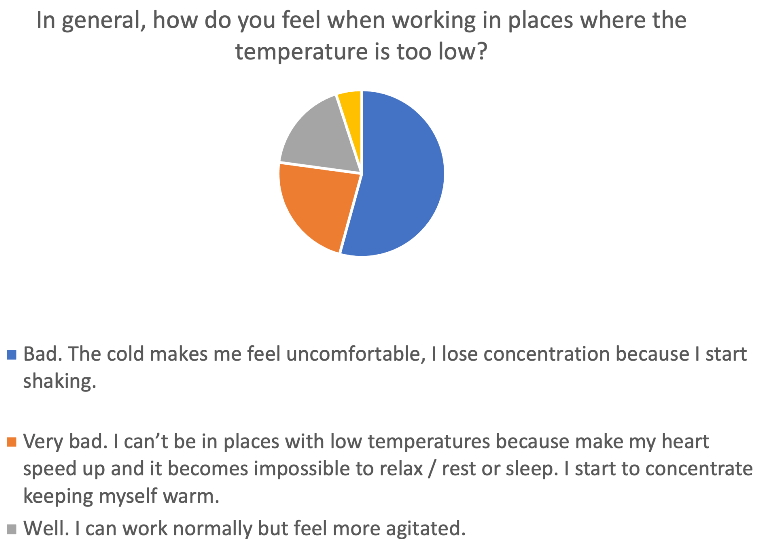


**Figure 4.5:** Results obtained for the question: *In general, how do you feel when you are working in places where the temperature is too low?*

Regarding feeling relaxed with high temperature, **42.99 percent** of respondents said they feel well, sleepy, but not totally comfortable. When asked what kind of sensations they had already experienced

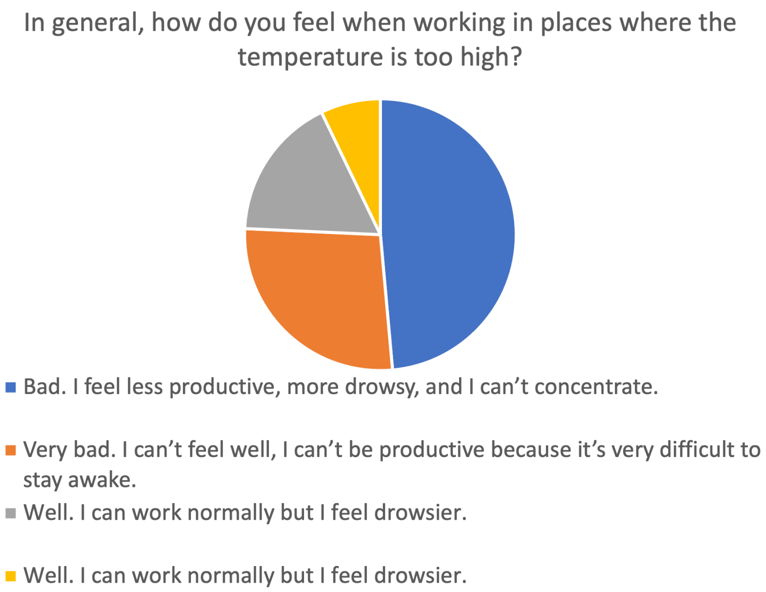


**Figure 4.6:** Results obtained for the question: *In general, how do you feel when working in places where the temperature is too high?*

when exposed to high temperature, respondents inserted most of the answers in: **Dizziness** with **68** answers, **Irritability** with **64** answers and **Headache** with **59** answers. When asked what kind of sensations they had already experienced when exposed to low temperature, respondents inserted most of the answers in: **Tremors** with **115** answers, **Muscles Tension** with **87** answers and **Unproductiveness** with **72** answers.

## 4.2 Test Environment

In order to analyze the procedure and the complexity with which a model of this type can be implemented, a simple local test environment was prepared using the following material (depicted in Figure 4.7):

- **Raspberry Pi 3**
- **Temperature Sensor DHT11**
- **IPhone 11**
- **Apple Watch Series 3**
- **Display**
- **Keyboard**
- **Mouse**

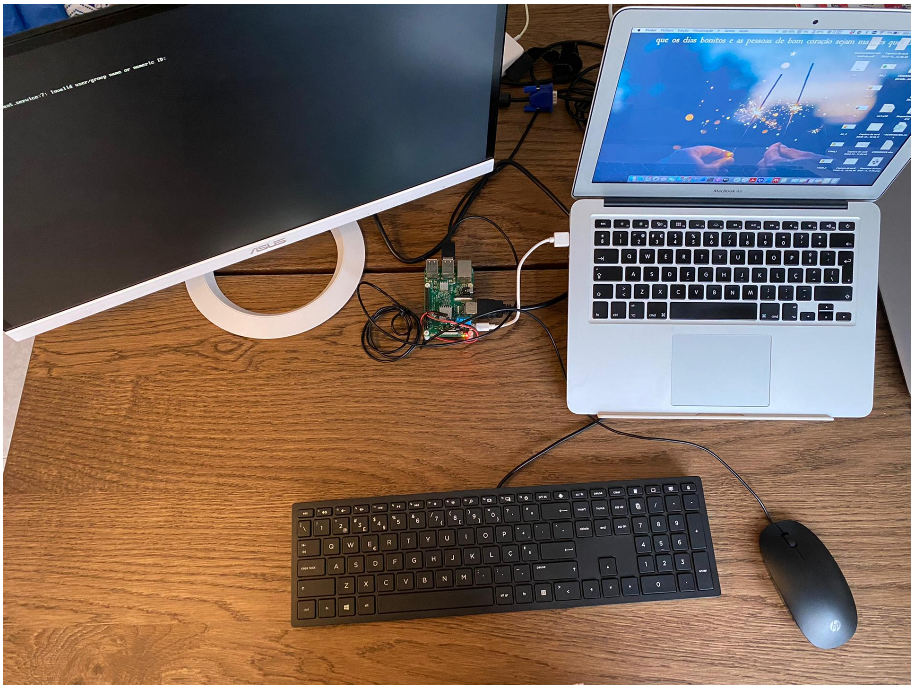

**Figure 4.7:** Environment Test - Hardware

In order to be able to connect all the devices and control them an automation software was used, in this case the Home Assistant (HA). HA is a free, open source home automation software designed to be the central home automation control system for controlling smart home technologies.

The first step was preparing HA to run on the Raspberry Pi, turning it into a networked home automation hub. The access to the interface page of the HA was made by knowing the Internet Protocol (IP) address of the Raspberry Pi, via the URL **http://X.X.X.X:8123** where X.X.X.X. After having the HA installed, a user/owner account had to be set up. This account is an administrator account with privileges to make changes. The next step was to configure a name for the home set also its location and unit system. After that step the HA was able to discover all the devices in the network.

After that, the DHT11 Sensor of Humidity and Temperature was installed in the Raspberry Pi allowing to immediately start collecting and displaying values in the interface, as illustrated in Figure 4.8.

With the application of HA in the iPhone and Apple Watch, the automation procedures were stated, allowing then to receive notifications at all the configured devices. The MQTT protocol was used in the development of a small example app installed in he smart devices, as illustrated in Figure 4.9.

With this integration it was also possible to trigger actions, such as controlling the intensity of the ambient light.

Through this simple test environment I was able to draw some conclusions:

- Through simple hardware and open software it is already possible for users with some basic knowledge to build their own intelligent environments;

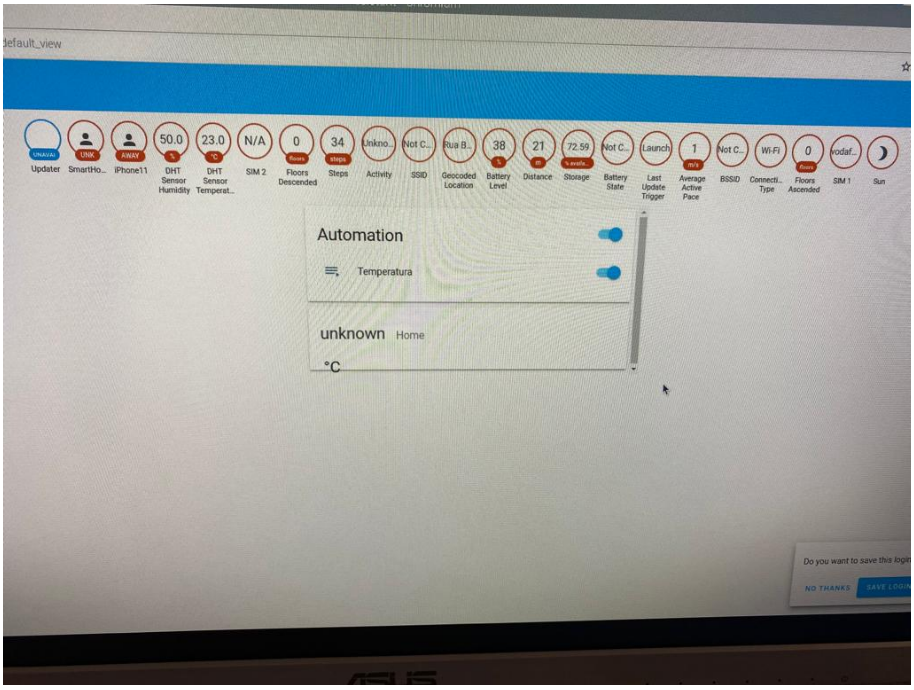


**Figure 4.8:** Home Assistant: Interface with Humidity and Temperature Data


**Figure 4.9:** Home Assistant: Notifications in the smart Watch

- Through automation procedures it is possible to create simple and common interactions between different devices of the user's living ambient such as sensors and actuators;
- With the combination of applications it is possible to go further, for example, with an application that reads and interprets vital signs, such as heart rates (captured by the Apple Watch) we can connect to the HA and create interactions with other sensors;

We concluded from this simple test environment that, with an implementation based on the designed Model, we would be able to create powerful interactions and adaptations in a larger scale, and even more powerful and reliable solutions that can make a difference in the user's life.

## 4.3 Demonstration Scenarios

In order to demonstrate the diversity of options that implementations based on the the developed model allows, some hypothetical (but close to reality) scenarios were defined.

### 4.3.1 Case Scenario 1: User without Pathologies

This use case includes household assistant system, wearables (smartwatches) and connected devices (stress sensor, smartphone and Wi-Fi radio). The household assistant system is connected to a certificated health app.

*Maria, 26, lives on the outskirts of the city and is a student worker. Despite not having any health problems, she lives alone and decided to equip her home to provide assistance to her health and well-being. The system installed in her home provides an environment with a variety of sensors, actuators and interconnected smart devices that work together to make her home a safe place that helps Maria maintain her well-being. These devices are easy to use and allow Maria to personalized their interfaces and also to configure the connectivity to her contracted operator. This also allows, if necessary, remote operation in some of the devices by authorized personnel. As part of the system's infrastructure, Luísa and José's smartphones, her parents, also interact with Maria's home. Maria uses her smartwatch daily, which allows her to see her physical activity and check her heartbeat. She can even do a simple Electrocardiogram (ECG) through the smartwatch. Maria has always been an anxious young woman and at the time of college exams, under the pressure to manage her professional work and obtain good results in the exams the anxiety grows. In order to ensure that her stress levels are kept under control, Maria also uses a portable sensor that measures her stress levels daily. Her home system is capable of storing both her heart rate and values measured by her stress sensor, as well as interpreting them. Through an algorithm, the system combines the measurements in order to provide assistance to Maria (in her well being status). During the afternoon Maria felts a little anxious and the system detected that* *her heart rate values were higher than usual, so the system sent to her a notification to her smartwatch and smartphone, with an advice saying: "Hi Maria, you seem a little anxious, why don't you do some breathing exercises?". Later, the system continues to detect that although the values are not dangerous, they are still slightly altered and notifies Maria again with the following message: "Do you want to make the house more relaxing?" with Maria's option choosing "Yes" or "No". Maria chooses "Yes" through her smartwatch and the system adapts her home to help Maria to stay more relaxed by decreasing the brightness and color temperature of the house lights and activating her radio with the playlist that Maria has set to relax.*

### 4.3.2 Case Scenario 2: User with Diabetes Type 2

This use case introduces a vital parameter and mental state monitoring system. The system can measure and report sleep quality. It also can detect emergencies like heart attacks or upcoming depression bouts, being then able to activate an emergency call and give first aid advices to the user. The system also includes a reminder function for medical measurements (blood values).

*Leonel, 68, is diabetic and like most adults over 65 has difficulty sleeping. To help, he monitors the quality of his sleep. His home system has been fitted with sensors located on Leonel mattress that record his movements, breathing and ECG data during the night. Leonel, woke up at 6 am and the monitor, his Smart TV, indicates that his sleep quality index had been 50 percent, a not very nice value. Leonel is also prone to isolation and outbreaks of depression due to his low self-esteem related to his overweight. So, his home was also equipped with mechanisms and sensors that can constantly measure his cognitive and emotional states. When the system detects an emergency situation, his family and the medical emergency are triggered. Due to his difficulty in getting around, Leonel is followed by his psychotherapist through weekly tele-consultations. To remind Leonel of measuring glucose levels in the morning, the system uses the home sound system to warn Leonel, through a personalized message recorded with her granddaughter's voice, in order to motivate him for his health: "Good morning Grandfather, are we going to measure your goblins?". When measuring his levels, on this day, Leonel noticed that they were a little high. After having breakfast, when he went to the living room, he started to feel a strong pain in his heart and his smartwatch detects that he is having a heart attack. His home system automatically triggers the medical emergency and his family while his system instructs him to do a cardiac massage.*

### 4.3.3 Case Scenario 3: User in a Hospital Environment

This use case is for a hospital environment. Users/patients are equipped with smart bracelets, and the environment is equipped with smart lamps, as well as devices for well-being external factors that have influence in the individuals, such as controlled aromatherapy Air diffusers.

*The 10-year-old Salvador, today, goes with his parents to the downtown health center to get the tetanus vaccine. Salvador is always a little nervous when he goes to the vaccines and, before entering the office, he is usually already crying. But the health center installed in its pediatric office a system with smart lamps with different color temperatures and tonalities, as well as remotelly controlled relaxing aroma air diffusers. In addition, the children, before entering for each consultation, receive an electronic bracelet that is personalized with the information of their favorite color and favorite cartoons. Salvador received his bracelet, containing the information of his favorite color (orange) and favorite cartoon (Mickey Mouse). Upon entering the office with his bracelet, the TV monitor started displaying an episode with Mickey, the lamps changed their color to a cozy orange and a light lavender scent was felt in the air. Salvador quickly forgot that he was going to take a vaccine and kept instead his attention on Mickey while feeling comfortable with the orange lighting environment, and the lavender scent that made him relax. Without realizing, he took the vaccine without crying.*

# 5

# Evaluation

## Contents

The fifth phase of the DSRM methodology, corresponds to the evaluation of the produced artefact, in our case, the Model. The evaluation consists of measuring how well the model supports a solution to the formulated problem, comparing it with the objectives proposed in Section 1.3 with the results obtained in the demonstration, Chapter 4. For that purpose, the consistency of the model will be evaluated through the designed case studies described in Chapter 4.

## 5.1 Evaluation of the Model

The evaluation of the functionalities provided by the developed model will be based on mapping them in a role play of each of the case studies, in order to assess how the model corresponds and respects the formulated requirements in different situations.

### 5.1.1 Evaluation: Case Scenario 1

In the first scenario (User without Pathologies) it is straightforward to confirm that all requirements are met. The generation of data is initiated by the smartwatch that measures Maria's heart rate and her stress sensor that measures her stress levels. The data is captured/collected differently (the data from the watch automatically and the data from the stress sensor is inserted into the application manually by Maria) and in different formats. In this way, the collected data undergoes transformations into normalized and perceptible formats, then stored in a cloud based platform to be quickly accessible. These data also undergo analytical processes in order to be organized in the best way. Once contextualized, they are used by the system to interpret and make decisions (these actions are not visible to the user but are essential to the core functions of the model).

In this situation, the platform eventually detects that the current measurements from the user are slightly altered, which leads the system to activate the notification subsystem and to send Maria a first notification with an advice for her to perform breathing exercises. The system, through the heart rate data that is continuously being generated and captured into the system, realizes that the values continue to changed and sends another notification to Maria with the possibility of taking adequate action.

The notification asks Maria if she wants to turn the environment more relaxing and Maria, by choosing "yes" triggers an action to order the device manager and the actuation subsystem to activate the smart lamps (turn off or dim the lamps), the blinds (they will lower slightly) the smart wi-fi radio (which already has the playlist relax stored). Figure 5.1 demonstrates the adaptation of the environment.

In this way, we can do the match between the requirements of the model and the use case scenario:

- **Data Generation:** smartwatch and stress Sensor

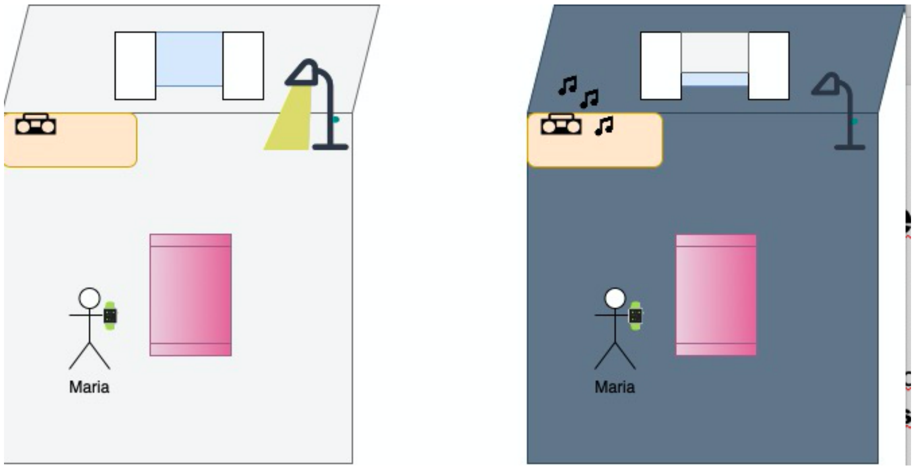


**Figure 5.1:** Use Case Scenario 1: User without Pathologies

- **Processing and Storage Subsystem:** the system shows the ability to store information and to process it, being able to interpret and combine the data it receives.
- **Consumer Subsystem:** health app.
- **Device Manager:** the function of the device manager is demonstrated through the way sensors and actuators are activated in order to take the necessary actions.
- **Appropriate Access Control Policies:** Maria and her parents could access the system.
- **Notifications Service:** advice to perform breathing exercises and authorization to adapt the house.
- **Actuation Subsystem:** smart lights, smart blinds and wi-fi radio.

The advantage that we can see in this use case scenario is that the model provides the functions of a holistic system that aims at the well-being of the user and that users without any pathology may be interested in using a system like this in order to improve their quality of life and prevent health problems in the future.

### 5.1.2 Evaluation: Case Scenario 2

The second scenario shows the adaptation of a system based on the model, for a user suffering from chronic Diabetes Type 2. The generation of data is represented by the sensors included in the smart mattress that capture different signals from the user, by the glucose meter and by the user smartwatch. Derived from his age, Leonel also has consumer systems that are better suited to his dexterity with technologies, such as a less intrusive application and even tele-consultations. The notification system in this scenario is also adapted as we see that Leonel receives audio notifications, which to be more

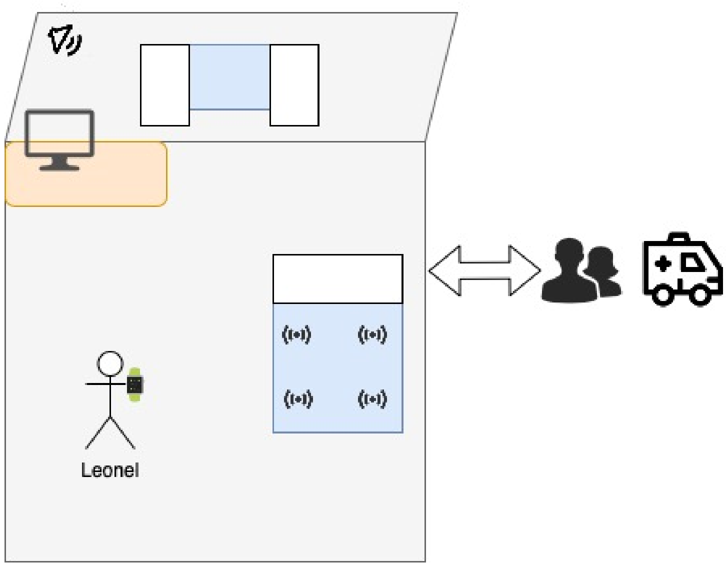


**Figure 5.2:** Use Case Scenario 2: User with Diabetes Type 2

noticeable, are from a familiar voice. Derived from Leonel's health problems, we see that the access control policies allow the direct family members and the medical emergency personnel to have access to the system continuously, in order to be able to provide assistance as quickly as possible. The actuation system is then visible when the system of his home is active for the detection of heart attack and this takes the action to notify the family members and medical emergency personnel. At the same time the system gives Leonel instructions to start a cardiac massage. The process of adaptation in this scenario is illustrated in Figure 5.2.

In this way, we can do the match between the requirements of the model and the use case scenario:

- **Data Generation:** sleep sensors, smartwatch.
- **Processing and Storage Subsystem:** the system shows the ability to store information and to process it when it is able to interpret and combine the data it receives.
- **Consumer Subsystem:** health app and tele-consultations.
- **Device Manager:** the function of the device manager is demonstrated through the way sensors and actuators are activated in order to take the necessary actions:
- **Appropriate Access Control Policies:** family and medical emergency having access to the platform.
- **Notifications Service:** warning to remind to measure diabetes, and to perform cardiac massage.
- **Actuation Subsystem:** home sound system.

In this use case scenario we can see that people with chronic diseases could be monitored even at a distance, allowing them to have a better quality of life and also to live without depending on the continuous local care of others. Even in situations of some mental illnesses, in this case represented by ageing, it is also possible to be properly accompanied without having to travel constantly for consultations.

### 5.1.3 Evaluation: Case Scenario 3

In the third scenario, the data generation is represented by the smart bracelets that are personalized with adequate information about the user, allowing the actuation system to be activated and in turn changes the ambient environment devices of the consumer system, by starting displaying the preferred cartoons on the TV set and also activating the intelligent air diffuser to release the light lavender aroma through the office, as well as changing the color of the smart lamps for the user's liking. Figure 5.3 demonstrates the adaptation of the environment for this use case scenario.

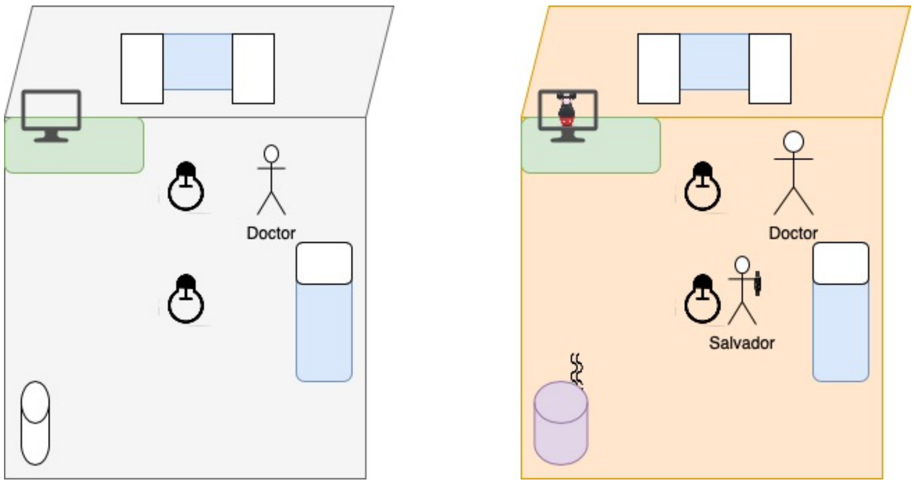


**Figure 5.3:** Use Case Scenario 3: User in a Hospital Environment

In this way, we can do the match between the requirements of the model and the use case scenario:

- **Data Generation:** smart bracelets.
- **Processing and Storage Subsystem:** the system shows the ability to store information and to process it when it is able to interpret and combine the data it receives.
- **Consumer Subsystem:** cartoons in the medical TV set.
- **Device manager:** the function of the device manager is demonstrated through the way sensors and actuators are activated in order to take the necessary actions.
- **Appropriate Access Control Policies:** system is fully controlled by the hospital.

- **Notification Service:** not represented.
- **Actuation Subsystem:** the consulting room display, smart air aroma diffuser and smart lamps.

The great advantages of a system in operation like the one here described in pediatric offices are that this type of solution may have a relatively low cost and can make all the difference in child care. A calm and distracted child makes it easier for the doctor to do his job correctly.

The higher level of security and protection are requirements that are mandatory to be fulfilled on platforms such as these, in order to be commercialized to the public because they use and work with sensitive, personal and confidential data of the individual.

## 5.2 Limitations of the Model

The model may be limited in its non-functional requirements, that can be strongly related with the hardware and software chosen for each solution. The type of devices, personal and environmental, will dictate the type of adapters/interfaces to be used, the way in which sensors or wearables generates data and also the cloud platform solutions used for processing and storing all the information, all directly linked to the quality of service that such platform can provide, as well as its scalability.

Common and usual problems are those related with the integration of different devices from different manufacturers or using different types of protocols. Solutions to overcome these limitation, are typically on the development of adequate adapters and converters as well as new/updated functionalities in the APIs and User Interfaces.

# 6

# Conclusion

## Contents

The main objective of the work in this thesis, was to develop a proactive, non-intrusive and user-friendly ambient intelligent model for life reinforcement to help users in their daily health and wellness decisions. That objective was derived from the problem that currently exists, of people living longer and acquiring various chronic diseases, increasing the burden on society. This burden typically falls on health services, caregivers and families, with potentially serious consequences, such as the overload of health services, as factually occurred all over the World in early 2020, as consequence of the COVID-19 pandemic.

## 6.1 Discussion and Conclusion

To conduct this research, I followed the DSRM methodology, which consist of 6 phases. I started by identifying the problem and the research on current technologies and projects developed in the area, with possible solutions to the problem, allowing subsequently to discover the gaps in the market. After aligning the requirements for a model of a Platform envisioned to provide the adequate functionalities, I started its design to match the required features. In order to demonstrate the feasibility of the solution, some case studies were created considering hypothetical scenarios, but close to reality, in order to understand the real application of the designed model. Finally, to evaluate the accuracy of the methodology, I analyzed if the functionalities mapped from the playout of the use cases corresponded to the defined requirements. From the evaluation results I can conclude that the model meets the requirements and objectives formulated.

Some of the advantages of the model, are:

- It can be completely adapted to the needs of each user;
- It can help people with chronic illnesses and also people who are concerned with maintaining their well-being;
- It has the ability to help the physical and psychological well-being of the user, showing to be a holistic model;
- It is scalable and can integrate a wide variety of devices and software;
- It is reliable because regardless of the solutions developed based on the model, it conforms to the connections to healthcare infrastructures;
- It is an asset for helping to relieve the burden of health systems, caregivers and family members;
- Introduces a proactive health concept that allows users to start taking care of their health as soon as possible;

- It is an asset in pandemic situations as it allows the control of patients infected with mild symptoms with medical support at a distance, thus protecting patients and health professionals.

## 6.2 Communication

The last phase of the DSRM methodology is to communicate the problem, the solution and the results to the scientific community. In this way, this document with all the work developed has as its purpose the communication.

## 6.3 Future Work

Regarding the outcome of this thesis work, there are several research opportunities that can be addressed for future work:

- Develop a real prototype of this model;
- Develop a solution in partnership with hospital networks that wish to have this type of services for their customers;
- Collect more opinions and suggestions from health professionals and users to reformulate the model with more options;
- Attract several companies that can be involved in solutions based in this model, for its divulging in the market;

Concluding the thesis work, it was done positively, it achieved the objectives that I set myself and the presented solution can bring many advantages for the health and well-being of individuals.

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# A

# Survey

This survey was published online until obtaining 140 answers. Below is the survey content:

*As part of the study for my Master's thesis with the theme Ambient Intelligent Model for Life Reinforcement to obtain the Master of Science Degree in Telecommunications and Informatics Engineering in Instituto Superior Técnico, I am asking the public how external factors can affect the individual's well-being in order to create an adaptive and proactive platform that can help not only individuals with chronic illnesses but also help everyone improve their overall health. This form collects your email address.*

**Background Noise**

**A. How do you feel when working in places where background noise is too loud?**

1. Well. I can refrain from background noise and continue my task.

2. Very bad. I just cannot deal with the noise and I have to stop what I am doing.

3. Very well. The background noise makes me feel focused and I work better with it.

4. Bad. I have to do an effort to keep working but I manage it.

**B. How do you feel when you are at home and your neighbors are doing works at home (regarding noise)?**

1. Well. I can refrain from the background noise and continue my life.
2. Very bad. I just can't deal with the noise and I have to ask for the works to stop.
3. Very well. The background noise makes me feel focus and I can rest better with it.
4. Bad. I have to do an effort to keep calm but I manage it.

**C. Can you rest when there is noise around you, e.g., at the beach, at home in the living room, on the terrace, etc.?**

1. Very well. I can abstract myself and the noise makes me feel secure.
2. Well. I can even calm down but never fully relax, for example I can't fall asleep, take a nap.
3. Bad. I get tense and want to leave the place.
4. Very bad. I simply can't be in places with background noise, makes my heart speed up and it becomes impossible to relax / rest.

**D. Please choose 3 feelings that you already felt when you were exposed to background noise:**
[ ] Accelerated heart [ ] Insomnia [ ] Stress [ ] Headache [ ] Difficulty Communicating Verbally [ ] Muscle Tension [ ] Loss of Hearing [ ] Loss of Attention [ ] Irritability

**E. Please choose the value ,with a X, that better describes your tolerance to the background noise (where 0 – very intolerant and 5 – very tolerant):**

| 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| | | | | | |

**Ambient Light:**

**F. In general, how do you feel when working in places where the light intensity is to low?**

1. Very well. I prefer to work in low light because I feel calmer and the environment tends to be quieter.
2. Well. I can work normally but I feel drowsier.
3. Bad. I feel less productive, more drowsy, and I can't concentrate.
4. Very bad. I can't see well, I can't be productive because I feel a huge difficulty in staying awake.

**G. In general, how do you feel when you are in a restaurant where the light is very intense?**

1. Very well. I'm filled with immense energy, excited and very willing to talk and even talk and laugh louder.
2. Well. I even feel good and more energetic, but notice that the surrounding environment is also noisier and people are more agitated.
3. Bad. The light makes me feel uncomfortable, I notice that my eyes start to get tired and I have difficulty to keep my concentration.
4. Very bad. I start getting headaches, my eyes start burning and it's very uncomfortable

**H. In general, can you rest when you are in places with high light intensity?an you rest when there is noise around you, e.g., at the beach, at home in the living room, on the terrace, etc.?**

1. Very well. I can rest/sleep everywhere, the light isn't a problem.
2. Well. I can even calm down but never feel fully relaxed, for example I can't fall asleep, take a nap.
3. Bad. I get tense, despite the tiredness, I can't fall asleep and it becomes difficult to close the eyes.
4. Very bad. I simply can't be in places with high light intensity, makes my heart speed up and it becomes impossible to relax / rest, sleep or close my eyes.

**I. Please choose 3 feelings that you already felt when you are exposed high intensity light:** [ ] Ocular Sensitivity [ ] Excitement [ ] Stress [ ] Headache [ ] Loss of Attention [ ] Insomnia [ ] Tendency to speak too loudly [ ] More Hasty [ ] Irritability

**J. From the 9 options below, please choose 3 feelings that you already felt when you are exposed to low intensity light:ease choose 3 feelings that you already felt when you are exposed high intensity light:** [ ] Ocular Sensitivity [ ] Sleepiness [ ] Relaxed [ ] Headache [ ] Loss of Attention [ ] Tired [ ] Uncommunicative [ ] Unproductive [ ] Tendency to talk down

**Ambient Temperature:**

**K. In general, how do you feel when working in places where the temperature is too high?**

1. Very well. I prefer to work in heat because I feel more comfortable.
2. Well. I can work normally but I feel drowsier.
3. Bad. I feel less productive, more drowsy, and I can't concentrate.
4. Very bad. I can't see well, I can't be productive because I feel a huge difficulty in staying awake.

**L. In general, how do you feel when you are working in places where the temperature is too low?**

1. Very well. I prefer to work in cold because I feel more comfortable.
2. Well. I can work normally but feel more agitated.
3. Bad. The cold makes me feel uncomfortable, I lose concentration because I start shaking and I start to concentrate in warming myself up.
4. Very bad. My heart rate increases, I can't stop shaking, it's impossible to concentrate.

**M. In general, can you rest when you are in places with high temperature?**

1. Very well. I can rest/sleep everywhere, the temperature isn't a problem.
2. Well. The heat helps me to become sleepy so I can fall asleep but I'm not totally comfortable.
3. Bad. I get tense, despite the tiredness, can't fall asleep and it becomes difficult to breath.
4. Very bad. I can't be in places with high temperatures because make my heart speed up and it becomes impossible to relax / rest or sleep. I start to concentrate on refreshing myself.

**N. Please choose 3 feelings that you already felt when you were exposed to high temperature:**

[ ] Nausea [ ] Dizziness [ ] Headache [ ] Insomnia [ ] Stress [ ] High heart rate [ ] Sleepiness [ ] Irritability

**O. Please choose 3 feelings that you already felt when you were exposed to low temperature:**

[ ] Tremors [ ] Arrhythmia [ ] Headache [ ] Anxiety [ ] Muscle Tension [ ] Rapid breathing [ ] Loss of Attention[ ] Unproductiveness [ ] Depression feeling

**Identification Group:**

**How old are you?:**

(Please enter your age)

**Gender:**

1. Female
2. Male

*The End! Thank you for your participation, your answers will be precious to the quality of this work!*