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# EHR System Modernization in the Republic of Moldova

by

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# Abstract

Abstract to be added

# Acknowledgements

Acknowledgements to be added

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# Chapter 1

# Introduction

## 1.1 Background

The Republic of Moldova is a small country in Eastern Europe that borders Romania and Ukraine, with a current population of 2.4 million people (National Bureau of Statistics of the Republic of Moldova, 2024). Since its independence in 1991, Moldova has faced a number of challenges, including political instability, corruption, and economic difficulties which have left Moldova as one of the poorest countries in Europe (BBC, 2024).

Despite these challenges, Moldova has made significant progress in its digital transformation efforts, with the government launching a number of initiatives to modernize its public services and improve the quality of life for its citizens (E-Governance Agency, n.d.[a]). An example is the Citizen's Government Portal (MCabinet), which allows citizens to access personal information such as 'valid identity documents, social contributions and benefits, own properties, information about the family doctor and the health institution where the person is registered, tax payments and other information about the citizen-government relationship' (E-Governance Agency, n.d.[b]).

To continue supporting the existing transformation initiatives, Moldova's Cabinet of Ministers has recently approved the 'Digital Transformation Strategy of the Republic of Moldova for 2023-2030', which aims to transform the country into a digital society by 2030, with the ultimate goal of having 'all public services available in a digitalized format' (United Nations Development Programme, 2023).

## 1.2 Problem Statement

The healthcare sector in Moldova has also seen some transformations, with the introduction of a new electronic health record system (EHR) in 15 hospitals across the country in 2017, called 'Sistemul informațional automatizat „Asistența Medicală Spitalicească" (SIA AMS)' (Ciurcă, 2021). While the system has been successful in helping doctors access patient information more efficiently such as medical history, examinations, test results, and prescriptions, the system hasn't been updated since its inception in 2017 and there are still challenges that need to be addressed in 2024.

The main challenge with the current system lies in the user experience (UX) – SIA AMS feels old and isn't user-friendly, with a clunky interface that is difficult to navigate, not adhering to modern accesibility standards and only accessible via Internet Explorer or legacy version of Microsoft Edge, with no support for other browsers or devices (Ciurcă, 2021).

Another big challenge with the system is its lack of interoperability within public and private medical institutions due to a lack of a nationally-wide integrated system – each hospital and clinic have their own, siloed, information system that contains the patient information, with no communication being made between systems in different hospitals (Ciurcă, 2021).

Finally, due to the current economic situation in Moldova, the government has not allocated any funds to upgrade the current or develop new systems, and the hospitals and clinics that use the system do not have the resources to update it themselves.

## 1.3 The Client

The client, "Nicolae Testemiteanu" State University of Medicine and Pharmacy in Moldova (USMF), is a public university in Chisinau, Moldova, that offers a range of medical programs, including medicine, dentistry and pharmacy (USMF, 2023). Many of the faculty at USMF are also practicing doctors at hospitals and clinics across Moldova, and have first-hand experience with the current IT systems used in both public and private medical institutions. The USMF faculty members that the student will be interacting with during the project are part of an innovation team that researches potential opportunities to improve the healthcare sector in Moldova through the use of technology. As such, the client has expressed a need for a prototype that can act as a proof of concept for a modern system that could either replace or augment the current system in Moldova.

## 1.4 Project Objectives

This project aims to initially conduct some research on the current situation of the IT systems used in the healthcare sector in Moldova by interviewing several stakeholders from various healthcare-related institutions. Afterwards, the project will conduct a literature review on the most appropriate technologies and methodologies for developing a modernized EHR system, and an analysis of existing EHR systems to identify their existing functionality. Finally, based on the information gathered, the project will focus on designing and developing a working prototype, based on the requirements gathered and the feasibility of the chosen solution for the Moldovan healthcare sector. The student's hope is that the solution can then be used as a proof of concept to secure funding for a full-scale implementation of the new system in Moldova by the relevant authorities, such as the Ministry of Health.

As such, the objectives of the project are as follows:

1. Identify 2 to 4 stakeholders from various perspectives, such as healthcare institutions in Moldova and patients, that can provide insights into the current IT systems used in the healthcare sector in Moldova.
2. Conduct interviews with the identified stakeholders to gather information on the current IT systems used in the healthcare sector in Moldova.
3. Carry out a literature review to research the most appropriate technologies (frontend, backend and database) and project management methodologies for developing a modernized EHR system.
4. Explore at least 2 existing EHR systems and identify their strengths and weaknesses.
5. Design and develop a working web or mobile app for an EHR system based on the requirements gathered and the feasibility of the chosen solution for the Moldovan healthcare sector.
6. Offer the client the prototype to be used as a proof of concept to secure funding for a full-scale implementation of the new system in Moldova.

# Chapter 2

# Research and Requirements

To gain a more complete understanding of the current situation in Moldova, the existing problems and possible needs of the people involved, it is important to start with an analysis to identify the possible key stakeholders for this project. As previously mentioned in the literature review, a diverse group of stakeholders is essential to ensure that the currrent situation is reviewed from multiple perspectives.

Afterwards, the next step is to utilise the chosen stakeholders to gather as much information as possible from various perspective to ensure that the project is aligned with the needs of both patients and healthcare professionals in Moldova and solves the existing problems.

## 2.1 Stakeholder Analysis

The student has identified the following possible stakeholders for the project:

- Doctors and other medical staff working in hospitals
- Department head in a hospital
- IT staff members in hospitals
- Staff members at CNAM (National Health Insurance Company)
- Staff members at the Ministry of Health
- Patients

These stakeholders have been identified so that they can provide a wider picture on the needs and requirements of the project, and to ensure that the project is aligned with the

expectations of workers within the healthcare industry in Moldova from multiple perspectives.

The stakeholders have also been placed in the stakeholder influence-interest grid (which will be discussed in section 3.2.2) to help the student understand the level of influence and interest that each stakeholder has in the project:

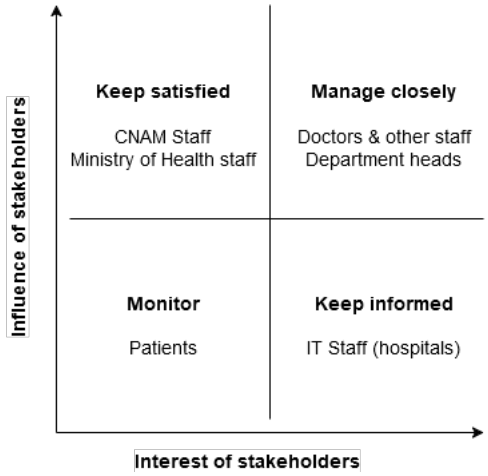



Figure 2.1: Chosen stakeholders in the stakeholder influence-interest grid

### 2.1.1 Current situation analysis

Following the analysis, the student has conducted several exploratory interviews with the chosen stakeholders to gather insights into current issues with the IT systems used in Moldova's healthcare sector. The student was able to reach out to every stakeholder, except for staff members at CNAM and the Ministry of Health.

After the conclusion of the interviews, three main issues and potential solutions have been identified:

1. Current EHR system is outdated and only accessible via Internet Explorer or legacy version of Microsoft Edge. A potential solution is to develop a new, modernized version of the existing system (retaining the core functionality) that is accessible via modern browsers, is more user friendly and has future upgrade capabilities.

2. Lack of interoperability between medical institutions due to a lack of a nationally-wide integrated system. A potential solution is to create a new system that acts as a patient history archive, where patients can upload their own medical records (such as lab tests, previous medical history, etc) and share them with any medical practitioner,

regardless of the institution they work at.

3. Lack of digitalizion for some systems that still rely on paper-based records or very rudimentary data structures, such as the national transplant registry. A potential solution is digitalized of said system, as is in the case of the transplant registry, that can be accessed by any medical practitioner in Moldova.

Analysing the current issues and potential solutions, the student has determined that the solutions for issues #1 and #3 are too complex, as they require a complete overhaul and integration with existing systems. As such, the student has decided to focus on issue #2, as it is the most feasible and an MVP can be develop within the timeframe of the project.

Consequently, the stakeholder list has been updated to reflect the changed focus of the project:

- Doctors working in hospitals and clinics
- Staff members at the Ministry of Health
- Staff members at CNAM
- Patients that are using both public and private healthcare institutions
- Other medical staff members (nurses, pharmacists, etc)
- Staff members at CNPDCP (National Center for Personal Data Protection)

At the same time, the stakeholder influence-interest grid has been updated to reflect the changes in the project focus:

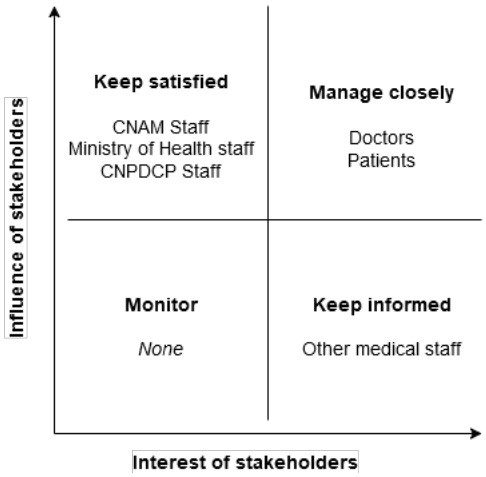



Figure 2.2: Updated stakeholders in the stakeholder influence-interest grid

## 2.2 Requirements

After the new stakeholders were identified, additional interviews were conducted to focus on the requirements for the chosen solution and enough information was gathered from the other stakeholders to identify the main requirements for the project. The student was unable to reach out to the staff members at CNAM, the Ministry of Health and CNDCP - instead legislation and regulations on their websites were reviewed (Compania Națională de Asigurări în Medicină, n.d.; Centrul Naţional pentru Protecţia Datelor cu Caracter Personal al Republicii Moldova, n.d.; Ministerul Sănătății al Republicii Moldova, 2024).

All of the gathered requirements can be found in the appendix (section A), but the most important requirements have been summarized in the table below:

| ID | Category | Requirement |
|---|---|---|
| 1 | Non-functional | The system must be accessible on all modern desktop and mobile-based browsers. |
| 2 | Non-functional | The system must store the data in a secure manner, ensuring that only the patient and the doctor can access the data. |
| 3 | Document upload | The system must allow patients to upload their own medical records in a variety of formats (PDF, DOC, etc). |
| 4 | Personal cabinet | The system must display the patient's history in a chronological order in the form of a timeline. |
| 5 | Personal cabinet | The patient personal cabinet must provide an overview of the patient's history through 3 main sections: personal information, lab tests, and doctor consultations. |
| 6 | Personal Cabinet | The system must allow patients to add their own personal information, such as name, date of birth, or address. |
| 7 | Personal Cabinet | The system must allow patients to add their own allergies and vaccinations. |
| 8 | Shareable link | The system must allow the patient to generate a shareable link to provide access to their medical records. |
| 9 | Doctor view | When shared with the doctor, the system must allow the doctor to only view the patient's history, not edit it. |
| 10 | Patient medication | The system must allow patients to enter their current medication including details such as the name of the drug, dosage, frequency and start/end date. |

Table 2.1: Summary of the Most Important Requirements

# Chapter 3

# Literature Review

This chapter will provide a review of the existing literature, which will be used guide the student in their planning and development efforts of the project.

As such, it will be covering the following areas:

- Software development methodologies
- Requirement and stakeholder management
- Tech stack (backend and frotnend )
- Large Language Models (LLMs)
- PHR Systems

## 3.1 Software development methodologies

### 3.1.1 Software Development Life Cycle

The Software Development Life Cycle (SDLC) is a process used to guide the development of software applications or systems (Ruparelia, 2010). The SDLC consists of multiple phases, each with its own set of activities and deliverables. Yas, Alazzawi, and Rahmatullah (2023) outline the phases of the SDLC as following:

1. **Requirement gathering and analysis phase** - the requirements are gathered saved in a document. Based on the requirements gathered, a development plan is created.

2. **Design phase** - requirements are written in a more technical manner and system desings are created.
3. **Implementation phase** - Actual development of the software occurs in this phase. Additionally, some smaller unit tests may be done during this phase.
4. **Testing phase** - may involve multiple types of testing, such as unit testing, integration testing, and system testing. Luo (2001) describes the different types of tests:
    - Unit testing - testing individual units or components of the software.
    - Integration testing - performed on two or more units combined together, focusing on the interfaces between these components.
    - System testing - focuses on the 'end-to-end quality of the entire system', testing it as a whole.
5. **Maintenance phase** - involves the deployment and maintenance of the software. Additionally, this phase may include end-user acceptance testing, to ensure that it meets their needs (Luo, 2001).

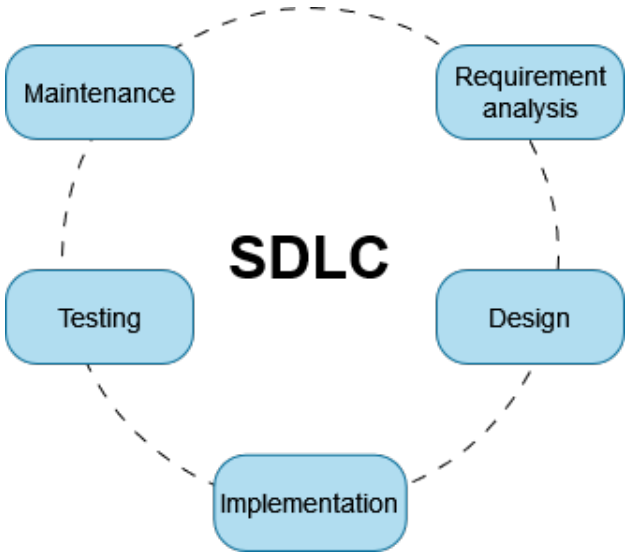



Figure 3.1: Software Development Life Cycle

### 3.1.2 SDLC Models

The literature describes several SDLC models that have been used in the development of software applications. Ruparelia (2010) and Yas, Alazzawi, and Rahmatullah (2023) highlight the most common ones: Waterfall model, V model, Spiral model, Interative model, and Agile model.

#### Waterfall Model

The Waterfall Model is probably the most well-known SDLC model. It is a linear model, where the development process is divided into distinct, sequential phases (which can be seen in figure 3.2).

The Waterfall Model's strengths lie in its simplicty of use, ease of understanding and a clear, structured approach (Alshamrani and Bahattab, 2015). An additional stregth that the authors note is its extensive documentation and planning, emphasizing quality and adherence to regulations.

On the other hand, one of Waterfall's main weaknesses is its lack of flexibility in regards to change (Mirza and Datta, 2019). Thus, this model is not suitable for projects where the requirements are not well understood or are likely to change. Additionally, the project deliverable is not avaialable until the end of the project, any changed or feedback cannot be done during its development (Mirza and Datta, 2019).

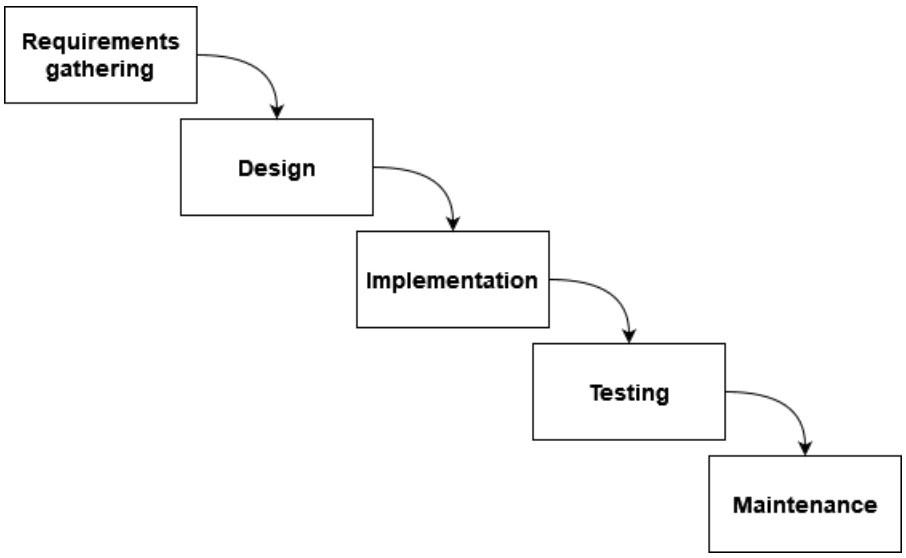



Figure 3.2: Waterfall model

**Agile Model**

Another well-known model is Agile. It has multiple frameworks, with Scrum and Kanban being the most popular ones. Scrum is a framework where the project is divided into sprints, each lasting between 2-4 weeks, that aim on delivering value to the customer through incremental software features (Alqudah and Razali, 2018; Sunner, 2016). Kanban focuses on visualizing the project workflow by using a visual board with columns, cards and swimlanes. It uses column limits and a pull system to make the flow of work through the system more efficient (Sunner, 2016).

Agile has some drawbacks - its lack of documentation and formal planning, especially in the early stages of the project, may not be suitable for large scale projects (Sunner, 2016; Yas, Alazzawi, and Rahmatullah, 2023). Similarly, lack of knowledge on how to use the frameworks may be a barrier for some teams (Mirza and Datta, 2019; Yas, Alazzawi, and Rahmatullah, 2023).

Nowadays, the combined use of Scrum and Kanban is becoming quite popular, with many teams employing both frameworks in their projects, allowing them to adopt the appropriate practices and adapt them accordingly based on their needs (Alqudah and Razali, 2018).

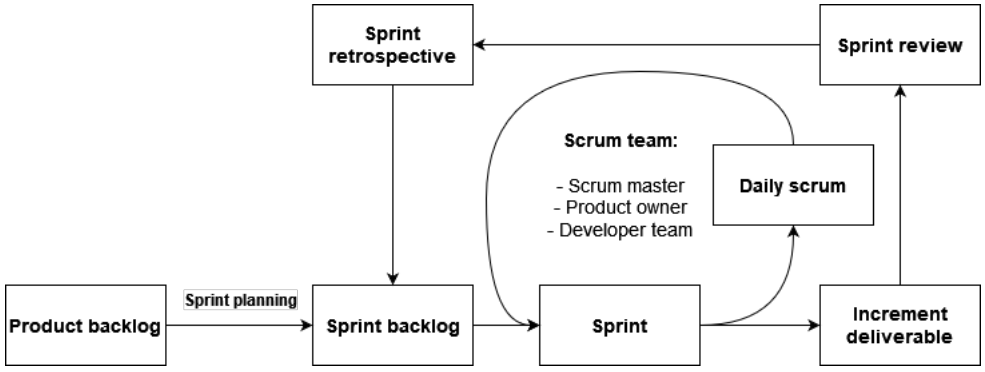



Figure 3.3: Scrum framework

### 3.1.3 A hybrid approach

A hybrid approach has also been emerging in software development projects. Various surveys report the most common combinations are Scrum, Iterative Development, Kanban, Waterfall and DevOps, with hybrid Waterfall and Scrum being the most popular one (Gemino, Reich, and Serrador, 2021; Prenner, Unger-Windeler, and Schneider, 2020). In this approach, the development part is done in an Agile way, with the rest of the project using Waterfall as a backbone (Prenner, Unger-Windeler, and Schneider, 2020).

Gemino, Reich, and Serrador (2021) note that projects using either Agile, traditional or hybrid approach show similar levels of success in terms of budget, time and quality. However, the authors have found that agile and hybrid approaches perform much better on customer satisfaction than the traditional ones.

## 3.2 Requirements gathering

Requirements gathering is the first step in any software development process. As described by Young (2002), a requirement is a 'necessary attribute in a system...that identifies a capability, characteristic, or quality factor of a system in order for it to have value and utility to a user'. Multiple studies mention how proper requirement gathering plays a pivotal role in the project success, with many project failures attributed to poor requirements gathering (Hickey and A.M. Davis, 2003; Sharma and Pandey, 2013; Alan Davis et al., 2006a).

### 3.2.1 Requirement types

Requirements can be classified into 2 categories: functional and non-functional. Functional requirements describe the system's behavior, while non-functional requirements describe the system's quality attributes, such as performance, security, reliability, etc. (Laplante, 2019, p. 6).

When writing the requirements in a document, it is important to ensure clarity and conciseness to avoid ambiguity. Based on the recommendations of Laplante (2019, p. 112) and IEEE (2018), the following principles and practices can be followed:

- Write in a simple and consistent language.
- Avoid technical jargon, vague terms, and combining multiple requirements in a single statement.
- Ensure that requirements are necessary, appropriate, complete, feasible, and verifiable.
- Include attributes for each requirement, such as identification, owner, priority, risk, rationale, difficulty, and type (functional/non-functional).

Prioritizing requirements is another crucial task, especially in projects with numerous requirements. Some methods mentioned by Khan et al. (2015) include using a low to high priority, assigning a numerical value within a specific range or MoSCoW, which classifies requirements into four categories:

- Must have - must be implemented in the software before being released

- Should have - important but not necessary for the software to be released
- Could have - desirable but not necessary for the software to be released
- Won't have - requirements that are not included in the current release

**Requirements in Agile**

In Agile projects, requirements are written in the form of User Stories, which are simple descriptions of a feature desired by the customer, using a specific format: 'As a [user], I want to [action] so that [benefit]' (Laplante, 2019, p. 191). Components of a User Story include a title, acceptance criteria, priority, story points and description. Epics are requirements that cannot be completed in a single sprint and can be broken down into user stories. Epics and User Stories are part of the Product and Sprint backlogs, which contain the requirements for the whole project and the current sprint, respectively.

### 3.2.2 Stakeholders

Stakeholders are the individuals who have some interest in the success of the system or project, thus it is important to identify all possible stakeholders in the early stages of the project to avoid missing important requirements or constraints (Laplante, 2019, p. 34).

Stakeholder analysis can help understand their position within the project. One way of doing it is by using a stakeholder matrix, such as the Influence/Interest grid (see figure 3.4), which classifies stakeholders based on their influence and interest in the project (Morphy, 2020; Reddi, 2023).

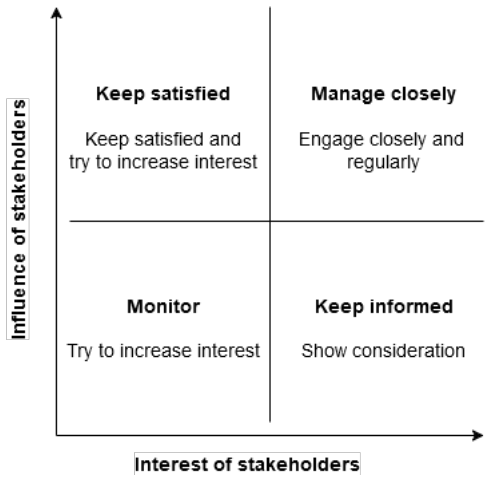



Figure 3.4: Stakeholder Influence/Interest matrix

### 3.2.3 Requirement gathering techniques

Multiple studies mention the most popular requirement gathering techniques are interviews, workshops, prototyping, modelling, brainstorming, storyboards and observing users (Hickey and A.M. Davis, 2003; Young, 2002; Sharma and Pandey, 2013; Tiwari, Rathore, and Gupta, 2012). In one of them, individuals with multiple years of experience in requirement gathering were interviewed, and the authors found that the most used techniques were collaborative meetings, interviews, ethnography and modelling (Hickey and A.M. Davis, 2003).

Multiple research papers recognise interviews as the most common technique for requirement gathering (Alan Davis et al., 2006b; Donati et al., 2017; Bano et al., 2019). Some studies have looked at best practices and common mistakes when conducting requirement gathering interviews. The recommended practices, based on Mohedas et al. (2022) and Loweth et al. (2021), and the common mistakes, from Donati et al. (2017) and Bano et al. (2019), are summarized in Table 3.1 below.

| **Common Mistakes** | **Recommended Practices** |
|---|---|
| Wrong opening: failing to understand the context before discussing the problem. | State goals at the beginning and allow customer input at the end. |
| Not leveraging ambiguity to reveal knowledge gaps. | Avoid ambiguity by asking clarifying questions. |
| Lack of planning: unstructured sequence of questions. | Plan interviews with a structured sequence of questions. |
| Failing to build rapport with the customer. | Building rapport through small talk or personal questions in the beginning. |
| Implicit goals: failing to ask or clarify stakeholder goals. | Verify alignment and current interpretation with the customer's vision. |
| Question omission: not asking about business processes or doing follow-up questions. | Be flexible by probing into relevant topics. |
| Weak communication: too much technical jargon usage or not listening to the customer. | Use projective techniques like scenarios to encourage deep thinking. |
| Poor question formulation: vague, technical, irrelevant, or too long. | Break down questions or responses into smaller parts and use story telling. |
| Wrong closing sequence: skipping interview summaries or feedback. | Leaving time at the end for the stakeholder to offer any feedback or thoughts. |

Table 3.1: Comparison of Common Mistakes and Recommended Practices

## 3.3 Tech stack

### 3.3.1 Database

There are several types of databases, such as: relational (SQL), NoSQL databases, graph databases or object-oriented databases (Oracle, 2020). The choice of database depends on the project or organisation requirements, such as the amount of data, the complexity of the data, the need for scalability, etc.

#### Relational databases

Relational databases store structured data in tables, linked through keys to create relationships between entries (Anderson and Nicholson, 2022). They use SQL (Structured Query Language) to create queries and schemas to help manage data efficiently. Anderson and Nicholson (2022) highlight that relational databases are used, thanks to their high data integrity, for industries like finance and healthcare. Relational databases are widely used, making it easier to find support and resources. However, the rigid schema limits adaptability to rapid data changes or usage of unstructured data. Examples include MySQL, PostgreSQL, Oracle, and Microsoft SQL Server.

#### NoSQL databases

NoSQL databases manage unstructured or semi-structured data without rigid schemas or relationships (Anderson and Nicholson, 2022). As the authors describe, NoSQL databases, such as key-value, document, column-family, and graph databases, excel in flexibility and scalability. NoSQL databases often prioritize performance over strict consistency, making them suitable for large datasets of unstructured data but less ideal for complex transactions. NoSQL systems lack SQL's mature standardization and support. Examples include MongoDB, Cassandra, Couchbase, and Redis.

### 3.3.2 Backend framework

Choosing the right backend framework is crucial - it is responsible for handling the business logic of the application, such as processing requests, interacting with the database, and returning responses to the client. A good framework also comes with the added benefit of included features such as security and authentication, database support, a big community and documentation.

Based on recent a recent survey by Vailshery (2024), the most popular backend frameworks are Express, Flask, Spring Boot, Django and Laravel. This data is also supported by the

Stack Overflow Developer Survey 2024, which lists the most popular programming languages as JavaScript (Express), Python (Flask, Django), Java (Spring Boot) and PHP (Laravel) (Stack Overflow, 2024).

Due to their high popularity among developers, the above frameworks will be compared. Using the information from Broadcom (2024), Laravel Holdings Inc. (2024), OpenJS Foundation (n.d.), and Django (2024), table 3.2 will compare the frameworks based on the following criteria: programming language used, learning curve, community support, security features, database features, and project size suitability.

| **Framework** | **Django** | **Laravel** | **Spring Boot** | **Express** |
|---|---|---|---|---|
| **Language** | Python | PHP | Java | JavaScript |
| **Learning curve** | Medium | Low | High | Low |
| **Community Support** | High | High | High | High |
| **Security features** | High | High | High | Medium |
| **Database features** | Medium | Medium | High | Medium |
| **Project size suitability** | Small to medium | Small to medium | Medium to large | Small to medium |

Table 3.2: Comparison of backend frameworks

### 3.3.3 Frontend framework

Similar to the backend frameworks, choosing a suitable frontend framework is equally important - it is responsible for the user interface of the application, such as displaying data, handling user interactions, and making requests to the backend.

Based on the same survey by Vailshery (2024), the most popular frontend frameworks are React, Angular, Vue.js, and Svelte. This data is also supported by the Stack Overflow Developer Survey 2024, where those frameworks rank among the highest for desirability and admirability among developers (Stack Overflow, 2024).

Table 3.3 will use the information from Meta Platforms (n.d.), Google (2024b), You (2024), and Svelte (n.d.) to compare the frameworks based on the following criteria: learning curve, community and documentation, ecosystem and tooling support, performance, state management, and project size suitability.

| Framework | React | Angular | Vue.js | Svelte |
|---|---|---|---|---|
| **Learning curve** | Low | High | Medium | Low |
| **Community and documentation** | High | High | High | Medium |
| **Ecosystem and tooling support** | High | High | Medium | Low |
| **Performance** | High | Medium | Medium | High |
| **State management** | High | High | Medium | Low |
| **Project size suitability** | Small to large | Medium to large | Small to medium | Small to medium |

Table 3.3: Comparison of frontend frameworks

## 3.4 Large Language Models (LLMs)

Large language models (LLMs) are artificial intelligence systems that are used for natural language processing (NLP) tasks such as text generation, translation, summarization and question answering (Naveed et al., 2023; Nazi and Peng, 2024). Additionally, LLMs have been found to have emergent capabilities, like reasoning, planning, decision-making and in-contenxt learning (Naveed et al., 2023). These extraordinary capabilities are achieved through extensive training on large corpus of text data, high parameter count (in the billions) and usage of techniques such as fine-tuning or prompt engineering to improve their performance (Naveed et al., 2023; Nazi and Peng, 2024).

LLMs are built on the transformer architecture, which allows them to understand text by learning and remembering the relationships between words (Vaswani et al., 2017). These models are first pre-trained on large amounts of unlabeled data using, allowing them to excel in a wide variety of tasks (C. Zhou et al., 2023; Naveed et al., 2023). These pre-trained models, known as foundation models such as the GPT or Llama families, can then be fine-tuned for specific tasks, improving their performance and accuracy even further (OpenAI et al., 2024; Dubey et al., 2024; Naveed et al., 2023).

### 3.4.1 Multimodal LLMs

One advancement in the field of LLMs has been the addition of multimodal abilities, allowing them to process, understand and generate text and images, audio or videos (Yin et al., 2024; D. Zhang et al., 2024). These new multimodal LLMs (MLLMs) utilise existing reasoning capabilities of LLMs, which are connected to an encoder that can processes images, audio or videos and a generator that helps with generating multimodal outputs (Yin et al., 2024). This integration of new modalities allows MLLMs to become versatile tools, expanding their possible use cases and bridging the gap between human and machine interaction (Nazi and Peng, 2024).

### API model providers

Running and hosting LLMs locally can be a challenge, considering their big model sizes and high computational requirements. As such, many platforms offer APIs that allow users to access LLMs through the cloud. A list of some free API providers, the models offered and their rate limits has been compiled by Cheah and Markham (2024) and some are listed in the table below.

| **Provider** | **Model name(s)** | **Free tier limits** |
|---|---|---|
| Groq | Llama 3.2 11B Vision | 7,000 requests/day, 7,000 tokens/minute |
| | Llama 3.2 90B Vision | 3,500 requests/day, 7,000 tokens/minute |
| OpenRouter | Llama 3.2 11B Vision Instruct<br>Llama 3.2 90B Vision Instruct<br>Gemini 2.0 Flash Experimental | 20 requests/minute, 200 requests/day |
| Google AI Studio | Gemini 2.0 Flash | 4,000,000 tokens/minute, 10 requests/minute |
| | Gemini 1.5 Flash | 1,000,000 tokens/minute, 1,500 requests/day, 15 requests/minute |
| | Gemini 1.5 Pro | 32,000 tokens/minute, 50 requests/day, 2 requests/minute |
| GitHub Models | OpenAI GPT-4o<br>OpenAI GPT-4o mini | Rate limits dependent on Copilot subscription tier |
| Cloudflare Workers AI | Llama 3.2 11B Vision Instruct | 10,000 tokens/day |
| glhf.chat | Any model on Hugging Face that fits on an A100 node ( 640GB VRAM) | 480 requests/8 hours |

Table 3.4: API providers for LLMs

### 3.4.2 LLMs in healthcare

One application of MLLMs is in healthcare, where the growing volume and complexity of data creates the need for more advanced tools to process and analyze it. LLMs and MLLMs have found use in various healthcare applications, either by using existing models or by developing new, specialized medical models such as Med-PaLm2, BioMistral or Med-Gemini (Labrak et al., 2024; Google, 2024a; Singhal et al., 2023). Some of these applications include:

- **Improving medical diagnosis:** By combining patient records, existing symptoms, and medical history, LLMs can use their reasoning capabilities and memory to assist in diagnosing or preventing health conditions (Nazi and Peng, 2024; Niu et al., 2024; Xiao et al., 2024).
- **Medical Imaging and Multimodal Capabilities:** In diagnostic imaging, multimodal models can assess both text and images (such as X-rays and MRIs) to offer comprehensive analysis. Clinicians can input medical images and contextual information, making MLLMs valuable assistants in the real-time diagnostic processes (Niu et al., 2024).
- **Virtual Health Assistants:** LLMs can also be deployed as virtual assistants, helping patients with personalised care and general health inquiries (Nazi and Peng, 2024; Niu et al., 2024). Patients in areas with limited healthcare access can benefit from these assistants, which also supports healthcare providers by lightening their workloads.
- **Administrative Support:** LLMs can assist in generating Electronic Health Records (EHRs), allowing healthcare providers to focus more on patient interaction (Xiao et al., 2024). Additionally, they can also help translate complex medical terms into more simple language, assist in administrative tasks, and more.

### 3.4.3 Prompt Engineering

The success of LLMs depends not only on the model itself - but also on how it's effectively used by the users, using techniques like prompt engineering, which involves the constant designing and refining of prompts to guide the output of LLMs (Meskó, 2023; Amatriain, 2024). Prompts represent instructions given to the model to guide its output, such as providing context, examples, or constraints to the model (Giray, 2023; Schulhoff et al., 2024; Amatriain, 2024).

There are multiple techniques for prompt engineering, ranging from simple to more advanced. The tables and subsections below outlines some of the most common techniques.

### Zero-Shot Prompting

Zero-shot prompting are techniques where the LLM is given a prompt without any examples, allowing it to generate an output based on the prompt alone (Schulhoff et al., 2024).

| Technique | Description | Source |
|---|---|---|
| Role prompting | Assigning a specific role to the LLM in the prompt. The authors note that generally it provides mixed results but may be useful in certain settings. | Zheng, Pei, and Jurgens (2023) |
| Style prompting | Specifying the desired style or tone in the prompt. | Lu et al. (2023) |
| Emotion prompting | Incorporating phrases of psychological relevance to humans in the prompt. | Cheng Li et al. (2023) |
| Re-reading | Adding the phrase 'Read the question again' to the prompt in addition to repeating the question. | Xu et al. (2023) |
| Self-Ask | Prompting the LLM to decide if it needs to ask any follow-up questions for a given prompt. | Press et al. (2022) |

Table 3.5: Zero-Shot Prompt Techniques

### Few-Shot Prompting

Few-shot prompting are techniques where the LLM learns how to complete a task based on a few examples given in the input prompt (Schulhoff et al., 2024).

| Technique | Description | Source |
|---|---|---|
| Self-Generated In-Context Learning | Using the LLM to automatically generate examples when training/example data is not avaialable. | Kim et al. (2022) |
| Prompt Mining | Scanning the training data to discover common formats that can be used as prompt templates. | Jiang et al. (2020) |

Table 3.6: Few-Shot Prompt Techniques

### Thought Generation Prompting

Thought generation are techniques where the prompt encourages the LLM to explain its reasoning process while solving a given problem (Schulhoff et al., 2024).

| Technique | Description | Source |
|---|---|---|
| Chain-of-Thought (CoT) | Adding a phrase like 'Let's think step by step' at the end of the prompt to encourage the LLM to describe its thought process before offering a final answer. | Kojima et al. (2022) |
| Contrastive CoT | Using CoT and also adding both incorrect and correct examples in order to provide the LLM a more diverse example set. | Chia et al. (2023) |
| Auto-CoT | Using CoT with another LLM to automatically generate CoT examples that can be used to create few-shot CoT prompts for other LLMs. | Z. Zhang, A. Zhang, M. Li, and Smola (2022) |
| Least-to-Most | Starts with asking the model to break down a problem into sub-problems without solving them. Afterwards, it solves them one by one, appending the result each time, until it arrives at the answer. | D. Zhou et al. (2022) |
| Tree-of-Thought (ToT) | Starts with an initial problem and then generates multiple possible steps by using CoT. Then, it evaluates each step, decides which one to take and creates more thoughts until it reaches an answer. | Yao, D. Yu, et al. (2023) |

Table 3.7: Thought Generation Prompt Techniques

### Multimodal and Multilingual Prompting

Multimodal and multilingual prompting are techniques which aim to improve an LLM's performance by leveraging multiple modalities or languages in the prompt (Schulhoff et al., 2024).

| Technique | Description | Source |
|---|---|---|
| Translate-first prompting | Translating the input prompt into English to leverage LLMs strengths in dealing with English inputs, compared to non-English inputs. | Etxaniz et al. (2023) |
| English prompting | Writing the prompt in English may usually be more effective than using the task language for multilingual tasks. The authors argue it may because of the predominance of the English language in the pretraining data. | Ahuja et al. (2023) |
| JSON/XML output formatting | Asking the LLM to format the response in a JSON or XML format and providing the expected schema has been found to improve the accuracy of LLM outputs | Hada et al. (2023) |
| Multimodal CoT | Similar to the textual CoT, this technique encourages the model to solve a given image-based problem step by step by step. | Z. Zhang, A. Zhang, M. Li, H. Zhao, et al. (2023) |
| Image-as-Text | Generating or writing a textual description of an image that can then be included in a text-based prompt. | Hakimov and Schlangen (2023) |
| Chain-of-Images (CoI) | Using the CoT process to generate images as part of its thought process to reason visually. | Meng et al. (2023) |

Table 3.8: Multimodal and Multilingual Techniques

### Agents

Agents are techniques which encourage LLMs to use external tools or resources to complete a task (Schulhoff et al., 2024).

| Technique | Description | Source |
|---|---|---|
| Program-aided Language Model (PAL) | Using the LLM to translate a problem into code, which can then be sent to an interpreter to generate an answer. | Gao et al. (2023) |
| ReAct | Firstly, the model generates a thought based on the input. Then, the model takes an action and observes the result. This process is repeated until the model arrives at an answer. | Yao, J. Zhao, et al. (2022) |
| Retrieval Augmented Generation (RAG) | This technique involves retrieval of information from an external source and inserting it into the prompt. | Lewis et al. (2020) |

Table 3.9: LLM Agent Techniques

### 3.4.4 Challenges and concerns of using LLMs

While LLMs bring many benefits when applied to the healthcare domain, it is important to note that their use does come with several challenges:

- **Data Privacy and Compliance:** Patient data is highly sensitive, thus ensuring compliance with standards is essential, requiring data anonymization and secure handling practices to ensure patient data safety.(Nazi and Peng, 2024; Harrer, 2023; Xiao et al., 2024).
- **Transparency and Explainability:** LLMs are often described as 'black boxes', making it difficult to explain their decision-making processes. In healthcare, transparency is crucial - lack of it poses risks and raises ethical concerns about relying on such systems in high-stakes scenarios (Nazi and Peng, 2024; Harrer, 2023; Xiao et al., 2024)..
- **Bias and Fairness:** LLMs trained on vast datasets can inherit biases in the data, leading to skewed or unfair outcomes (Harrer, 2023).
- **Hallucinations:** LLMs sometimes generate false or fabricated outputs, also known as 'hallucinations'. In healthcare, this poses significant risks, as incorrect or misleading information could jeopardize patient safety and trust in the technology (Xiao et al., 2024; Nazi and Peng, 2024).
- **Accountability:** Responsibility must be clearly communicated and understood by all parties involved in the development and use of the model (Harrer, 2023). The author

recommends the usage of clear guidelines, policies and code of conducts to ensure that all parties are aware of their obligations.

- **High Costs and Infrastructure Needs:** Training and operating LLMs requires extensive computational resources, which can be a limiting factor for healthcare institutions (Xiao et al., 2024).

## 3.5 PHR Systems

A Personal Health Record (PHR) is an electronic resource used by patients to manage their own health information (Hosseini et al., 2023; Lee et al., 2021). PHRs are different from Electronic Health Records (EHRs) and Electronic Medical Records (EMRs) which are inter-organisational or internal systems to organise patient health records (Heart, Ben-Assuli, and Shabtai, 2017; Lee et al., 2021). Three different types of PHRs are described by Hosseini et al. (2023): stand-alone, which require manual entry to update the records; instituion-specific, which are connected to a specific healthcare institution; and integrated, which can connect to multiple healthcare systems to aggregate data from multiple sources.

Usage of PHRs can bring many benefits to patients, such as: empowering patients to manage their health, improving patient outcomes, decreasing the cost of healthcare and improving the taking of medication (Hosseini et al., 2023).

PHRs contain highly sensitive health information, so it is important to ensure that the data is secure and private. Based on a survey of health information management and medical informatics experts, Hosseini et al. (2023) identified 7 dimensions that need to be addressed when developing a PHR system:

1. Confidentiality
2. Availability
3. Integrity
4. Authentication
5. Authorization
6. Non-repudiation
7. Access rights

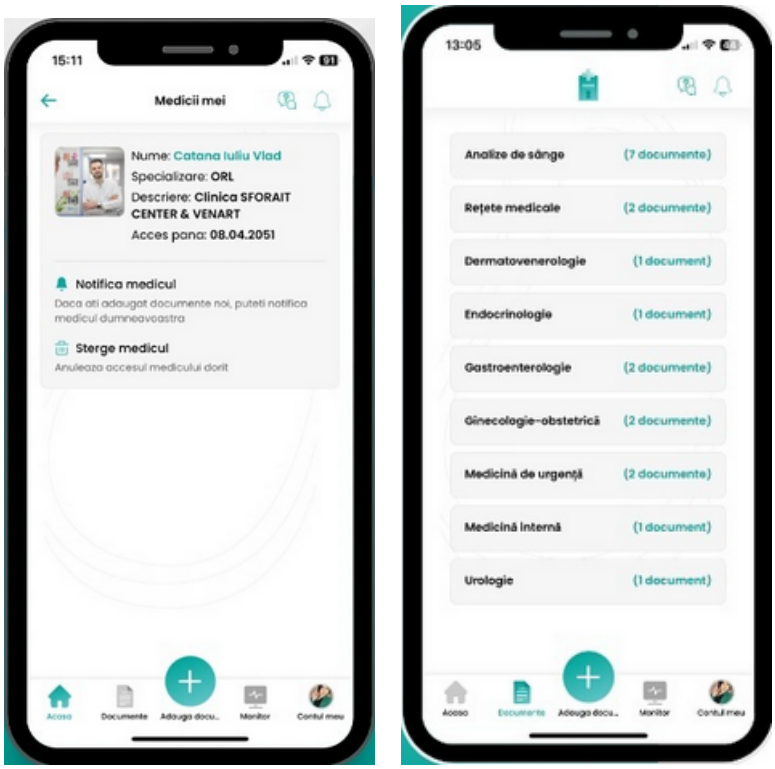
The authors recommend mechanisms to ensure adherence to the above-mentioned dimensions, such as encrypting the data in the database, using backups or defining user access to data and access rights.

### 3.5.1 Existing Solutions

PHR systems have been implemented nation-wide in many developed countries, such as the NHS App in the UK (Lee et al., 2021). Additionally, there are many private solutions that offer similar features to the one proposed in this project. The next sections will provide a brief overview of 3 existing systems: Medvalet, Andaman7 and Fasten Health.

#### Medvalet

A mobile app developed in Romania that allows patients to upload their medical history as PDFs or scanned documents (Medvalet, 2024). See Table 3.10 for a summary of its features and limitations and figure 3.5 for a screenshot of the app.




(a) My doctors screen (b) Uploaded documents screen

Figure 3.5: Medvalet screenshots

| Key Features/Benefits | Limitations/Drawbacks |
|---|---|
| • Upload medical history as PDFs or scanned documents.<br>• Categorize documents by type (e.g., prescriptions, lab results).<br>• Graphically track vitals like blood pressure and weight over time.<br>• Patients can input personal details such as name, age, and weight.<br>• Doctors can access patient history directly via the app. | • Requires doctors to create accounts, which may deter use.<br>• Doctors can access patient history without explicit consent, raising privacy concerns.<br>• App acts as document storage, which can be cumbersome to access for lengthy histories.<br>• Lacks data extraction or summarization features from uploaded documents.<br>• Only available as a mobile app, limiting accessibility for desktop-only users. |

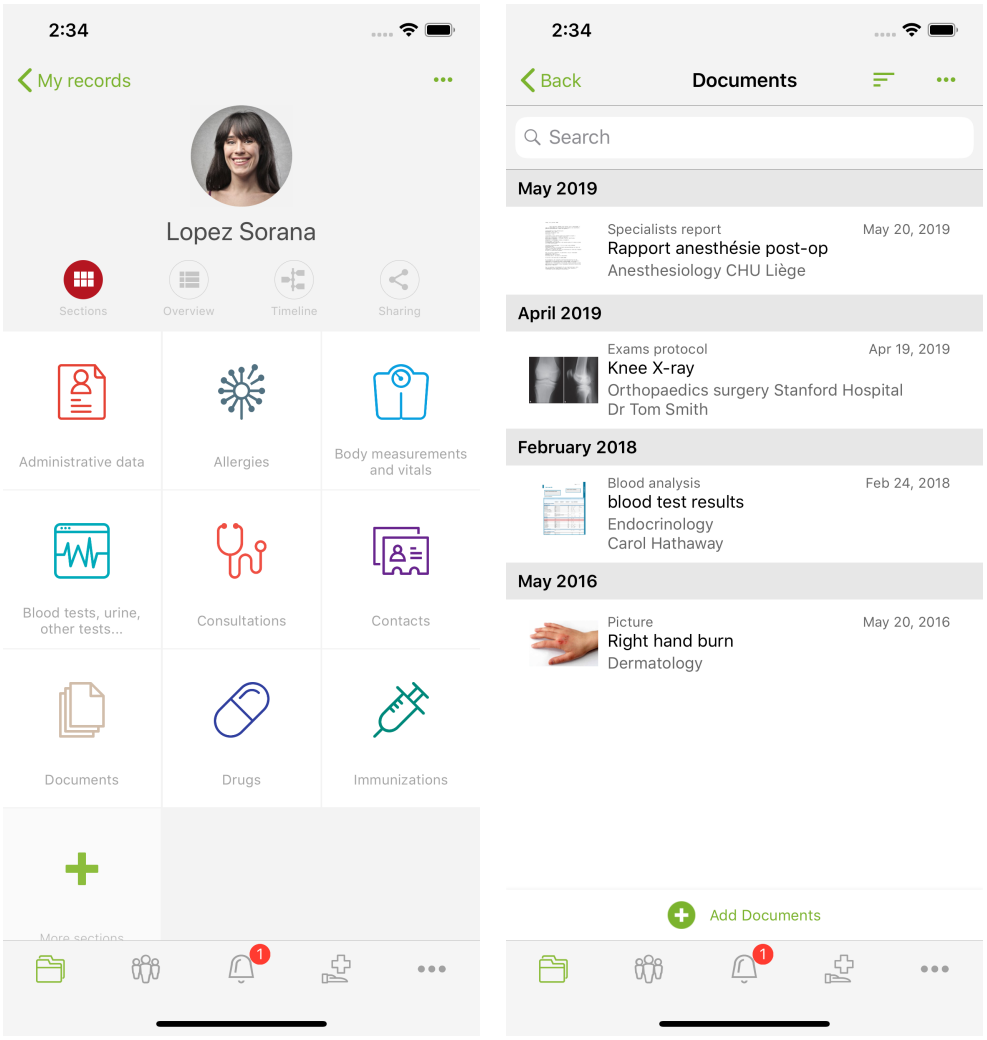
Table 3.10: Medvalet Features and Limitations

**Andaman7**

A mobile app developed by a Belgian-American eHealth company with the goal to improve doctor-patient communication, compliant with GDPR and HIPAA (A7 Software, 2022). See Table 3.11 for a summary of its features and limitations and figure 3.6 for a screenshot of the app.

| Key Features/Benefits | Limitations/Drawbacks |
|---|---|
| • Offers sections for personal information, medical history, allergies, vaccinations, medications, etc.<br>• Automatically collects health data from over 300 hospitals and clinics in the US and Europe.<br>• Supports input from diverse sources like hospitals, labs, smart devices or even manual input.<br>• Stores data locally on patients' devices, ensuring privacy.<br>• Data sharing with QR codes and revokable access.<br>• AI tools for summarization, translation, and simplifying medical jargon. | • Requires patients and doctors to both create accounts.<br>• Does not extract data or values from uploaded documents like lab results.<br>• Limited to mobile platforms, which may limit usability for desktop-only users. |

Table 3.11: Andaman7 Features and Limitations




(a) PHR Sections screen

(b) Documents section screen

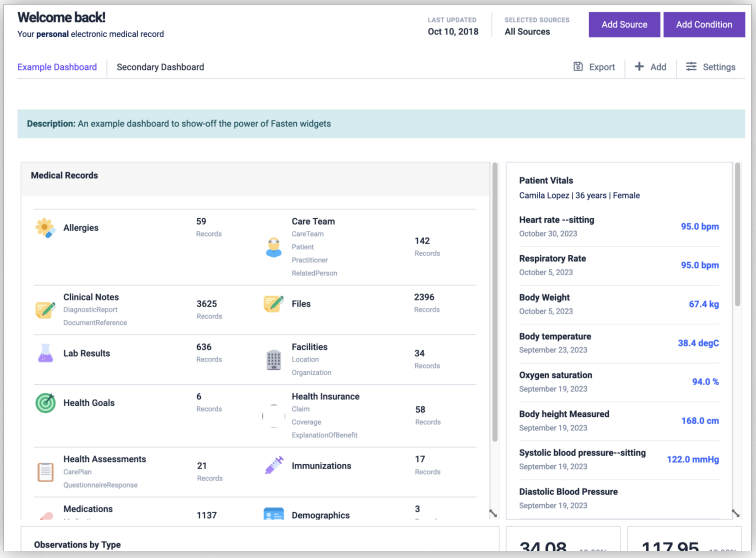
Figure 3.6: Andaman7 screenshots

### Fasten Health

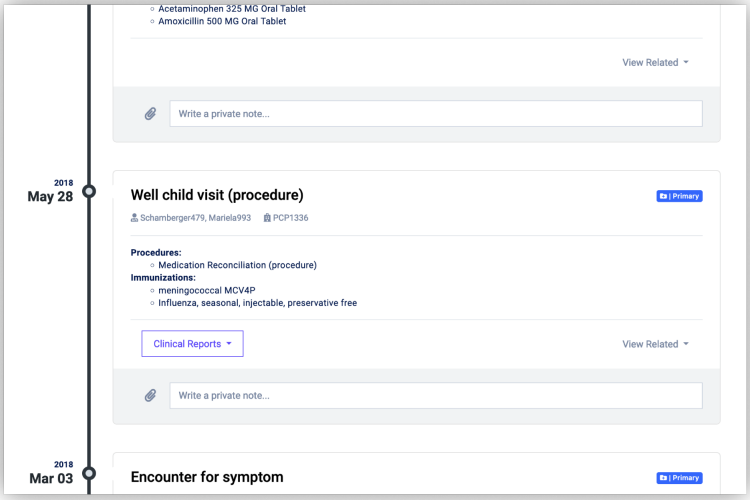
An open-source, self-hosted electronic medical record aggregator with optional paid desktop versions for Windows and Mac (Fasten Health, 2022). See Table 3.12 for a summary of its features and limitations and figure 3.7 for a screenshot of the app.

| **Key Features/Benefits** | **Limitations/Drawbacks** |
|---|---|
| • Automatically aggregates records from multiple providers, like hospitals and labs.<br>• Supports self-hosting for complete control over data, stored locally.<br>• Compatible with protocols such as DICOM, FHIR, and OAuth2.<br>• Allows manual entry for allergies, vaccinations, and medications.<br>• Offers multiple dashboards with graphs to visualize health data.<br>• Supports multi-user functionality for families. | • Paid desktop versions may deter users.<br>• Manual data entry limited to new or existing encounters, complicating usage.<br>• Does not support OCR or automatic data extraction from documents.<br>• Lacks data-sharing capabilities with doctors.<br>• Requires technical expertise for self-hosting.<br>• Restricted to healthcare providers in the United States. |

Table 3.12: Fasten Health Features and Limitations




(a) Dashboard screen




(b) Visit history screen

Figure 3.7: Fasten Health screenshots

# Chapter 4

# Project Planning and Design

## 4.1 System Design

### 4.1.1 UML Diagrams

UML, or Unified Modeling Language, is a standardized modeling language that consists of a set of diagrams used for modeling business processes and documenting software systems, helping better communicating potential designs and architectural decisions (Paradigm, 2024).

The most common UML diagrams include:

- **Use Case Diagram** - Illustrates the system's intended functionality in terms of actors, use cases, and their relationships, showing how the system delivers value to users.
- **Class Diagram** - Depicts the structure of the system by showing classes, attributes, operations, and static relationships between classes.
- **Sequence Diagram** - Demonstrates how objects interact in a particular, timed sequence scenario, focusing on the messages passed between objects.
- **Activity Diagram** - Represents the workflow of a target use case or business process through a series of activities, emphasizing steps, choices, iterations, and concurrency.

The student has used UML diagrams to present the stakeholders with a visual representation of the system's design and architecture. The diagrams can be found below.

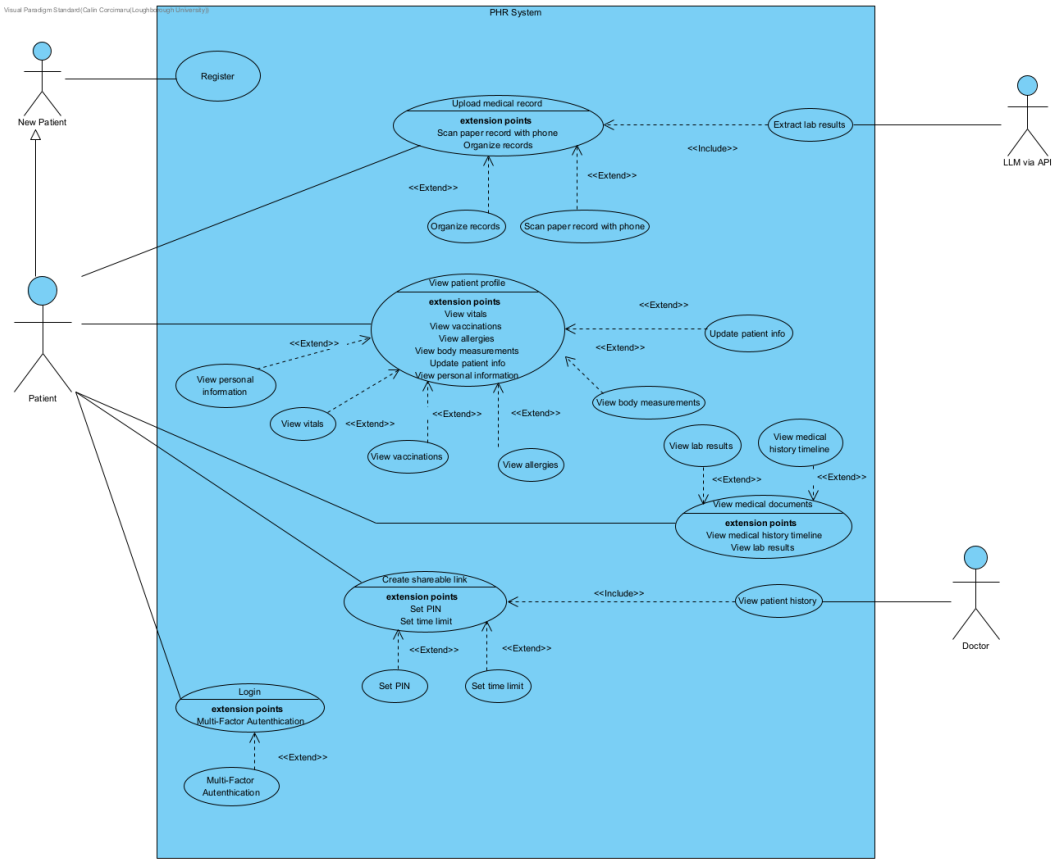



Figure 4.1: UML Use Case Diagram

### 4.1.2 Database Design

### 4.1.3 Wireframes

## 4.2 Project Tech Stack

### 4.2.1 Frontend

### 4.2.2 Backend

### 4.2.3 Database

## 4.3 Project Management

### 4.3.1 Methodology and Tools

Based on the research above, the student has decided that he will be using a hybrid approach, with Waterfall as the main methodology for planning managing the project. The development part of the project will be done using ScrumBan, so that the student will be able to utilise elements from both frameworks. There are several reasons for this choice:

1. The nature of the project - the student is working on a project that has a limited timeframe (about 6-7 months) and is of a smaller scale.
2. Documentation requirements - the student is required to document the progress during the project in this report, including the requirements gathered, design considerations and implementation decisions and outcomes.
3. Regulatory requirements - the student is required to adhere to the regulations and standards of the healthcare industry, which may require extensive documentation and planning.
4. Customer involvement - the student will be working closely with the project stakeholder, who will be providing feedback and guidance throughout the project.
5. Familiarity with both Agile and Waterfall - the student has experience with both Agile (specifically Scrum and Kanban) and Waterfall methodologies, and has worked on projects that have used both approaches.

The student will use Jira Software as their project management tool, which is one of the most popular project management tool for software development projects that supports working with Agile frameworks such as Scrum and Kanban (Springer, 2023). The student has experience with Jira Software, having used it in previous projects, and is familiar with its features and capabilities.

### 4.3.2 Project Backlogs

### 4.3.3 Sprints planning

# Chapter 5

# Development

## 5.1 Feature #1

## 5.2 Feature #2

## 5.3 Feature #3

## 5.4 Feature #4

## 5.5 Feature #5

## 5.6 Feature #6

# Chapter 6

# Evaluation

## 6.1 Deployment

## 6.2 System Testing

## 6.3 User Acceptance Testing

## 6.4 Client feedback

# Chapter 7

# Conclusion and Future Work

## 7.1 Areas of Improvement

## 7.2 Future Work

## 7.3 Lessons Learned and Reflections

## 7.4 Final Thoughts

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# Appendix A

# Requirements

| ID | Requirement | Priority |
|---|---|---|
| 1.1 | The system must be accessible on all modern desktop and mobile-based browsers. | Must Have |
| 1.2 | The system must be accessible from any location by using an internet connection. | Must Have |
| 1.3 | The system must store the data in a secure manner, ensuring that only the patient and the doctor can access the data. | Must Have |
| 1.4 | When shared with the doctor via a link, the system must load within 3 to 5 seconds when accessed via a desktop browser. | Should Have |
| 1.5 | When shared with the doctor via a link, the system should secure the data with a unique token or PIN that expires after the specified time frame. | Could Have |
| 1.6 | The system could be accessible on all modern mobile devices via a mobile application. | Could Have |

Table A.1: Non-functional Requirements

| ID | Requirement | Priority |
|---|---|---|
| 2.1 | The system must provide a secure login mechanism for patients via Multi Factor Authentication. | Must Have |
| 2.2 | If used on mobile, the system should allow the patient to use biometric authentication for logging in. | Should Have |

Table A.2: Login Requirements

| ID | Requirement | Priority |
|---|---|---|
| 3.1 | The system must allow patients to upload their own medical records in a variety of formats (PDF, DOC, etc). | Must Have |
| 3.2 | The system must allow the patient to specify and categorise the type of document they are uploading (lab test, doctor consultation, etc). | Must Have |
| 3.3 | If used on mobile, the system should allow the patient to take a picture of the document and upload it. | Could Have |

Table A.3: Document Upload Requirements

| ID | Requirement | Priority |
|---|---|---|
| 4.1 | The system must allow the patient to generate a shareable link to provide access to their medical records. | Must Have |
| 4.2 | When creating the shareable link, the system must allow the patient to set an expiration date for the link. | Must Have |
| 4.3 | When creating the shareable link, the system should allow the patient to set an access password for the link. | Should Have |
| 4.4 | When creating the shareable link, the system should allow the patient to select which records to share with the doctor. | Should Have |

Table A.4: Patient Shareable Link Requirements

| ID | Requirement | Priority |
|---|---|---|
| 5.1 | The patient personal cabinet must provide an overview of the patient's history through 3 main sections: personal information, lab tests, and doctor consultations. | Must Have |
| 5.2 | The system must display the patient's history in a chronological order in the form of a timeline. | Must Have |
| 5.3 | The system must allow patients to add their own personal information, such as name, date of birth, or address. | Must Have |
| 5.4 | The system must allow the patient to add their own allergies. | Must Have |
| 5.5 | The system must allow the patient to add their own vaccinations. | Must Have |
| 5.6 | When viewing doctor consultations, the system should divide them into categories based on the domain of the doctor (cardiology, neurology, etc). | Should Have |
| 5.7 | The system should allow the patient to enter vitals information, such as height, weight, blood pressure, etc. | Should Have |
| 5.8 | When multiple vital entries are made, the system could display a historical graph of the patient's vitals. | Could Have |
| 5.9 | The system could allow the patient to switch between viewing the lab tests in the document format or in a tabular, numerical format. | Could Have |

Table A.5: Patient Personal Cabinet Requirements

| ID | Requirement | Priority |
|---|---|---|
| 6.1 | The system must provide an overview of the patient history through 3 main sections: personal information, lab tests, and doctor consultations. | Must Have |
| 6.2 | When shared with the doctor, the system must allow the doctor to only view the patient's history, not edit it. | Must Have |
| 6.3 | The system must allow the doctor to view blood tests in a graphical format. | Must Have |
| 6.4 | The system must allow the doctor to view blood tests in a numerical, tabular format. | Must Have |
| 6.5 | The system must allow the doctor to view the patient's history in a chronological order. | Must Have |
| 6.6 | The system must display the doctor consultation and every lab test, except for blood tests, in a free text or document format. | Must Have |
| 6.7 | When viewing blood test results, the system should show the source document of the blood test value. | Should Have |
| 6.8 | For blood test results, the system should display the normal range values for each test. | Should Have |

Table A.6: Shared Patient Information Requirements (Doctor View)

| ID | Requirement | Priority |
|---|---|---|
| 7.1 | The system must allow patients to enter their current medication including details such as the name of the drug, dosage, frequency and start/end date. | Must Have |
| 7.2 | The system must allow patients to add new medication to their list. | Must Have |
| 7.3 | When adding medication, the system should have 2 options: add a simplified version of the medication or add a detailed version of the medication. | Should Have |
| 7.4 | When choosing the simplified version, the system should allow the patient to just add the name, dosage and duration of the medication. | Should Have |
| 7.5 | When choosing the detailed version, the system should allow the patient to add the name, dosage, frequency, start/end date, and the reason for taking the medication. | Should Have |
| 7.6 | The system should allow patients to add their past medication | Should Have |
| 7.7 | The system should allow patients to set medication reminders. | Should Have |
| 7.8 | After entering the medication, the system could allow the patient to track the medication intake. | Could Have |

Table A.7: Patient Medication Requirements