FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO

Analysis and Prototyping of Remote Patient Monitoring Applications

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Resumo

O setor da saúde atravessa uma grande transformação digital, sendo a pandemia covid-19 um contribuinte significativo para a mesma. A monitorização remota de pacientes é uma das principais áreas prioritárias desta transformação. Através deste tipo de monitorização é possível fornecer cuidados de saúde mais personalizados aos pacientes, permitindo aos profissionais médicos alcançar decisões mais rápidas e individuais. Isto é conseguido fornecendo a ambos plataformas que exibem os dados relacionados com a saúde do paciente em tempo real e lhes permitem comunicar entre si através de funcionalidades como o envio de mensagens ou o reporte de sintomas do paciente. Com isto, é possível alcançar uma visão de 360º, em que o paciente e os profissionais médicos visualizam exactamente os mesmos dados, estando assim ambos conscientes do estado de saúde actual do paciente a ser monitorizado.

A Deloitte Portugal tem um grande interesse em fazer parte desta transformação, particularmente na área da monitorização remota. À luz disso, este projecto de dissertação proposto teve como objectivo analisar e prototipar aplicações de monitorização remota de pacientes na plataforma *OutSystems*. Em primeiro lugar, foi realizada uma pesquisa sobre o estado da arte da monitorização remota de pacientes, com particular incidência em aplicações, e plataformas de baixo-código. Posteriormente, com os resultados da pesquisa e as opiniões da empresa baseadas na experiência na área, foi possível conceber e implementar um protótipo inovador, consistindo em duas aplicações para a monitorização remota da saúde geral de pacientes: aplicação *RPM Mobile* para pacientes e aplicação *RPM Web Reactive* para profissionais médicos.

O protótipo desenvolvido foi validado pela recolha de feedback através de questionários a um médico e a colegas da Deloitte especialistas na plataforma *OutSystems*. De acordo com os resultados, ambas as aplicações são simples de utilizar e têm interfaces intuitivas, o que é crucial para os utilizadores idosos. Os resultados indicam também que as aplicações são eficientes e úteis, com um significativo potencial futuro.

De acordo com os resultados, é viável concluir que o protótipo foi desenvolvido com sucesso, satisfazendo os objectivos da dissertação. De facto, devido às suas características inovadoras, o protótipo será demonstrado numa próxima reunião com a equipa *OutSystems* da Deloitte, sendo possível a sua útilidade para projectos em curso ou futuros. Importa também notar que os resultados do estado de arte irão permitir à Deloitte tomar decisões informadas e atualizadas relativamente à estratégia a desenvolver nesta área.

Palavras-chave: transformação digital; monitorização remota de pacientes; cuidados de saúde; personalizado; aplicações; *OutSystems*.

Abstract

The health sector is undergoing a major digital transformation, with the covid-19 pandemic being a significant contributor. Remote patient monitoring is one of the main priority areas of this transformation. Through this type of remote monitoring, it is possible to provide more personalised healthcare to patients by enabling medical professionals to reach faster and individual decisions. This is accomplished by providing both of them with platforms that display the patient health-related data in real-time and allow them to communicate with each other through functionalities such as messaging or reports of patient symptoms. With this, it is possible to achieve a 360º vision: the patient and the medical professionals view exactly the same data, thus both are aware of the current health status of the patient being monitored.

Deloitte Portugal has a vested interest in being a part of this transformation, particularly in the area of remote monitoring. In light of that, this dissertation project aims to analyse and prototype remote patient monitoring applications in the OutSystems platform. Firstly, a research on the state of the art regarding remote patient monitoring, with particular focus on applications, and low-code platforms, was performed. Then, with the outcomes of the research and the company's opinions based on experience in the area, it was possible to design and implement an innovative prototype, consisting of two applications for the remote monitoring of patient's general health: RPM Mobile application for patients and RPM Web Reactive application for medical professionals.

The developed prototype was validated by gathering feedback through questionnaires to a doctor and Deloitte colleagues with expertise in the OutSystems platform. According to the results, both applications are simple-to-use and have intuitive interfaces, which is crucial to elderly users. The results also indicate that the applications are efficient and useful, with significant future potential.

In accordance with the results, it is viable to conclude that the prototype was successfully developed, satisfying the dissertation objectives. In fact, due to its innovative characteristics, the prototype will be demonstrated in a forthcoming meeting with Deloitte's OutSystems team, thus being possible its utility for ongoing or upcoming projects. It is also important to mention that the outcomes of the state of the art will allow Deloitte to make informed and updated decisions regarding the strategy to be developed in this area.

Keywords: digital transformation; remote patient monitoring; healthcare; personalised; application; OutSystems.

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Aos chatos de todas as horas, António e Tomás, pelas conversas e brincadeiras que partilhamos juntos. Obrigada por me fazerem rir nos momentos em que o meu feitio não é o melhor.

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Inês Xavier de Carvalho

"However difficult life may seem,
there is always something you can do and succeed at."

Stephen Hawking

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Abbreviations

DTTL	Deloitte Touche Tohmatsu Limited
RPM	Remote Patient Monitoring
DSS	Decision Support System
CDSS	Clinical-Decision Support System
CAGR	Compound Annual Growth Rate
mHealth	Mobile Health
IoT	Internet of Things
ECG	Electrocardiogram
BCG	Ballistocardiogram
CGM	Continuous Glucose Monitoring
AQI	Air Quality Index
TVOC	Total Volatile Organic Compound
PM	Particulate Matter
PROMs	Patient-Reported Outcomes Measures
PROMIS	Patient-Reported Outcomes Measurement Information Systems
GPH	Global Physical Health
GMH	Global Mental Health
NRS	Numeric Rating Scale
WHO	World Health Organization
LCAP	Low-Code Applications Platform
LCDP	Low-Code Development Platform
API	Application Programming Interface
MTM	Medical Team Member
SOA	Service-Oriented Architecture
HIPAA	Health Insurance Portability and Accountability Act
GDPR	General Data Protection Regulation

Chapter 1

Introduction

The present document, developed in the scope of the Course Unit Dissertation of the Master in Electrical and Computer Engineering, presents a project on remote patient monitoring developed at Deloitte Portugal.

This first chapter consists of the introduction of the present document.

Section 1.1 introduces the company responsible for the proposed dissertation's projects and the environment where the project was developed.

Section 1.2 describes and justifies the context and motivations, from a business and personal point-of-view, of the dissertation project, and section 1.3 the objectives of the dissertation.

Lastly, section 1.4 details the methodology adopted for the development of the dissertation's project, as well as the document structure for better navigation throughout the document.

1.1 About Deloitte

Deloitte is a brand composed of independent firms from all over the world that work together to offer services such as audit and assurance, consulting, financial advising, risk advisory, tax, and associated services to clients in various industries. These firms are members of DTTL (Deloitte Touche Tohmatsu Limited) or, in simpler words, Deloitte Global, and are structured in compliance with national laws and regulations, among other factors [24].

Deloitte Portugal, one of DTTL's firms, currently employs approximately 4000 professionals based in offices in Lisbon, Porto and Viseu [25]. Deloitte Technology S.A., one of the companies within this firm, proposed the dissertation project. This company comprises, among others, a team named LCNC (Low-Code/No-Code) which is dedicated to the development of applications using the OutSystems low-code platform.

1.2 Context and Motivation

The covid-19 pandemic impacted both negatively and positively the healthcare sector. Although the pandemic caused a high pressure on this sector due to the gap between increasing demand and decreasing capacity, it served as a catalyst for its digital transformation in this. The pandemic enabled an increase in the integration of virtual care into our healthcare system, which would take years to achieve otherwise [1].

The five current priority areas in the digital transformation of the health sector are the ones illustrated in figure 1.1.

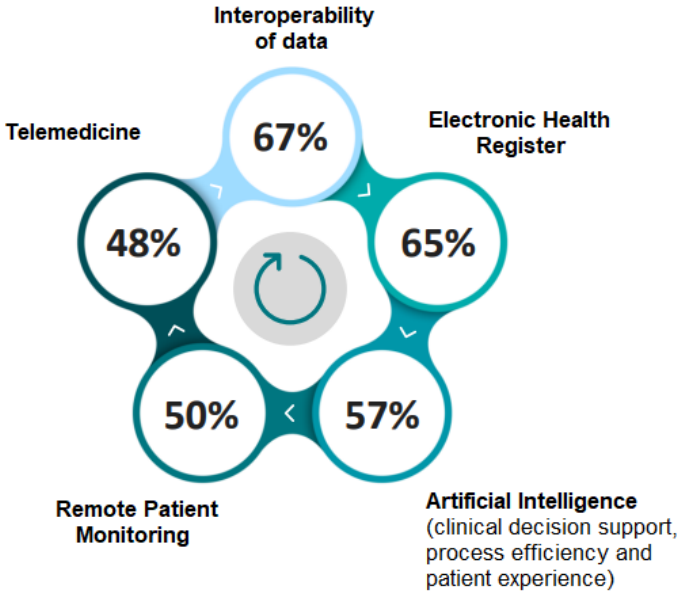


Figure 1.1: Priority Areas in the Digital Transformation of the Health Sector.
Adapted from [1].

Regardless of what has been previously stated, a study found that approximately 88.00% of healthcare providers had already invested in remote patient monitoring or planned to do so in the near future. As a result, it was also predicted an anticipation of the increase in wearable devices, as these aid in the delivery of medical treatment by personalising and optimising it [26].

The focus of the dissertation corresponds to the fourth priority, remote patient monitoring. This type of monitoring allows a more accessible, optimised and cost-effective patient-centered healthcare. In turn, the patient-centered approach enables appropriate care by allowing the medical professionals to make personalised medical decisions in real-time. In general, RPM can be viewed as a tool for improving the medical service [27] [2].

> "Remote monitoring opens up the ability to see the nuances and changes that are happening in the moment with that patient and the ability to be able to intervene" - Cindy Vunovich, Vice President Clinical Integration and Performance at Allegheny Health Network [28]

Deloitte Portugal is not indifferent to this global digital transformation, wanting to be part of it. Indeed, they have already begun integrating themselves into these areas, especially in remote patient monitoring. Section 3.2.1 introduces their most recent work in this area: the development and implementation of a remote monitoring functionality into the pre-existed MY LUZ application of the Luz Saúde Group. This work is present several times during the development of the dissertation's project since the project was developed with the support, based on experience, and suggestions, based on the outcomes of the state of the art research of Nuno Parreira Jacinto, the Deloitte manager involved in the development of the pre-mentioned work. With that said, the motivation for this project proposal by Deloitte Portugal stemmed from an interest in exploring and innovating the remote patient monitoring area of digital transformation.

On a more personal basis, the motivation corresponds to obtaining a distinctive work experience in an area of interest and constant growth, as well as programming skills on the OutSystems platform.

1.3 Objectives

In accordance with what is presented in the context and motivation section 1.2, it is Deloitte's interest to continue exploring and innovating in the area of remote patient monitoring. Thereby, the primary objective is the design and implementation, in the OutSystems platform, of a prototype consisting of two applications, one destined for patients and another for medical professionals, to remotely monitor patients' general health

To complete the primary objective, a state of the art research on remote patient monitoring, with a particular focus on this type of remote monitoring applications, is necessary. A research on the current available low-code platforms, with specific emphasis on the OutSystems platform, is also viable. The outcomes of this research are crucial both for the definition of the applications requirements and for Deloitte to obtain more current knowledge on this digital transformation area. In order to thoroughly verify the quality of the two applications, a pre-implementation medical validation is also essential.

Following the implementation of both applications, it is crucial to assess their usability, among other factors. Thereby, a post-implementation validation is also implied.

1.4 Methodology and Document Structure

The methodology adopted for this dissertation project, which is based on the systems engineering processes, is depicted in figure 1.2.

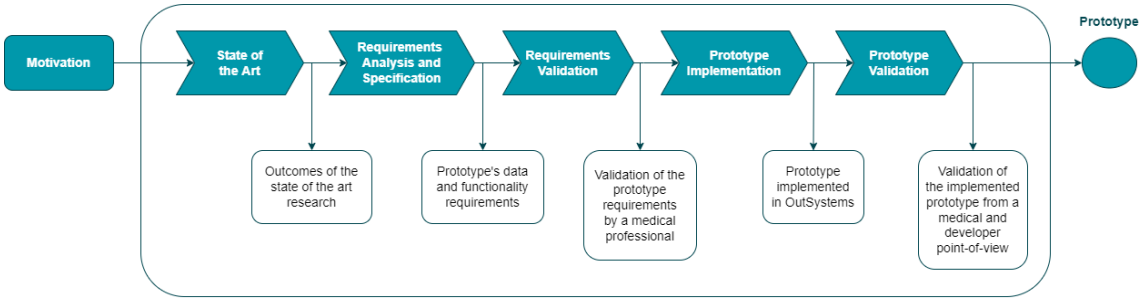


Figure 1.2: Methodology

The methodology consists of five steps. As illustrated in the figure above, the dissertation's motivations, which are detail in section 1.2, correspond to the methodology input, i.e., the factors that sparked to the project's development.

The first step, state of the art, corresponds to an academic research and subsequent analysis of remote patient monitoring systems. It is also included in this stage a review regarding the low-code platforms available for implementing the two applications, with a particular focus on the OutSystems platform, which Deloitte earlier selected.

Chapters 2, 3 and 4 comprise this first step. The three chapters were divided so that Deloitte could more easily consult the research, with a summary section at the end of each.

The second step consist of, after determining what currently exists and does not exist regarding remote patient monitoring, analysis and subsequent specification of the prototype requirements. This step includes, as is detailed further in the document, the Deloitte's intervention which was condition by the outcomes of the state of the art research.

The third step corresponds to a pre-implementation validation of the prototype requirements by a medical professional. The quality of the prototype must be ensured, with the previously mentioned requirements being adjusted or not, depending on the feedback received.

Both these two steps are comprised in chapter 5.

The fourth stage corresponds to the implementation of the prototype applications on the OutSystems platform, according to the pre-specified requirements.

This fourth step is detailed in chapter 6.

The fifth and final step, which is crucial to evaluate the dissertation project, consists of the final validation of the usability of the implemented prototype.

This final step is comprised in chapter 7.

Finally, chapter 8 consist of the dissertation's conclusions.

Chapter 2

Remote Patient Monitoring, RPM

This chapter corresponds to the first chapter of the state of the art which is, as previously mention in section 1.2, divided in three chapters. The chapter addresses the past, present and future of remote patient monitoring.

Section 2.1 address the evolution of the interest and, consequently, investment in RPM.

Sections 2.3 and 2.3 explore the benefits from four different perspectives and the effectiveness of RPM, respectively.

Lastly, section 2.4 describes the present and future state of the global RPM market, including the current world's best solution providers.

Remote patient monitoring can be considered as a DSS (decision support system), more specifically a CDSS (clinical-decision support system), that improves the medical response, in real-time, to a patient [2]. The patients and medical professionals are the users of these monitoring systems, which comprise both hardware and software components [29].

Figure 2.1 illustrates the general architecture of a RPM system.

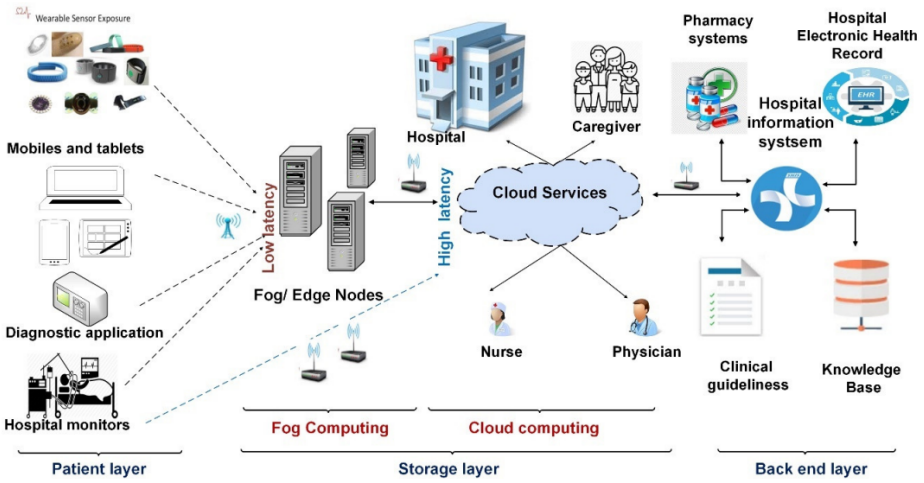


Figure 2.1: The General Architecture of a RPM System [2]

The RPM systems rely heavily on knowledge bases: the system receives several types of data from the patient, collected in real-time or self-inserted, which are then shared with the patient and medical professionals, via digital interfaces. With this patient-centered approach, it is possible to achieve a more personalised and, consequently, better healthcare for each patient [2] [27].

On the other hand, it is vital to emphasise that these systems have extremely stringent standards since their quality reflects on the patient's health. The quality of RPM systems directly depends on the accuracy of the medical data. Wrong and/or inconsistent data can lead to poor or, in the worst-case scenario, to wrong medical decisions that can badly affect the patient's health [2].

2.1 Previous Interest in RPM

A study conducted by the Cell Therapy Laboratory and the Health Sciences Postgraduate Program of the University of Caxias do Sul [3] reveled that the investment in RPM has been increasing over the past years. Their methodology consisted in a worldwide systematic research in order to find studies on RPM published between the years of 2000 and 2018. Another important aspect to consider is that in order to take into account the consistency of the documents that were examined, they were categorized into two levels of efficiency: OCEBM Level of Evidence 1 and OCEBM Level of Evidence 2 [30].

Following the examination of approximately twelve hundreds of documents the study showed that 43.00% of the publications were made in between 2015 and 2018. As a result, the study concluded that the number of publications has higher increased over the years, in particularly, in the last few ones inside the study years range [3].

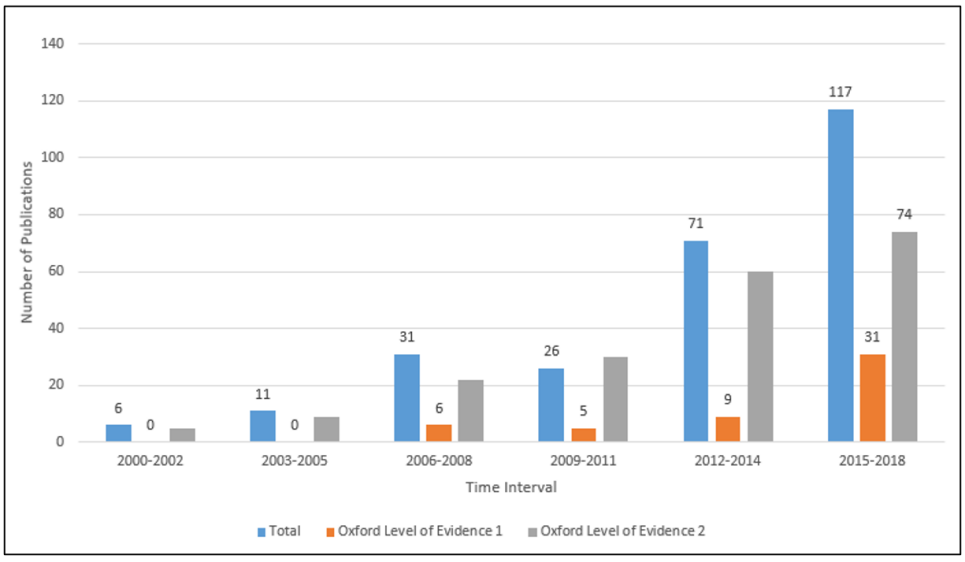


Figure 2.2: Graph of the Number of Publications by Year and Level of Evidence. Adapted from [3].

Regarding the strategy to implement the remote motorization, it was discovered that 75.07% of the strategies, i.e., the most popular, included mobile applications and/or wireless devices. It is also important to mention that the United States of America accounted for 38.02% of all the publications [3].

2.2 Benefits of RPM

There are countless benefits of using remote patient monitoring systems. The main results from the research conducted on them, which are classified into four different perspectives, such as medical, economic, social and psychological, are illustrated in figure 2.3.

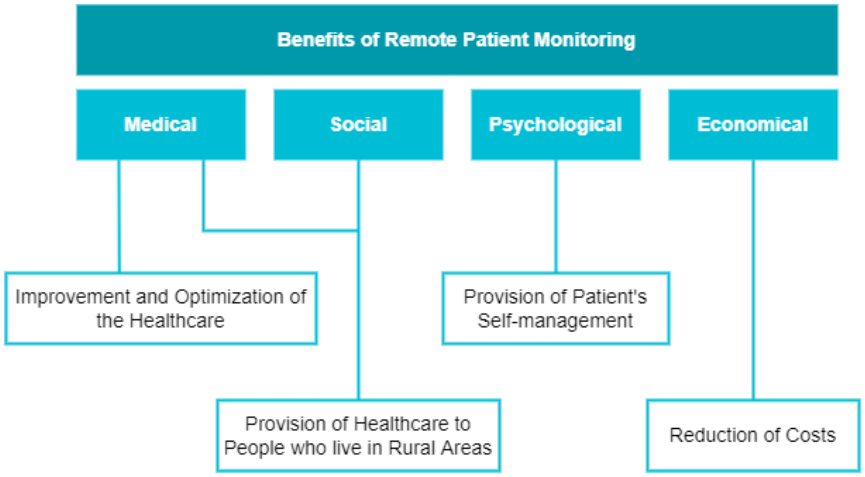


Figure 2.3: Benefits of RPM

Improvement and Optimization of the Healthcare

A RPM system collects real-time health-related data, allowing medical professionals, such as doctors and nurses, to reach better medical decisions regarding the patient's diagnosis, treatment and/or recovery [2]

With RPM, the medical professionals can view and, consequently, interpret and evaluate changes in a patient's health status over time. It also allows them to prioritize care delivery by triaging each patient based on their near-real-time health status. As a result, the medical professionals are able to achieve a better and opener clinical understanding of their patient's health status, allowing them to provide more personalised and proactive care [28].

Provision of Healthcare to People who live in Rural Areas

Initially, it was personally thought that this benefit would face a significant challenge: the age of the individuals who generally live in rural areas, especially the elderly. However, according to a study conclusion, this is not considered an obstacle if the application is concise and simple to use [31]. Section 2.3 delves deeper into this topic.

Aside from this non-obstacle, another study concludes that RPM systems can assist patients in overcoming two significant barriers: distance and the shortage of medical professionals such as doctors and nurses [32].

This benefit is critical to consider since statistics reveal that a significant number of individuals reside in rural areas around the world and, as demonstrated above, have limited access to physical health care. Figure 2.1 depicts the historical data of the world's rural populations.

Table 2.1: World Rural Populations - Historical Data. Adapted from [18].

World Rural Population - Historical Data			
Year	Population	% of Total	Change
2020	3 398 794 081	43.85	0.04
2019	3 397 375 496	44.29	0.07
2018	3 395 164 032	44.73	0.10
2017	3 391 638 218	45.18	0.14
2016	3 386 902 997	45.63	0.16

From the table presented above, i.e., from mathematical analysis, it is possible to conclude that, in the perspective of the total world population, the percentage of the rural population is decreasing. However, these percentages are still high, around 40.00%, so it is essential to consider this topic [18].

Provision of patient's self-management

The RPM provides the patient with easy-to-use tools for being aware of their health status and, consequently, their condition better [28].

Although the medical professionals are responsible for medical decisions and not the patients, it is crucial from a social point of view that patients have access to their health status in order to increase self-awareness. By having access to this information, patients are better informed about their current health status and can thus manage it well, reducing insecurities, stress and the so-called fear of the unknown [28].

Reduction of Costs

When approaching services provided to entities it is inevitable to look from an economic perspective. Two entities on opposing sides of the RPM benefit economically from this service: medical facilities and, of course, the patient.

- Hospitalizations:
  It is mathematically confirmed, through numerous medical and economic studies, that adopting a RPM system positively affects hospitalizations. According to studies, RPM clearly reduces the hospitalization rate [33].
  Admissions and readmissions to a medical facility that aren't necessary are proven to be reduced by RPM. Also, this type of monitoring can allow earlier acute discharges. These two consequences examples of the use of a RPM system result in non-stay or shorter length

of stay in the medical facility, respectively, which reduces the costs of healthcare for both the medical facility and the patient [28] [34].

- Medical Appointments:
  It is widely known that medical appointments can be extremely costly to patients, especially if they choose a private hospital or clinic and do not have a good health insurance.
  RPM does not intend to end all face-to-face appointments as, for the most part, they are essential, but rather the face-to-face appointments that can be avoided through remote monitoring. This decrease is directly reflected in the reduction of costs for, again, both the medical facility and the patient. With RPM, the patient can avoid costs related to, for example, travel and parking [28].

2.3 Effectiveness of RPM

To demonstrate the effectiveness of a RPM system, i.e., the ability of this system to produce and/or develop something effective, a study that performs a meta-analysis of RPM systems [31] is considered. In order to reach accurate conclusions, the study conducted a subgroup analysis by age, the severity of symptoms, measurement frequency, medication management and speed of intervention.

Age

The study implies that age is a non-obstacle factor to the effectiveness of these systems. The study suggests that even in elderly patients unfamiliar with new technologies such as smartphones or computers, the RPM will be equally effective if the system designed is simple for everyone to use. As a result of this, as well as other situations, when developing, for example, a RPM mobile application, it is necessary to keep in mind that this needs to be simple and easy to understand.

Severity of Symptoms

The study concluded that in patients with higher symptoms severity, the effectiveness of a RPM is unquestionably more heightened than in the patients with lower symptoms severity. In terms of mathematics, the measurement frequency of data is directly proportional to the effectiveness of RPM.

Measurement Frequency

The measurement frequency corresponds to the frequency with which data is measured. The study shows that with higher measurement frequency, the effectiveness of RPM tends to be higher too. A plausible justification for this result is that measurements with high frequency correspond to more sensitive and accurate data that, consequently, lead to better medical decisions. However, nowadays, this factor is not considered relevant since, at the moment, all RPM systems are designed with real-time data collection.

Medication Management

It was concluded that the effectiveness of RPM is undoubtedly higher when the RPM system incorporates medication management than when not. Remote medication management is necessary to respond as soon as possible to changes in the patient's health condition, thereby decreasing patient appointments and hospitalization rates.

Speed of Intervention

It is necessary to note that this one is considered by the study as the most important factor. Obviously, higher speed of intervention reflects in a higher effectiveness of the RPM system. It is critical for the effectiveness of the system that exists rapid management of patients by a trained medical team. For example, daily adjustment of patient's medication doses based on their medical data such as blood pressure.

2.4 Global RPM Market

According to statistics, the current worth of the global RPM market is approximately 53.06 billion dollars. In terms of the future, predictions state that this market will reach more than 175.02 billion dollars by 2025, with a CAGR (compound annual growth rate) of 33.03% [35].

As can be seen in the graph presented in figure 2.4, North America, followed by Europe, dominates the development of mHealth (mobile health) platforms, i.e., applications for devices such as smartphones or tablets that remote monitoring someone's health status [4].

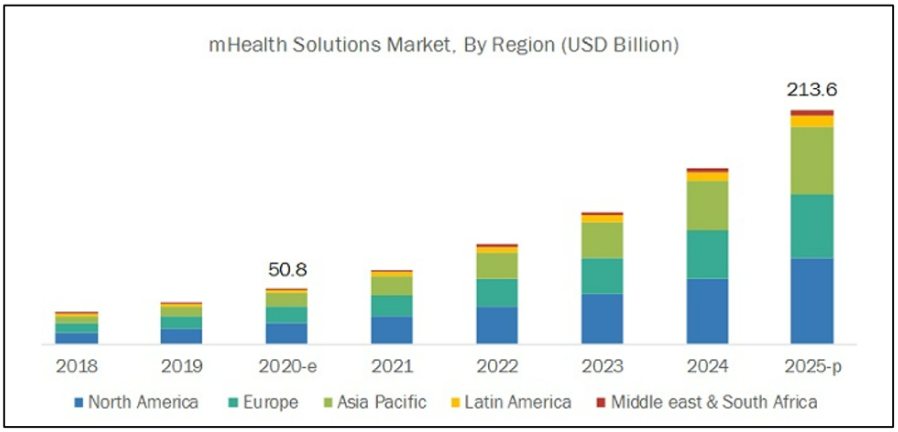


Figure 2.4: mHealth Solutions Market by Region in Billions of Dollars [4]

Since it is in North America that the market for technological solutions for RPM is largest, especially in the United States of America, it is appropriate to look from an end user's perspective at this type of RPM solutions. Therefore, the graph illustrated in figure 2.5 depicts the past, present and future of the percentage of RPM users in the United States of America [5].

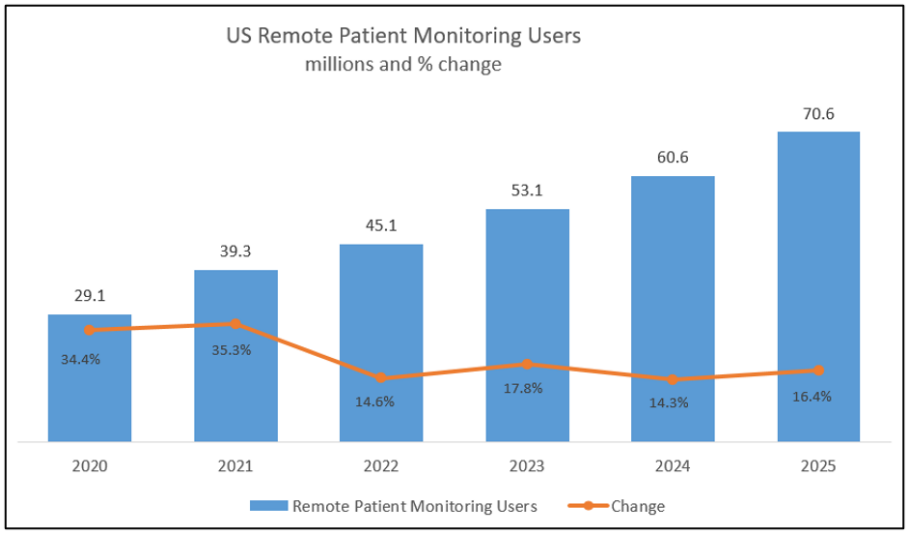


Figure 2.5: USA Remote Patient Monitoring Users. Adapted from [5].

Within this market, there are clearly two distinct categories of RPM systems: general monitoring and monitoring of a specific disease, usually a chronic disease [36].

- **General RPM** — Corresponds to remote patient monitoring without a specific disease focus. Although it is a more general system, it does not mean it cannot manage the health of patients with particular diseases. An example of this type of system is the MY LUZ application which is introduced in sub-section 3.2.1.
- **Disease-Specific RPM** — Corresponds to the remote patient monitoring focused on one specific disease. Generally, the disease monitored is chronic, i.e., a disease that typically lasts three months or more and can worsen over time. AA study based on articles published from 2014 to 2019 [2] concluded the percentages of diseases monitored by these remote systems. Figure 2.6 presents the corresponded percentages.

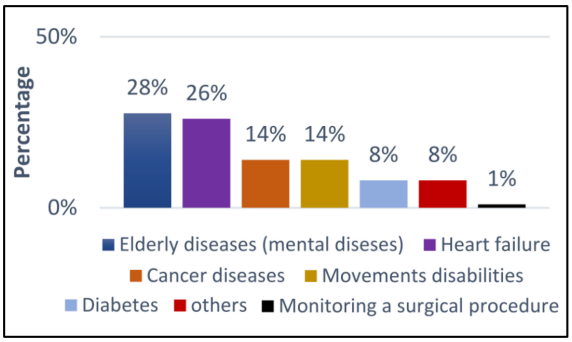


Figure 2.6: Distribution of RPM Systems according to Diseases. Adapted from [2].

2.4.1 World's Best RPM Solution Providers

According to an Insider article published this year, eight companies stand out in this market [36], as can be seen in table 2.2.

These companies design and develop software applications and hardware devices to remotely monitor a patient's specific disease or, in a most general case, their general physical and/or mental health status. It is also important to mention that most of these companies developed applications that also rely on wearable devices, such as smartwatches or wristbands, to measure some of the patient's data [36].

Table 2.2: World's Best RPM Solution Providers

Company	Type of Monitoring
Dexcom	Disease-specific
Senseonics	Disease-specific
Philips Healthcare	General Health Status + Diseases-specific
AT&T	General Health Status
Medtronic	General Health Status
Resideo	General Health Status + Diseases-specific
ResMed	General Health Status + Diseases-specific
VRI	General Health Status + Diseases-specific

Some companies, such as Philips, existed prior to the investment in RPM and have expanded their services to cover this area. Meanwhile, others were created specifically for this purpose, such as Dexcom and Senseonics, which are further detailed in section 3.1.1.1.

Philips is a 130 years old Netherlands-based company that expanded its service to invest in remote monitoring. In 2020, Philips announced a partnership with BioInteliSense to create an innovative product for a general RPM, i.e., remote monitoring for patients that may or may not have a disease. This includes an above-the-skin sensor, the BioSticker, with a battery life of up to 30 days that supports a Bluetooth wireless data transmission. The sensor is capable of collecting both basic biomedical measurements, such as skin temperature or heart rate, as well as more complicated measures, for example, related to the patient's body position and sleep. The product also includes a BioHub that connects to the sensor and transmits the data collected to a medical team and a simple-to-use application, named eCareCompanion, where the patient can communicate and check his/hers health status, i.e., the application provides self-management. The price of one BioSticker is approximately 130€ [37] [38].

2.5 Summary

At the conclusion of this chapter, it is feasible to conclude that, while the Covid-19 pandemic consisted of a remarkable catalyst for the interest and, subsequently, investment in RPM, the interest already existed. Several excellent RPM systems products are available on the current market, either for general monitoring, disease-specific monitoring, or both.

It is also possible to conclude that it is necessary to take into account some crucial factors, such as the speed of intervention, to ensure the effectiveness of the remote monitoring system.

In resume, RPM consists of an excellent tool for improving the provision of healthcare to the patients.

Since the aim of the dissertation is to design and implement a prototype consisting of two applications for RPM, it is necessary to focus on the software component. However, as explained in the next chapter, in some cases, it is needed to explore the other component as well, the hardware component.

Chapter 3

RPM Applications

As previously stated, as the dissertation aims to design and implement a prototype of two applications for general RPM, a chapter dedicated solely to the software component of an RPM system is essential. However, as explained further, since the hardware and software components rely on each other, it is necessary, in some situations, to analyse both components.

Section 3.1, which addresses the types of data that can be included in an innovative RPM application, is divided in two subsections. Subsection 3.1.1 presents automatic data, whereas subsection 3.1.2 addresses manual data.

Lastly, section 3.2 considers and presents three RPM applications projects.

3.1 Data of a RPM Application

After collected, processed and transmitted, the data of a RPM system is displayed to both the patient and the medical professionals, via digital interfaces [2]. Before designing RPM applications with innovative functionalities, which is the aim of this dissertation, it is necessary to understand which data is relevant and can be integrated into this type of monitoring applications.

Therefore, this section presents a research on the two data categories incorporated in a RPM application: automatic data and manual data [32]. Even though the synchronization with devices was outside the scope of the dissertation, for the first category of data, the automatic data, it was crucial to conduct a research on the hardware to better understand which data can be current automatically collected. In this way, the design of applications that would collect data that cannot be automatically collected is avoided.

3.1.1 Automatic Data

Automatic data corresponds to the data that is collected automatically through various types of sensor-equipped devices.

Nowadays, IoT (Internet of Things) is successfully growing and spreading across a wide range of areas, including healthcare. The continual decline in prices and increased functionalities accounts for this growth. [39]

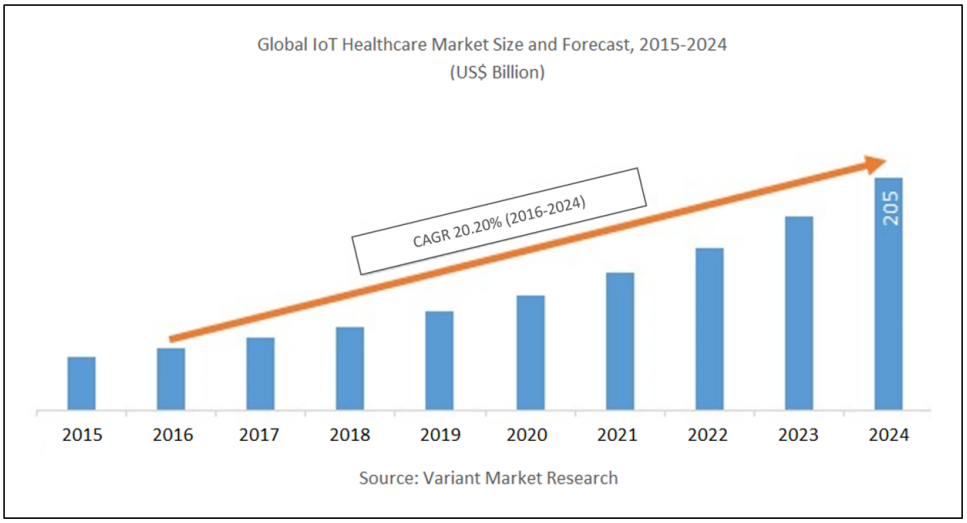


Figure 3.1: Global IoT Healthcare Market Size and Forecast, 2015-2024. Adapted from [6].

The IoT refers to the concept of connecting "things" and allowing them to communicate and operate remotely across a variety of networks and technologies. Using IoT technology, IoT devices collect data and transmit it to software applications through a wireless network. As a result, this network of interconnected devices enables healthcare providers to monitor the patient's health status outside of a medical facility, i.e., to remotely monitor. [39] [40]

Within the automatic data category, there are two different sub-categories of automatic data that can be collected, through various devices: biomedical and living-environment data. The following two subsections explore the importance and relevance of each one of these two subcategories for a RPM application, as well as how they are currently obtain.

3.1.1.1 Biomedical Data

The biomedical data consists of row facts regarding a person's medical condition. This subcategory of automatic data must be further analysed by a specialized person in the medical field and/or processed using technological resources, such as machine learning models and artificial intelligence algorithms, resulting in biomedical information. [41] [42] The biomedical information necessary to remotely monitor the physical and mental health of a patient can only be collected through sensor-equipped devices [40].

Simple vital signs such as heart rate, blood oxygen saturation, body temperature, blood pressure, and physical activities are among the most commonly measured biomedical data, as are more complex signs such as ECG (electrocardiogram) and BCG (ballistocardiogram). These vital signs can then be combined, i.e., processed together, resulting in derived signs, such as stress, which allow not only physical health monitoring but also mental health monitoring. [43]

It is crucial to conduct a market research to understand what biomedical data can be automatically collected through the devices currently available in the market. As a result, the risk of

developing an application that intends to collect data from devices that cannot yet be collected automatically is avoided. The research is divided into two different categories of devices: day-to-day and medical.

Day-to-Day Devices

The day-to-day devices, better known as wearables, are able, due to their wearables-based technology, to connect with smartphones, thus passing them the data measure by them.

Wearable devices are able to measure the user's physiological condition and record its activity status through the various types of flexible sensors of which they are composed. These sensors can be incorporated into elastic bands, textile fibers and clothing, thus being considered non-invasive wearables. Alternatively, it can be directly attached or implemented in the user's body, which is considered invasive wearables. [44]

As illustrated in figure 3.2, there are numerous types of wearable devices for various body parts [7]. Although the figure does not show it, it is essential to mention that implant wearable devices are also available in the market, both above-the-skin and under-the-skin, which is mentioned further on.

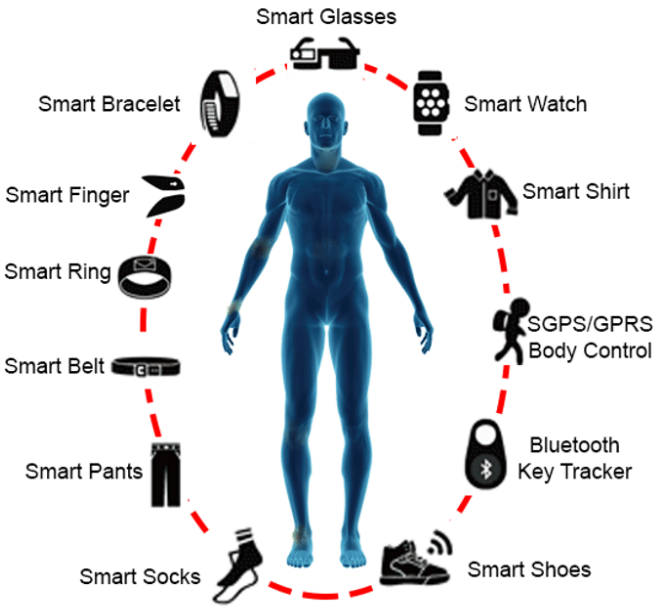


Figure 3.2: Different Types of Wearable Technology [7]

According to statistics [8], as depicted in the graph illustrated in figure 3.3, the most common wearable devices are the smartwatches, followed by wristbands. As a result, the research was filtered and focused on the automatic data collected by these wearable devices.

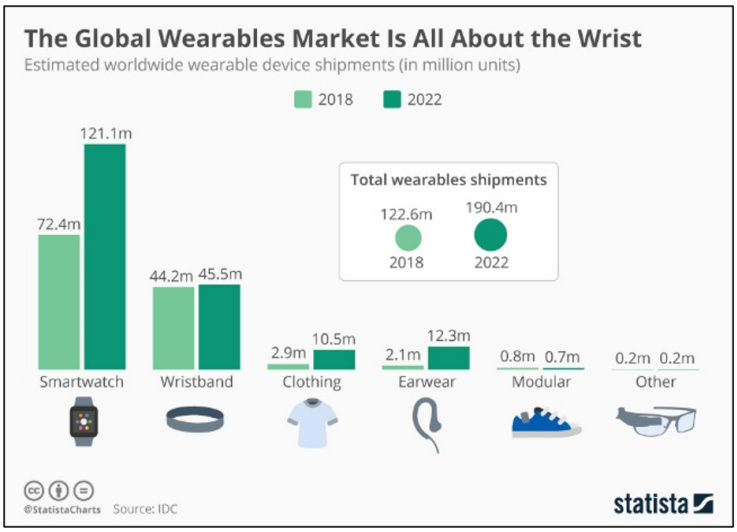


Figure 3.3: The Global Wearables Market [8]

In order to conduct more concrete and current market research, statistics were gathered [45] to determine which companies were responsible for the worldwide shipment of wearable devices: the top four companies, last year, were Apple, Xiaomi, Samsung and Huawei.

Therefore, a research is vital to conclude which health features are included in the current smartwatches of the top four companies in this market. After some consideration, it was decided to select, for the research, the most recent smartwatch model of each company so that the research outcomes correspond to the most recent and innovative health features present in the market. The results can be found in table A.1 in appendix A.

It is important to note that some smartwatches, such as the Xiaomi smartwatch, allow the measurement of environment data such as air pressure and ambient light. Also, according to the market research, the Huawei smartwatch is the only one that can measure the body temperature [21]. However, it is important to mention that all the companies intent to integrate this revolutionary health feature in their next smartwatch model [23].

Medical Devices

The medical devices are essential to consider as it is sometimes necessary to obtain in-depth medical data that cannot be obtained through day-to-day devices, despite their increasing development. As a result, when dealing with these situations, the patient must obtain specific medical equipment to collect this medical data.

Currently, no smartwatch can collect glucose levels, which are necessary for monitoring diabetes. This functionality is expected to be included in the brand's next models. For the time being, the two leading companies in glucose monitoring via medical devices are Dexcom and Senseonics:

- Dexcom is an US company that provides software and hardware solution for diabetes management. Their most recent product is the "Dexcom G6" which offers continuous glucose

monitoring (CGM) through an above-the- skin sensor, i.e., a sensor placed over the skin that lasts 10 days. The product kit includes the sensor, a simple auto-applicator, a transmitter and a display device and/or mobile application compatible with Apple and Android. The product has a cost of approximately 190€ per month [46].

- Senseonics Holdings, Inc is another US-based company that, like the previous one, manages blood sugar levels, i.e., glucose levels. The distinction between this and the previous company is that this one provides an under-the-skin sensor that lasts 90 days and needs to be implemented by a health care provider. Their product consists of a sensor, a waterproof transmitter that sends data every five minutes and a mobile application that receives and displays the data collected and monitors the patient's activity. The product costs approximately 485€ per month. The price difference between this product and the one above is remarkable, as this one requires a minor surgical procedure to implement and remove the sensor. However, eligible patients are entitled to a discount [47].

GalaxyWatch4 is the only smartwatch of those previously presented with the ability to measure blood pressure. [22] This ability is justified by the fact that this type of wrist measurement is still at an early stage of development. Therefore, it is relevant to approach blood pressure measurements using medical devices. One of the most well-known products on the market, which is compatible with both IOS and Android, is QardioArm. This product is a wireless blood pressure monitor that measures systolic and diastolic blood pressure and heart rate. It also detects irregular heartbeats. The product has a cost of approximately 150€ [48].

3.1.1.2 Living-Environment Data

The living-environment data provides context awareness, which is a relevant aspect to consider when developing an innovative RPM application. The incorporation of context in these types of systems improves understanding of the patient's health status by drawing more specific inferences about the patient's environment. As a result, the medical professionals can make better and more personalised medical decisions based on the patient's environmental context. [49]

This subcategory of automatic data is extremely important to be incorporated into these systems, especially for those who spend most of their time at home, such as elder, disabled or recovering patients [49]. According to a Portuguese academic paper [50], it is extremely relevant to frame the biomedical data, addressed in section 3.1.1.1, such as the patient's vital signs and activity, within its environment. The biomedical data could be statistically linked to the patient temperature, light or humidity environmental conditions.

According to WHO (World Health Organization), for healthy adults wearing suitable clothes among other factors, the acceptable indoor temperature range is 18ºC to 24ºC. In other words, this range was proven to be unrelated to health risks [51].

According to the National Asthma Council Australia, the acceptable indoor humidity range is 30% to 50%. Low humidity raises the risk of contracting airborne viruses, as well as aggravating eczema and dry skin. In other hand, high humidity encourages the growth of dust mites and mould

which corresponds to two of the most frequent asthma and allergy triggers [52]. It is important to note that relative humidity impacts people's comfort in their houses regardless of the climate in which they reside [53].

It is also relevant to address the importance of the living-environment data on its own, i.e., the relevance of this data category without any relation to another type of data. Depending on the complexity of the RPM system regarding its hardware capabilities, the gathered data can be used to alert the medical professionals in the event of an abnormality or emergency situation. [49]

Finally, according to another article, as well as the more fundamental data such as temperature, lightness and humidity, it is also important to integrate living-environment data regarding indoor air quality. In general, this data is obtained through different measures such as CO2, O2, O3 and N02 levels, TVOC (total volatile organic compound) and PM (particulate matter). This more complex data would be advantageous to, for example, a patient with a pulmonary chronic diseases such as asthma. An asthmatic's condition can worsen if the air they breathe isn't very good. [54]

Environmental Devices

The living-environment data can be measured and collected through environmental devices composed of multiple environmental sensors.

Contrarily to the devices referenced in the sub-section 3.1.1.1, these can correspond to general and straightforward products. Therefore, there is no need for such intensive market research as the previous ones since this sub-category of automatic data is easily collected through a general environmental device installed in the living environment.

3.1.2 Manual Data

Some of the data required to collect for a RPM application is manual data, i.e., data that, contrary to the automatic data, cannot be automatically obtained through a device. This category of data is obtain directly from the patient and it is essential for good and innovating remote monitoring, allowing an holistic approach [55].

Within the manual data category, there are three different subcategories of manual data: PROMs (patient-reported outcomes measures), symptom and addiction data. As in the previous section, the next three subsections discuss the importance and relevance of each of these subcategories.

3.1.2.1 PROMs Data

Some types of self-reported data can only be obtained through PROMs. PROMs correspond to questionnaires and/or forms, answered by the patients, regarding both their physical and psychological health status. [55]

According to a recent academic and medical article, the incorporation of this type of manual data into RPM systems has been increasing over the years. Initially, this data was only used to assess the health service provided to the patient. However, nowadays, PROMs data is becoming increasingly relevant as it is incorporated into the periodic monitoring of patients: periodic

distribution of PROMs to patients in order for the medical professionals to view and gauge their perceptions and views on their own health. This holistic approach allows better communication between the patient and the medical professionals, allowing the latter to track the patient's progress and reach better medical decisions. From a patient perspective, this approach is proven to improve patient self-management, outcomes and satisfaction with its health care. [56]

Within this scope, there are clearly two distinct categories of PROMS: general health PROMs and condition-specific PROMs [57]:

- **General Health PROMs**: assess patients with any condition, i.e., the patient's general health status, namely general well-being, mental health and/or life quality.
- **Condition-specific PROMs**: focus on the symptoms of a particular condition or disease, and inquire about the patient's mobility, function, and pain levels in specific areas of the body.

The most widely used and scientifically confirmed general health PROMs are depict and detailed in table 3.1.

Table 3.1: Patient-Reported Outcome Measures for General Health. Adapted from [19].

General Health PROMs	Proprietary	Patient Derived	Items	Domains
SF-36	Yes	Yes	36	Physical function Role-physical Bodily Pain General Health Vitality Social Functioning Role-emotional Mental Health
SF-12	Yes	Yes	12	Same as SF-36
VR-36	No	Yes	36	Same as SF-36
VR-12	No	Yes	12	Same as SF-36
PROMIS Global 10	No	Yes	10	General Health Physical Health Pain Fatigue Quality of Life Mental Health Social Discretionary Emotional Problems

The PROMIS, Patient-Reported Outcomes Measurement Information Systems, is an initiative of the National Institutes of Health, the US's national medical research agency. [58]

This initiative was created to accomplish an individual and, thereby, a personalised evaluation of a patient experience and outcomes, at a national level. It is being developed to be able to respond to the patient's answers, in real-time. Following a specific patient response to an initial

question, for example, further items might be eliminated or adjusted to improve the accuracy of the questionnaire. In more technical words, the initiative aims to create a computer-adaptive PROM. [19]

PROMIS Global 10 consists of a static PROM, not a computer-adaptive one. It comprises ten questions regarding the patient's perceptions of his general physical and mental health. The questionnaire responses are then converted into two numeric values ranging from 0 to 20: GPH (global physical health) and GMH (global mental health). Higher values indicate a healthier patient. These values can then be standardized to the general national population of the country where the patient resides. [19] [59]

The PROMIS Global 10 questionnaire, as well as the GPH and GMH formulas, can be found in appendix B.

3.1.2.2 Symptoms Data

The symptoms data, which can only be self-inserted by the patient, allows the doctor to combine it with the automatic data obtained through devices and, consequently, obtain faster, more personalised and better medical conclusions [50].

Incorporating this type of manual data in a RPM systems is crucial to allow medical decisions to be made without the need for a physical medical appointment. When a patient reports a new symptom, the medical team receives an alert and can then proceed to assess the symptom remotely. This corresponds to a constant-care approach [60].

Pain, which is considered the most common symptom, has an important part in medical treatment as a valuable and relevant biological tool. As stated by Sir Charles Scott Sherrington, pain is "the psychical adjunct of an imperative, protective reflex" [61]. The most often used unidimensional pain intensity scales are [62]:

- Numeric Rating Scale (NRS)
- Visual Analog Scale (VAS)
- Verbal Rating/Descriptor Scale (VRS/VDS)

The most widely used pain scale for general purposes is NRS. This scale has a high degree of sensitivity and produces data that can be analysed for auditing purposes. As illustrated in figure 3.4, a patient can rate his pain on a scale of zero to ten (or zero to five). [9] [62]

Figure 3.4: Numeric Rating Scale (NRS) [9]

3.1.2.3 Addiction Data

It is widely known the existence of countless addictive behaviors all over the world. The most common ones are the use of tobacco and alcohol, i.e., smoking and consumption of alcoholic drinks [63].

The WHO states that 22.30% of the global population used tobacco in 2020, with male smokers accounting for the majority. Furthermore, the organization affirms that tobacco is responsible for the death of up to half of those who use it. [64]

WHO also claims that 3.3 million people die each year as a result of excessive alcohol consumption. Alcohol is responsible for 5.10% of the worldwide illness burden. [65]

As both tobacco and alcohol are incredibly harmful to health and can cause and/or aggravate diseases [64] [65], it is interesting to visualize the quantity of use of these substances from a health standpoint.

Smoking

The smoking data is classified as a routine sign that can be very useful for the monitoring of a smoking patient. The acquisition of the smoking data is event-driven, i.e., depends on the patient smoking and its subsequent reporting of the cigarette [66].

Alcoholic Drinks

The alcohol data is, as the previous one, classified as a routine sign being its acquisition event-driven. In this case, the collection of data depends on the patient's consumption of alcoholic drinks and their reporting [66].

An Oxford academic article states that a variety of self-reports are used to assess alcohol consumption. These correspond to a retrospective self-reporting of the amount of alcohol consumed, every day, by a particular patient, differing in the chosen periods of time for the self-reporting. According to the article, the reports associated with short periods for the patient self-reporting are preferred over those with more extended periods since the reporting relies on the patient recalling the number of drinks consumed daily. In simpler words, it is better to self-report daily the number of drinks consumed on that particular day than weekly self-report the drinks consumed every day of that week [67].

Although patient self-report is already proven to be widely reliable and a valid way to obtain the frequency with which the patient consumes alcoholic drinks, for a more precise alcohol monitoring, it would be necessary to combine the frequency with the quantity of the alcohol in the patient's body since this last one is consider to be more relevant in a medical context. This combination is crucial when the patient chooses to reduce consumed quantity rather than wholly abstain from consumption. It is essential to mention that the quantity is measurable data and can only be obtained through devices such as breathalyzers [67] [68].

3.2 Related Work

This section presents three projects related to RPM applications, i.e., projects with similarities to the one developed in the aim of this dissertation. The projects considered were chosen for the following reasons:

- **Luz Saúde Project** — in addition to being an innovative project with a lot of potential in the field of remote monitoring, it was carried out as a result of a collaboration between Luz Saúde and Deloitte.
- **CareSimple Project** — due to the past and current world situation, i.e., the Covid-19 pandemic. This project helped thousands of symptomatic people recovering from Covid-19 virus infection at home and, as a result, has assisted hospitals in maintaining their capacity.
- **Vector Remote Care** — it is also important to address projects centered on remote monitoring of a specific condition or disease.

3.2.1 Luz Saúde – General Patients Remote Monitoring

Luz Saúde was founded in 2000 and is one of the largest privately-held healthcare companies in Portugal. The company claims technology and innovation as one of its missions: personalised healthcare based on the doctor-patient relationship built on complete trust, accompanied by data science and computerized medical technology [69].

Deloitte Portugal was responsible for developing and implementing the "Health Monitor" functionality in the pre-existing MY LUZ application, which is illustrated in figure 3.5.

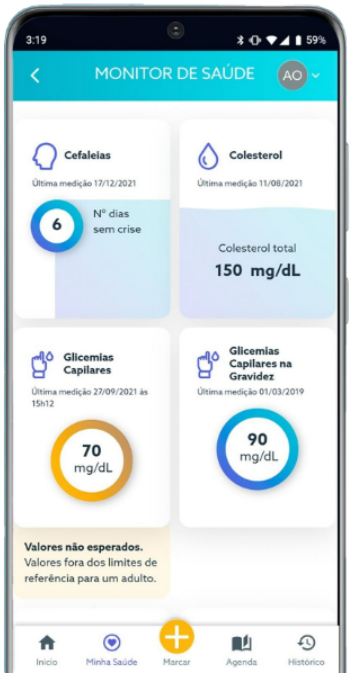


Figure 3.5: My LUZ App - Health Monitor

This functionality enables the patient to synchronize the application with Google Fit or Apple Health, depending on the smartphone's operating system, which in turn may be synchronized with, for example, a wearable device. This connection allows for importing healthcare data into the application, which can then be accessed by both patients and medical professionals at any time. It is also important to mention that MY LUZ allows the patient to enter additional health-related data manually [70].

3.2.2 CareSimple – Covid-19 Patients Remote Monitoring

CareSimple is a company with over 10 years of experience in the RPM field and with 4.5M health application downloads. The company states that its three big focuses are quality, security and customer satisfaction [71].

During the Covid-19 pandemic, the company developed a "Covid-19 Care Program" to manage their user's isolation due to Covid-19 infection. This program was specially designed for patients with symptoms after discharge from the hospital and continue their self-isolation at home. The primary goal was to preserve the medical facility's capacity, which is vital for the more severe Covid-19 cases by helping decrease the number of non-necessary re-admissions.

The company's platform provides an application that performs a collection of automatic and manual data. In other words and more specifically, the platform tracks the body temperature, oxygen levels in the blood and the symptoms of the application's user. It is important to note that this last one corresponds to self-insert data by the patient. The platform also provides communication between the patient and medical professionals through real-time messaging, video-calling, and alerting.

3.2.3 Vector Remote Care – Cardiac Patients Remote Monitoring

Vector Remote Care is a small US-based company focused on cardiac disease management. According to their statistics, they increased on-time patient reporting by 61.00%, decreased false alerts by 90.00% and increased in-clinic revenue by 58.00% [72].

The company provides a platform named "The Cardiac Intelligence Platform", which includes three types of management: cardiac rhythm, heart failure and hypertension management. It also includes other measurements such as blood pressure and weight.

The platform aims to persuade patients to improve their behavior by displaying to them their pre-analysed data and, as a result, improve their health status. It is divided into two types of remote monitoring solutions:

- CIED (Cardiovascular Implantable Electronic Device) Monitoring — as the name implies, this solution is capable of monitoring implantable devices, such as pacemakers. It includes two of the three types of management mentioned above, heart rhythm and heart failure.
- CardiacRPM — this solution allows the monitoring of cardiac patients that don't have an implantable device. It includes hypertension and heart failure management.

3.3 Summary

In conclusion with outcomes of the articles presented throughout this chapter, it is possible to summarize the data requirements to consider when designing innovative RPM applications.

Figure 3.6 summarises the reasons why the five sub-categories of data, presented throughout this chapter, should be considered in a RPM application and figure 3.7 depicts a concept map of the data that can be integrated into this type of remote monitoring applications.

Automatic Data		Manual Data	
Sub-Category	**Motive**	**Sub-Category**	**Motive**
Biomedical	Crucial data to include in this type of applications	Patient-reported outcomes measures (PROMs)	This data is becoming increasingly relevant as it is incorporated into the periodic monitoring of patients Questionnaire: PROMIS Global 10
Living-Environmental	Data that provides context-awareness, which is a relevant aspect to be consider when developing innovative RPM applications	Symptoms	Patient is able to report symptoms that he/she is current experience and the medical professionals are able to assess those symptoms
		Addiction	Data such as the daily number of cigarettes smoked or the alcoholic drinks taken are relevant to incorporate in innovative RPM applications

Figure 3.6: Motives of the Data of a RPM Application

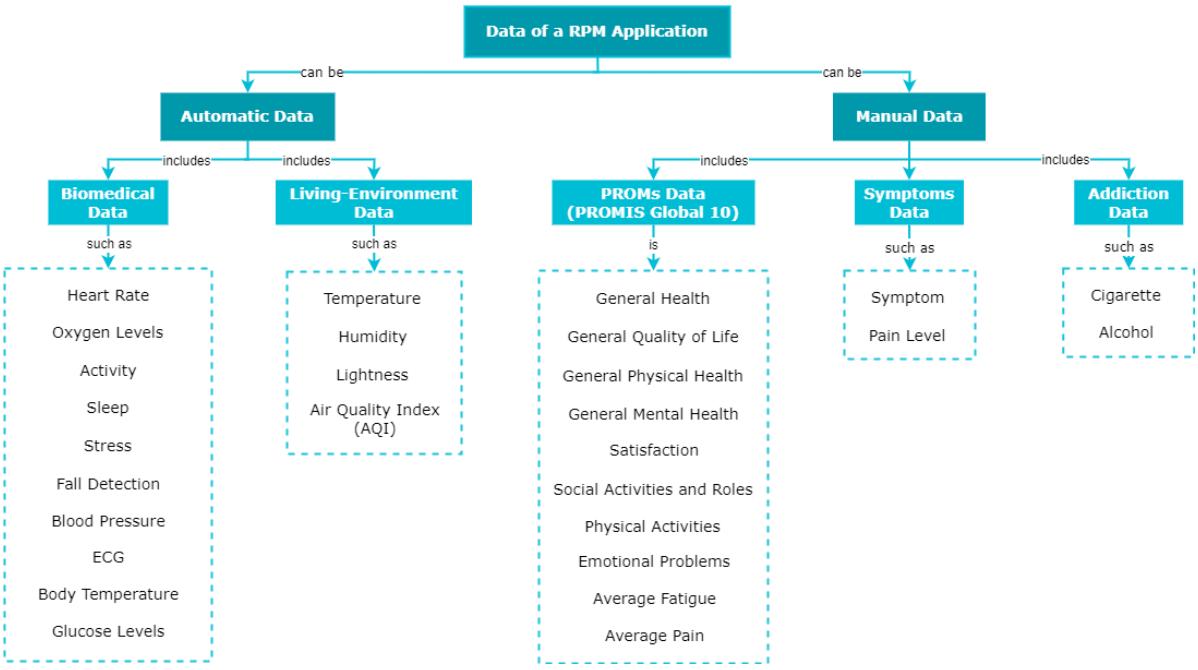


Figure 3.7: Map of the Data of a RPM Application

Chapter 4

Low-Code Platforms

This chapter, which corresponds to the last chapter of the dissertation's state of the art, introduces and explores low-code platforms, with a particular focus on OutSystems, which, as previously stated, corresponds to the platform that will be used to implement the RPM applications.

Section 4.1 explores the concept of low-code platforms as well as the platforms that are currently available on the market.

Finally, section 4.2, which is divided into three subsections, introduces and details the low-code platform on which the RPM applications will be implemented, the OutSystems platform. Subsection 4.2.1 discusses when OutSystems is the best choice for implementing an application. Subsection 4.2.2 presents the four main advantages of OutSystems in the health sector. Lastly, as in the last chapter, this one has a subsection, subsection 4.2.3, that depicts a real project, implemented in OutSystems, related to the one developed in the aim of this dissertation.

4.1 What is a Low-Code Platform?

In general terms, a LCAP (low-code applications platform) abstracts and minimizes hand-coding turning, consequently, the development of an application more straightforward and faster. These platforms can also be referred to as LCDP (low-code development platform) [11].

Formerly, the development of a application was regarded as an arduous task that took far too long to be completed. It also required highly trained programmers. Nowadays, this concept is no longer as linear as it once was since, as previously stated, low-code platforms consist of an alternative to hand-coding [73] [10].

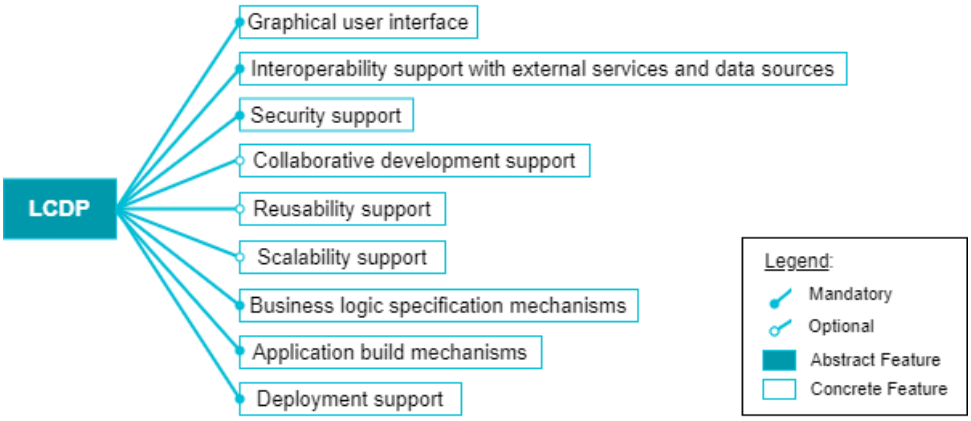


Figure 4.1: Top-level Areas of Variation for LCDPs. Adapted from [10].

According to a study that compared twelve low-code platforms available in the market, OutSystems is the leading LCAP, as illustrated in figure 4.2 [11].

Figure 4.2: Magic Quadrant for Enterprise Low-Code Application Platforms [11]

Statisticians claim low-code or no-code technologies will be used in 70.00% of new professional applications by 2025. This statistic consists of an increase from less than 25.00% in 2020. In monetary terms, between 2020 and 2025, the LCAP market is expected to grow by approximately 10 billion dollars [11].

4.2 OutSystems, a Low-Code Platform

OutSystems is a Portuguese-founded company that provides a low-code platform whose name is the same. This company has grown exponentially since 2020, the year of its creation, being one of the great pioneers in the low-code market [74].

Their vision is to transform how businesses deliver enterprise software to customers, being their number one priority customer success. Therefore, the platform provide by them enables the improvement of the application developer productivity for creating modern enterprise applications, both mobile and web applications, by providing robust security, multi-experience development, i.e., visual and model-driven development, and AI-augmented development capabilities. The combination of all of these tools speeds up and simplifies application's development [11] [75].

Compared to other low-code platforms, such as Mendix and Zoho Creator, OutSystems is distinguished by the rapid mechanism for publishing developed applications, the ability to link various services, its security mechanisms and its real-time dashboards [10].

Figure 4.3 summarizes the strengths and cautions of the OutSystems platform [11].

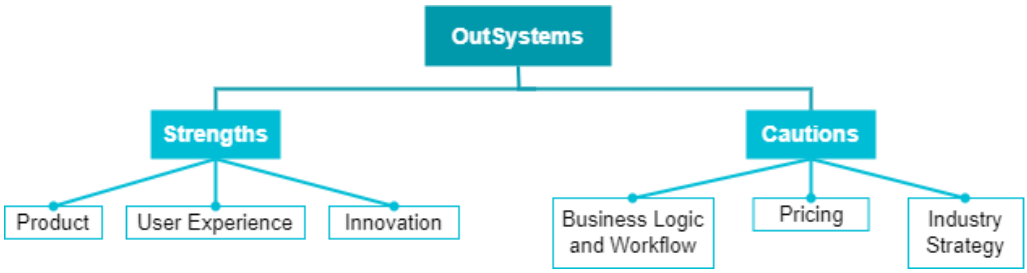


Figure 4.3: OutSystems Strengths and Cautions

In the context of the dissertation's project with Deloitte, it is essential to mention that the this company has a long-term partnership with OutSystems since 2007. Together, it is possible to achieve the vision: "less time coding, more time innovating" - Deloitte [76]

4.2.1 When OutSystems is the Best Choice?

Although this platform is the leader in the low-code market, it is essential to investigate in greater depth when it makes sense to use it or not, depending on the application type needed to develop. As a result, figure 4.4 depicts a Venn diagram to understand better why and when OutSystems is the best choice.

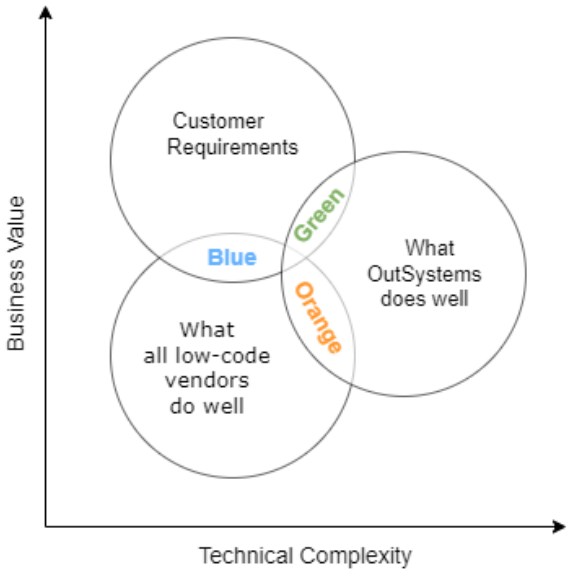


Figure 4.4: When OutSystems is the Best Choice? [12]

The Veen diagram above contains three circles with three overlaps, each one with a different color. The "Customer Requirements" circle corresponds to the customer's requirements regarding the application development. The "What OutSystems does well" circle consists of the platform strengths previously presented in figure 4.3. Finally, the "What allows code vendors to do well" circle corresponds to the general low-code strengths of all the twelve vendors presented in the quadrant illustrated in figure 4.2.

The three overlaps of the circles allow the proper choice to be made, based on the sort of application that needs to be developed:

- **Orange Overlap** — not required overlap since OutSystems gives rise to a competitive advantage by providing the customer the freedom to focus solely on what is required, resulting in greater customer success.
- **Blue Overlap** — low-code comfort zone overlap as this consists of the capability to use an agile approach to design and develop a simpler mobile or web enterprise application. For example, form-based applications.
- **Green Overlap** — OutSystems overlap as this corresponds to the one where OutSystems is the best choice. With this platform, it is possible to develop enterprise applications by focusing on four keys:
    - Technology – visual development of complex, resilient and secure enterprise-grade applications from the ground up.
    - Talent – easy and efficient to use for both programmers and non-programmers, whereby OutSystems provides numerous learning materials, such as online courses.
    - Agility – deeply and continuously involvement of members of the business team in

the design and development of the application. Therefore, the changes required by the user throughout the development process are easier to make since the business team members and the developers work alongside one another.

- Experiences – creates both mobile and web applications, in other words, i.e., allow for a unified omnichannel customer experience

4.2.2 Advantages of OutSystems in the Health Sector

According to the company itself and from a healthcare point of view, the OutSystems low-code platform enables the implementation of an integrated care approach, which is an excellent method to provide a value-based care model. In simpler words, the platform allows an excellent and fast development of an application that offers better communication and collaboration, resulting in better healthcare [13].

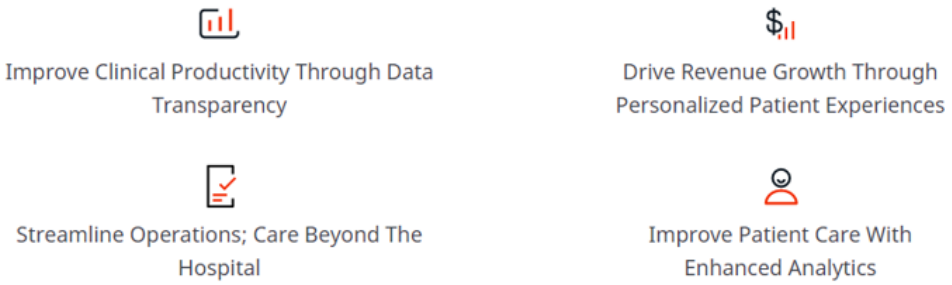


Figure 4.5: General Advantages of OutSystems in Healthcare [13]

- Improve Clinical Productivity Through Data Transparency: OutSystems platform has an open application programming interface (API) layer, which enables the integration of multiple data sources and systems into a single source about the patient. Therefore, it is possible to archive a single and unified view of the patient, allowing the medical professionals to make real-time medical decisions based on all the data gathered.
- Drive Revenue Growth Through Personalised Patient Experiences: The platform enables the implementation of a patient-centric model by providing self-management to the patients, i.e., allows the patients to manage their own condition. A few examples include giving them access and control over their medical information, which can lead to a personal assessment of treatment options or allowing them to search for their prescribed medication.
- Streamline Operations; Care Beyond The Hospital: OutSystems platform enables the creation of an unified omnichannel healthcare solution for both patients and medical professionals, such as telehealth systems or, with this project in mind, RPM mobile and web applications. It allows the companies to quickly prototype, test and make changes to an application, with significantly lower operational costs than non-low-code platforms. It is estimated that companies save 1 million dollars per year by using the OutSystems platform.

- Improve Patient Care With Enhanced Analytics: The platform's open API layer also allows the creation of a 360º vision that is, as previously stated, a fundamental characteristic of a RPM system. This vision is accomplished by the ability of OutSystems to pull data from various devices, such as wearable, medical and environmental devices, and mobile health applications, such as iOS Health Kit App from Apple or Google Fit App from Google.

4.2.3 Related Work – Redevelopment of a RPM application in OutSystems

It is also important to approach the advantages of developing a healthcare application from a real perspective. Therefore, this subsection presents and discusses the digital heart monitoring service developed by Medtronic and redeveloped in OutSystems.

The company's application, FocusOn, which consists of a heart monitoring and triage system, was redeveloped using the OutSystems platform [14]. Medtronic states that they choose OutSystems because of its extensive experience in the eHealth sector, scalability and security at the enterprise level and accelerated development with increased agility. The last reason is supported by the fact that Medtronic only needed six months to fully redevelop their pre-existing application [77].

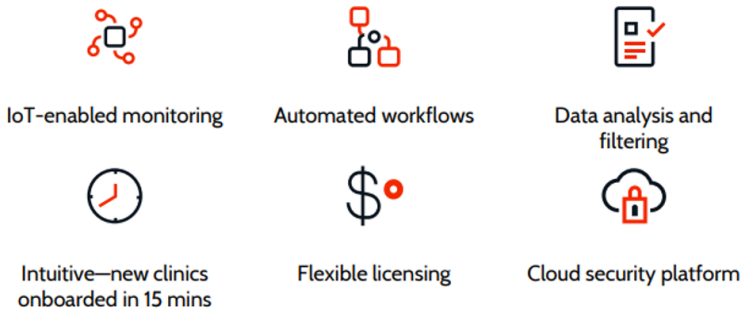


Figure 4.6: Advantages of OutSystems in Medtronic Application Redevelopment [14]

4.3 Summary

At the end of this chapter, it is feasible to conclude that the low-code platform market is expanding and that several excellent low-code solutions are currently available on the market.

Despite all the low-code platform options, the OutSystems platform corresponds to the leading one. It is also possible to conclude that this platform is an excellent choice for developing the dissertation's project since it has numerous advantages in the health sector context.

Since this chapter corresponds to the last one of the state of the art, it is now possible to go to the second and third stages of the dissertation's methodology, presented in figure 1.2: the requirements analysis, specification and validation stage.

Chapter 5

Requirements of the Prototype

This chapter details the analysis and specification stage and the validation stage of the dissertation's project methodology, illustrated in figure 1.2.

Section 5.1, which is divided into two subsections, presents and details the analysis conducted to decide the application's requirements. Subsection 5.1.1 presents the data requirements, and subsection 5.1.2 the functionality requirements.

Section 5.2, which is also divided into two subsections, consists of the specification of the requirements of the two applications. While subsection 5.2.1 specifies the functional requirements of both applications, separably, subsection 5.2.2 specifies the non-functional requirements.

Lastly, section 5.3 presents the medical validation of the prototype.

The prototype consists of two applications: RPM Mobile and RPM Reactive Web. The first is a mobile application for patients and the second a reactive web application for medical professionals.

Figure 5.1 illustrates the components of the prototype, as well as the interaction between them.

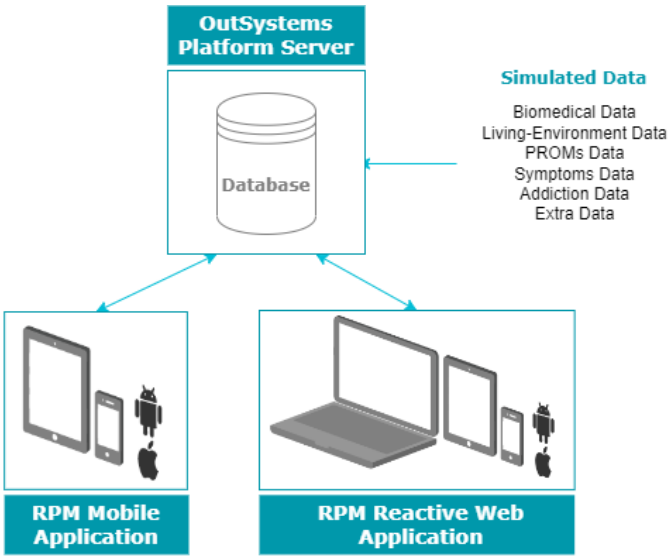


Figure 5.1: Interaction between the Components

As illustrated in the previous figure 5.1, the applications share the same database and are, thereby, able to communicate with each other. Since the synchronization of the applications with devices was outside dissertation's scope of the dissertation, the data was inserted into the database being considered, thereby, static data. The automatic data, i.e. data collected via devices, corresponds to hourly data, which is the necessary amount of data to test and demonstrate the prototype.

5.1 Requirements Analysis

The analysis of the application requirements consists in the first part of the second step of the dissertation's project methodology illustrated in figure 1.2.

After the state of the art stage, i.e., knowing what exists on an academic and medical basis and what is currently available on the RPM applications market, it is possible to analyse the requirements of the applications to be developed. This analysis was conducted with Deloitte support in order to get a business point-of-view: several meetings were held with Nuno Parreira Jacinto, a manager at Deloitte with significant expertise in this field, who was also highly involved in the development of the MY LUZ application presented in the sub-section 3.2.1.

5.1.1 Data Analysis

In order to define which types of data the application's prototype has to include, an analysis was performed using three analysis vectors previously define in a meeting with Nuno Parreira Jacinto. Each of which has an associated priority, presented in table 5.1. The corresponded analysis vectors model, which presents the types of data decided to implement in a first instance[1], i.e., for the prototype developed within the scope of the dissertation, is depicted in table 5.2

Table 5.1: Analysis Vectors

Priority	Analysis Vector	Description
1	Generality of the Data	The main goal is to develop a RPM applications prototype for the patient's general health and not for a specific condition/disease The data types were classified as general/not-general.
2	Innovation of the Data	Another goal is to include in the general RPM applications prototype innovative functionalities. The data types were classified as innovative/not-innovative.
3	Availability of Credible Data Values	To ensure that the applications prototype would display credible data values, a pre-implementation research was conducted to found, within the time available to do so, real data values. This vector is crucial in order to give credibility to the applications prototype: - From a dissertation point-of-view: if, after the implementation, the prototype is going to be presented to medical professionals to assess its utility. - From a business point-of-view: considering what type of company Deloitte is, if the prototype is going to be presented to potential clients.

[1]The types of data outlined in blue correspond to those chosen to be implemented.

Table 5.2: Analysis Vectors Model

			Analysis Vectors		
			Globability of the Data	Innovation of the Data	Availability of Credible Data Values
Automatic Data	Biomedical	Heart Rate	✓	×	✓
		Oxygen Levels	✓	×	×
		Activity	✓	×	×
		Sleep	✓	×	×
		Stress	✓	×	×
		Fall Detection	✓	✓	×
		Blood Pressure	✓	×	✓
		ECG	✓	×	×
		Body Temperature	✓	×	✓
		Glucose Levels	×	×	×
	Living-Environment	Temperature	✓	✓	✓
		Humidity	✓	✓	✓
		Lightness	✓	✓	✓
		Air Quality Index (AQI)	✓	✓	✓
Manual Data	PROMs	PROMIS Global 10	✓	✓	NA
	Symptom	Symptom	✓	×	NA
		Pain Level	✓	✓	NA
	Addiction	Cigarette	×	✓	NA
		Alcohol	×	✓	NA
	Extra	Weight	✓	×	NA
		Height	✓	×	NA

It was previously decided that the applications would include at least one type of data for each of the subcategories of automatic and manual data to develop a complete, comprehensive and innovative prototype. It is also important to mention that an extra subcategory was added, in this phase, to the manual data category. This addition allows the inclusion of two of the most basic data crucial to this type of monitoring applications: weight and height.

5.1.2 Functional Analysis

The analysis of the functional requirements is, as previously mentioned, a direct result of the state of the art outcomes, especially from section 3.2, and the several meetings held with Nuno Jacinto, as well as a demonstration meeting of the MY LUZ application.

As with all applications, the applications must provide two essential functionalities: notifications and associated-account profile visualisation. The notifications are crucial to be present in any application to provide the users with timely information, such as alerts or reminders. The viewing of the profile associated with the account logged in the application corresponds to another essential crucial of any application.

Since one of the fundamentals of this type of applications is to create or reinforce a trusting relationship between the patients and the medical professionals, as mentioned in section 3.2.1, it is crucial to include a communications platform in the applications.

An option that allows the patients to call for immediate assistance and, consequently, alert the medical professionals should also be incorporated into the applications. However, this functionality will not be fully implemented since the project is just a prototype.

As previously detailed in sub-section 3.1.1.1 of the state of the art, biomedical data corresponds to the baseline data of this type of monitoring applications. Therefore, these applications being no exception, a biomedical monitoring needs to be included.

An innovative functionality, which increases the personalised healthcare that, according to chapter 2, is one of the main objectives and benefits of this applications, was specially required by Deloitte due to the outcomes of the state of the art: enabling medical professionals to define a maximum and minimum threshold values for heart rate, blood pressure and body temperature. Together, the thresholds establish an acceptable range within which these values must remain.

The data should be displayed to patients and medical professionals, accompanied by statistical values such as average, maximum and minimum, in the exact same way, thus allowing the 360º vision previously refereed:

- **Today's Line Chart** — chart containing three lines, each one of them representing: today's values, maximum threshold and minimum threshold;
- **Yesterday's Line Chart** — chart containing three lines, each one of them representing: yesterday's values, maximum threshold and minimum threshold;
- **Last 7 Days Column Chart** — chart containing seven columns, one for each day of the last seven days, with each column representing the average value of the respective day.

As detailed in sub-section 3.1.1.2 of the state of the art, living-environment data corresponds to the context-awareness data.

Again, an innovative functionality was specially required by Deloitte due to the state of the art outcomes: each house's temperature and humidity value must have a color indicating its quality. If the value is within the acceptable range, the color is green, otherwise, it is yellow.

According to WHO and the National Asthma Council Australia, as refereed in sub-section 3.1.1.2, the ranges of acceptable values are the following:

- **Acceptable Range of House Temperature Values** — 18ºC to 24ºC
- **Acceptable Range of House Humidity Values** — 30% to 50%

Like the previous one, data should be displayed to patients and medical professionals, accompanied by statistical values such as average, maximum and minimum, in the exact same way:

- **Today's Line Chart** — chart containing one line with the today's values, each with a colour denoting its quality.
- **Yesterday's Line Chart** — chart containing one line with the yesterday's values, each with a colour denoting its quality.
- **Last 7 Days Column Chart** — chart containing 7«seven columns, one for each day of the last seven days, with each column representing the average value of the respective day.

As previously detailed in sub-section 3.1.2.1 of the state of the art, PROMs data corresponds to the self-reported data regarding the patient's physical and mental health status.

Incorporating the PROMIS Global 10 questionnaire into the applications allows the patients to give their view on their current health status, which would be displayed to both patients and medical professionals. As previously mentioned in the same sub-section, this inclusion comprises a holistic approach that allows better communication between the patient and the medical professionals and, consequently, the reach of better and more personalised medical decisions. It also improves the patient's self-management, which, as refereed in section 2.3, is one of the main benefits of this type of monitoring applications.

As mentioned in sub-section 3.1.2.2 of the state of the art, symptoms data corresponds to the self-reported data regarding symptoms experienced by the patient in real-time.

Including a functionality that allows the patients to report their symptoms in real-time, which would be then assess by a medical professional, is a must in these type of applications. As detailed in the same subsection of the state of the art, this provides a faster reach of more personalised medical decisions. Also, this would allow to minimise the dislocations of the patients to medical facilities, which would reflect positively on the main benefits of this type of monitoring applications, explored in section 2.3, especially the provision of healthcare to people who live in rural areas and the reduction of patient's costs.

Consider the following real-life scenario: a patient suffers from a disease characterized by a wide range of symptoms. Each of these symptoms is very relevant to the doctor to identify the disease progression stage. The constant dislocation of the patient to the medical appointments can be avoided by having remote monitoring of symptoms.

As detailed in sub-section 3.1.2.3 of the state of the art, addiction data corresponds to the self-reported frequency of addictive actions. In the case of cigarettes, the data consists of the number of times the patients have smoked.

The incorporation of smoking monitoring consists of an important innovative functionality since, as refereed in sub-section 3.1.2.3, cigarette addiction can be responsible for causing or aggravating diseases. This inclusion increases the provision of personalised healthcare that, as previously explored in chapter 2, is one of the main objectives and benefits of this applications.

The data should be displayed to patients and medical professionals, accompanied by the smoking times, in the exact same way:

- **Last 7 Days Column Chart** — chart containing 7 columns, one for each day of the last 7 days, with each column representing the number of cigarettes smoked in the respective day.

5.2 Requirements Specification

Following the requirements analysis, it was possible to proceed to their specification, which corresponds to the second part of the second step of the methodology illustrated in figure 1.2.

Subsections 5.2.1 and 5.2.2 specify the functional and non-functional requirements of the application, respectively.

5.2.1 Functional Requirements

The functional requirements are crucial to be specify when developing an application.

Firstly, it is necessary to specify the application's type of users. Each application has one different type of user, as illustrated in table 5.3.

Table 5.3: Application's Users

Application	User	User's Description
RPM Mobile	Patient	Person that is going to be remotely monitored.
RPM Reactive Web	Medical Team Member (MTM)	Person responsible for the medical supervision. It can be a doctor, a nurse, or even a person with specific training for this type of medical monitoring. The medical facilities are responsible for defining who this type of user is.

Following the user's specification of each one of the two applications, it was feasible to proceed with the specification of the application's functionalities.

Functionalities of the RPM Mobile Application

The patient's application should provide the following functionalities:

Notifications

- Display of notifications which can be found in table C.1 in appendix C;
- View notification's historical list;
- Delete a notification from the historical list.

Personal Profile Consultation

- View personal information: name, gender, height, date of birth and home address;
- View contact information: email and phone number;
- View medical information: PDF file uploaded by a medical professional;
- View smoking controller information: if the controller is on/off;
- Turn on/off the smoking controller.

Communication via Messages

- View message's historical list;
- View main information preview of the messages in the historical list;
- View, in case of response, the message's reply;
- Send a new message;
- Filter messages by its status;
- Delete a message from the historical list.

Emergency Request

- Press a button if immediate assistance is required

Biomedical Monitoring

- View the last measured/inserted weight, heart rate, blood pressure and body temperature values, as well as the correspondent date and time.
- View weight chart and the statistics associated with it;
- Add new weight record;
- View today's, yesterday's and last 7 days' charts of heart rate, blood pressure and body temperature, as well as the statistics associated with them.

House Monitoring

- View the last measured temperature and humidity values, as well as the correspondent date and time, and if this values are good or not.
- View today's, yesterday's and last 7 days' charts of temperature and humidity, as well as the statistics associated with them.

View Monitoring

- View questionnaire's historical list;
- View the information of the questionnaires in the historical list: filling date and time, scores and answers;
- Fill a new questionnaire;
- Delete a questionnaire from the historical list.

Symptoms Report

- View number of symptoms under assessment;
- View symptom's historical list;
- View main information preview of the symptoms in the historical list;
- View, in case of assessment, the symptom's assess;

- Report new symptom;
- Filter symptoms by its status;
- Delete a symptom from the historical list.

Smoking Monitoring

- View total number of cigarettes smoked today, yesterday and in the last 7 days, as well as the correspondent times;
- View last 7 days' chart of cigarettes smoked;
- Add new cigarette.

Functionalities of the RPM Reactive Web Application

The medical team's application should provide the following functionalities:

Notifications

- Display of notifications which can be found in table C.2 in appendix C;
- View notification's historical list;
- Delete a notification from the historical list.

Personal Profile Consultation

- View personal information: name, gender, date of birth and home address;
- View contact information: email and phone number;

Communication via Messages

- View message's historical list;
- View main information preview of the messages in the historical list;
- View, in case of response, the message's reply;
- Send a new message;
- Filter messages by its status;
- Delete a message from the historical list.

Single Patient Monitoring

- View list with all the patients;
- View personal information of each patient: name, gender, height, date of birth and home address;
- View contact information of each patient : email and phone number;
- View smoking controller information of each patient: if the controller is on/off.
- View and upload a PDF file with medical information for each patient.

Patient's Biomedical Monitoring

- View the last measured/inserted weight, heart rate, blood pressure and body temperature values, as well as the correspondent date and time.
- View weight chart and the statistics associated with it;
- View today's, yesterday's and last 7 days' charts of heart rate, blood pressure and body temperature, as well as the statistics associated with them;

- Define heart rate, blood pressure and body temperature maximum and minimum thresholds.

Patient's House Monitoring

- View the last measured temperature and humidity values, as well as the correspondent date and time, and if this values are good or not.
- View today's, yesterday's and last 7 days' charts of temperature and humidity, as well as the statistics associated with them.

Patient's View Monitoring

- View questionnaire's historical list;
- View the information of the questionnaires in the historical list: filling date and time, scores and answers.

Symptoms Assessment

- View number of symptoms to assess;
- View symptom's historical list;
- View main information preview of the symptoms in the historical list;
- View, in case of assessment, the symptom's assess;
- Assess symptoms;
- Filter symptoms by its status.

Patient's Smoking Monitoring

- View total number of cigarettes smoked today, yesterday and in the last 7 days, as well as the correspondent times;
- View last 7 days' chart of cigarettes smoked.

Once the functionalities of the two applications are acknowledged, it is possible to note that the RPM Reactive Web application's functionalities are, for the most part, similar to the ones of the RPM Mobile application. Accordingly, it is viable to confirm that together the two applications reach a 360º vision: the patient and team member view the same monitoring data.

The functional requirements of any application are described in use cases from the user's perspective. In light of that, figure 5.2 depicts the use case diagram of the applications prototype.

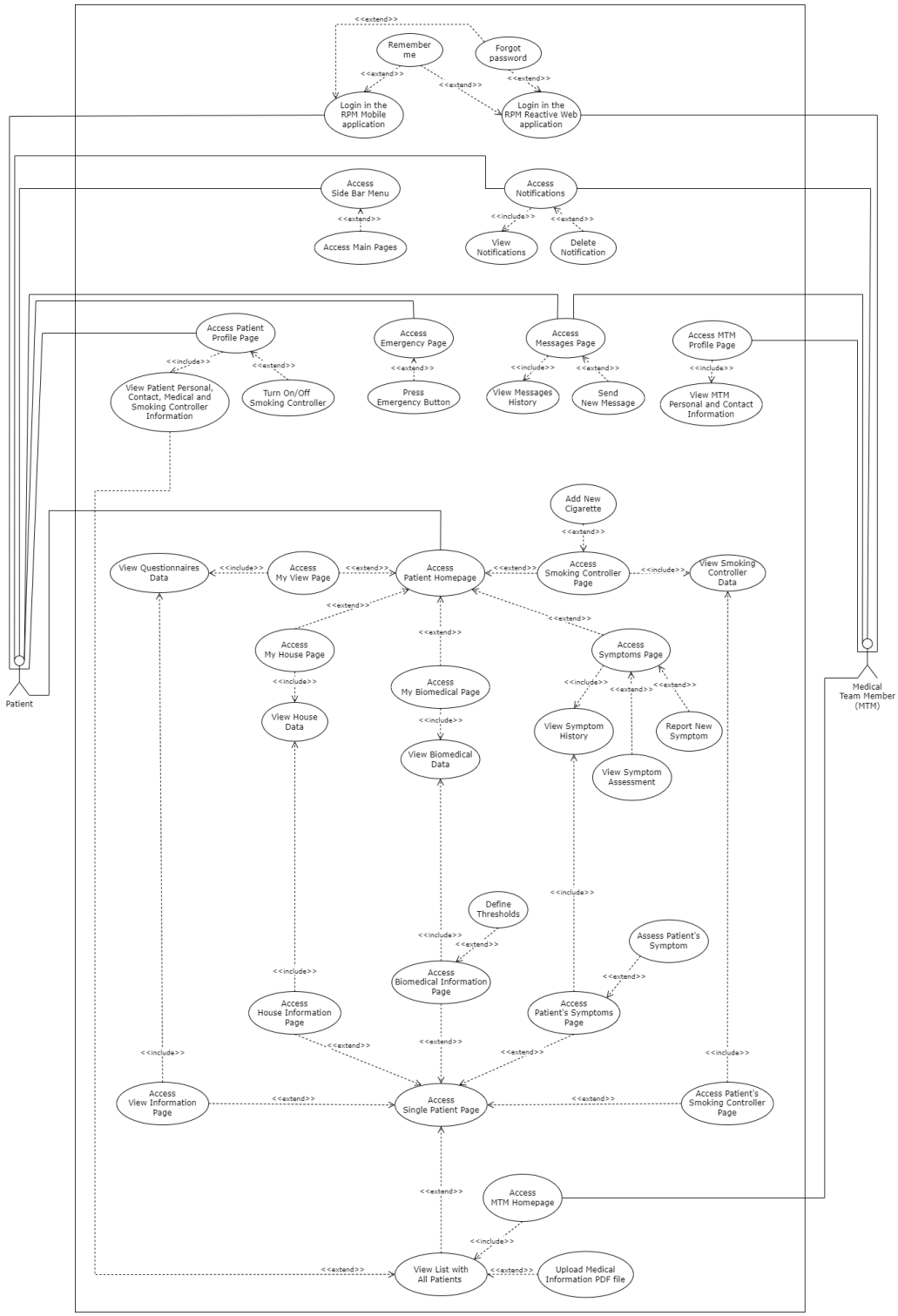


Figure 5.2: UML Use Case Diagram

5.2.2 Non-Functional Requirements

The application's design must adhere to the following five non-functional requirements:

Fault Prevention

Both the patient and the medical team member only have access to what they need to access. This limiting approach allows for the minimisation of failures that could occur if users have access to functionalities that they should not, such as miss-clicking a button.

Reliability

It is essential that the users feel that they can trust the applications. In other words, it is crucial that the users feel that the respective applications will not fail them. Therefore, reliability is an important aspect to consider when developing this prototype.

Robustness

Indeed, both applications are designed to avoid errors. However, if they occur, the applications must be able to handle them and continue to function correctly. A comforting message should be displayed to the application's user, as a lengthy error message could confuse the user since he/she would not comprehend it. It is also important to mention that, similarly to these messages, success messages should also be displayed in case of successful user actions, such as the successful login into the application.

Security

Since the applications deal with medical data, which is considered sensitive data, extra security is required. Security is one of the many reasons the applications are implemented in the OutSystems platform, as this one provides robust security at an enterprise level, as mentioned in section 4.2.

Usability

Both applications must be simple-to-use and understandable in order to achieve better utilisation. This requirement is essential to consider, especially for the RPM Mobile application, where the users can be elderly patients, who are more likely to lack advanced technological capabilities.

5.3 Requirements Validation

Following the analysis and specification of the requirements of the two applications, it is possible to proceed to the next step, the fourth step, of the dissertation's project methodology illustrated in figure 1.2, the requirements validation.

A pre-implementation validation of the prototype requirements by a medical professional is necessary in order to ensure its quality. Thereby, a document introducing and detailing the prototype to be implemented was prepared. This document includes the mock-ups of both applications and a brief questionnaire for the medical professional to complete in order to collect feedback on the prototype to be implemented.

The document, which can be found in section D.1 in appendix D, was sent, via e-mail, to Drª Maria Clotilde Osório who is 29-old doctor in Centro Hospitalar do Tâmega e Sousa.

The questionnaire results, which can be found in section D.2 in appendix D, are fairly positive. Therefore, no adjustments to the prototype requirements were necessary being possible to proceed to the next step, the implementation of the prototype in the OutSystems platform.

Chapter 6

Implementation of the Prototype

This chapter details the implementation stage of the project methodology in figure 1.2.

Section 6.1 details the technologies used in the implementation of the applications. It also presents the application's architecture which was crucial in order to define an implementation order, i.e., an implementation methodology.

Section 6.2 presents the database model, specifically the entity relationship diagram.

Finally, section 6.3, which is divided into two subsections, illustrates the implemented user interfaces for both applications. While subsection 6.3.1 depicts the user interfaces of the RPM Mobile application, subsection 6.3.2 depicts the interfaces of the RPM Reactive Web application.

6.1 Technologies and Architecture

As previously indicated, the RPM applications were developed and implemented using the OutSystems platform. As stated in section 4.2, this platform minimises hand-coding by allowing visual and model-driven development.

Figure 6.1 depicts the components and tools of the OutSystems platform.

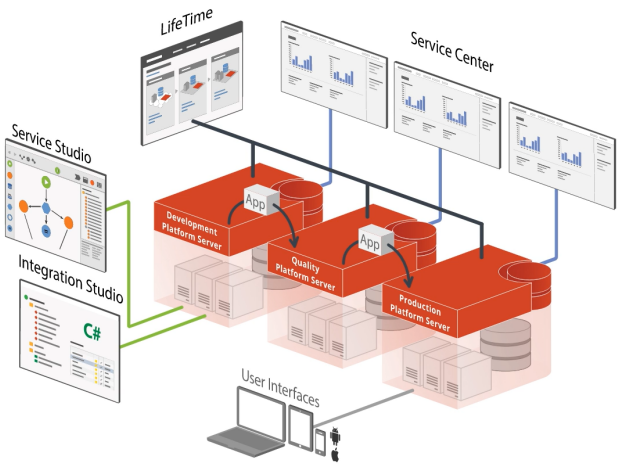


Figure 6.1: OutSystems Components and Tools [15]

For the dissertation's project, the main focus is on the service studio component. This component, presented in figure 6.1, corresponds to the visual design and development environment in which both reactive web and mobile applications were built. The applications are then compiled using standard and optimised code such as HTML, CSS, JavaScript and .NET, which includes all the resources required to run the applications [15].

However, in some cases, it was necessary to manually program due to the complexity of the situation. Table 6.1 details the situations where the use of three programming tools was required.

Table 6.1: Extra Programming Tools Used

CSS	Used for the stylization of more complex application's screens
JSON	Used for the creation of more complex application's charts
SQL	Used for the a more deep and complex aggregation of data

Before the initiation of the development of the applications in the platform, it was crucial to design the application's architecture. This way, it was possible to define the order of implementation to be followed during this stage.

The architecture developed is based on the OutSystems architecture tool, the architecture canvas, which simplifies SOA (Service-Oriented Architecture) design. Layers and sub-layers allow separation into distinct functional modules, with each sub-layer corresponding to a module. The separation provides independence between modules, which is a good programming practice, especially for cases of multiple application development.

Figure 6.2 illustrates the applications' architecture, consisting of two layers, each one with two sub-layers.

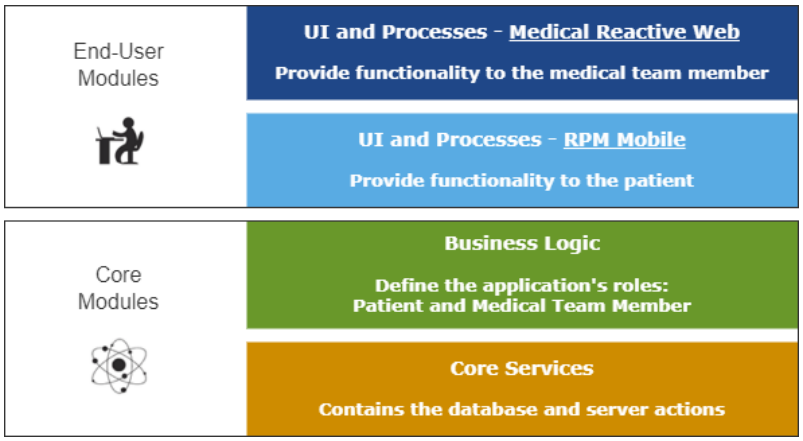


Figure 6.2: OutSystems Architecture

From the figure above it is possible to conclude that while the bottom layer contains reusable services, thus being its modules are common to all the others, the top layer doesn't contain any.

Therefore and not only, the implementation order was bottom-up in the architecture, hence the core services module was the first to be developed.

6.2 Database Model

The entity relationship diagram consists of an abstract model use to represent the data of the applications, as well as the relationships that exist between them. Since the data is stored in a database, it can be said that this diagram is also use to structure and manage the database.

Figure 6.3 depicts the entity relationship diagram of the applications.

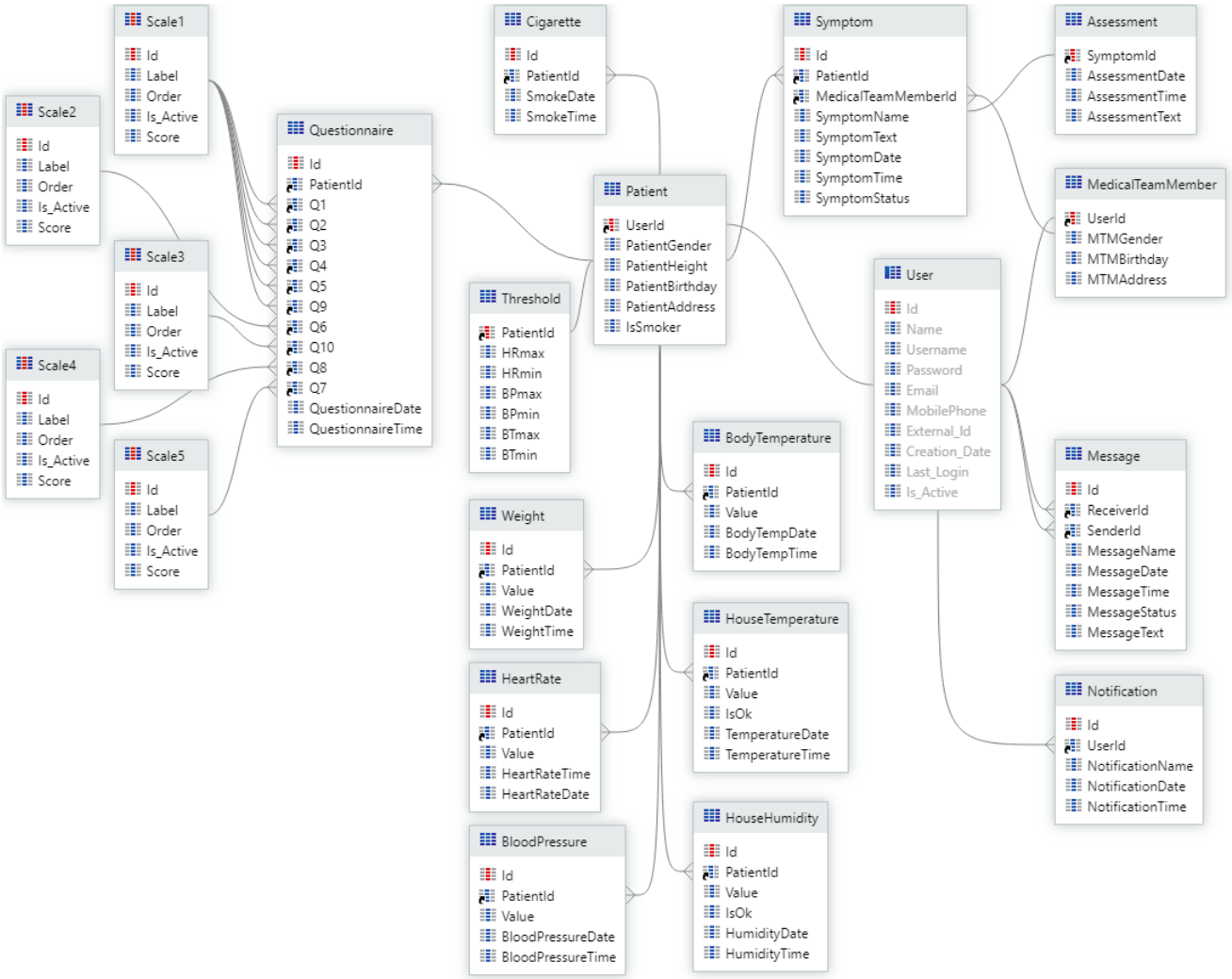


Figure 6.3: Entity Relationship Diagram

For better understatement, the following table 6.2 contains the description of each one of the entities presented in the previous entity relationship diagram.

Table 6.2: Entities Description

User	Represents the end-users of the applications
Patient	User of the RPM Mobile application, as detailed in table 5.3
Medical Team Member (MTM)	User of the RPM Reactive Web Application, as detailed in table 5.3
Notification	Both the patient and the MTM can receive notifications triggered by events, as specified in appendix C
Message	The patient can send a message to a MTM and, in turn, the MTM can reply to the message sent
Threshold	The MTM can define maximum and minimum thresholds for the patient's heart rate, blood pressure and body temperature values
Weight	The patient can self-insert is current weight value
Heart Rate	Patient's heart rate values
Blood Pressure	Patient's blood pressure values
Body Temperature	Patient's body temperature values
House Temperature	Patient's house temperature values, as well as an indication of the value's quality
House Humidity	Patient's house humidity values, as well as an indication of the value's quality
Questionnaire	The patient can fill a PROMIS Global 10 questionnaire
Scale 1	Static entity containing the scale 1
Scale 2	Static entity containing the scale 2
Scale 3	Static entity containing the scale 3
Scale 4	Static entity containing the scale 4
Scale 5	Static entity containing the scale 5
Cigarette	In the case of being a smoker, the patient can indicate the smoke of a cigarette
Symptom	The patient can report a new symptom
Assessment	The MTM can assess a symptom reported by a patient

6.3 User Interfaces

Following the analysis and specification of both functional and non-functional requirements and their subsequent validation, it was possible to proceed to the next stage of the dissertation's project methodology present in figure 1.2, the implementation stage.

In order to obtain an efficient demonstration of the interfaces, data was, as previously stated, simulated in the database. Three accounts were also created, two for patients and one for MTM:

- Dante Reynolds - Patient
- Priya Shelton - Patient
- Rachel Kay - Medical Team Member

The user interfaces result from the combination of the functional and non-functional requirements. The following subsections, subsection 6.3.1 and 6.3.2, correspond to the user interfaces of the RPM Mobile application and RPM Reactive Web application, respectively.

6.3.1 RPM Mobile Application Interfaces

The RPM Mobile application is aim only to the patients. Therefore, the login into the application will only be successful if the account logging in belongs to this type of user.

Figure 6.4 presents the login page of the RPM Mobile application.

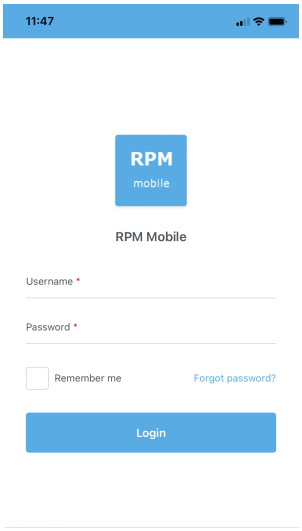
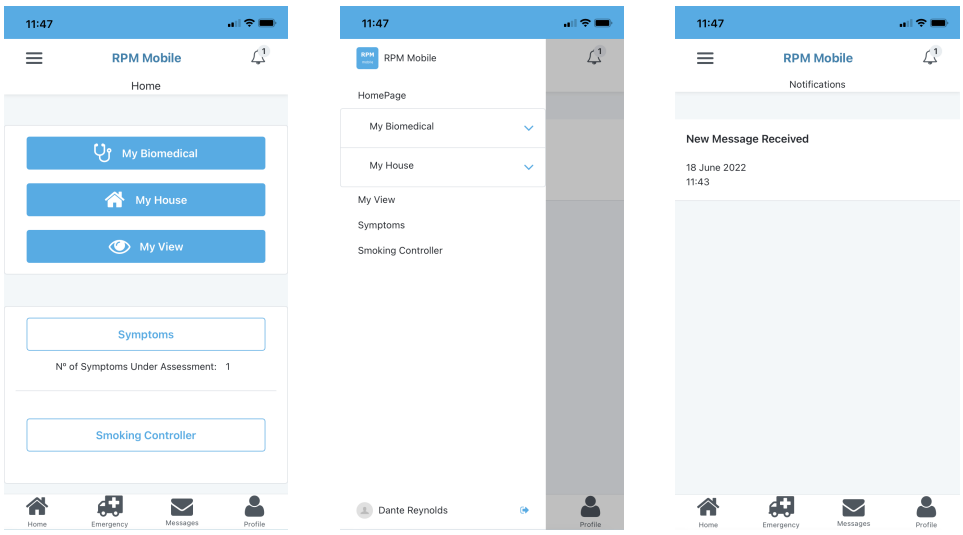


Figure 6.4: RPM Mobile - Login

After a successful login, the patient is redirected to the homepage, as illustrated in figure 6.5.

The homepage has, among with other components, two fixed icons, i.e., icons that can be found on every application page, placed on top: menu icon and notification icon. The menu icon opens a side bar containing the 6 main pages links, which facilitates the navigation through the application, and the logout. The notification icon redirects the user to the notification page.



(a) (b) (c)

Figure 6.5: RPM Mobile - Home: (a) homepage; (b) side-bar menu; (c) notifications

Besides the previous fixed icons, the application contains a fixed bottom bar with four icons: home, emergency, messages and profile. Figure 6.6 presents the bottom bar associated-pages.

The home icon redirects the patient to the main page, i.e., the homepage.

The emergency icon redirects the patient to a page containing a button that should be pressed in case of the patient needing immediate assistance.[2]

The message icon redirects the patient to a page that displays the messages history and also allows the sending of a new message to a MTM.

Finally, the profile icon redirects the patient to a page that displays all his/her personal, contact, medical and smoking monitoring information. This last one allows the patient to turn on/off the smoking monitoring.

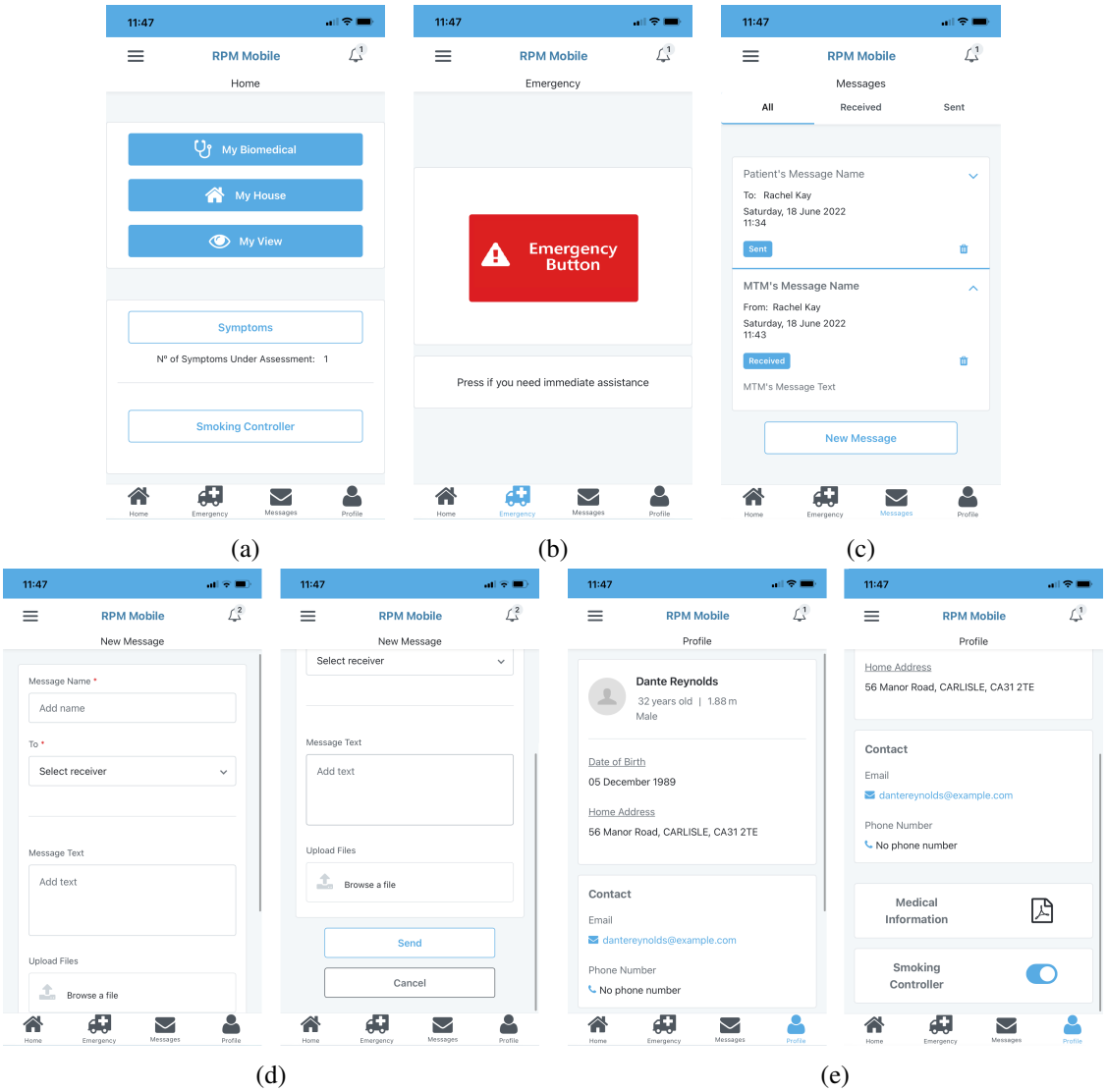


Figure 6.6: RPM Mobile - Bottom Bar: (a) homepage; (b) emergency; (c) messages; (d) new message; (e) profile

[2] As this application is only a prototype, the emergency button is not fully implemented.

After clicking the my biomedical button of the homepage, illustrated in figure 6.5, the patient is redirect to a page that displays four different types of biomedical data: weigh, heart rate, blood pressure and body temperature. The data displayed corresponds to the last value inserted or read by the patient's wearable device, and also the date and time of the reading.

It is important to remember that this data, as well as all the others present in this application, corresponds to the one selected, after the state of the art, through a vector analysis method present in section 5.2, to be integrated in the applications.

Figure 6.7 depicts the biomedical monitoring page.

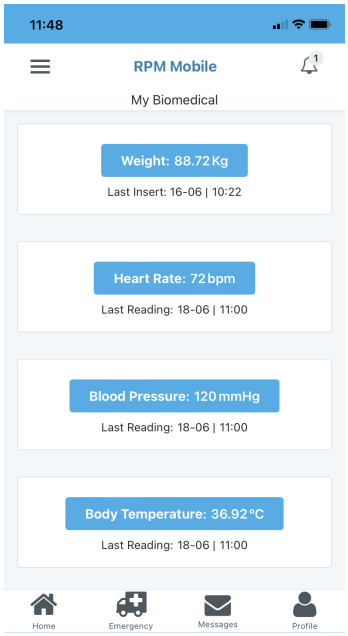
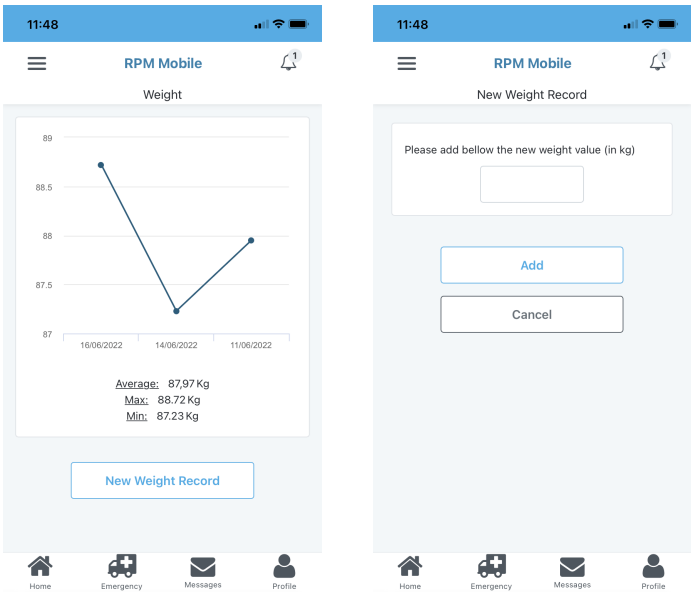


Figure 6.7: RPM Mobile - My Biomedical

The weight button of the my biomedical page, illustrated in figure 6.7, redirects the patient to a page that displays the weight values inserted by the patient it-self into the application. Accordingly, this page also gives the patient the option to add a new weight value, which will be then added to the chart.

Figure 6.8 presents the two weight associated-pages.



(a) (b)

Figure 6.8: RPM Mobile - Weight: (a) weight; (b) new weight record

The heart rate button of the my biomedical page, illustrated in figure 6.7, redirects the patient to a page that displays the heart rate values for today, yesterday and the last 7 days.[3] The maximum and minimum thresholds are also display, as previous detailed in sub-section 5.1.2.

Figure 6.9 illustrates the heart rate page.

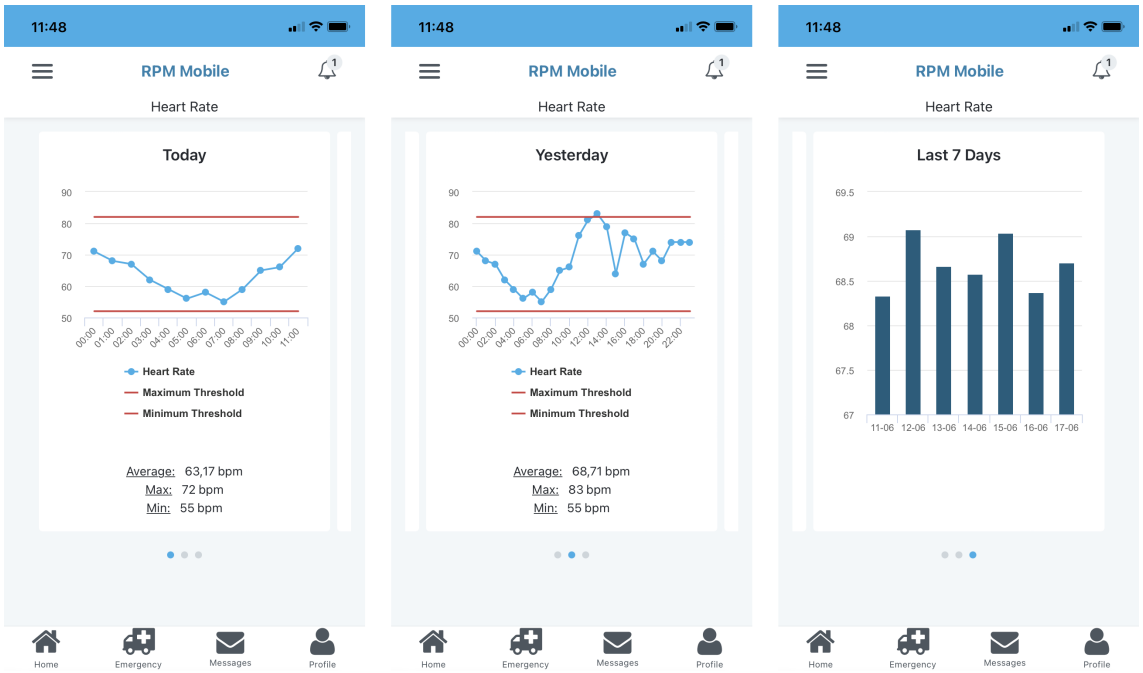


Figure 6.9: RPM Mobile - Heart Rate

[3] This is the same for blood pressure and body temperature.

After clicking the my house button of the homepage, illustrated in figure 6.5, the patient is redirect to a page that displays two different types of environment data: temperature and humidity. The data displayed corresponds to the last value read by the patient's device(s), and the date and time of the reading. Also, as previous stated in section 5.1.2, the quality of the values is indicated by their color.

Figure 6.10 depicts the house monitoring page.

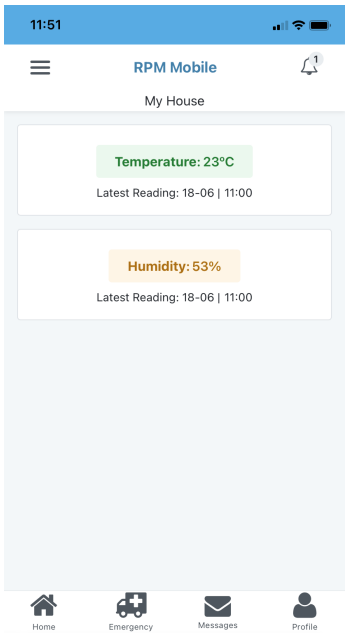


Figure 6.10: RPM Mobile - My House

The house temperature button of the my house page, illustrated in figure 6.10, redirects the patient to a page that displays the house temperature values for today, yesterday and the last 7 days.[4] In addition, the quality of the values is indicated for each one by its color.

Figure 6.11 illustrates the house temperature page.

[4]This is the same for house humidity.

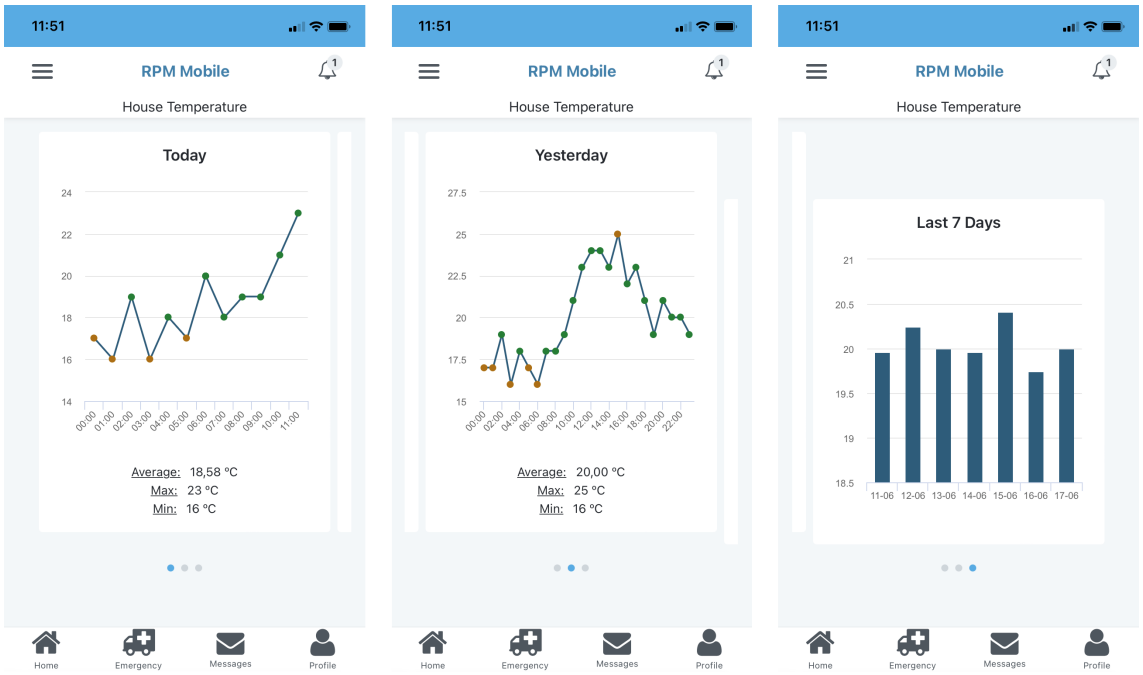
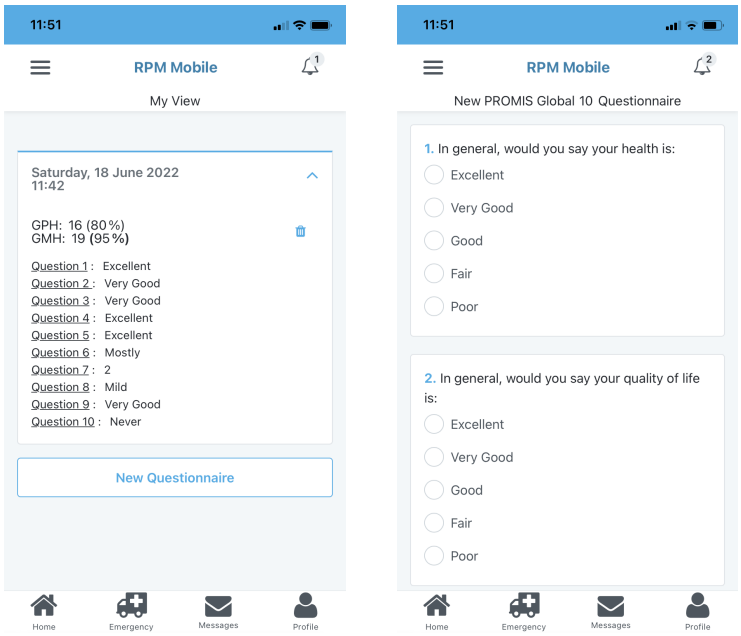


Figure 6.11: RPM Mobile - House Temperature

After clicking the my view button of the homepage, illustrated in figure 6.5, the patient is redirect to a page displays the questionnaire historic. Also, this page allows the patient to submit a new PROMIS Global 10 questionnaire.

Figure 6.12 depicts the view monitoring associated-pages.



(a) (b)

Figure 6.12: RPM Mobile - My View: (a) my view; (b) PROMIS global 10 questionnaire

After clicking the symptoms button of the homepage, illustrated in figure 6.5, the patient is redirect to a page that displays the symptoms historic and also allows the report of a new symptom.

The status of the symptom can be “assessed” or “under assessment”. If it is “assessed” it means the symptom reported was already assessed by a MTM. Therefore, by clicking on it the patient is redirect to a page that displays the respective assessment. Otherwise, i.e., if the status is “under assessment”, it means that the symptom reported was not yet assessed by a MTM.

Figure 6.13 depicts the symptoms associated-pages.

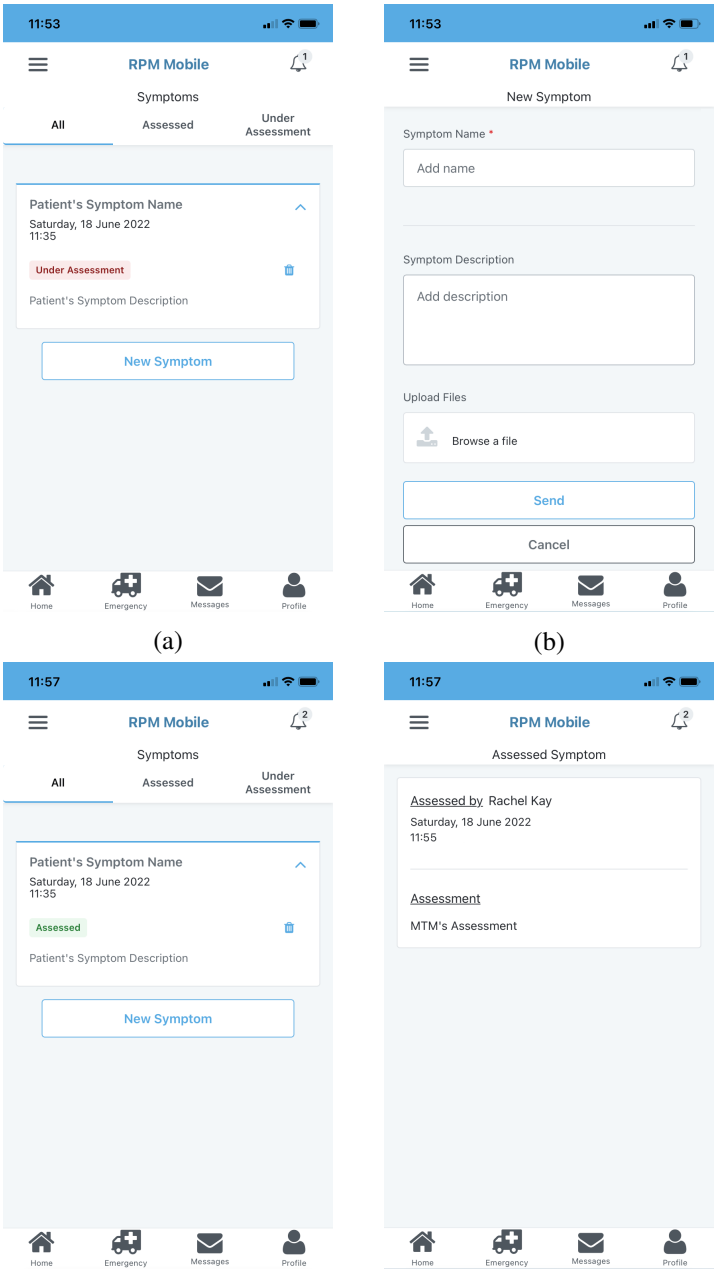


Figure 6.13: RPM Mobile - Symptoms: (a) pre-assessment symptom; (b) new symptom (c) post-assessment symptom; (d) assessment

In case of the smoking controller being turn on, after clicking the smoking controller button of the homepage, illustrated in figure 6.5, the patient is redirect to a page that displays the smoking information. The page also allows the patient to add a cigarette, which will be then added to the statistic values and chart.

Figure 6.14 depicts the smoking monitoring page.

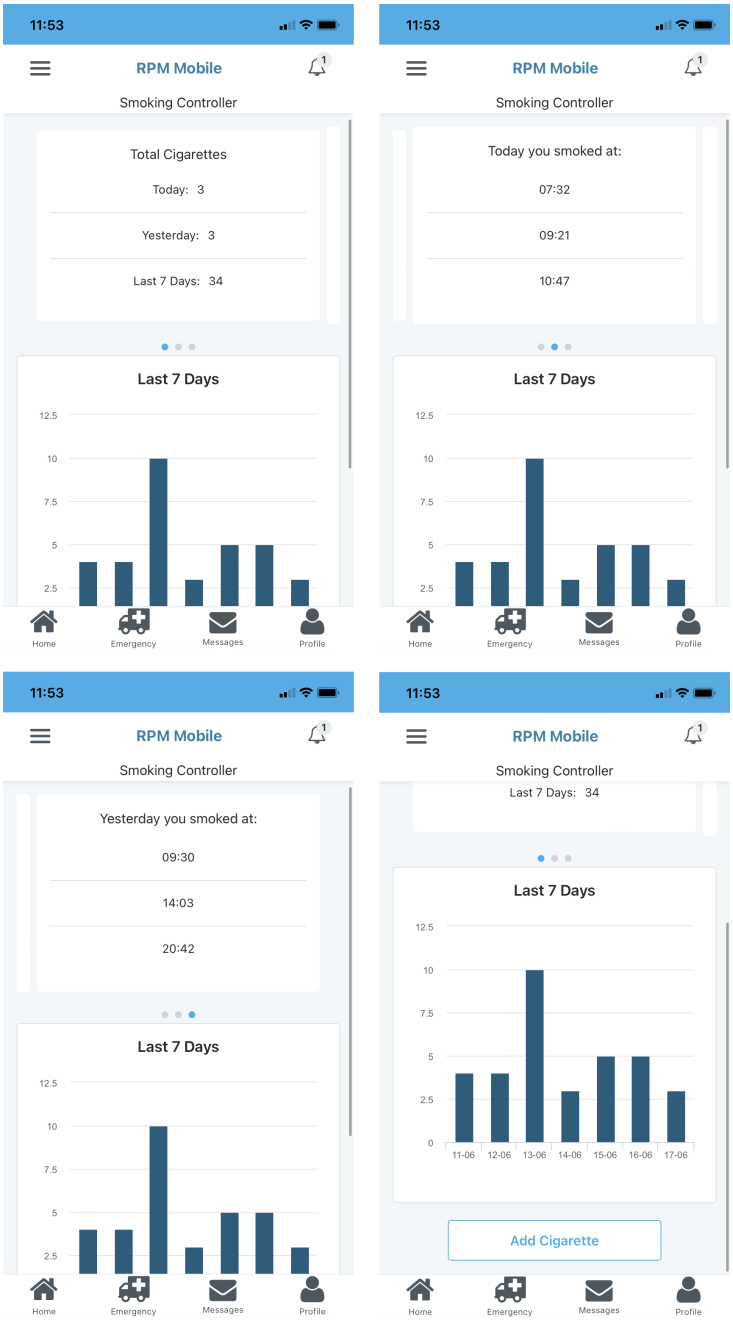


Figure 6.14: RPM Mobile - Smoking Controller

6.3.2 RPM Reactive Web Application Interfaces

The RPM Reactive Web application is aim to medical team members. Thereby, as in the previous application, the login into the application will only be successful if the account logging in belongs to a medical team member.

Figure 6.15 presents the login page of the RPM Reactive Web application.

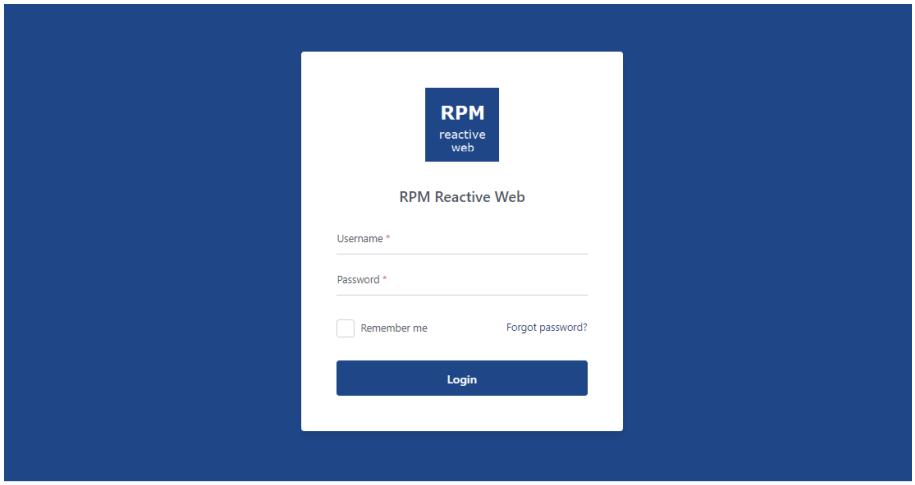


Figure 6.15: RPM Reactive Web - Login

After a successful login, the patient is redirected to the homepage, as illustrated in figure 6.16.

The homepage has, among with other components, one fixed icons, placed on top: notification icon. This icon opens a side bar containing the notification historic.

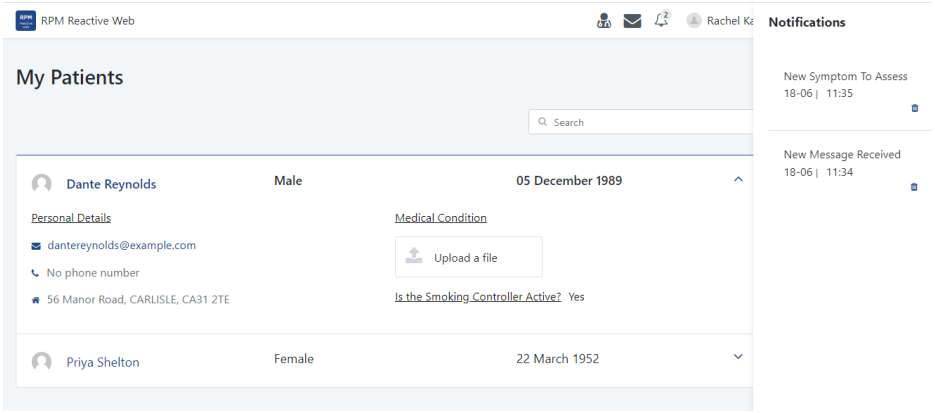
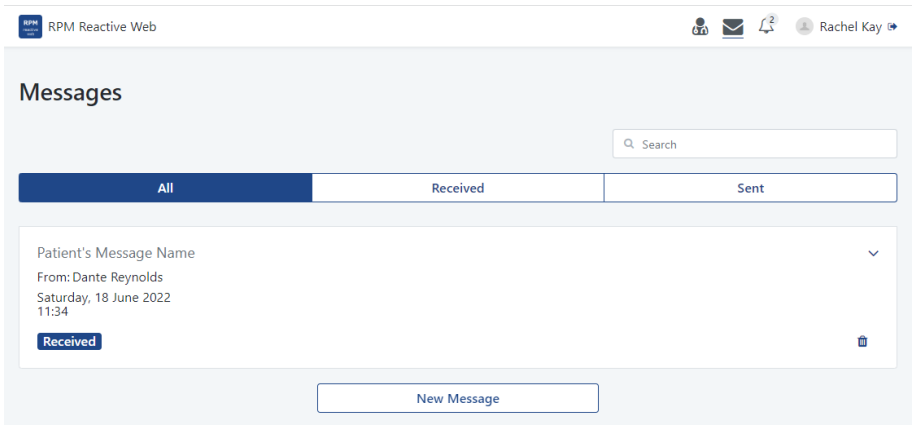


Figure 6.16: RPM Reactive Web - Homepage with Notifications Bar Open

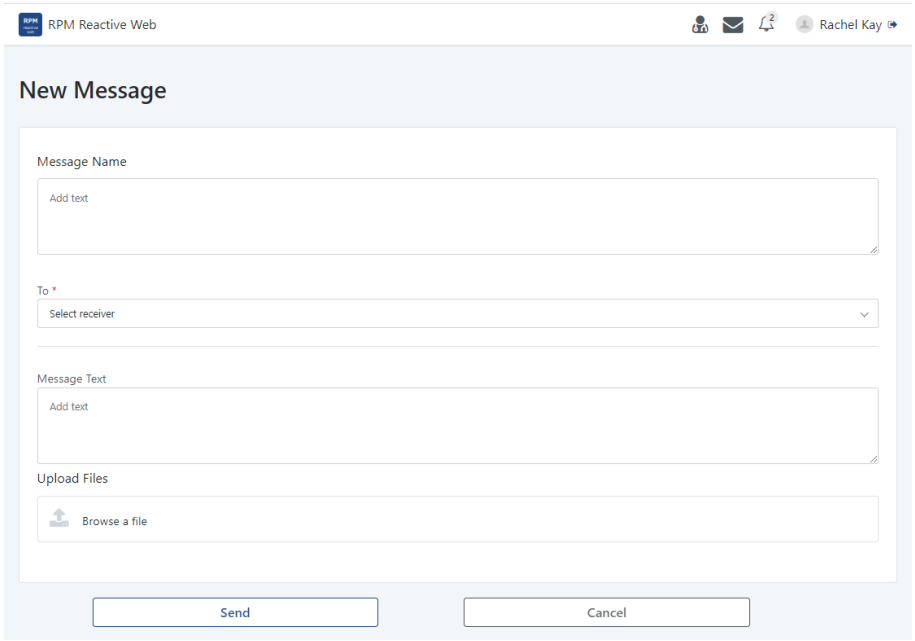
The application contains a fixed top bar with, besides the notification icon and the logout option, two additional icons: messages and profile. Figures 6.17 and 6.18 present the top bar associated-pages.

The message icon redirects the MTM to a page that displays the messages history and also allows the sending of a new message to a patient or another MTM.

Figures 6.17 depicts the messages associated-pages.



(a)



(b)

Figure 6.17: RPM Reactive Web - Top Bar | Messages: (b) message; (c) new message

The profile icon redirects the MTM to a page that displays all his/her personal and contact information.

Figures 6.18 depicts the profile page.

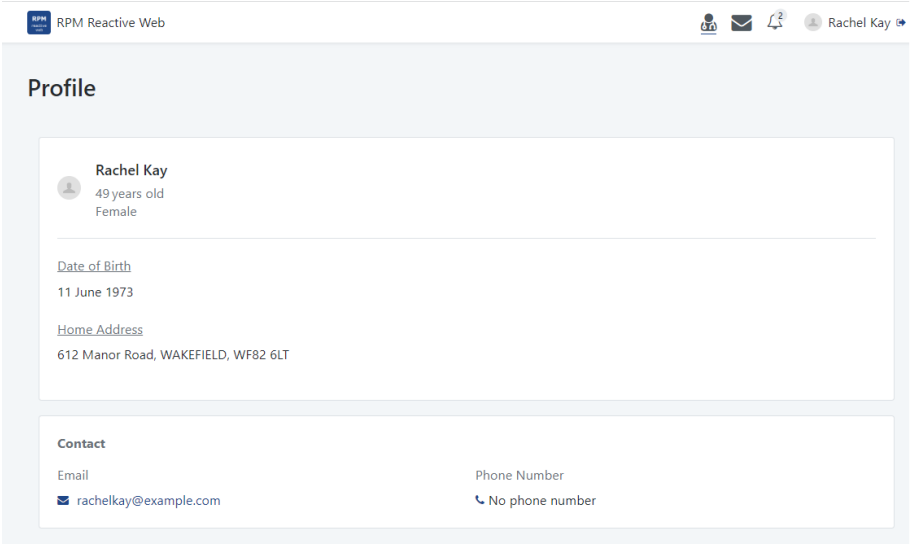


Figure 6.18: RPM Reactive Web - Top Bar | Profile

After clicking on a patient name in the homepage illustrated in figure 6.16, the MTM is redirected to the respective patient page where, from there, will be able to monitor the patient's health.

Figure 6.19 depicts the single patient page, i.e., the patients page.

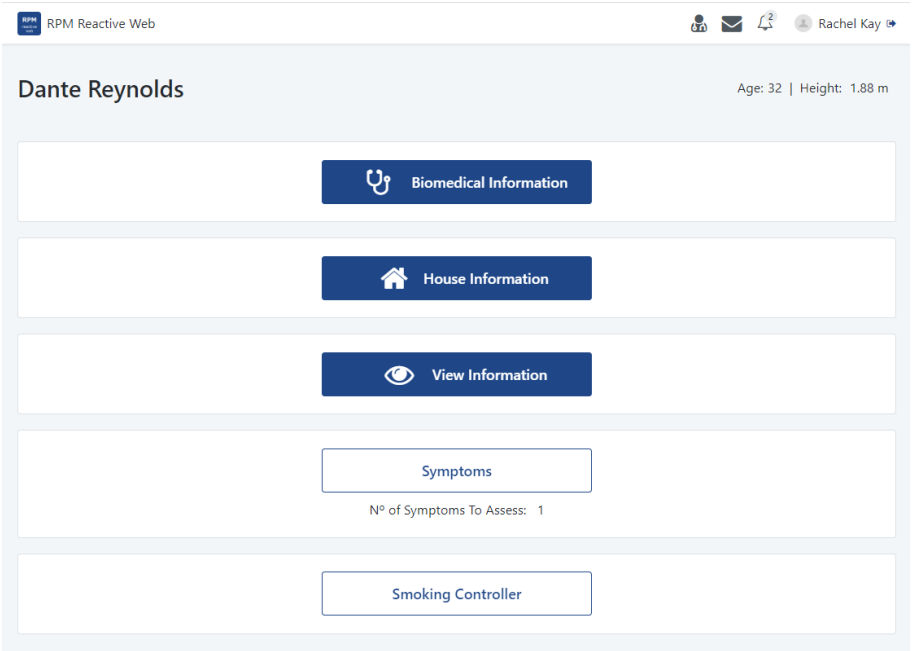


Figure 6.19: RPM Reactive Web - Patient

After clicking on the biomedical information button of the patient's page, illustrated in figure 6.19, the MTM is redirect to a page that displays the same biomedical information that is displayed to the patient through the RPM Mobile application.

Figure 6.20 depicts the patient's biomedical monitoring page.

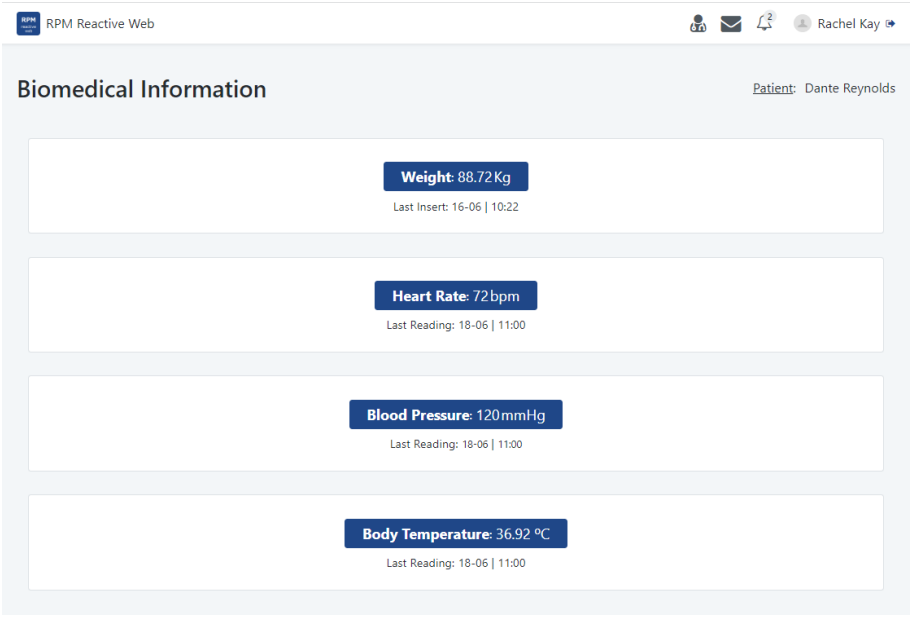


Figure 6.20: RPM Reactive Web - Biomedical Information

The weight button of the biomedical information page, illustrated in figure 6.20, redirects the MTM to a page that displays the patient's weight information.

Figure 6.21 presents the patient's weight page.

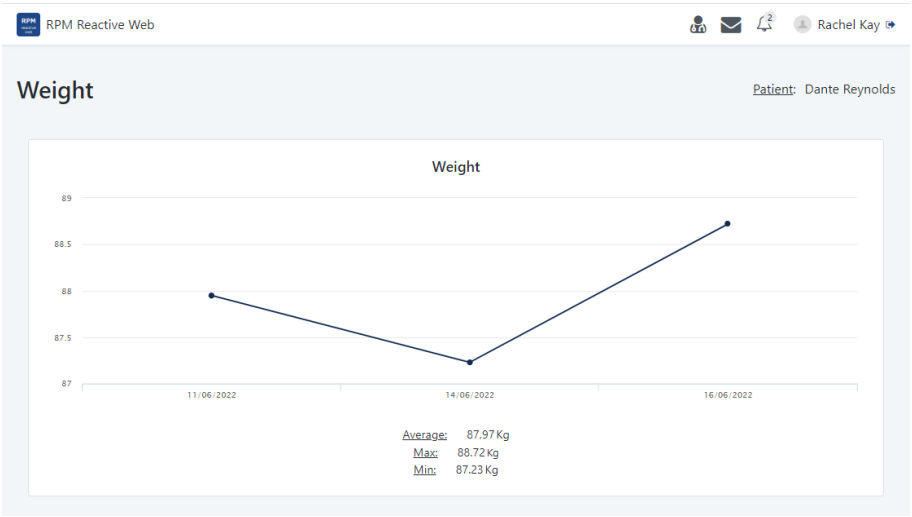


Figure 6.21: RPM Reactive Web - Patient's Weight

The heart rate button of the biomedical information page, illustrated in figure 6.20, redirects the MTM to a page that displays the patient's heart rate information.[5]

Figure 6.22 presents the patient's heart rate page.

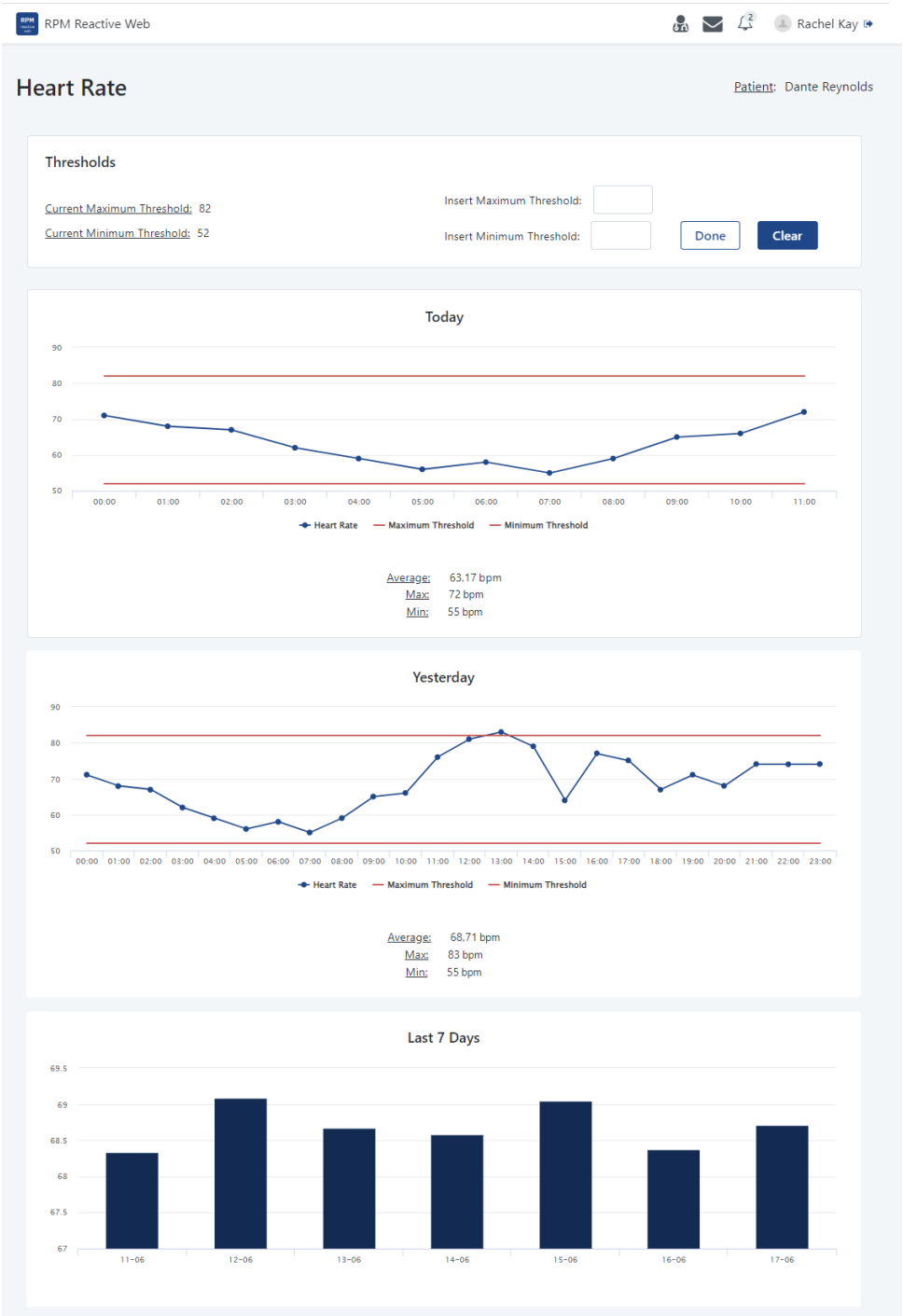


Figure 6.22: RPM Reactive Web - Patient's Heart Rate

[5]This is the same for blood pressure and body temperature.

After clicking the house information button of the patient's page, illustrated in figure 6.19, the MTM is redirect to a page that displays the same house information that is displayed to the patient.

Figure 6.23 depicts the patient's house monitoring page.

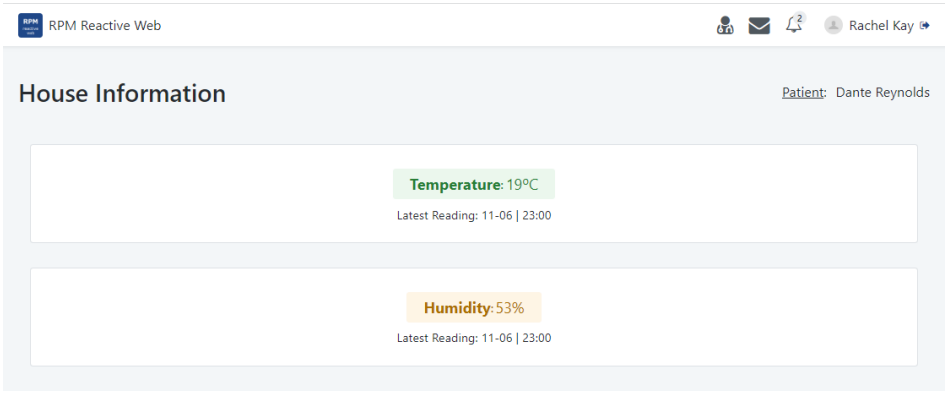


Figure 6.23: RPM Reactive Web - House Information

The house temperature button of the house information page, illustrated in figure 6.20, redirects the MTM to a page that displays the patient's house temperature information.[6]

Figure 6.24 presents the patient's heart rate page.

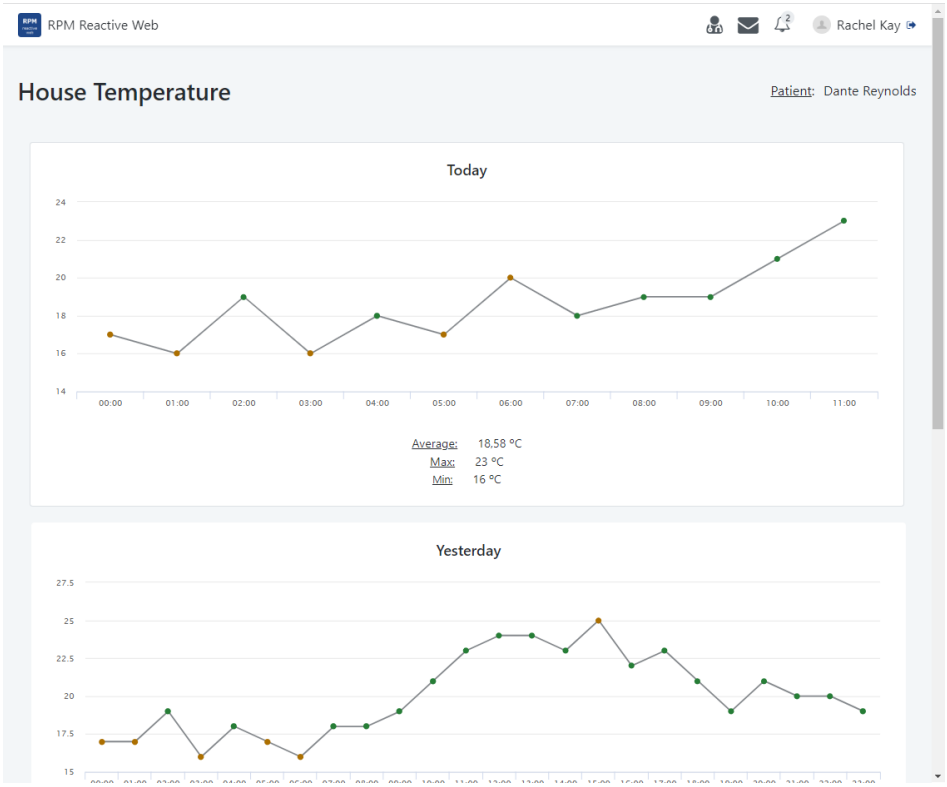


Figure 6.24: RPM Reactive Web - Patient's House Temperature

[6]This is the same for house humidity.

After clicking the view information button of the patient's page, illustrated in figure 6.19, the MTM is redirect to a page that displays the same view information that is displayed to the patient.

Figure 6.25 depicts the patient's view monitoring page.

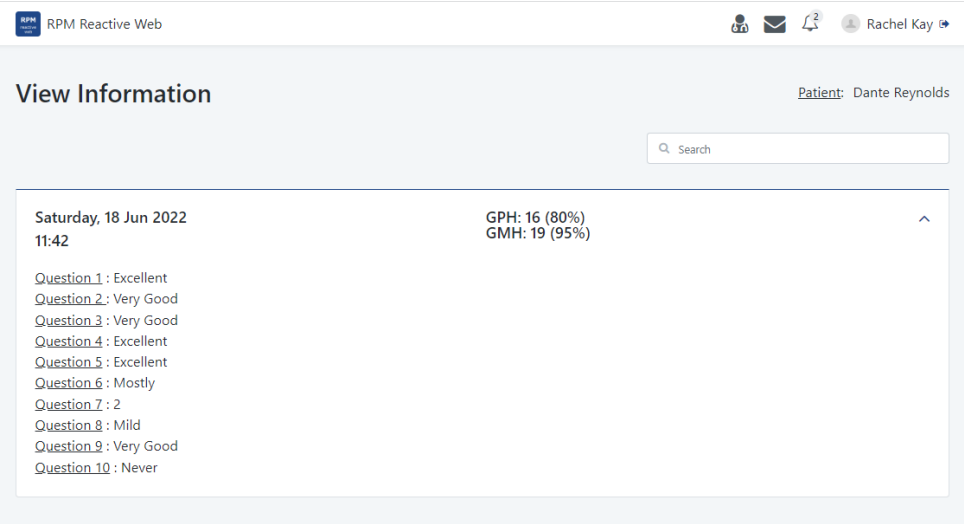


Figure 6.25: RPM Reactive Web - View Information

After clicking the symptoms button of the patient's page, illustrated in figure 6.19, the MTM is redirect to a page that displays the same symptom information that is displayed to the patient.

The status of the symptom can be "assessed" or "to assess". If the status is "to assess" it means the symptom was not yet assessed. Figure 6.26 depicts the patient's pre-assessment symptom page.

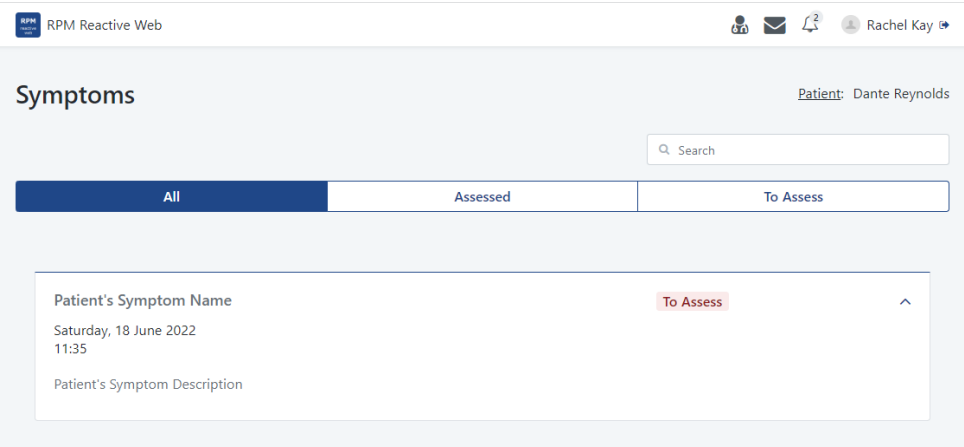
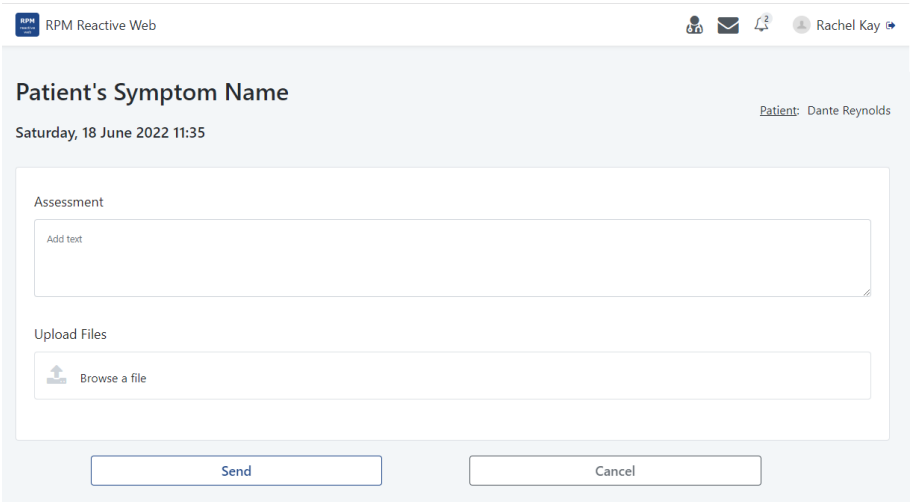


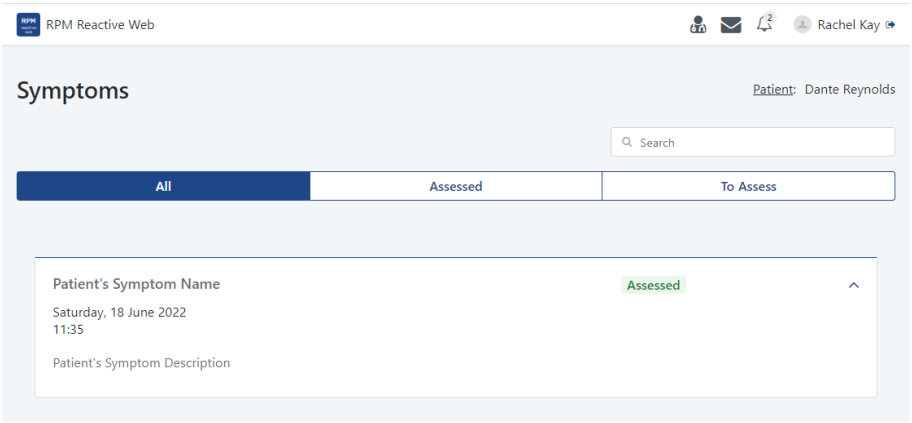
Figure 6.26: RPM Reactive Web - Symptoms | Pre-Assessment

The MTM is able to assess a non-assessed symptom by clicking in it. Consequently, the status of the symptom changes to "assessed".

Figure 6.27 depicts the patient's post-assessment symptom page.



(a)



(b)

Figure 6.27: RPM Reactive Web - Symptoms | Post-Assessment: (a) assessment; (b) post-assessment

After clicking the smoking controller button of the patient's page, illustrated in figure 6.19, the MTM is redirect to a page that displays the same smoking information that is displayed to the patient.

Figure 6.28 depicts the patient's smoking monitoring page.

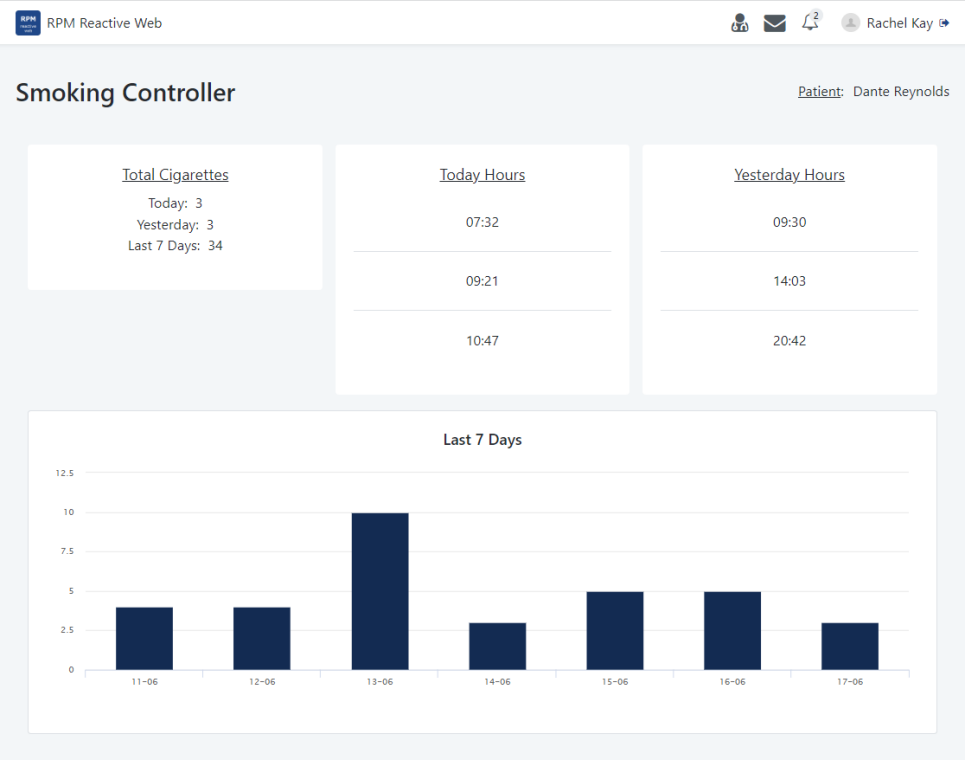


Figure 6.28: RPM Reactive Web - Smoking Information

Chapter 7

Validation of the Prototype

This chapter presents the validation of the prototype, i.e., the implemented applications, which consists of the final stage of the dissertation's project methodology illustrated in figure 1.2.

Section 7.1 depicts the method used for validating the prototype.

Section 7.2 presents the outcomes of the validations, i.e., the results.

7.1 Validation Method

An analysis of the outcomes of actual user usage over a pertinent period of time would be the optimum method of validating the prototype. This method allows the validation of the applications by both patients and medical team members. However, as the applications consists of a prototype, it was not possible to perform this near-to-reality validation.

Two meetings were held, one with a doctor, i.e., a medical professional, and another with three Deloitte colleagues from the OutSystems team. The purpose of these meetings was to gather feedback, from two separate point-of-views, regarding the usability of the applications.

For both meetings, a questionnaire was created for the participant(s) to complete at the end of the demonstration of the applications. The questionnaires are composed of two sections: while the first section consists of multiple-choice questions ranging from one to five, the second consists of open-ended questions. The composition of the questionnaires is the same, varying only on the questions made.

First Demonstration Meeting

The first meeting consisted of a demonstration of both applications to Drª Maria Clotilde Osório, the same doctor consulted for the pre-implementation validation of the prototype requirements detailed in section 5.3. The purpose of this meeting was to collect feedback from a medical professional point-of-view.

The questionnaire of this meeting can be found in figure E.1 in appendix E.

Second Demonstration Meeting

The second meeting involved a more technical demonstration of both applications to three Deloitte colleagues. It is viable to mention that every participant is an OutSystems developer and has significant expertise with the platform used for the prototype implementation. The purpose of this meeting has to gather feedback from a developer and also a possible patient point-of-view.

The questionnaire of this meeting can be found in figure E.2 in appendix E.

7.2 Validation Results

The results gathered in both meetings are quite promising, being indicators of the extraordinary success of the development of both applications.

The feedback gathered at the first meeting with the doctor was highly positive and included a constructive suggestion. In the multiple-choice questions, each question received the highest mark, proving that the medical professional found both applications appealing and of excellent quality. On the other hand, in the open-answer questions, a suggestion for improving communication between patients and medical professionals was made. The results of this first meeting can be found in table E.1 in appendix E.

At the second and last meeting with the Deloitte colleagues, positive feedback was obtained, including a few technical suggestions. In the multiple-choice questions, each question, except for one, received the highest mark, indicating that OutSystems developers and potential patients, i.e., potential prototype users, found both applications attractive and of high quality and efficiency. On the other hand, in the open-answer questions, two suggestions regarding the integration between both applications were made. The results of this second and last meeting can be found in table E.2 in appendix E.

Overall, the outcomes of both questionnaires indicate that the prototype was successfully developed, albeit some adjustments will be needed in the future to improve and extend its quality. Therefore, the results are consistent with the notion that this prototype could be highly useful for remote patient monitoring.

Chapter 8

Conclusions and Future Work

This final chapter contains both the conclusions and perspectives for future work.

While section 8.1 presents the final conclusions of the dissertation based on the satisfaction of the objectives detailed in section 1.3, section 8.2 explores the future work.

8.1 Conclusions

The healthcare sector is currently undergoing a global digital transformation, being remote patient monitoring one of the priority areas of this transformation. As Deloitte Portugal has a particular interest in exploring and innovating this growing area, the dissertation project was proposed.

After thorough research on the current state of the art of RPM, several ways of innovating and improving general health monitoring were encountered. With the Deloitte suggestions based on the outcomes of the research and the experience in the area, it was possible to design and implement, using the OutSystems platform, a prototype consisting of two applications, one for patients and another for medical professionals, to remote monitor general health.

The prototype was successfully developed, i.e., properly designed and implemented, with simple-to-use and intuitive interfaces and a great deal of future potential. Its principal aim is to enable medical professionals to reach faster and more personalised medical decisions based on the view of patient's health data and a closer relationship with them.

The RPM Mobile application, which is destined for patients, allows them to view their health status and also to communicate closely with medical professionals.

The RPM Reactive Web application intends for the medical professionals to view the same health-related data that the patients view, i.e., their health status, as well as allowing a closer communication with them.

Due to its innovative characteristics, the prototype developed within the framework of the dissertation will be demonstrated in a meeting with Deloitte's OutSystems team. It is possible that the prototype will be useful for ongoing or upcoming Deloitte projects.

In summary, it is plausible to conclude that the dissertation project was successful since its objectives, detailed in section 1.3, were accomplished with success and even exceeded.

8.2 Future Work

In accordance with the feedback gathered from the medical professional and the OutSystems developers at Deloitte, the functionalities scheduled for future work are the following:

- Synchronization with devices, which would allow the real-time data collection, as this was outside the scope of the dissertation with the data present in the database being static hourly data;
- Chat messages to allow better communication between the medical professionals and the patients since the prototype only allows both users to send new messages being the message history confused;
- Incorporation of all the other types of data that where not included in the prototype, detailed in figure 5.2 in section 5.1.

In addiction, two researches should also be conducted in order to uncover new elements to include in the applications that would improve it:

- 5G in heath applications — 5G is the fifth and most recent generation network of cellular mobile communications and, thereby, can positively impact the quality of the monitoring applications as far as their speed is concerned.
- Regulations for data protection — the data of this applications corresponds to health-related data, which is considered to be sensitive data. Therefore, it is essential to consider the pre-defined standards established to prevent the disclosure of patient health information without the patient's consent. GDPR (General Data Protection Regulation) and HIPAA (Health Insurance Portability and Accountability Act) correspond to the European and the United States of America market regulations, respectively.

Appendix A

Current Smartwatch Market

Table A.1: Current Smartwatch Market Research [20] [21] [22] [23]

Company	**Product Name**	**Price**	**Health Features**								
			Heart Rate	Oxygen Levels	Activity Tracker	Sleep Tracker	Stress Tracker	Fall Detection	Blood Pressure	ECG	Body Temperature
Apple	Apple Watch Series 7	439,00€	✓	✓	✓	✓	✓	✓	Need extra medical equipment	✓	×
Xiaomi	Xiaomi Watch S1 Active GL	200,00€	✓	✓	✓	✓	✓	×	×	×	×
Samsung	Galaxy Watch 4	214,90€	✓	✓	✓	✓	✓	✓	✓	✓	×
Huawei	Huawei Watch 3	329,90€	✓	✓	✓	✓	✓	✓	×	×	✓

Appendix B

PROMIS Global 10 v1.2

B.1 Questionnaire

Global health items

Variable name	Item context	Item stem	Responses
Global01		In general, would you say your health is:	5 = Excellent 4 = Very good 3 = Good 2 = Fair 1 = Poor
Global02		In general, would you say your quality of life is:	5 = Excellent 4 = Very good 3 = Good 2 = Fair 1 = Poor
Global03		In general, how would you rate your physical health?	5 = Excellent 4 = Very good 3 = Good 2 = Fair 1 = Poor
Global04		In general, how would you rate your mental health, including your mood and your ability to think?	5 = Excellent 4 = Very good 3 = Good 2 = Fair 1 = Poor
Global05		In general, how would you rate your satisfaction with your social activities and relationships?	5 = Excellent 4 = Very good 3 = Good 2 = Fair 1 = Poor
Global09r		In general, please rate how well you carry out your usual social activities and roles. (This includes activities at home, at work and in your community, and responsibilities as a parent, child, spouse, employee, friend, etc.)	5 = Excellent 4 = Very good 3 = Good 2 = Fair 1 = Poor
Global06		To what extent are you able to carry out your everyday physical activities such as walking, climbing stairs, carrying groceries, or moving a chair?	5 = Completely 4 = Mostly 3 = Moderately 2 = A little 1 = Not at all
Global10r	In the past 7 days	How often have you been bothered by emotional problems such as feeling anxious, depressed or irritable?	5 = Never 4 = Rarely 3 = Sometimes 2 = Often 1 = Always
Global08r	In the past 7 days	How would you rate your fatigue on average?	5 = None 4 = Mild 3 = Moderate 2 = Severe 1 = Very severe
Global07r	In the past 7 days	How would you rate your pain on average?	5 = 0 No pain; 4 = 1; 4 = 2; 4 = 3; 3 = 4; 3 = 5; 3 = 6; 2 = 7; 2 = 8; 2 = 9; 1 = 10 worst pain imaginable

Figure B.1: PROMIS Global 10 - Questionnaire. Adapted from [16] [17].

B.2 GPH and GMH Formulas

GPH Score = Global03 + Global06 + Global07r + Global08r [17]

GMH Score = Global02 + Global04 + Global05 + Global10r [17]

Appendix C

Application's Notifications

C.1 RPM Mobile Application

Table C.1: RPM Mobile Application Notifications

Notification	Event-Trigger
Medical Information Uploaded	Upload of a medical information PDF file by a MTM
New Message	Reception of a new message
New Symptom Assessed	Assessment of a symptom by a MTM
New Heart Rate Threshold Values	Setting of new heart rate threshold values by a MTM
New Blood Pressure Threshold Values	Setting of new blood pressure threshold values by a MTM
New Body Temperature Threshold Values	Setting of new body temperature threshold values by a MTM

C.2 RPM Reactive Web Application

Table C.2: RPM Reactive Web Application Notifications

Notification	Event-Trigger
New Message	Reception of a new message
New Symptom to Assess	Reporting of a symptom by a patient

Appendix D

Medical Validation of the Requirements

D.1 Pre-implementation Document

General Health RPM Applications Prototype

Document Purpose: This document aims to present the functionalities (features) of the general remote patient monitoring (RPM) applications prototype, proposed within the framework of the dissertation. On the last page of this document, a set of questions are posed in order to get feedback on the proposed applications.

The prototype consists in two applications: RPM Mobile and RPM Reactive Web.

The primary goal of this prototype is to remotely monitor a patient's general health by displaying to him/her and to medical professionals his/her health-related data. This allows the medical professionals to make accurate and more personalized medical decisions based on the patient's data.

This type of applications have countless benefits such as the reduction of costs to the patient and to the medical facilities and the provision of healthcare to people that life in rural areas. Another important benefit that is important to mention is the provision of patient's self-management: by displaying all his/her data, he/she become more aware of his/her health status. Consequently, this prototype allows the patient to manage better his/her health condition.

The data of the applications can be divided into two categories: automatic data and manual data. The automatic corresponds to the data collected through devices such as wearables and home sensors. In other hand and contrary to the automatic, the manual consists in the data that cannot be automatically obtained through a device.

After an academic and current market research (dissertation's state of the art), it was decided to include in the prototype the following types of data:

Automatic Data		Manual Data	
Sub-Category	**Motive**	**Sub-Category**	**Motive**
Biomedical	Crucial data to include in this type of applications	Patient-reported outcomes measures (PROMs)	This data is becoming increasingly relevant as it is incorporated into the periodic monitoring of patients Questionnaire: PROMIS Global 10
Living-Environmental	Data that provides context-awareness, which is a relevant aspect to be consider when developing innovative RPM applications	Symptoms	Patient is able to report symptoms that he/she is current experience and the medical professionals are able to assess those symptoms
		Addiction	Data such as the daily number of cigarettes smoked or the alcoholic drinks taken are relevant to incorporate in innovative RPM applications

1. Types of Data incorporated in the RPM Prototype

Depending on the application, the prototype has two different types of users:

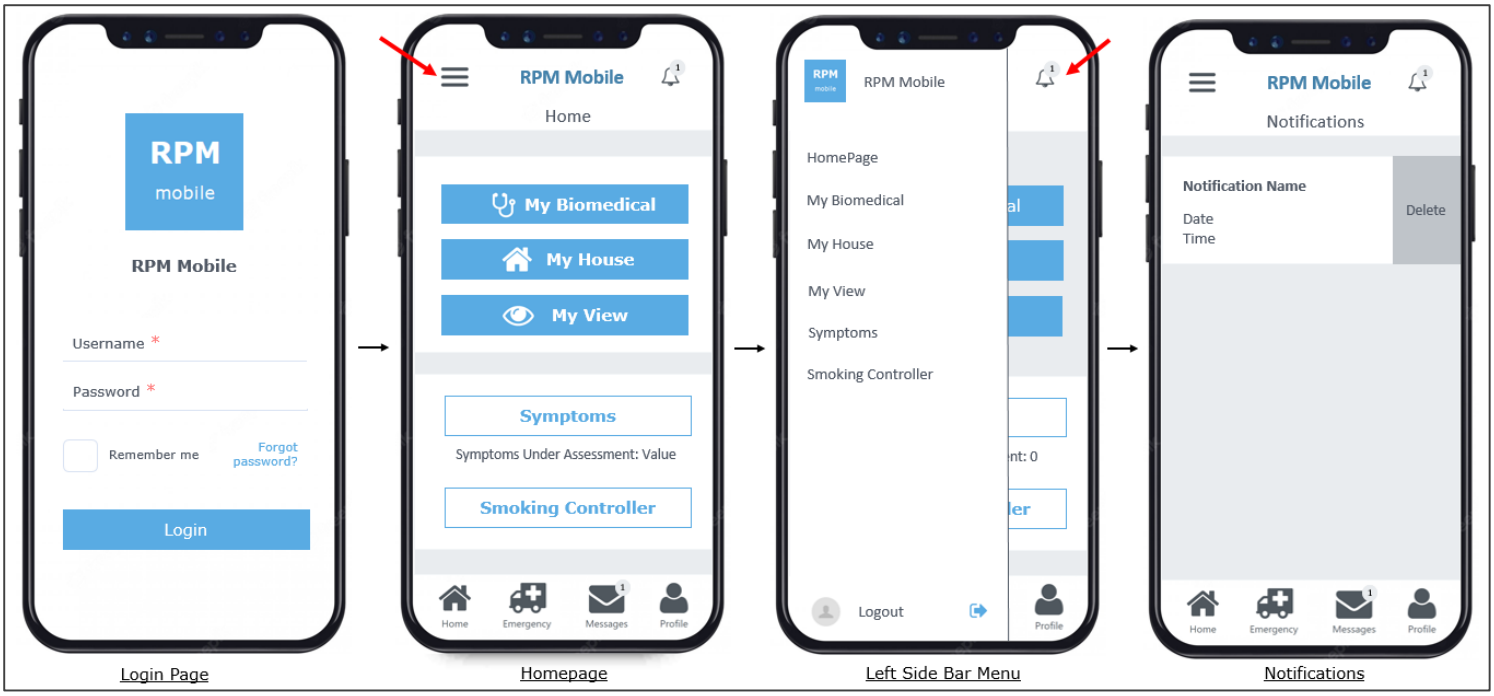
- RPM Mobile – Patient
- RPM Reactive Web – Medical Team Member (consists in a more wide-ranging name than medical professionals)

RPM Mobile - mobile application for the patients

The homepage has, among with other components, two icons placed on top: left side menu icon and the right side notification icon.

By clicking on the left side menu icon a side bar is open with the 6 main pages links, which enable the user to better navigate through the application, and the logout.

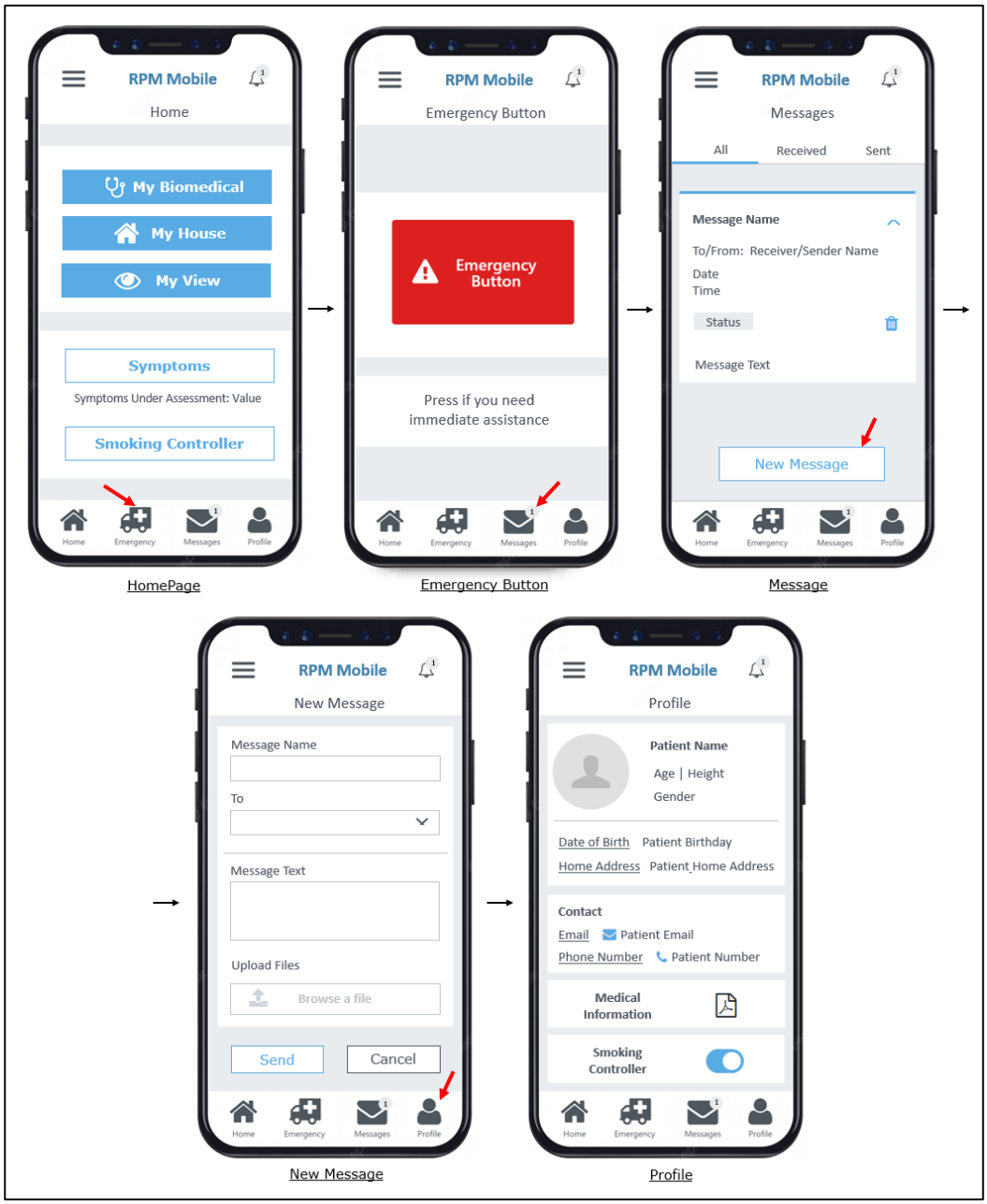
By clicking on the right side notification icon the user is redirect to a page with the notification history.



2.1. RPM Mobile – Home Page

The bottom bar consists in 4 icons: home, emergency, messages and profile.

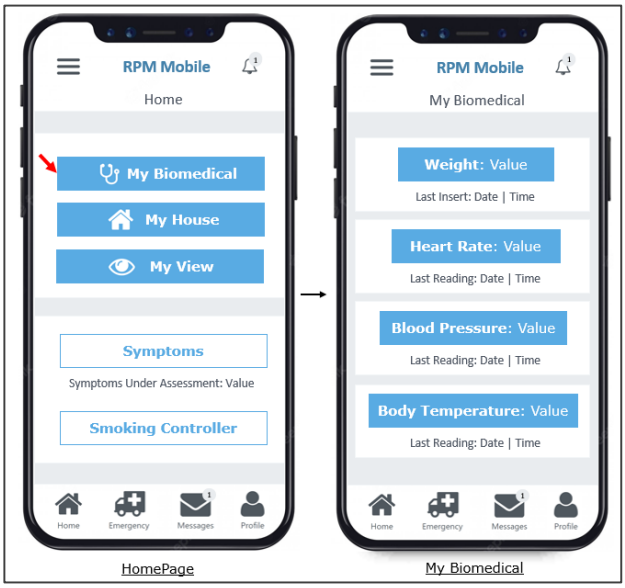
The home icon redirects the patient to the homepage. The emergency icon redirects to a page where the patient can press a bottom in case of need immediate assistance. Clicking on the message icon the user is redirected to a page that displays the messages history and also allows him/her to send a new message to a MTM. Finally, the profile icon redirects the patient to a page that displays all his/her personal information and contains a PDF file with is medical information (the file can be uploaded by a MTM and also a button that allows him/her to turn on/off the smoking controller.



2.2. RPM Mobile – Bottom Bar

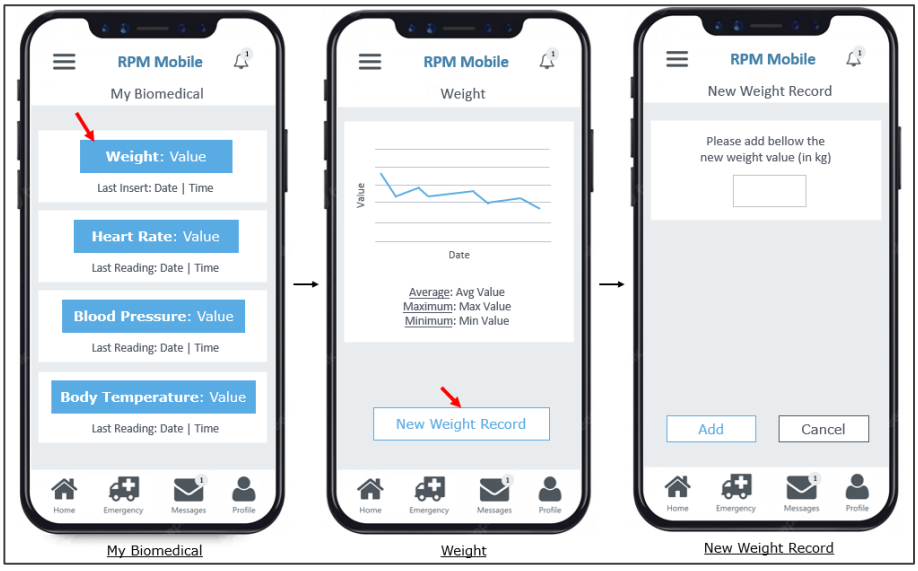
By clicking on the my biomedical button the patient is redirect to a page that displays 4 different types of biomedical data : weigh, heart rate, blood pressure and body temperature. The data displayed on this page corresponds to the last value read by the patient's wearable device and also the date and time of the reading.

It is important to mention that other types of biomedical data were considered: oxygen levels, activity, sleep, stress, fall detection, ECG and glucose levels. However, being this a prototype, it was decided, after careful analysis, that the example data to be implemented in the prototype are the ones mention above.



2.3. RPM Mobile – My Biomedical

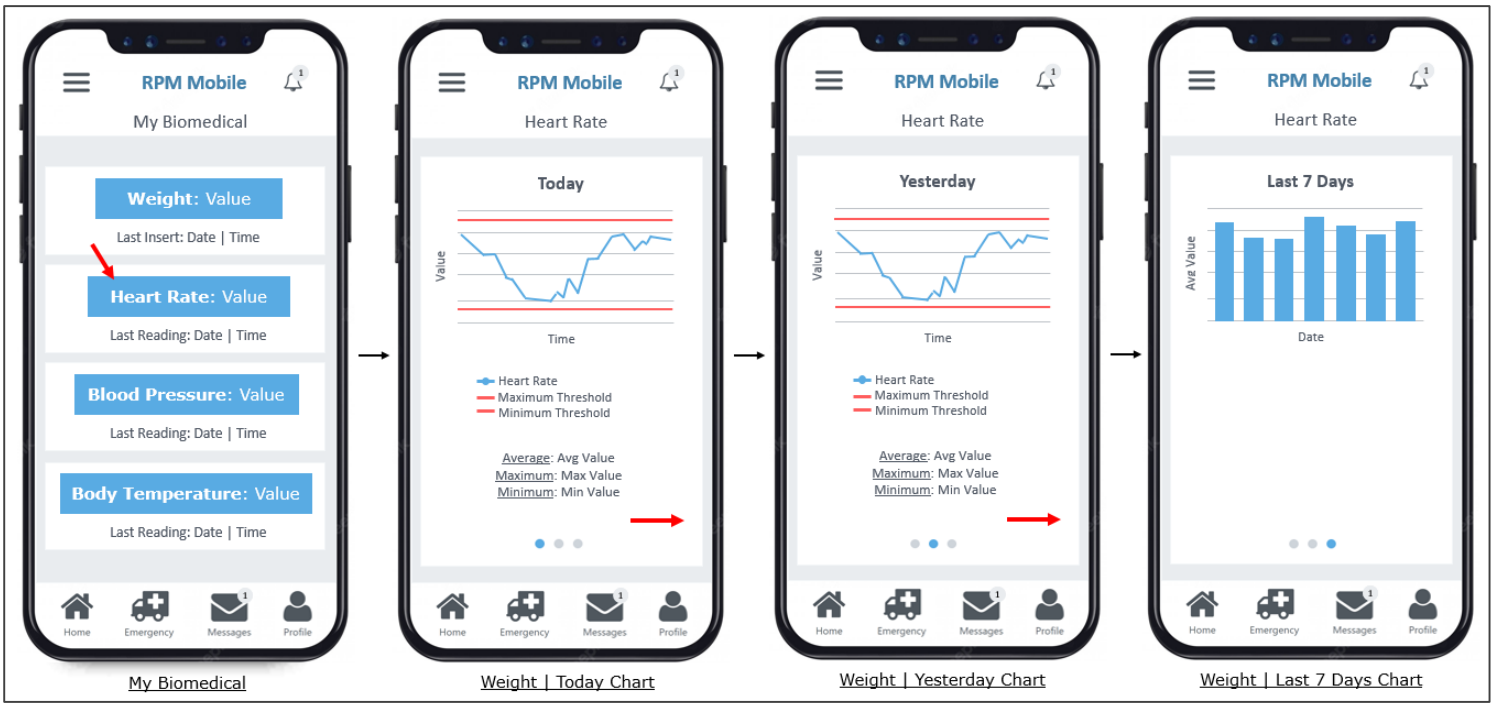
The weight button redirects the patient to a page that displays the weight chart and 3 statistic values. Also in this page, the patient can add a new weight value which will be then added to the chart.



2.3.1. RPM Mobile – My Biomedical | Weight

The heart rate button redirects the patient to a page that displays 3 charts: today line chart, yesterday line chart and the last 7 days column chart. Statistical values are displayed for line graphs. It is also important to mention that in the two line charts there are 3 different lines: heart rat, maximum threshold and minimum threshold. The thresholds are values, pre-defined by a MTM, that together form a range of acceptable values. That said, all the heart rate values should be within the range defined by the thresholds lines.

This is the same for the blood pressure button and body temperature button.

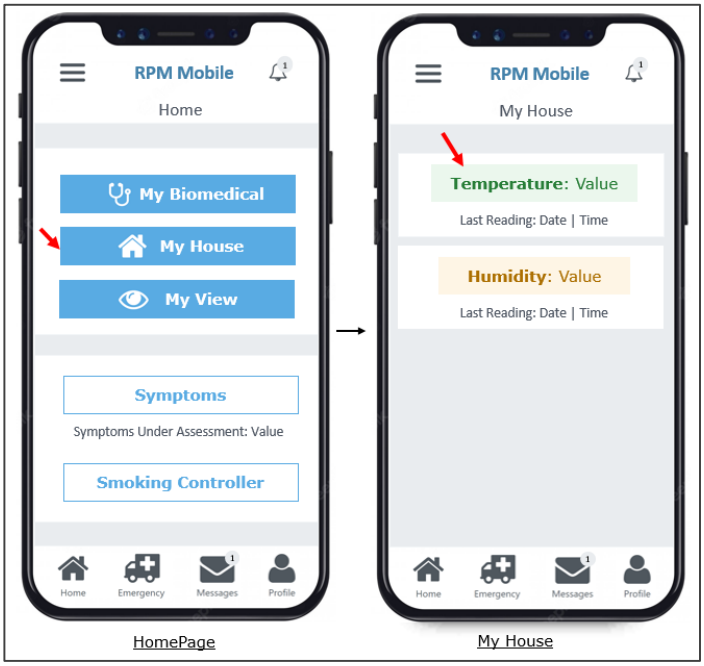


2.3.2. RPM Mobile – My Biomedical | Heart Rate

By clicking on the my house button the patient is redirect to a page that displays 2 different types of environment data: temperature and humidity. The data displayed on this page corresponds to the last value read by the patient's house device and also the date and time of the reading.

As you can see in the image bellow, the temperature and humidity can have 2 different colours, green and yellow, according to their last read value. If the value is an acceptable value it will have de colour green. If not, it will have the colour yellow. The range used for acceptable indoor temperature values was defined by WHO (World Health Organization) and the range used for acceptable indoor humidity was defined by the National Asthma Council Australia.

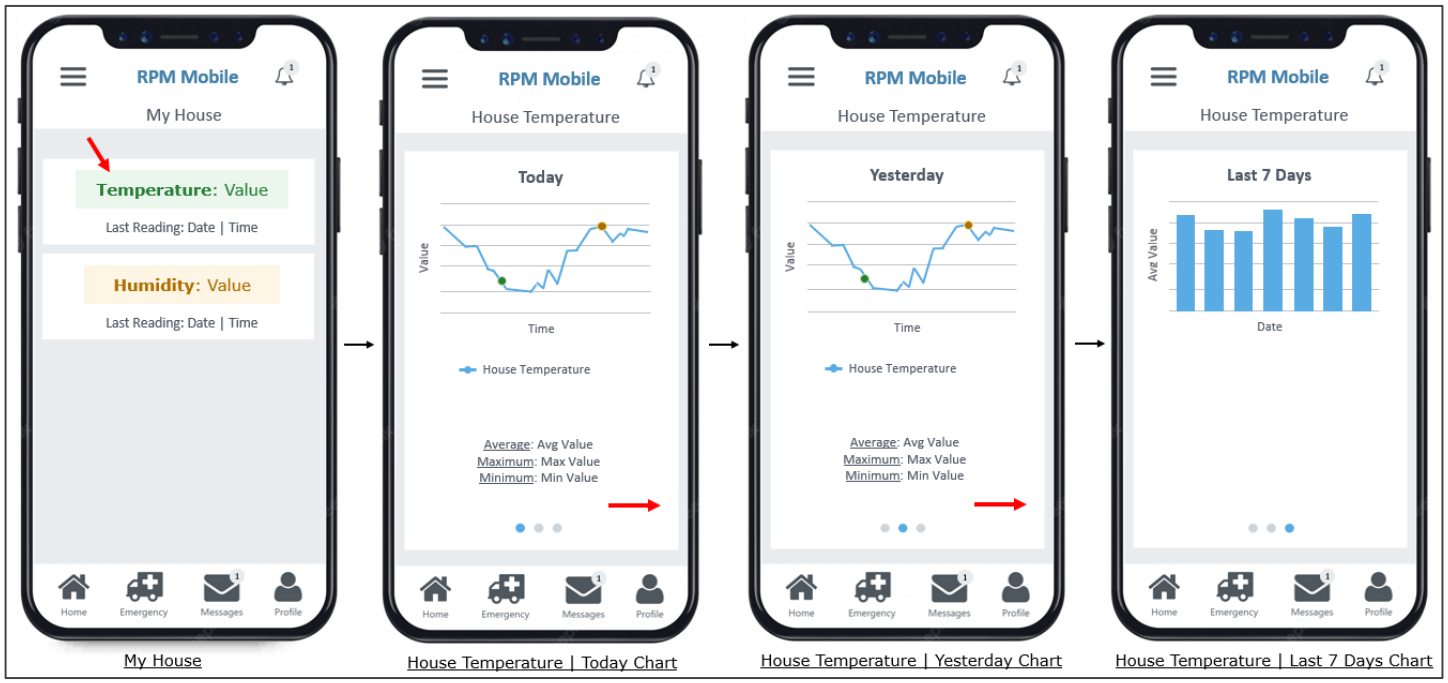
It is important to mention, as in the previous feature, my biomedical, other types of environment data were considered: lightness and air quality index (AQI).



2.4. RPM Mobile – My House

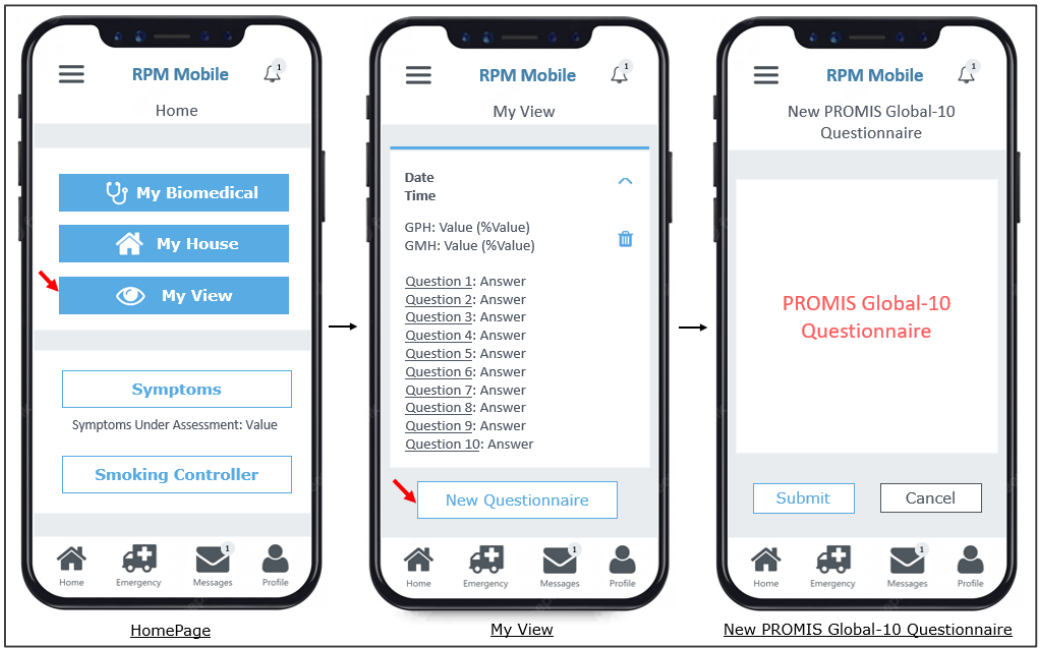
The temperature button redirects the patient to a page that displays 3 charts: today line chart, yesterday line chart and the last 7 days column chart. Statistical values are displayed for line graphs. It is also important to mention that the points on the line charts have the same colour system as mentioned above.

This is the same for the humidity button.



2.4.1. RPM Mobile – My House | Temperature

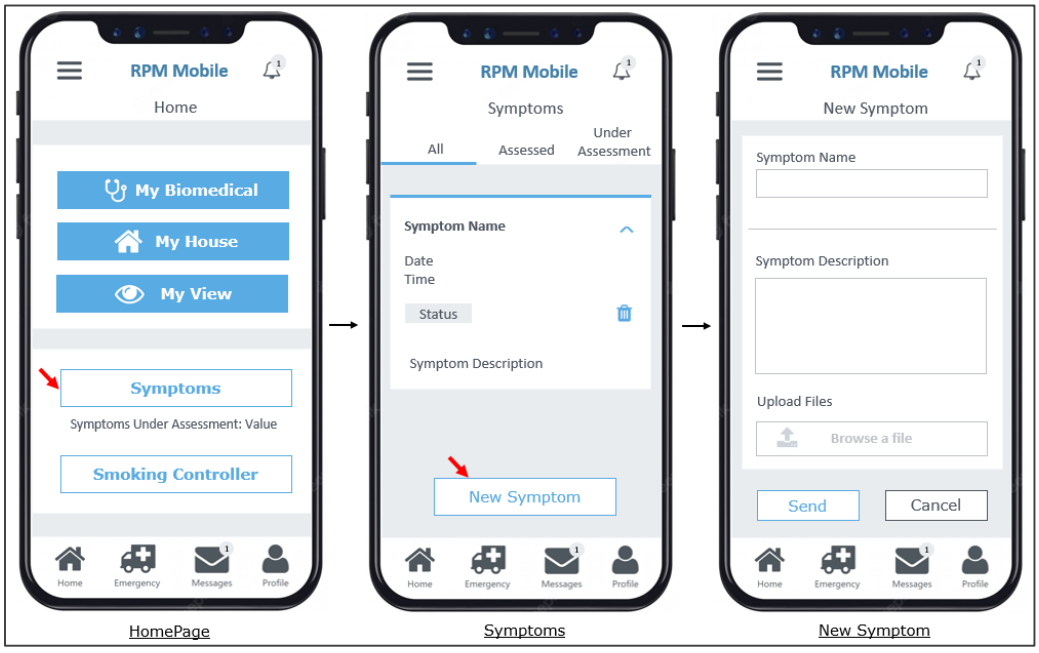
By clicking on the my view button the patient is redirect to a page that displays the questionnaire history and allows the creation of a new questionnaire.



2.5. RPM Mobile – My View

By clicking on the symptoms button the patient is redirect to a page that displays the symptoms history and allows him/her to report a new symptom. It is important to mention that the status of the symptom can be "assessed" or "under assessment".

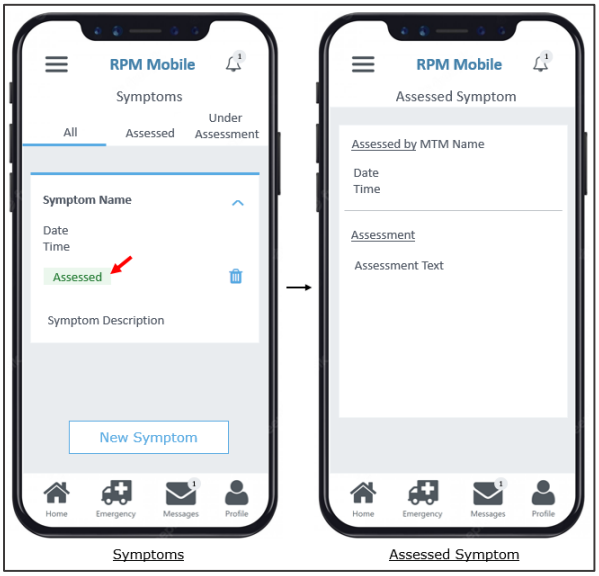
It is important to mention, as in the previous features, other type of symptom data was considered: addiction of a pain level scale, in case of the symptom being painful.



2.6. RPM Mobile – Symptoms

If the status is "assessed" it means that the symptom reported was already assessed by a MTM. Therefore, by clicking the assessed button the patient is redirect to a page that displays the MTM assessment to that symptom.

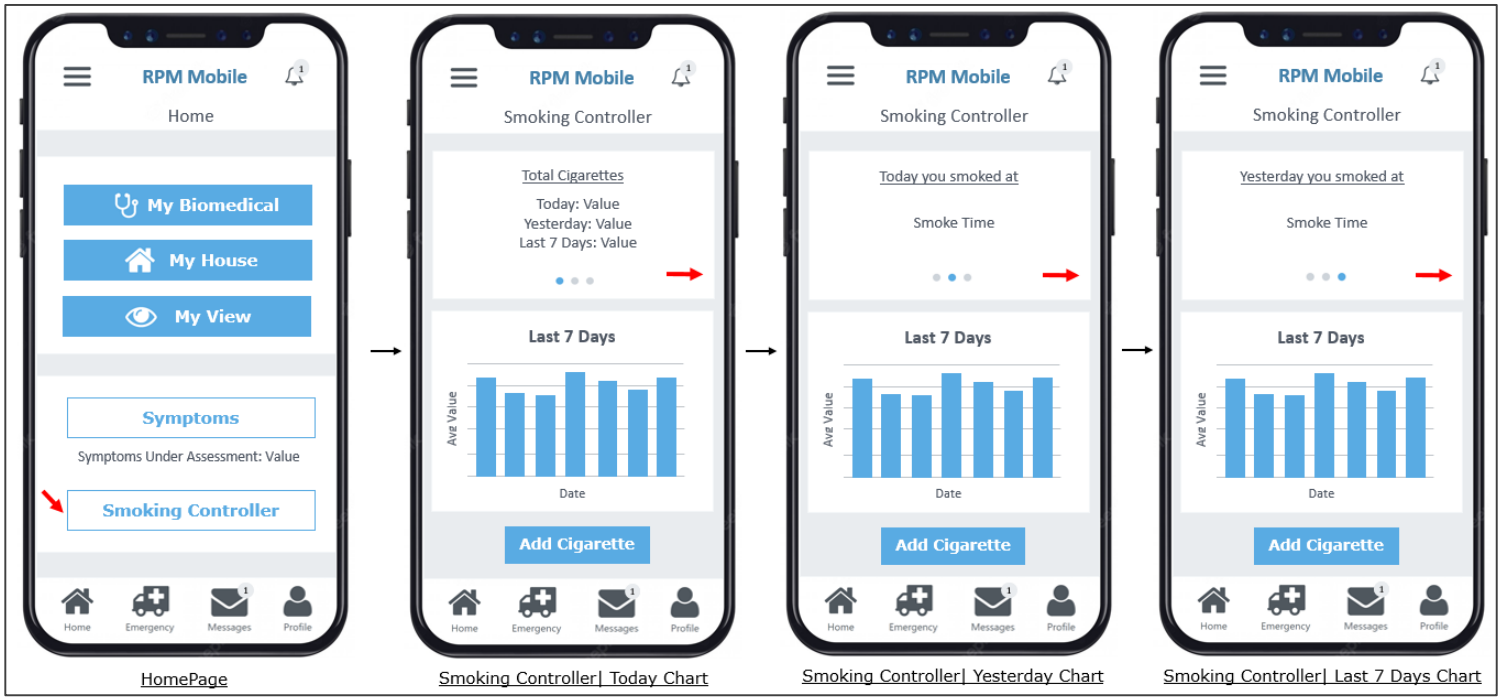
Otherwise, i.e. if the status is "under assessment", it means that the symptom reported was not yet assessed by a MTM.



2.6.1. RPM Mobile – Symptoms | Assessed Symptom Example

In case of the smoking controller being turned on, by clicking on the smoking controller button the patient is redirected to a page that displays the total number of cigarettes smoked today, yesterday and in the last 7 days as well as the times when the cigarette was smoked. It also displays the last 7 days column chart. Finally, in the end of the screen, there is a button where the patient can click to add a cigarette, i.e. he/she has to click the button when smoking a cigarette.

It is important to mention, as in the previous features, other type of addiction data was considered: alcoholic drinks.



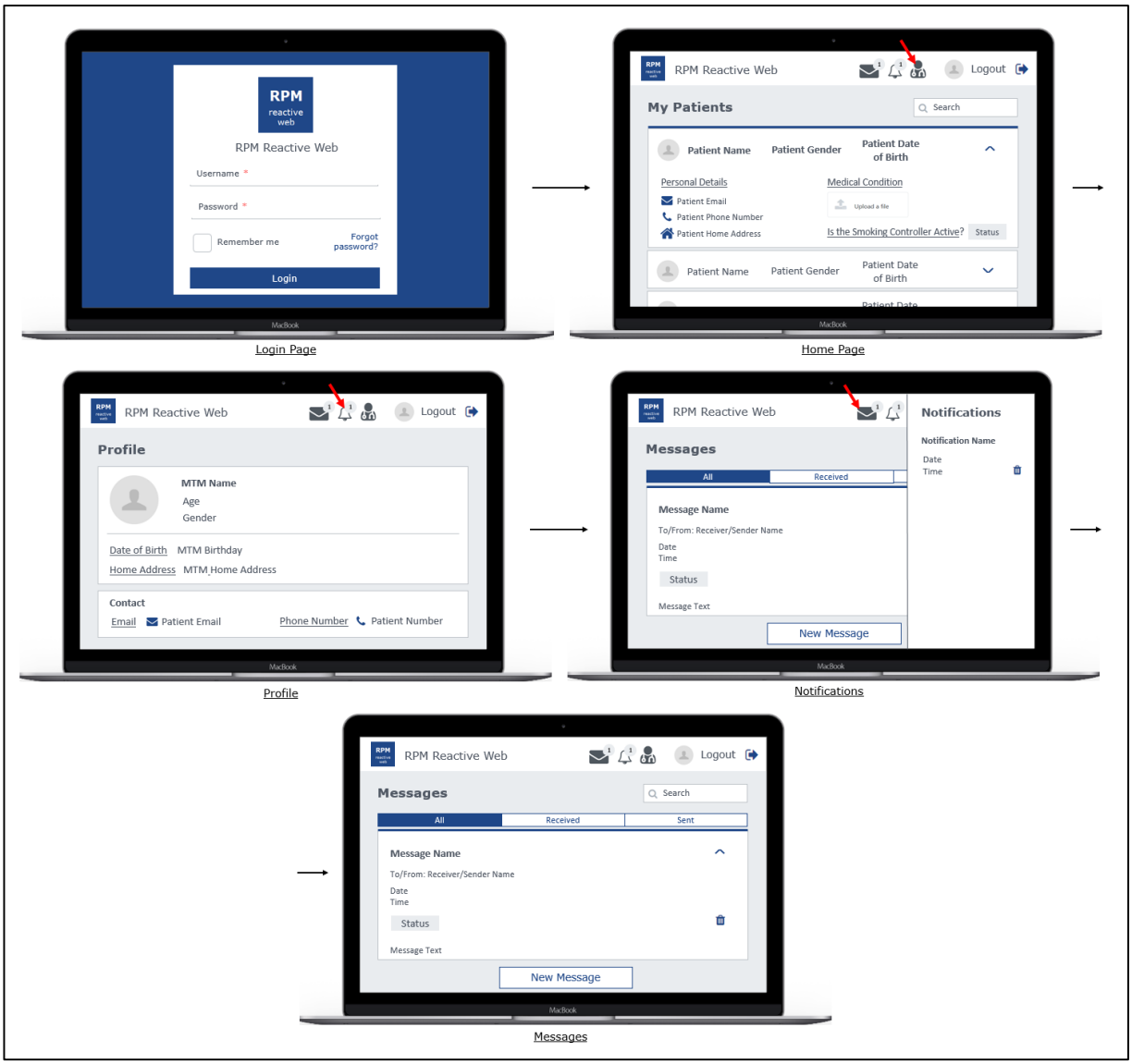
2.7. RPM Mobile – Smoking Controller

RPM Reactive Web – reactive web application for the MTM

The homepage has, along with other components, four icons placed on top: message icon, notification icon, profile icon and the logout icon.

By clicking on the profile icon the user is redirect to a page that displays all his/her personal information and on the notification icon to a page with the notification history.

By clicking on the message icon the MTM is redirected to a page that displays the messages history and allows him/her to send a new message.



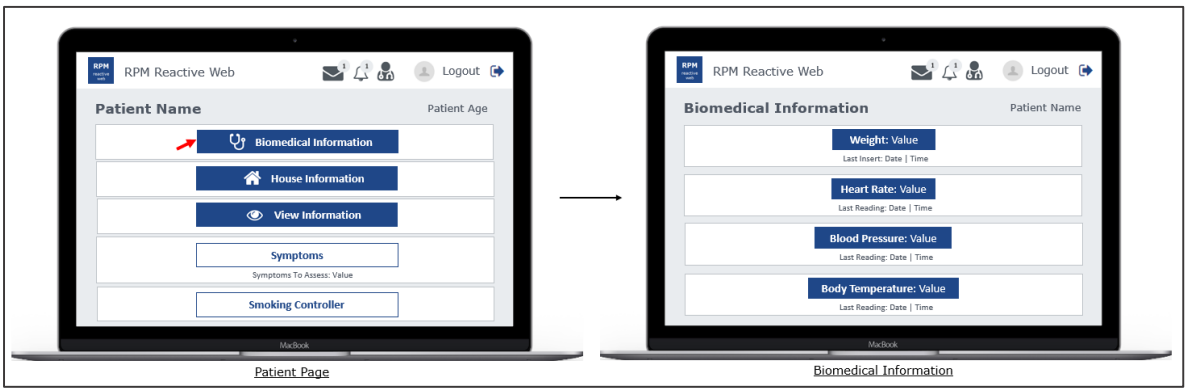
3.1.1. RPM Reactive Web – Homepage | Top Bar

The homepage main content consists in a list with all the patients that are assigned to the logged-in MTM. By expending an item of the list, that corresponds to a patient, his/her personal information is displayed. The MTM can also upload or open an already upload PDF file that contains the patient medical information. Finally, it is also displayed if the smoking controller functionality is turn on/off.

Home Page Patient Page

3.1.2. RPM Reactive Web – Homepage | Main Content

By clicking on the biomedical information button the MTM is redirect to a page that, as the RPM Mobile App, displays 4 different types of the patient's biomedical data.



Patient Page Biomedical Information

3.2. RPM Reactive Web – Biomedical Information

The weight button redirects the MTM to the patient's weight page.

Biomedical Information Weight

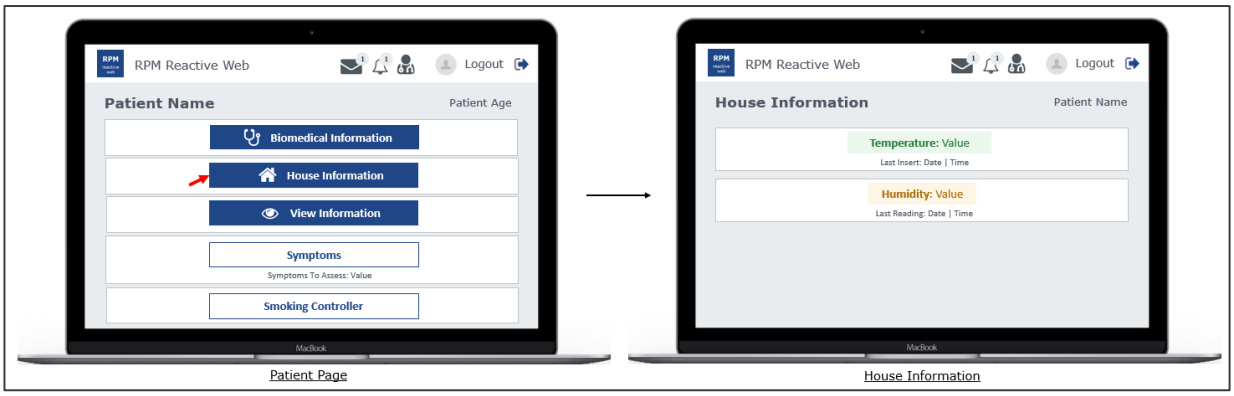
3.2.1. RPM Reactive Web – Biomedical Information| Weight

The heart rate button redirects the MTM to the patient's heart rate page. The only functionality, present in this page, different from the ones the patient has is the possibility to set a maximum and minimum threshold as explain below.

This is the same for the blood pressure button and body temperature button.

3.2.2. RPM Reactive Web – Biomedical Information | Heart Rate

By clicking on the house information button the MTM is redirect to a page that, as the RPM Mobile App, displays 2 different types of the patient's house environment data.



Patient Page | House Information

3.3. RPM Reactive Web – House Information

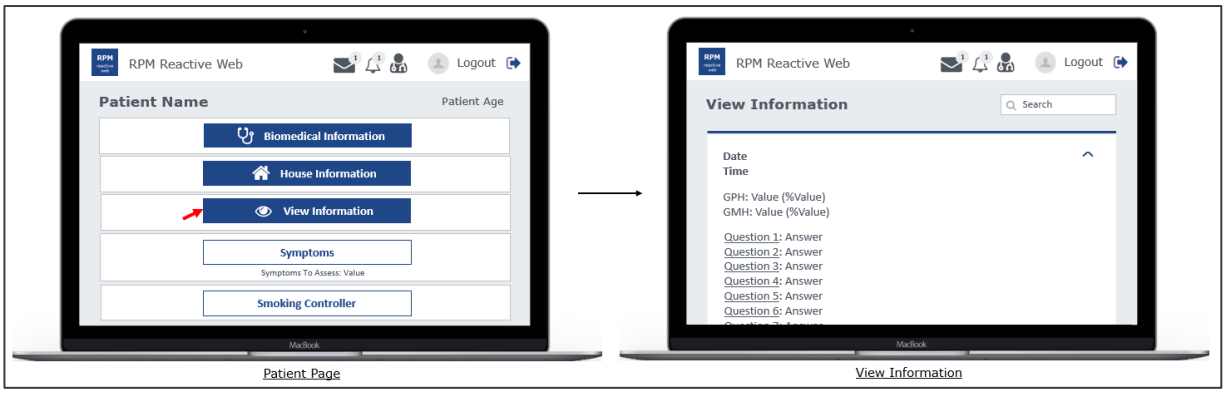
The temperature button redirects the MTM to patient's house temperature page. This is the same for the humidity button.

House Information | House Temperature| Today Chart

House Temperature| Yesterday Chart | House Temperature| Last 7 Days Chart

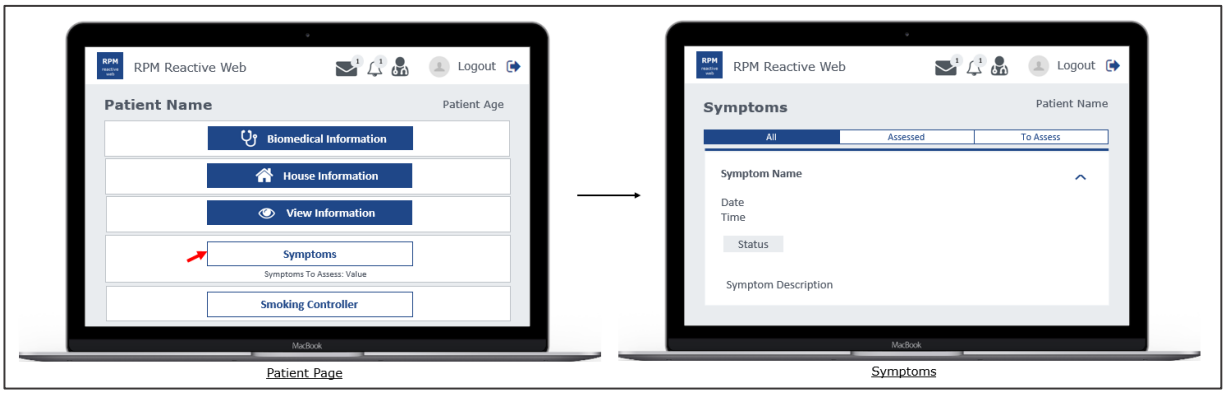
3.3.1. RPM Reactive Web – House Information | House Temperature

By clicking on the view information button the MTM is redirect to a page that, as the RPM Mobile App, displays the patient's questionnaire history.



3.4. RPM Reactive Web – View Information

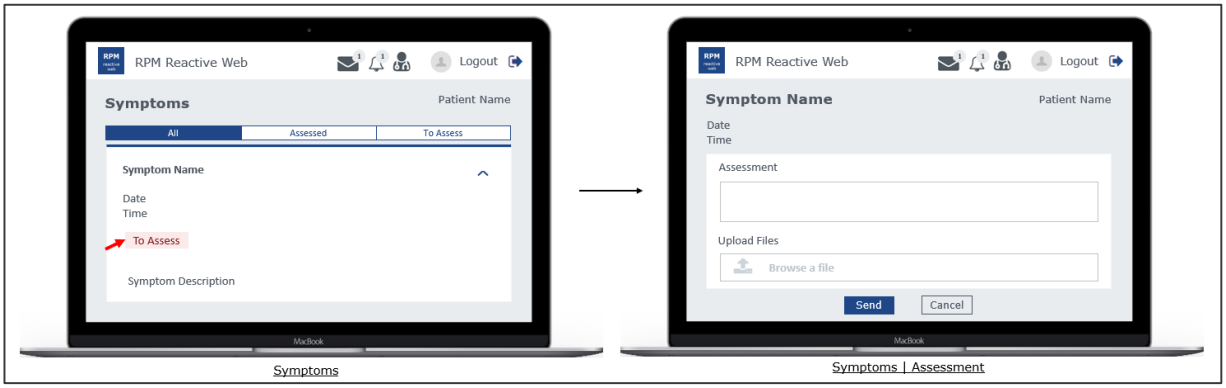
By clicking on the symptoms button the MTM is redirect to a page that displays the patient's symptoms history. It is important to mention that the status of the symptom can be "assessed" or "to assess".



3.5. RPM Reactive Web – Symptoms

If the status is "to assess" it means that the symptom reported by the patient was not yet assessed by a MTM. Therefore, by clicking the to assess button the MTM is redirect to a page where he/she can assess the respective symptom.

Otherwise, i.e. if the status is "assessed", it means the symptom reported by the patient was already assessed by a MTM.



3.5.1. RPM Reactive Web – Symptoms | Symptom To Assess Example

In case of the smoking controller being turn on by the patient, By clicking on the smoking controller button the MTM is redirect to a page that, as the RPM Mobile App, displays the patient's smoking controller history and chart.

3.6. RPM Reactive Web – Smoking Controller

Your Feedback

Question 1. Do you think this prototype is useful and has potential for future work?

Question 2. Do you consider the interfaces intuitive?

Question 3. Do you think the prototype contains the relevant features? Note: in the RPM Mobile application the features correspond to "my biomedical", "my house", "my view", "symptoms" and "smoking controller".

Question 4. Are there any features that you consider of small relevance? If yes, which one(s)?

Question 5. Do you suggest any additional features? If yes, which one(s)?

Additional Commentaries:

Name: Inês Xavier de Carvalho
University Email: up201705511@up.pt

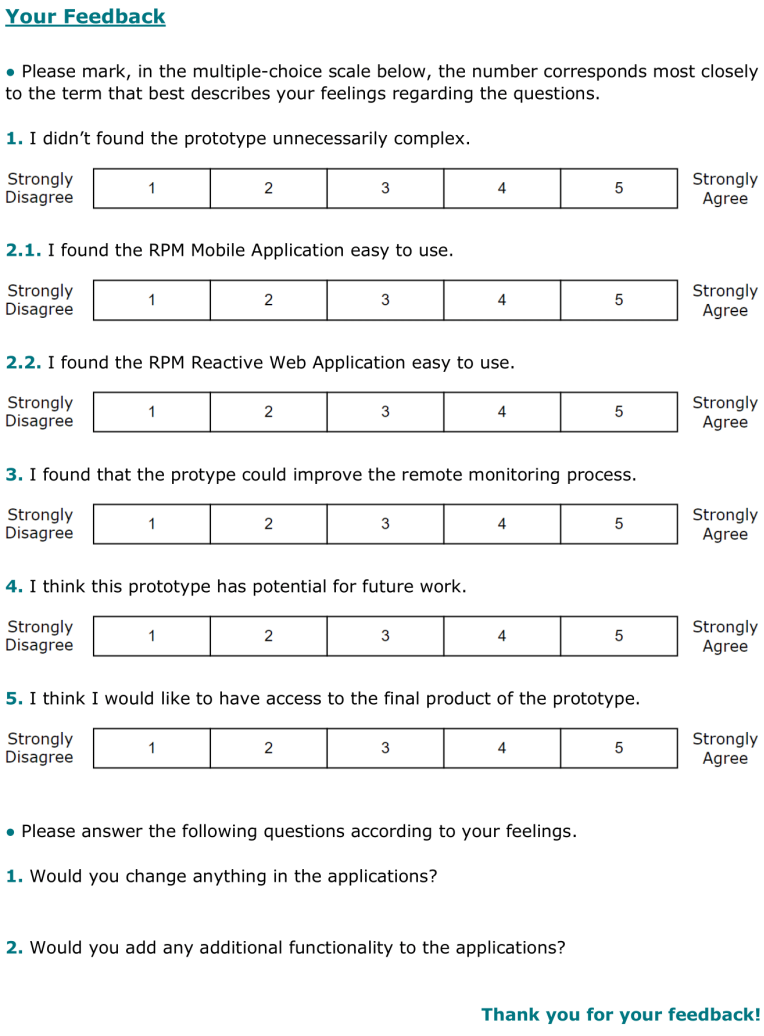
D.2 Pre-implementation Questionnaire Results

	Original Answers	Translated Answers
Question 1	Sim	Yes
Question 2	De um modo geral, sim	In general, yes
Question 3	Sim	Yes
Question 4	Não	No
Question 5	Não	No
Additional Commentaries	Na minha opinão, de um modo geral, o protótipo está bem conseguido, sendo viável avançar para a sua implementação.	In my opinion, in general, the prototype is well design and it is feasible to proceed to its implementation.

Appendix E

Prototype Validation Questionnaires

E.1 Feedback Questionnaires



Your Feedback

• Please mark, in the multiple-choice scale below, the number corresponds most closely to the term that best describes your feelings regarding the questions.

1. I didn't found the prototype unnecessarily complex.

Strongly Disagree	1	2	3	4	5	Strongly Agree

2.1. I found the RPM Mobile Application easy to use.

Strongly Disagree	1	2	3	4	5	Strongly Agree

2.2. I found the RPM Reactive Web Application easy to use.

Strongly Disagree	1	2	3	4	5	Strongly Agree

3. I found that the protype could improve the remote monitoring process.

Strongly Disagree	1	2	3	4	5	Strongly Agree

4. I think this prototype has potential for future work.

Strongly Disagree	1	2	3	4	5	Strongly Agree

5. I think I would like to have access to the final product of the prototype.

Strongly Disagree	1	2	3	4	5	Strongly Agree

• Please answer the following questions according to your feelings.

1. Would you change anything in the applications?

2. Would you add any additional functionality to the applications?

Thank you for your feedback!

Figure E.1: Medical Professional Questionnaire

Your Feedback

• Please mark, in the multiple-choice scale below, the number corresponds most closely to the term that best describes your feelings regarding the questions.

1. I didn't found the prototype unnecessarily complex.

Strongly Disagree	1	2	3	4	5	Strongly Agree

2. I didn't found the prototype had many inconsistencies.

Strongly Disagree	1	2	3	4	5	Strongly Agree

3. I found the functionalities of the prototype to be well integrated.

Strongly Disagree	1	2	3	4	5	Strongly Agree

4.1. I found the RPM Mobile Application easy to use.

Strongly Disagree	1	2	3	4	5	Strongly Agree

4.2. I found the RPM Reactive Web Application easy to use.

Strongly Disagree	1	2	3	4	5	Strongly Agree

5. I think I would like be a user of the RPM Mobile application.

Strongly Disagree	1	2	3	4	5	Strongly Agree

• Please answer the following questions according to your feelings.

1. Would you change anything in the applications?

2. Would you add any additional functionality to the applications?

Thank you for your feedback!

Figure E.2: Deloitte's Questionnaire

E.2 Questionnaires Results

Table E.1: Medical Professional Feedback

Question 1	**Question 2.1.**	**Question 2.2.**	**Question 3**	**Question 4**	**Question 5**
5	5	5	5	5	5

(a) multiple-choice questions

	Original Answers	Translated Answers
Question 1	Melhoria na troca de mensagens visto que é apenas possível o envio de novas mensagens e não a resposta a uma mensagem recebida, não permitindo assim uma resposta direta. Da maneira como está poderá ser difícil perceber a linha de comunicação.	Improvement in message exchange since it is only possible to send new messages and not reply to a received message, thus not allowing a direct reply. The way it is, it may be difficult to understand the communication line.
Question 2	Não.	No.

(b) open-answer questions

Table E.2: Deloitte's Feedback

	Participant 1	Participant 2	Participant 3
Question 1	5	5	5
Question 2	5	5	5
Question 3	5	5	4
Question 4.1.	5	5	5
Question 4.2.	5	5	5
Question 5	5	5	5

(a) multiple-choice questions

		Participant 1	Participant 2	Participant 3
Question 1	Original	Não.	Não.	Não. Boas apps e fáceis de usar.
	Translated	No.	No.	No. Great apps and simple to use.
Question 2	Original	Não.	São aplicações com muito potencial de utilização real dada a facilidade de comunicação entre o paciente e o profissional, tendo um acompanhamento muito mais personalizado. Facilmente pode ter novas features como a integração por wi-fi ou bluetooth com dispositivos externos, por exemplo com balanças para medir o peso (em vez de inserção manual). E, como mencionado na reunião, a possível utilização de inteligência artificial para calcular os valores biomédicos aceitáveis em.	Melhor integração entre as duas apps, mas para protótipo está bastante completo.
	Translated	No.	These are applications with a lot of potential for real use given the ease of communication between the patient and the professional, having a much more personalized follow-up. It can easily have new features such as wi-fi or bluetooth integration with external devices, for example with scales to measure weight (instead of manual insertion). And, as mentioned in the meeting, the possible use of artificial intelligence to calculate acceptable biomedical values.	Better integration between the two apps, but for a prototype it is quite complete.

(b) open-answer questions

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