POLITECNICO DI TORINO

Master's Degree in Computer Engineering

Master's Degree Thesis

Design of a Medical Software Platform for Periodontitis Data Collection and Clinical Workflow Support

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Summary

This thesis illustrates the design, development, and analysis of a digital platform for dental practice management with a specific focus on the integration of patient information, radiographic records, and treatment planning. The work started with a collaboration with the Dental School, which is part of the University of Turin, where the existing clinical workflow, adopted by dentists and students in managing cases of periodontitis based on an experimental clinical protocol, was observed and studied thoroughly. This observation of real-world practices constituted the foundation for establishing fundamental requirements in data collection, workflow organization, and clinical record-keeping.

The software was initially conceived to support this experimental periodontal protocol, in particular by facilitating the systematic collection of clinical data for research on periodontitis. However, in the analysis and design phase, particular care was taken to create a flexible and extensible system that would be valuable not only in other clinical trials but also in the daily operations of general dental practices.

One of the system's main objectives is the unification of patient care data, including medical histories, clinical notes, radiographic and photographic records, and treatment plans within one integrated interface. Currently, such information is frequently dispersed among various platforms, local applications, and even personal devices, resulting in inefficiency, redundancy, and data management risks. By bringing information together and facilitating clinical workflows through an integrated platform, the system improves efficiency, reduces errors, and facilitates collaboration. Meanwhile, it offers a structured setting for research by enabling clinicians to extract consistent datasets to support biomedical research on the clinical study of periodontitis. Methodologically, the development and analysis adhered to best practices in medical software engineering. The design started with process modeling, where extensive information on the current workflows, their actors, and the data inputs and outputs flow was gathered. These were formalized through synopsis diagrams, workflow diagrams, and Swimlane Activity Diagrams to ensure all the roles and interactions within the clinical environment were well

portrayed.

Then, the anticipated functions of the software were derived during the requirements elicitation process. This was supplemented by the utilization of use case diagrams in delineating system interactions, along with interface prototypes and activity diagrams to specify the anticipated behavior of the application. Lastly, the project concluded with the exact definition of all the entities involved, supported by entity-relationship models and communication diagrams for showing the logical links between system components.

Through the combination of specific knowledge in periodontology and formal software modeling techniques, the study contributes both to dental clinical practice and to the broader field of biomedical informatics. The platform represents a concrete example of how structured software design techniques can be applied to real-world healthcare problems, while laying the groundwork for subsequent developments in other aspects of dentistry and medicine.

Keywords: Dental School, Periodontology, Process Modeling, Clinical workflow, Requirements Elicitation, Digital health, Software design, Practice management systems.

To my family,
whose love, support, and trust
made this milestone possible.

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Chapter 1

Introduction

Thanks to the active collaboration with the Politecnico di Torino and the Dental School division of the Università di Torino, I have the opportunity to work on this thesis, which relates to the application of Biomedical Informatics and Digital Healthcare technologies in a complex healthcare setting. The research was born out of the necessity to create a digital platform that could more effectively gather and analyze data for a periodontology clinical study. Moreover, it examines how digital solutions can assist clinical decision-making, enhance healthcare practitioners' workflows, and facilitate the management of health data, thereby offering valuable insight into their effectiveness in meeting the increasing demands placed on modern healthcare systems. This project applies these principles in a real-world context, with the multiple objectives of improving clinical practice and assisting research in clinical protocols.

The first chapter introduces the field of Biomedical Informatics, defining its historical development, main teachings, and its place in the whole context of Digital Healthcare. It also explains the technological and organizational environment within which these innovations are being introduced today, both the opportunities they offer and the challenges they present. Lastly, the host institution, Dental School of the Università di Torino, is introduced, including a presentation of their activities, goals, and functions within the healthcare environment.

1.1 Biomedical Informatics and Digital Healthcare

Biomedical Informatics and Digital Healthcare are the technological and scientific backbone of this thesis project. They are, together, a field of study and practice that exists at the intersection of computer science, medicine, health policy, and clinical practice. These are the domains on which the platform presented here is conceived, as they provide both the methodological underpinnings and the technological frameworks necessary to create digital solutions for real-world healthcare environments. In this section, the most important historical advances, underlying principles, and significant innovations that have defined the discipline are presented. It also discusses how the integration of digital technologies has increasingly transformed the notion of care, affecting delivery systems and medical software.

1.1.1 Biomedical Informatics

Biomedical Informatics is an interdisciplinary field that studies the organized application and efficient use of biomedical data, information, and knowledge to enhance human health through research, problem-solving, and clinical decision-making. [1] The discipline already started to develop in the late 1970s with the original designation of Medical Informatics, corresponding with the first international MEDINFO conferences. Those first conferences demonstrated the early interest in introducing computational techniques into medicine when hospitals were just starting to computerize patient records.

The initial wave of developments had a strong focus on data management, with hospitals moving from paper records to computerized systems able to manage demographic, clinical, and administrative data. The following decades witnessed the emergence of increasingly sophisticated patient record systems, laboratory information systems, and decision support applications, laying the groundwork for clinical tools that could actively support healthcare professionals. [2]

Biomedical informatics was liberated from the limitations of the hospital by the advent of the internet and was enabled for remote access to patient information, joint research activities, and telemedicine applications. The more recent integration of artificial intelligence, big data analysis, and machine learning, in turn, reinvented the discipline and catapulted it onto a cornerstone of precision medicine and evidence-based care.

Biomedical informatics today is more than software development for the clinical setting. It encompasses the whole infrastructure of data governance, ethics, interoperability, and workflow integration to ensure that the software tools not only work effectively and are safe for application, but also in accordance with clinical specifications and standards. [3]

1.1.2 Digital Healthcare

Digital Healthcare constitutes the new advancement and practical aspect of Biomedical Informatics, representing a discipline that includes information, medicine, and technology in the everyday life of healthcare. The World Health Organization (WHO) describes Digital Health as "the field of knowledge and practice associated with the development and use of digital technologies to improve health." [4] In this regard, it denotes not just a technical change, but also a paradigm shift with regard to designing, delivering, and living with health systems.

This field encompasses a variety of instruments and platforms, including electronic health records (EHRs), telemedicine platforms, mHealth apps, wearable monitoring devices, and AI-assisted diagnostic and decision-support platforms. In no instance are any of these technologies supposed to replace clinicians and physicians yet instead aim at supplementing clinical practice with additional safety nets, precision, and knowledge. For instance, AI algorithms for the detection of radiologic image anomalies can act as a "second reader" for radiologists, and surgical planning software allows clinicians to rehearse procedures prior to patient application and reduce risk and enhance patient outcomes.

In the past, Biomedical Informatics began as a discipline with the initial use of computational approaches for medical research during the mid-20th century. But it is in the recent couple of decades that Digital Health has probably prospered as a high-level notion because of the remarkable increase in the Internet, phone connectivity, and analytics of big data. This has also been acknowledged at the political level: the European Commission's Digital Health Strategy and the United States' 21st Century Cures Act, for instance, identify the pivotal role of digital technologies in achieving sustainable and patient-centric healthcare systems. [5] Above all, digital health is considered to be more than the digitalization of clinical practices or medical records. It expands the very definition of health itself beyond the treatment of disease and extends it so far as to include overall physical, mental, and social well-being. Through the use of continuous monitoring, predictive analysis, and personalized recommendations, individuals are enabled as active participants in their care, facilitating a preventive and proactive healthcare model.

The COVID-19 pandemic has been a historical accelerator of digital health adoption. In a few months' time, teleconsultation, remote monitoring of patients, and e-prescription transitioned from edge use cases to common practices. All the technologies played a significant role in ensuring continuity of care, safeguarding vulnerable groups of individuals, and easing the pressure on hospitals. Digital healthcare, however, will always be a complement and not a substitute for face-time and reminds us of the necessity of merging the two strategies as part of an equitable and inclusive healthcare system. [6]

Finally, Digital Health is the practical implementation of Biomedical Informatics for the 21st century, bringing science and technology together with patient-oriented care. Its effectiveness not only rests on technical innovation but also on ethical concerns, regulatory policies, and organizational flexibility so that these instruments are utilized to complement the human aspect of medicine. In this regard, confidentiality and security of patient information emerge as central issues: healthcare professionals emphasize that access to data should be restricted on a “need-to-know basis,” and that safety policies must be periodically updated to prevent human behavior from undermining security measures. [7]

1.1.3 Care Delivery Models

Healthcare delivery has experienced tremendous reorganization in the past decades, moving from being strongly based on individual physician experience to evidence-based, standardized, and technology-supported practice. Before the late 1970s and early 1980s, the outcome of care would often rest largely on the treating physician’s experience and ability. Variation in prognosis was significant: for example, in oncology, patients would travel long distances to see a highly experienced specialist who was able to accurately diagnose their condition, while others with the same condition would receive less effective therapy because of geographic disparities. [8]

To counteract these differences, international scientific societies and regulating authorities began to release clinical guidelines with the aim of providing uniform recommendations for diagnosis and treatment. Basing itself on this, the introduction of "Percorsi Diagnostico-Terapeutico-Assistenziali" (PDTA), or diagnostic–therapeutic–care pathways, placed yet more care delivery on a systematized basis. By way of these protocolized procedures, it is guaranteed that, for all pathologies, healthcare organizations can provide a minimum guaranteed level of care, based on the most recent available evidence and consistent with available resources. This shift has made possible the delivery of standardized care to the majority of patients (over 90% in some settings), and yet retaining the recognition that physician talent is still irreplaceable in the face of unusual or highly complex cases. [9]

Contemporary models of care achieve a balance between individualization and standardization. While guidelines and PDTAs create a powerful point of reference for patient management for individuals who possess common attributes, on the other hand, accuracy and personalized medicine make possible treatments founded upon the individual patient's distinct biological, genetics-based, and clinical attributes. In the case of the treatment for breast cancer, for example, genetic biomarkers such as mutations in the BRCA gene could dictate treatment decisions beyond the standard. [10] Precision medicine, specifically speaking, focuses on omics variables upon the point of how technology now increasingly enables clinicians to more effectively tailor interventions than at any prior moment in history.

This transition is one of a broader cultural movement in medicine: from individual physicians' judgment to decision-making based on data, driven by evidence, and facilitated by technology. The latest digital technologies in health, including clinical decision support systems, artificial intelligence, and mobile applications for health, now incorporate additional layers of intelligence. In spite of the challenge of implementing such technologies, particularly issues of workflow modification and regulatory compliance, they represent an imperative step toward optimizing care delivery.

Healthcare is no longer restricted to hospitals. Instead, it encompasses the entire spectrum of patient needs, from acute conditions to chronic disease care, from prevention to terminal care. The major categories of care can be summarized thus:

- Primary Care: General medicine, typically the initial contact for a patient. It includes prevention, health promotion, and early detection through physical exams and screenings. Specialist referrals are managed by primary care physicians.
- Specialty Care: Medical attention provided by specialists (e.g., cardiologists, neurologists, orthopedists) for specific health problems requiring expert attention.
- Emergency Care: Care required to avoid death or severe harm, and is typically provided in emergency rooms.
- Urgent Care: Speedy but not life-and-death care. In most models, community health centers are taking on more responsibility for minor cases, thereby taking the pressure off emergency rooms.
- Long-term Care: Treatment and care for an extended period, typically for degenerative or chronic conditions requiring continuous management.
- Hospice and Palliative Care: Care designed to relieve suffering and improve the quality of life for terminally ill patients.

Within this framework, the patient journey and clinical pathway must be distinguished. The PDTA is the theoretical, normalised path that has been drawn up by care organisations on the basis of evidence, whereas the patient journey accounts for the actual sequence of diagnostic and therapeutic steps taken by the patient. These can often diverge in order to accommodate individualization, with emphasis on the balance between normalized models and personalized care. [11] [12]

A further vital concern of care delivery is the integration of caregivers. These are individuals, usually family members, but not always, who support patients in maintaining their health and their daily existence. Where professional "carers" or attendants differ from them, it is that caregivers share a unifying function to provide continuity of care and quality of life, even for patients who remain partially independent. Their function focuses on extending healthcare delivery beyond the formal health facility to the social and community environment. [13] [14]

The meaning of a healthcare system is therefore wider than the hospital and the doctors' clinics. It extends to include preventive interventions, public health programs, and broader social, economic, and environmental determinants of health. Functions extend from preventing disease and promoting health to workforce planning and improving conditions in which populations live. [15]

Finally, the role of digital technologies in modern care models cannot be overstated. Telemedicine systems enable remote consultations, reducing unnecessary patient travel, and software platforms more and more bundling different diagnostic and monitoring devices together. While formerly medical software systems used to operate in isolation, sometimes not even allowed to coexist on the same computer, now everything is about interoperability. This transition, though, poses overarching data security and cybersecurity concerns and challenges. Interoperability alone is not enough; medical information's integrity, confidentiality, and security need to be assured as well. Software firms are responsible for securing their devices, yet secure integration amongst platforms must be from a holistic perspective. The ability of different tools to be able to speak well, without compromising on their protection and privacy, is today the key to the delivery of high-quality and trustworthy healthcare. [16] [17]

1.1.4 Medical Device Software

The roles of medical software have expanded significantly in the healthcare space of today. On the basis of functionality, a medical software may categorically be classified into three types:

- Administrative software, which covers back-office functions such as staff scheduling, billing, and resource management.

- Embedded software, which is embedded directly into medical devices such as infusion pumps, pacemakers, or imaging systems.
- Standalone medical software, which processes clinical data independently, for example, diagnostic imaging viewers, laboratory reporting tools, and clinical decision-support systems.

Under international regulations—such as the United States' Food and Drug Administration (FDA) and Europe's Medical Device Regulation (MDR) both embedded and standalone software are considered medical devices when they perform diagnostic, therapeutic, or monitoring functions. This includes even apparently simple functions, like the generation of clinical graphs, when they directly affect medical decision-making. [18]

This regulatory landscape has made interoperability, cybersecurity, and data protection imperative concerns. Such next-generation platforms are likely to be based on mobile applications and cloud infrastructure and encompass wearable sensor or IoT-connected medical device data. They would then need to achieve stringent patient confidentiality requirements (e.g., European GDPR), clinical verification, and quality management systems (e.g., ISO 13485) in such a way that they to be introduced for safe use. [19] [20]

Lastly, software for medical devices forms the technological basis of computerized healthcare, such that it not only allows precise clinical functionality but also secure and seamless integration within healthcare workflows.

1.2 The host institution: Università di Torino

1.2.1 History and foundation

The Dental School of the University of Turin is a Research, Teaching, and Clinical Care Center of Excellence in Dentistry and Oral Medicine operating within the *Città della Salute e della Scienza* and is a center of the Italian National Health System. It covers around 8,000 square meters of the second level of the historic multifunctional Lingotto building and has the latest advanced technologies and state-of-the-art facilities.

The Dental School was formally opened on February 15, 2008, through the initiative of Professor Giulio Preti and under the management of Professor Stefano Carossa. It is hosted in the Lingotto complex, an early 20th-century symbol of industrial architecture that in the past hosted the FIAT automobile factory. The area has been more recently converted into a multifunctional center by the world-renowned architect Renzo Piano and is now equipped with a congress center, auditorium, art gallery, hotels, restaurants, and a shopping mall.

In 2013, the Interdepartmental Research Center Dental School was set up with the aim of supporting the quality of the school's research and stimulating postgraduate studies in the field of dentistry. Today, the institution is a benchmark in the Piedmont area, blending superior teaching, postgraduate study, and specialized patient care. [21]

1.2.2 Mission and Educational Role

Turin Dental School is a Center of Excellence in Oral and Dental Sciences Research, Teaching, and Clinical Care, closely integrated with the National Health Service. Its foundation is built on three pillars: scientific development of research, high-level academic education, and cutting-edge patient care. The School offers a wide array of educational choices, including undergraduate studies in Dentistry and Dental Hygiene, postgraduate schools of specialization, and master's degrees.

A great feature of Dental School is the multi-year collaboration with leading manufacturers of professional dental equipment and precision instruments essential in the dental profession. Thanks to these partnerships, students are offered access to the latest technologies and cutting-edge instrumentation, which allow them to learn and refine the most recent and advanced operative procedures. Such alignment ensures that training is responsive to the evolving standards of modern dentistry and prepares graduates to begin the profession with cutting-edge skills. [21]

1.2.3 Clinical and Research Activities

Apart from teaching and academic activity, the Dental School also plays an important role in patient care, integrating education and clinical activity. Its healthcare mission is achieved through two big complex care units:

- Oral Rehabilitation, Maxillofacial Prosthodontics, and Dental Implantology Unit, directed by Professor Stefano Carossa
- Preventive and Restorative Dentistry Unit, directed by Professor Elio Berutti

Thanks to these two units, Dental School provides highly specialized interventions, ranging from basic restorative and preventive treatment to elaborate maxillofacial rehabilitation and implantology. The School provides care to a great number of patients every year, with over 109,000 procedures performed in 2019. In the latest years, specific focus has been placed on the management of patients with systemic pathologies, integrating dental care into general therapeutic pathways.

The School is equipped with the latest technological and diagnostic tools, and its infrastructure allows it to offer the full scope of dental treatment, from straightforward care to highly complex interventions.

On the research side, the Interdepartmental Research Center, established in 2013, facilitates scientific output in the form of publications, funded projects, and collaboration with industry. Over the past ten years, the School has produced 347 scientific publications at a rate of around 45 per year, with a huge increase in competitive research funding. The new Research and Training Centre also enhances research in surgery, digital diagnostics, and tissue regeneration by taking a highly multidisciplinary approach and by promoting technological innovation and knowledge transfer. [21] [22]

1.2.4 Structure and Facilities

The physical structure of the School is central to making possible both educational and clinical activities. It is characterized by two important innovative building features:

- It occupies a historically and socially prominent heritage building, representing the city's investment in health and education.
- In contrast to most large hospital complexes, the building was specifically designed for dentistry, with clinical and teaching areas being wholly committed to dental practice instead of being modified from previously existing spaces.

The building covers a total of 13,000 m^2, with 9,000 m^2 on the second floor for clinical and preclinical teaching and patient care and 4,000 m^2 on the third floor for teaching.

The teaching comprises:

- A main lecture theater with approximately 144 seats
- Six classrooms of approximately 50 seats each
- A preclinical simulation lab for dental and periodontal procedures

- A laboratory for anatomical modeling, orthodontic training, and prosthetic fabrication
- A library

The clinical arena comprises 71 functional units (dental chairs) distributed across 10 specialized outpatient clinics, covering all the major dental specialties. The educational and clinical equipment is modern and technologically advanced, addressing high-quality patient care and training. [23]

1.2.5 Governance and Organization

The Center of Excellence for Research, Teaching, and Clinical Care in Dentistry, commonly known as the Dental School, was founded by the Board of Directors of the University of Turin on December 20, 2012.

It falls under the departmental jurisdiction of the Department of Surgical Sciences under the broader School of Medicine.

Both in administrative and financial terms, the Dental School also falls under the University's Polo Centri, a shared office for handling its internal service and accounting.

The governance structure of the Centre consists of the following major Bodies:

- President
- Director
- Scientific Committee
- Management Committee

[24]

Chapter 2

Problem Analysis and State-of-the-Art Solutions

2.1 The Problem Context

This project was motivated by the clinical research setting of the University of Turin Dental School, in particular in relation to periodontitis. Periodontitis is a multi-factorial and chronic disease that requires systematic examination of a number of clinical parameters, i.e., probing depth, clinical attachment loss, gingival bleeding, plaque indices, and radiographic examination. Both for clinical care and research, these parameters have to be measured and recorded in a structured, consistent, and reliable manner.

Presently, clinicians and students within the institution employ the Turin University Periodontal Chart (TUPC), which is a digital document which is compiled for capturing patient information and periodontal data. While the TUPC is a comprehensive method of clinical data capture, it finds use is limited by the fact that data end up being segregated in the local workstation or individual devices, without there being centralized control or interoperability with other clinical reports.

Furthermore, other patient data, such as radiographs stored on clinic computers and intraoral photographs taken on personal cameras, are not directly associated with the periodontal charts. This non-integration causes redundancies, hinders data retrieval, and prevents a unified patient record. From a research perspective, this fragmentation also makes it harder to consolidate datasets, which is imperative in developing standard protocols and clinically examining large-scale studies.

The problem, therefore, is how to create a system able to consolidate these distinct sources of information and structure them in some meaningful way. The system has to be both usable by practicing clinicians and yet robust for those researchers who require stable, consistent data sets for clinical research. A balance between usability and robustness is attained via a disciplined process of specification, process modeling, and validation.

2.1.1 The Clinical Context

Periodontitis Introduction

Periodontitis is a chronic inflammatory disease of the periodontal support tissues of the teeth (periodontium), such as the gingiva, periodontal ligament, cementum, and alveolar bone. It is caused by an imbalance of bacterial biofilm inhabiting the surfaces of the tooth in provoking an overreacting host's immune system, leading to destruction of the periodontal tissues. Periodontitis evolves from gingival inflammation to irreversible loss of attachment and alveolar bone loss, potentially leading to loss of the teeth unless properly managed.

Multifactorial in cause is the illness: the local etiology is dental plaque and calculus, but systemic disease (e.g., diabetes mellitus) and genetics also play a role. The environment (e.g., smoking) and the patient's own actions (e.g., failure in oral hygiene) also contribute to the development and onset of the illness. The clinical picture of periodontitis is insidious and the slow progressive illness then manifests without or with very slight pain and necessitates early repeated diagnosis and monitoring.

Epidemiological questionnaires reveal that up to half the world's adult human population is exposed to at least one kind of periodontal disease, which is now a sharp acute public health concern. Furthermore, mounting evidence reveals its system-wide implications by correlating periodontal inflammation and cardiovascular illness, diabetes, pregnancy disorders, and chronic obstructive pulmonary disease. Therefore, precise and methodical documentation of periodontal observations is important in clinical practice and research protocol development. [25]

Periodontal Parameters and Charting

Periodontal charting provides a methodical approach to recording clinical findings and monitoring disease progression over time. The parameters most relevant are:

- **KT (Keratinized Tissue)**: Width of keratinized gingiva on the tooth, useful for periodontal health and surgical purposes.

- **PPD (Probing Pocket Depth)**: Measurement from the gingival margin to the base of the periodontal pocket, taken using a periodontal probe; indicates current pocketing due to tissue loss.
- **REC (Recession)**: The coronal movement of the gingival margin away from the cemento-enamel junction (CEJ); a measure of attachment and tissue loss.
- **CAL (Clinical Attachment Level)**: The sum of PPD and REC, a measure of actual periodontal support loss.
- **BOP (Bleeding on Probing)**: Presence or absence of bleeding upon probing; a reflection of gingival inflammation and disease activity.
- **Plaque Index**: Presence of dental plaque at the gingival margin; a reflection of oral hygiene status.
- **Mobility**: Degree of tooth mobility as a result of periodontal support and bone loss.
- **Bifurcation (V = Vestibular / P = Palatal)**: Presence of furcation defects in the tooth root.
- **Type**: Identifies if the location is a natural tooth, an implant, or if there is a missing tooth in that position.

Combined, these parameters form the basis of periodontal charting and enable clinicians and researchers to obtain a systematic impression of the periodontal status of each patient.

Clinical Workflow and Documentation

During my visit to the Dental School, I had the opportunity to observe the workflow currently adopted in the clinical management of patients undergoing periodontal examination. This is broken down into a series of very well-defined stages, each committed to the sequential collection of clinical data, the refinement of diagnosis, and the establishment of the most appropriate treatment plan.

The workflow typically begins with an initial screening appointment. During this initial visit, the patient is welcomed and requested to complete a questionnaire that delivers demographic information, systemic medical history, and lifestyle factors known to influence periodontal health (e.g., smoking habit, diabetes, medication, and family history of periodontal disease). Then the clinician performs a standardized anamnesis by asking specific questions following the research protocol in progress. During the first visit, the clinician also performs a general extraoral and intraoral examination and takes a set of photographs documenting the patient's occlusion, dentition, and soft tissues. The stage allows for a general view of the oral and systemic conditions of risk and forms the foundation for the diagnosis.

Periodontal probing assessment is the subsequent step and is the foundation of periodontal diagnosis. It is often performed in a subsequent visit. Using a manual millimeter-marked probe, clinicians measure probing pocket depth, clinical attachment level, bleeding on probing, gingival recession, and tooth mobility, quantifying these variables systematically for each tooth. The probing enables a comprehensive mapping of disease extent and severity. The clinician provides the patient with an initial explanation of the periodontal status at the conclusion of this visit, illustrating possible treatment options.

On certain occasions, particularly if the patient resides very far, like in a different region from the Dental School, it may be possible to combine the screening appointment and probing session into a single longer appointment, minimizing the travel requirements and optimizing patient convenience.

A follow-up visit usually includes radiographic inspection. Standard procedure includes taking periapical radiographs ("lastrine"), which involve a high level of detail visualization of the alveolar bone levels and root morphology. Usually, a panoramic radiograph is also obtained to augment this diagnostic assessment.

Once all the clinical and radiographic details are in place, the clinician then goes about filling in the Turin University Periodontal Chart (TUPC). The chart is the center around which the integrated details in the questionnaire, the anamnesis, the probing details, and the clinical remarks are systematically stored in one place. The TUPC provides a systematic, synoptic representation of the patient's periodontal picture such that diagnosis and presentation of the case are simplified.

Following chart completion, the case is presented in a collegial discussion session. The findings are presented by the student or clinician who worked with the patient to colleagues and professors, opening it up to critical analysis and interdisciplinary feedback. Not only do peer discussions validate diagnostic conclusions, but they also allow the group to come to an agreement on a final treatment plan.

The patient is then contacted again in order to initiate the treatment process. Therapy is usually initiated with non-surgical treatment, comprising professional oral hygiene instruction, motivation, and dental scaling. This is followed by a sequence of non-surgical periodontal treatment, usually four to six sessions of subgingival instrumentation. After this initial care, the patient is reassessed in order to assess clinical improvement and residual disease. If the disease remains, surgical procedures can be considered. This formalized sequence allows the plan for treatment to continue at a patient-centered and sensitive-to-individual-needs level while staying grounded in evidence-based practices.

2.1.2 The Technical Context

Increased application of computer systems in healthcare has radically redesigned clinical workflows, enabling better documentation, effective patient management, and novel opportunities for research. The use of Electronic Health Records (EHRs), computerized imaging systems, and specialty applications in many different forms of medicine is the norm in the majority of healthcare facilities. These applications have the potential for compressing the interval for the collection of information, for improved communications by clinicians, and for the accumulation of an integrated repository of knowledge that can be mined for use in both therapy and research.

However, in the midst of all these innovations, the computer systems of healthcare still have many challenges. One big challenge is one of integration with the clinical workflow: software packages are not infrequently created without much thought about the realities of the working clinician, such that they are clumsy and discourage use at a day-to-day level. A related challenge is one of usability: an inflexible interface and unintuitive design will cause a work habit to be imposed upon by the software instead of the other way around, and will foster frustration and inhibit use. Thirdly, a failure in interoperability of various tools causes fragmentation of information, duplication, and inconsistencies across systems.

In the Turin Dental School, the above-mentioned concerns are especially evident in the periodontal patient management. At the present time, there is no centralized software system that collates all the clinician-related information.

Various kinds of information are stored and collated in various locations and formats:

- The Turin University Periodontal Chart (TUPC) is manually prepared and stored as static files in personal or study computers.
- The radiographs are saved in the computer in the dental school.
- Images are frequently stored on personal devices, beyond institutional management.

- Questionnaires and case notes are handled separately from other records.

This kind of fragmentation leads to the vexing reality that the relevant patient information does, in fact, exist but is scattered across various platforms and formats in a disjointed manner. The clinicians and the students then have difficulty in retrieving the information in a timely manner, in having the records in a consistently similar format, and in utilizing the patient information in the care planning or in scholarship.

The absence of a common system, therefore, is believed to constitute at the same time a methodological shortcoming for clinical practice and a potential loss for research, whose systematic, centralized, and reusable datasets would probably hugely improve the research in periodontal diseases.

2.1.3 Problem Definition and Thesis Objective

Although there is also structured documentation available, like the Turin University Periodontal Chart (TUPC), the present-day clinical procedure of periodontal patients at the University of Turin Dental School encompasses various limitations. As mentioned previously, the information concerning the patients is dispersed among various devices and document forms: the TUPC is stored as a static file in local PCs, the radiographs in the local systems of the dental school, and the photos in personal devices. The diffusion renders information integration more complex, causes errors and omissions more probable, and renders the retrieval of information more time-consuming.

Furthermore, the TUPC as such is populated manually. The process is laborious, time-consuming, and prone to transcription errors during the act of collating data from questionnaires, clinical measurements, and imaging. Clinicians and postgraduates therefore face difficulties in terms of keeping themselves up-to-date, keeping the information comprehensive, and easily shareable with peers and supervisors.

Research-wise, the current system prevents the systematic aggregation of large-scale, structured data that would be available to be used in clinical investigations in periodontitis. Since there is no centralized, standardized system, information that is valuable is underutilized and impossible to analyze in the case of longitudinal or multiple-patient research.

Thesis Objective

The objective of this thesis is to contribute to the design of a digital system that would be able to support the organized collection, integration, and administration of periodontal patients' clinical data. The conceived platform should:

- Establish the digital compilation of the TUPC and of supplementary documents.
- Integrate various sources of clinical information, such as radiographs, photos, and questionnaires, in an overall system.
- Enhance usability and data-entry velocity of both clinicians and learners.
- Ensure data quality, consistency, and availability across clinical discussions and therapy planning.
- Create the foundation for the systematic retrieval of standardised sets of data that become available in aid of periodontological research protocol.

By meeting the objectives, the project will deliver the Dental School system that not only maximizes information quality and accessibility in research protocol, but also facilitates routine clinical practice.

2.2 Theoretical Background

To put into perspective the research undertaken for this thesis and to provide the reader with the background necessary to follow the design choices laid out in Chapter 3, this section introduces the major theoretical foundations and best practices guiding the development of healthcare-oriented digital systems. In particular, it focuses on the methodological approaches and techniques that are usually adopted when dealing with projects in the healthcare sector: process modeling notations such as UML, the basics of requirements engineering, human–computer interaction problems in the medical context, and finally the general software development process for medical software. Together, these elements create a structured framework that ensures safety, usability, and consistency with clinical processes.

2.2.1 Process Modeling

Process modeling is often an essential preliminary step in the development of medical device software. It lets us represent a provided process using different tools, normally of a graphical type. Its primary focus is normally the identification of the requirements, but it provides a set of additional applications, including the generation of the indicators, patient journey assessment, and service optimization.

Multiple types of diagrams can be used, and the practice of the field has become quite standardized. Varying methods can be applied to different aspects; three of them will be examined in detail. And they are exactly those applied in practice for this project. Those methods can be aided by specific software that provides the basic elements, while for others, such as when using PowerPoint, one needs to build these elements manually before entering the modeling. For certain situations, researchers have put forward methodologies based on a set of specifically defined diagrams.

The objectives that can be achieved through process modeling include:

- Documenting processes, describing and formalizing them to identify potential issues
- Pointing out weaknesses in order to improve the process
- Assessing improvements in the processes themselves
- As a communication device: the graphical representation of a process facilitates discussion
- Assisting in automating procedures
- Explain processes to stakeholders and achieve agreement (e.g., by showing how software integrates within the process)
- Facilitating the onboarding of new staff
- Compliance with accrediting standards and with regulatory requirements, particularly regarding functionality (as in technical spec)

While drawing a diagram, one must make clear the graphical elements constituting it. It is a critical step, particularly in an assessment situation. I present three examples of diagrams below, which are the ones used in the project.

Synopsis Diagram does not describe the process's activities, but the environment in which it takes place. It brings out the actors, the event responsible for triggering the process, the results (which are normally several), and the data (input and output).

In describing different activities and hence the whole process, the Workflow Diagram, which is based on Petri nets, is employed. They are also utilized for the simulation of processes and are another type of modeling. But the primary limit of the tool is in its horizontal growth, rendering it not very efficient for processes having a huge number of different activities.

The Swim Lane Activity Diagram was specifically developed to overcome exactly such a difficulty. It preserves the temporal chronology of the activity with vertical time representation, and it emphatically places stress on the accountable actor for each activity: each of the columns represents one or several actors. The Workflow Diagram is typically employed in practice for a general representation of the process, and the Swim Lane Diagram for a deeper perspective.

Next, the three types of diagram tools will be presented. [26] [27]

Synopsis Diagram

In this diagram, the process is represented by a central ellipse, inside which an indicative name of the process is placed. The next step is to add the actors involved in the process. At this stage, if we intend to design a software system, it is included among the actors (unlike what is done later in the specification analysis).

In many cases, a double representation is made: the first without the software we aim to develop, and the second with the software included. In practice, however, a single representation with the software is often used, either because its intended role is already well defined or because the description is more accurate if the software is already in use.

The results of the process are then inserted (often more than one).

Then the data is considered. Input data refers to the data already available within the organization. Data brought by the patient are generally not included (as the patient is usually considered external to the organization), unless they are uploaded into the organization's database before the visit or procedure. In that case, the patient effectively becomes part of the organization.

Example: if a patient brings a CT scan performed in another clinic, that information is not considered input data; instead, it is treated as output. From an informatics perspective, what matters is whether the data are stored in the organization's databases or not. The "organization" can be an entire hospital, the national health system, a specific department, or a nursing home—depending on the scope of analysis. It is never defined solely by the group of people providing the service.

Output data refers to all information entered into the database during the process and retained after its completion.

A common mistake is to incorrectly classify the medical record as input data. In fact, the medical record belongs to the physician (either inpatient or outpatient), while the nursing record is compiled by the nurse and contains all care-related activities. The medical record is a collection of documents, such as:

- Patient registry: contains standardized demographic data that defines the patient. These can be updated by replacing older information (e.g., change of residence).
- Clinical diary: a set of dated and timed notes written in natural language by physicians or nurses.
- Therapy record: includes prescriptions (drug, dosage, schedule) and administered treatments, confirmed by nurses. In inpatient settings, therapy is updated daily; in outpatient care, at each visit. Changes never overwrite the previous record, as maintaining a history of administrations is essential for both legal and professional reasons.
- Medical history (anamnesis): the most difficult part to digitize, due to the sheer amount of data. It may include remote history (a structured overview of the patient's past health) and recent history or symptoms (the patient's current condition, which may vary over time).
- Laboratory tests

The medical record can only be included among the outputs if the specific elements used are explicitly indicated.

In general, the Synopsis Diagram is paired with other diagrams, as it does not provide enough detail on its own. [26]

Workflow Diagram

The Workflow Diagram describes the actions carried out during a process. It is based on Petri nets and is built from two fundamental elements: places and transitions. [28]

A place represents the state of the system.

A transition represents the activities performed within the system.

This representation highlights how a given activity leads to a change of state. Such formalism is particularly useful in certain cases for detailed analysis and for managing locations or spaces involved in the process. Importantly, a workflow must always begin with a place and end with a place (the system starts from one state and always terminates in another, possibly different, state).

There are four fundamental constructs used within Workflow Diagrams:

- Sequence – Activities are performed one after another in a linear order.
- Parallelism – Activities are carried out simultaneously or without a defined priority. Specific graphical elements are used to indicate the beginning and end of parallel execution.

  For instance, pre-admission examinations such as chest X-ray, electrocardiogram, and blood tests can be performed in parallel. However, all must be completed before the pre-anesthesiological visit, which follows them in sequence.
- Selection – A number of alternative activities are possible, but only one path is followed depending on a defined condition. The condition itself is written separately and connected to the block with a symbol or letter positioned on the left side of the rectangle.

  Selections can be nested within parallel structures and vice versa. Excessive nesting, however, is not recommended, as finer details can be represented more effectively in the Swim Lane Diagram.
- Loops (Cycles) – An activity is repeated until a certain condition is satisfied, or a condition is verified before performing the activity.

It is also possible to hierarchize activities by grouping them into a block, called a subprocess. This block begins and ends with an activity, since the corresponding places are already defined at the boundaries of the main diagram.

Another key concept in Workflow Diagrams is the use of triggers. Triggers are required to define activities that depend on:

- the intervention of a person,
- the occurrence of an external event,
- or specific timing (such as scheduled actions or alarms).

Some activities are time-dependent and take place at predefined hours. These are not directly linked to the preceding activity but are instead scheduled according to temporal constraints.

There are three main types of triggers:

- External event – e.g., receiving an email.
- Resource-based activity – e.g., staff availability at patient admission.
- Time signal – e.g., administering medication at a specific hour.

Swim Lane Activity Diagram

Similar to the Workflow Diagram, the diagram also indicates the activity flow and actions in the process. But the most distinctive feature it possesses it's the vertical configuration, structured in columns. A column stands for a certain actor or set of actors taking part in the procedure.

The placement of the columns can sometimes be critical, since certain activities may span across two columns—for example, when an actor interacts with a software system. Within the diagram, both parallel activities and selections can be represented.

Start and end symbols in Swim Lane Diagrams may vary:

- Start: an empty circle labeled Start
- End: a filled circle

In general, the choice of symbols is not crucial, as long as they are applied consistently within the diagram. [29] [30]

2.2.2 Requirement Elicitation

Medical software requirement elicitation involves the determination of functionalities and specifications to be provided by the software. It typically begins with an in-depth analysis of the processes in which the organizational and clinical use of the software is realized. Such an analysis is not only necessary in designing a new solution but also in reviewing the acquisition of an already available solution. It is typically gathered from three complementary sources: interviews, clinical pathways (PDTAs), and direct observation. While interviews and PDTAs capture the usual situations, observation is necessary in determining non-standard paths, such that the process unfolds correctly even in unusual or trouble situations. Observation in such a manner complements and details the resulting knowledge developed from the interview and pathway descriptions. [31]

After modeling processes, they need to be validated. Validation is for determining if the process representation indeed captures the real world and under what circumstances it holds. It normally requires several interviews with various stakeholders in an attempt to bring in a range of views. The activity then goes on iteratively until the whole representation is agreed upon and deemed to be a reliable one.

With confirmed diagrams, you can specifically identify the actual requirements. They include:

- End-user of the program, easily visible in the Swim Lane Diagram and in the Synopsis Diagram;
- Information processed in or data routed through the system;
- Functionalities, which are particularly evident in the Workflow Diagram.

Either a data-oriented approach or a process-oriented approach can be adopted for the elicitation of requirements. [32]

These collected requirements are then collated in a requirement report. It captures descriptions, functionalities, diagrams, and the conclusions drawn from the analysis. Importantly, such a report can also be included in the Technical File for submissions for regulations.

The software introduction inevitably modifies procedures in use, a consideration made evident when one compares Workflow and Swim Lane Diagrams. While in certain cases, informatization introduces new processes that did not previously exist, in others, it eliminates obsolete procedures no longer warranted. Common to both, however, is the necessity for the change to always bring about an improvement. A common pitfall is the introduction of rigid software that does not align with the real needs of those operating within the processes. Such software may become useless, with users refusing to adopt it, and could lead to the collection of error-prone data. For these reasons, adopting a process-based perspective is necessary for ensuring informatization actually enhances the clinical and organizational workflow.

2.2.3 Requirements Modeling

Requirements modeling is central to the software engineering approach, as it allows for a formalized abstraction of how the system should behave and interact with ultimate end users. In this project case is the last step performed. Modeling, in short, is an activity both for requirements gathering and validation against stakeholders and for checking that software design represents real-world business processes. The requirements model is above all a collection of various mutually complementary elements: use case diagrams, interface objects, control objects and activity diagrams, entity objects, and a communication diagram that sums up the whole.

The initial step in requirements modeling is to establish the Use Case Diagram. The Use Cases are the functional system behavior captured from the point of view of the system users, named actors. Actors are determined beginning from the synopsis diagram, while the chief use cases are determined by the workflow analysis. The practical approach is to save only the part of the workflow relevant to the software being developed, and exclude activities that are external to the system, for example, laboratory work that is done outside the platform. The Use Case Diagram that emerges captures the fundamental system functionalities and illustrates how actors interact with them. Some use cases are associated directly with actors, while others are without a direct actor and are also incorporated to illustrate internal system procedures. The diagram is refined afterward by adding relationships like «include» (shared common use case functionality across use cases) and «extend» (optional or conditional use case behavior), thereby giving a better idea about the extent of the system. Once the core use cases are identified, they are complemented by the representation of the various object types that constitute the system. There are the interface objects, the control objects, and the entity objects, and they each play a specific role in the modeling activity.

Interface objects are those elements that are seen by the end-user and are used by actors to interact with the system. They are the outward face of the platform and are needed to ensure usability and comprehensiveness. Interface design must be concerned with simplicity, clarity, and concordance: the navigator must be intuitive and usable even by those with limited IT skills, information must be correctly organized and meaningfully aggregated, and graphical elements (such as icons, color codes, and labels) must use conventional signs (e.g., green for confirmation, red for alert, a house icon for "Home"). Interfaces should also comply with usability conventions, risk assessment considerations, and navigational flexibility, where users are able to reach prime functionalities at various entry points. For example, invariably displaying the patient name clearly assists in the avoidance of clinical errors, while giving "Home" and "Exit" buttons assists in ease of use and session management.

Control objects demonstrate instruction flow at a high level. They are responsible for controlling the response of a system to input and for providing interfaces between data and interfaces. Control objects are best captured in activity diagrams, which show the different paths that the system and users can pursue when they perform a procedure. The activity diagrams show the most typical set of actions, the core scenario, at its center, and include alternative flows and exceptions in mind. They include decision nodes, parallel action nodes, and references to other use cases and provide for a complete mapping between user-system interactions. Each use case may therefore be mapped directly to one or more activity diagrams and provide a linkage between high-level requirements and low-level behavior.

Entity objects represent the data that the system manipulates. They embody well-structured information regarding patients, procedures, or clinical records, grouped into meaningful entities with attributes. Each entity possesses one or more attributes (e.g., patient ID, name, date of birth, clinical notes), which shall eventually represent database tables or fields. One important design choice is the determination of whether a particular dataset must be viewed as a distinct entity or as attributes within another entity. For instance, a "Patient" entity might possess an attribute for the clinical record number, yet repeated information, such as repeated hospitalization or therapeutic plans, ought to be represented as distinct entities. This avoids bloated or redundant constructs like a single "Clinical Record" object that has all information possible.

Using use cases, interfaces, controls, and entities, the final step in modeling requirements is constructing the communication diagram (also called collaboration diagram). The diagram illustrates the previously created objects and their interactions with each other, sending and receiving messages. The communication diagram pays special attention to the logical relationships: users are involved only with interfaces, to which they are linked to control objects; control objects direct the flow, calling other control objects if necessary, and interact with entity objects to retrieve, process, and save data. Direct links between entities and interfaces are not allowed, since data manipulation must always pass through a control object.

All these elements explained above, together form a complete requirements model, serving as a basis for the design and implementation stages. The use cases embody the functional requirements, the interfaces guarantee usability, the activity diagrams illustrate the control logic, entities specify the data structure, and the communication diagram amalgamates everything into a harmonious whole. This formal approach guarantees that the design for the system not only ensures technical viability but also observes the workflow in the clinical domain and the expectations of the users, eventually ensuring greater chances for successful use in practice. [33] [34] [35] [36]

Chapter 3

Analysis and Design of the Platform

In this chapter, the practical activities carried out during my thesis work are presented. In particular is highlighted the contribution I have made to the analysis of clinical workflows and transforming them into the design of a medical software platform. The chapter provides an overview of the analysis and design process, explaining the context in which the project was developed, the methodologies and tools applied, and the most important technical decisions that guided the development of the work.

The chapter starts with a presentation of the institutional context and my place in it, followed by the presentation of the objectives and scope of the project. Special focus is given to the process modeling techniques, requirement elicitation, and the proper choice of design methodologies to apply in a medical setting. The chapter continues with how these techniques were used to develop diagrams, models, and prototypes that complement each other to form the system blueprint.

Finally, the challenges and design trade-offs encountered during the work are alluded to.

3.1 Context and Role in the Institution

When I started the project in the fall of 2024, by the chance afforded by this thesis, the foundation for the system was already in place. In particular, my assistant had created an entity–relationship diagram for the key entities involved in the project and had initialized a first database system to contain the corresponding data. This provided me with a systematic starting point, but revealed the need to rationalize processes, to get precise requirements, and to move to the design of the entire system.

My own contribution to the team became defined as the process of requirement elicitation, process modeling, and system design. These activities represented the natural continuation of the preliminary work that had been carried out and required a deeper interaction with the real operational context of the Dental School.

My first step consisted of an on-visit observation at the Dental School, whereby I had the opportunity to watch dentists and students work on real patients. Alongside my assistant, I observed very closely the dynamics of the workflow, took organized notes, and posed clarifying questions to clinicians whenever necessary. This immersion in the clinical experience was essential for knowing not only the order of the operations but also the motivations and needs behind them, the documentation habits, and the relationship among the clinical personnel and the patients.

Specifically, I paid particular attention to the treatment and care of periodontal disease and the key position occupied by the *cartella parodontale* (periodontal chart) as a device for diagnosis, follow-up observation, and treatment plan. As I had not had a previous exposure to dentistry, most of my preliminary work consisted of becoming familiar with the terminology, processes, and parameters employed in the specialty. I became thoroughly familiar with the layout of the periodontal chart and the variables (like probing depth, bleeding on probing, and loss of clinical attachment) and how they connect to clinical decision-making and data handling needs.

One of the key challenges I experienced at this point was translating dentists' terminology to system requirements. Clinical practices and terminology rarely translate to information systems' terminology in a direct manner, and thus the consultation with clinicians became necessary to fill the gap.

The alignment of the activities brought my effort to the intersection point of the clinical experience of the Dental School and the technological advance of the information system. My work then played the role of the bridge: from the observation and understanding of real-world workflows, to the formal description of them, and then to the development of a system capable of sufficiently supporting the activities of education, research, and patient care.

This introductory step not only gave me the proper knowledge on the topic at hand but also served as the groundwork for the remainder of the project phases found in subsequent sections, and covers the phases of requirement analysis, process modeling, and system design in greater detail.

3.2 Project Description

It is by no means a trivial task to create a digital system for periodontal record management. While the initial aims are straightforward enough, computerizing the *cartella parodontale* and structuring the related data, arriving at a technically satisfactory but clinically meaningful solution requires a systematic and careful process. The project, therefore, focused on taking the high-level clinical requirements and transforming them into elaborate specifications, and from there into a formal design that could form the foundation for further development.

One of the main challenges was how to meet the requirement for the solution offered to be faithful to the real workflows observed in the Dental School while also being sensitive to technical constraints and usability concerns. Periodontal data involve a high number of fine-grained parameters, each of specific clinical significance, and these had to be captured in a way that preserved accuracy without causing unnecessary complexity for end users.

Equally important was the principle that the system should not force clinicians to change their working habits to fit into rigid digital templates. Rather, the design should offer flexibility, accommodating their day-to-day activities and simplifying their work so that the system would work for the clinicians' advantage rather than the other way around. This called for particular emphasis on usability and on the intuitive presentation of complex clinical information in a manner that would enable dentists to benefit from the tool without perceiving it as an obstacle or barrier.

My task was to bridge these worlds: to observe and understand the daily work of dentists, to translate it into formalized process models, and to develop an information system that could eventually find its place in the broader academic and clinical environment of the institution. This description of the project, therefore, focuses not only on the objectives of the work but also on the methodological challenges faced in attempting to establish congruence between medical practice, usability, and system design.

3.2.1 Project Technologies, Tools, and Methodologies Used

To support the design and development of the project, a series of tools and techniques were used to ensure good documentation, visualization, and collaboration throughout the process.

Collaboration and Data Management
OneDrive was used as the central storage and share point for the project documents. This provided easy collaboration between me and my assistant, where all the materials were accessible, versioned, and kept up-to-date in a centralized and secure repository.

Modeling and Documentation
Unified Modeling Language (UML) was utilized to formally define the system's structure and behavior. In particular, use-case diagrams, activity diagrams, and swimlane diagrams were created to detail functionality, workflows, and interactions between systems. This intense use of graphical components is key to closing the technical and non-technical divide and providing an easy representation to visualize information in a clear and accessible way.

Draw.io was the tool chosen to create the multiple kinds of diagrams needed, like system synopses, workflows, and swimlane diagrams. Its accessibility and integration with cloud storage made it possible to do rapid development and efficient process visualization.

Requirements Gathering and Specification
PowerPoint was used to organize and develop the requirements and specification lists, providing a format that is suitable for a presentation. This allowed for requirements to be presented in a well-formatted and easily visible form, which will be particularly useful when communicating with clinicians and other stakeholders. The presentation-based organization helped make it easier to gather feedback and organize information.

Interface Design and Prototyping
I decided to use Figma to design user interface prototypes. Its design system, which is based on components and collaborative nature, allowed for easy creation of uniform interactive mockups that could be shared and edited readily. Allowing clinicians tangible visual inputs of the proposed interfaces, Figma facilitated early validation and feedback, such that the final design met users' needs and expectations.

3.3 Design and Development Approach

3.3.1 Design Process

As already mentioned in earlier sections, I officially joined the project in autumn 2024. Until my contribution, my assistant had already reached out to the dentistry team in an effort to deliver a first digital product: an Excel template for periodontal charting. This spreadsheet made it easier for clinicians to input their measurements and automatically work out important variables, and produce a simple visualization of important information regarding every tooth. Even though it was a bit rough and ready, the first solution was a useful answer to a real need and established a precursor to the more organized software product that was in mind.

As previously introduced, the first direct work I undertook in the project was accompanying my assistant on an on-site visit to the Dental School on 5th November 2024. This time, I was directly observing a full visit to a patient, observing step by step how clinicians performed the consultation and recorded data. This was a crucial experience, as it enabled me not only to get acquainted with their clinical routine but also to make important notes and pose clarification questions to the team. This direct communication with the end-users allowed a much clearer understanding of their needs and expectations than could be gathered from their requirements by themselves. Initially, I was tasked with work on exploring technologies and possible solutions so as to develop a software platform that could collect and sort the vast clinical data required by the experimental protocol in question. But it was made clear in the early stages that it was essential first to follow the related best practices involved in designing medical systems. These are ones that are centered on a concern with safety, usability, and integration of information tools into existing workflow without disruption. Thus, my work was diverted in the course of process modeling work, which would then lay the foundation for the next stages of system design and development.

This redesign was the starting point in an iteration-based design process, whereby observation, analysis, and modeling played a critical role in ensuring that the end product would both technologically work and comfortably fit into clinicians' everyday practice.

As mentioned in the above paragraphs, once we decided to postpone implementation in favor of a thoughtful modeling and design phase, my first well-defined activity was process modeling. This phase was significant as it laid down the conceptual building blocks of the final system and provided the means by which we could capture the complexity of clinical workflows in a definitive and formal fashion.

The modeling activity was performed following the Unified Modeling Language (UML)'s best practices, which provide a standardized and broad collection of notations in order to describe processes, data flows, and interactions. The application of UML was particularly important in this case for two reasons: first, it ensured accuracy and simplicity in workflow representation, limiting the risks of ambiguities; second, it allowed a common language that was effortlessly interpretable by both technical actors and clinical stakeholders.

The initial activity was the definition of a generic workflow on a high level, aimed at giving an overall presentation of the entire clinical process, ranging from the time a patient is taken in charge through the actual implementation of the therapeutic plan. This bird's-eye view was intended to have the role of framing all follow-up analyses and preventing any fundamental phase from being overlooked.

From this initial workflow, we were thus in a position to distinguish and extract the key sub-processes, which were structured as below:

- P1: First screening visit
- P2: Periodontal probing visit
- P3: Radiographic exam
- P4: Completing the TUPC (activity done by either the student or clinician without the patient)
- P5: Case discussion among clinicians and professors, with therapeutic plan definition
- P6: Implementing the therapeutic plan

For each of these sub-processes, a Synopsis diagram was produced using draw.io. These diagrams were necessary in offering a brief and instantly understandable representation of the process by clearly highlighting:

- the actors involved;
- the trigger event which initiates the process;
- the input and output data;
- the final state resulting from the process resolution.

This step was especially useful in clearly exhibiting the processes in a form understandable by non-technical audiences, since it made it easily possible to immediately perceive the essential features without needing to specify in detail the general workflow.

After the Synopsis diagrams had been completed, we incorporated a Swimlane diagram or a Workflow diagram in each sub-process, one or the other according to the complexity of the individual process itself. These graphs showed the representation of the sequences and conditions of activities performed, the roles responsible for each activity, and the decisions that directed the trajectory of the process. This two-level approach, Synopsis on a larger level and Swimlane/Workflow on a smaller level, aided us in achieving simplicity in communication and the rigor needed in design.

The entire modeling phase was not an easy or linear process. It required repeated iterations, careful review, and several rounds of confrontation with my assistant. Thanks to a continuous cycle of feedback and refinement, it was possible to progressively improve the accuracy and completeness of the diagrams, reaching a level of detail that could be considered both sufficiently descriptive and reliable for subsequent design. This phase was a decisive point in the work: by assembling a well-defined and systematic picture of the clinical procedures, it provided the basic conditions for the design phase of the system. Once we verified this activity of modeling, we could then proceed to discuss the next steps, such as the definition of the system requirements and the investigation into design options for the software architecture.

After the clinical processes had been adequately modeled and verified, requirement elicitation was performed. This activity was characterized by the systematic collection, analysis, and formalization of the functional and non-functional requirements that the system would have to meet in order to support clinicians in their everyday practice. Requirement elicitation was the bridge between process modeling conducted in the previous phase and system design that would be achieved later.

In order to structure and present these needs in a good manner, I adopted a pragmatic approach. A preliminary list of requirements and needs was compiled, paying attention to user-related functionalities, system behavior, data processing, and usability. To make this material immediately accessible to all parties involved, I used PowerPoint as a medium: by breaking down requirements into tidy slides, the information was clearer, more visual, and more suitable for discussion in meetings. This choice is effective, especially with non-technical stakeholders, such as clinicians, as they can connect with the material more intuitively.

At the same time that I produced this list of requirements, I produced the initial Use Case Diagram, which was compiled using draw.io. Use Case Diagrams in UML specify the functional goals of the system from the perspective of external actors and the possible interactions the actors may have with the system. The original diagram provided a stylized image of the major expected functionalities, serving as a conceptual reference to which later refinements would refer. However, as the design process continued and greater specificity in requirements was developed, the diagram continued to be refined and added to. The final version of the Use Case Diagram was quite different from the initial one, illustrating the ongoing development in the granularity and completeness of the system design.

Subsequently, I moved on to the interface design phase, which I developed in close relationship with Activity Diagrams. The interfaces are the point of direct contact that the users have with the system and, therefore, play a significant role in determining usability and adherence to clinical workflow. I employed Figma for this task, an online collaborative graphical design tool for mocking up and prototyping. Having no experience with Figma prior to this task, its component-based methodology and intuitive interface made it easy for me to learn how to use what was needed. The learning curve involved longer periods and work, but the output was a set of draft mockups of the interface that laid out the system's anticipated behavior. It is critical to note that the mockups were not final designs but rather conceptual drafts to depict functionalities and interactions, an iterative map of the final product.

Concurrently, I created Activity Diagrams (drawn using draw.io) that detailed the behavior, interactions, and relationships between the interfaces. The diagrams described, for example, actions that one would perform on a specific interface, such as clicking a button, entering something, or selecting an option, and how these actions would lead one to other interfaces or system feedback. So, interfaces and Activity Diagrams were directly interdependent: altering one would usually mean alterations to the other, keeping both visual shape and logical flow consistent. Use Case Diagram was also continually updated in tandem with these activities, as newly discovered functionalities or interactions discovered during the interface/activity model stage needed to be accounted for in the overall functional map. This gave a triangular feedback loop among activities, interfaces, and use cases, each influencing and redefining the others.

Once this phase was completed to a satisfactory level of maturity, I then formalized the definition of entity objects. Entity objects are the main conceptual items that make up the system — e.g., patients, clinicians, examinations, radiographs, or therapeutic plans — and their attributes and relationships. This modeling activity was critical to the development of the data structure of the system because entities refer to the core objects on which operations and storage are founded. By making explicit their properties and interactions, I laid the groundwork for an eventual database schema and clarified the data model that would accommodate the activities of the system.

Finally, the modeling activity was completed with the development of the Communication Diagram. In UML, Communication Diagrams (previously named Collaboration Diagrams) concentrate on the interactions and exchanges between objects at run time. For me, the diagram was used to show the interactions between users, entity objects, interfaces, and control objects (which corresponded to the described activities in the Activity Diagrams). This representation was particularly useful to visualize how the different components of the system interact with each other, ensuring coherence between the static structure (interfaces, entities) and the dynamic behavior (activities, user actions).

Together, these phases, requirement elicitation, use case modeling, interface and activity design, entity definition, and communication diagram creation, were a step-by-step elaboration of the system design. From high-level requirements, the process evolved in cycles of iteration into progressively more concrete and detailed representations, yet always in harmony with the clinical workflow and with the guiding principle that the system be responsive to the clinicians' needs, not rigid about limiting their work.

3.3.2 Design Technicalities

In this section, the practical and technical details undertaken during the analysis and design phase will be outlined. Starting from process modeling and progressing to the system design, the main diagrams and the decisions made will be highlighted and discussed.

Process Modeling Details

The first step in process modeling was the definition of the various processes involved. Once these had been identified, I developed a main Workflow Diagram that represented the overall structure of the system and embedded the different sub-processes within it. I named this high-level representation Process Zero (P0).

After defining this general framework, the next step was to create a Synopsis Diagram for each sub-process. For every sub-process, I also produced a detailed

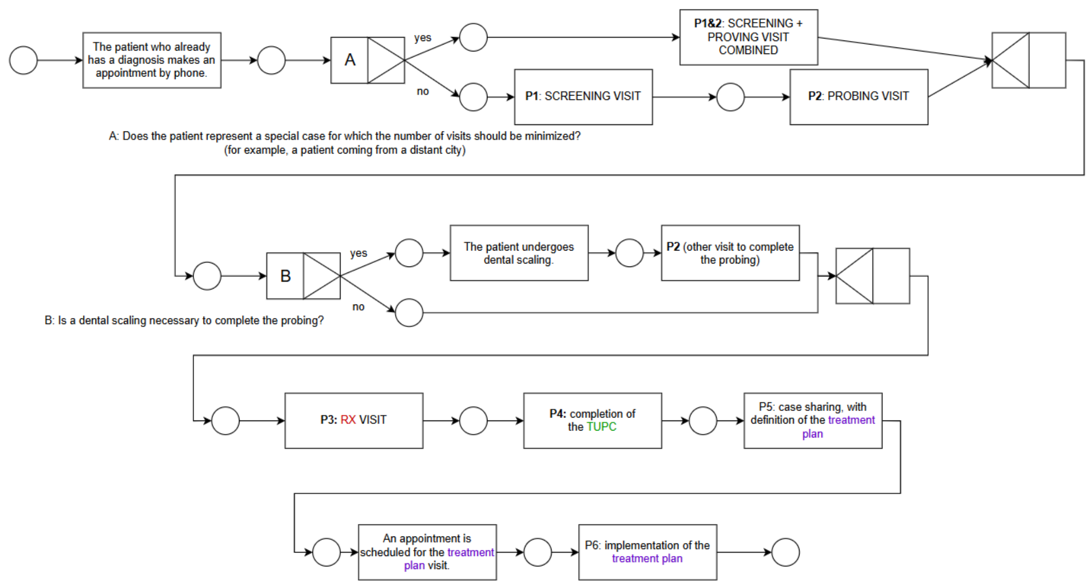

Figure 3.1: Workflow Diagram of Process P0

activity flow representation, choosing between a Workflow Diagram or a Swimlane Activity Diagram depending on the complexity and the number of actors involved.

During the patient visit I attended on-site, I encountered a particular case: the patient had traveled from a distant location, and therefore both the preliminary screening and the periodontal probing were performed during the same appointment. In practice, this meant that two normally distinct processes, which are usually separated in time, were merged into one. I defined the screening visit as P1 and the probing visit as P2. Since I observed them carried out together, I also created and modeled the combined process, which I called P1&2.

Given the importance and complexity of this combined workflow, I produced both a Synopsis Diagram and a Swimlane Activity Diagram. These representations highlighted the interactions between multiple actors and the chronological sequence of activities. I also introduced a color-coded convention for the data represented in the synopsis diagrams for this and all of the processes. This is done in order to achieve better readability and ensure that the flow of information between input and output is immediately clear.

- Patient records = light gray
- Periodontal chart = dark gray
- Notes = orange

- TUPC = green
- Photographs = ochre yellow
- Therapeutic plan = purple
- PowerPoint presentations = blue
- Radiographs = red

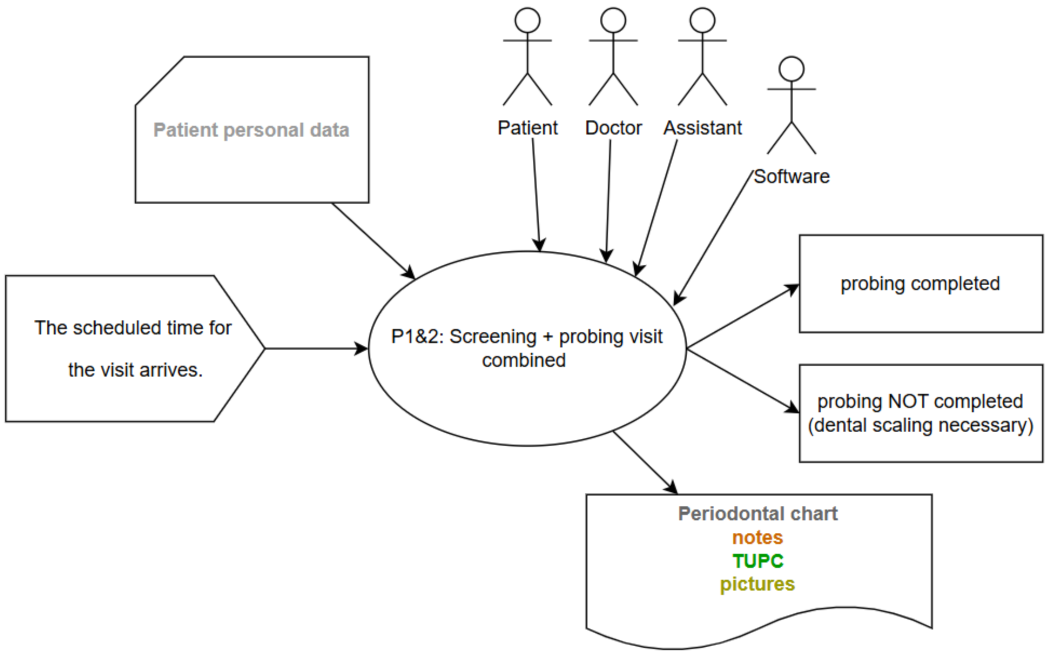

Figure 3.2: Synopsis Diagram of Process P1&2

The Swimlane Activity Diagram of P1&2 was structured into four columns, each corresponding to one of the actors: the patient, the doctor, the software, and the assistant. The process flow included multiple conditions and decision points, as well as a parallel branch representing activities carried out concurrently. This detailed mapping allowed me to capture both the sequential logic and the real-world complexity of interactions that occur during a clinical visit.

Since periodontal probing is a highly complex activity, it was also modeled with its own Workflow Diagram to accurately capture its cyclical nature. The procedure involves repeated actions and measurements for each tooth, typically across three sites per tooth, on both the vestibular and the palatal/lingual surfaces. I named

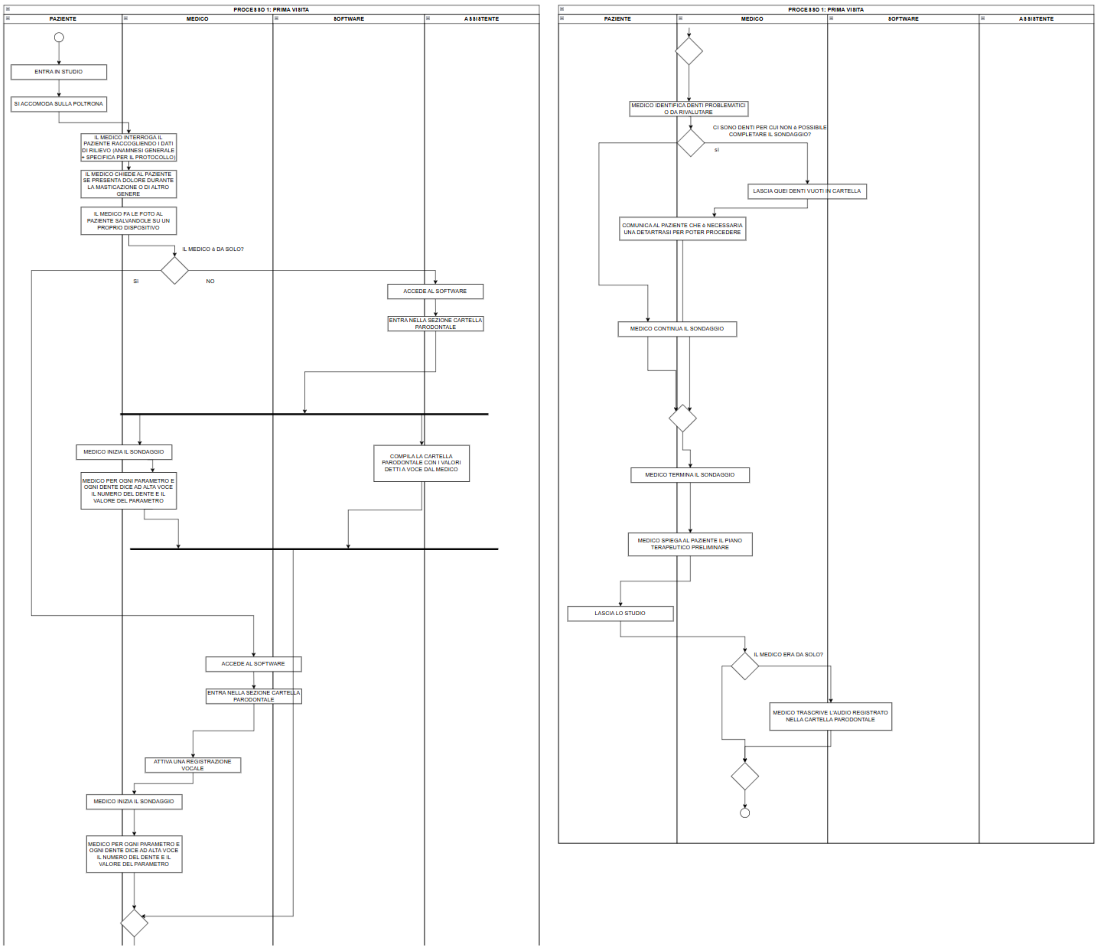

Figure 3.3: Swimlane Activity Diagram of Process P1&2 (Italian Language)

this process P1S with the S standing for *Sondaggio* (probing).

For the other, less complex and more straightforward sub-processes, only the Synopsis Diagrams were realized.

These diagrams were carefully discussed with my assistant and refined multiple times before reaching their final form.

Use Case Diagram and Requirement Elicitation details

Once the process modeling phase was concluded, the next step I was tasked to complete was producing the first Use Case Diagram along with the list of Requirements.

The first version of the Use Case Diagram was visualized as a rough first draft,

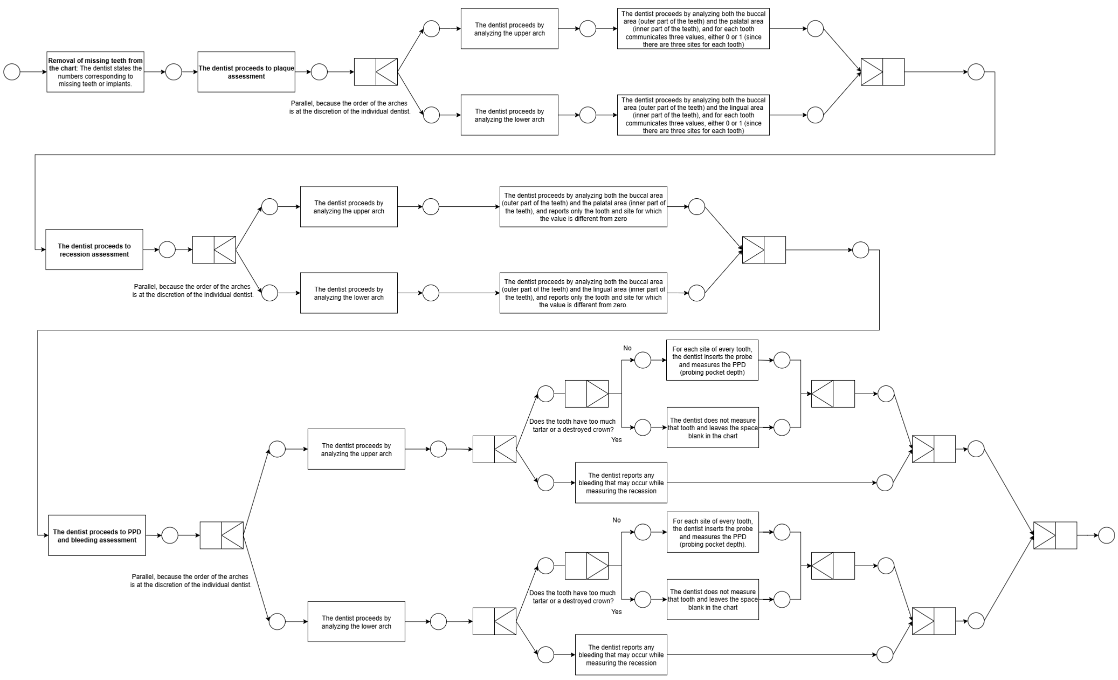

Figure 3.4: Workflow Diagram of process P1S

one which could capture the basic interaction with the system and still be subject to adjustment within the following stages of interface development and preparation of the activity diagrams. During this stage, one actor, the primary user of the system, i.e., the Dentist (or, for some situations, the Assistant under supervision), was identified.

These first use cases were tied directly to the actor and the core functionalities created for the platform. Some were listed as single actions, and some linked other use cases together through inclusion relationships, where the logical dependents for tasks were taken into consideration. As an example, most use cases included viewing patient details and the patient list. This first draft was completely altered during development.

This first diagram wasn't meant to be complete but only to establish the conceptual foundation for the refinements that followed. It served as a mental model for aligning the software design with the conceptualized clinical workflow established through the process diagrams. In the versions that followed, the diagram became more complete and perfected as the prototypes of the interface and the activity diagrams became more specific regarding the order of actions, the points for decision, and the user interaction.

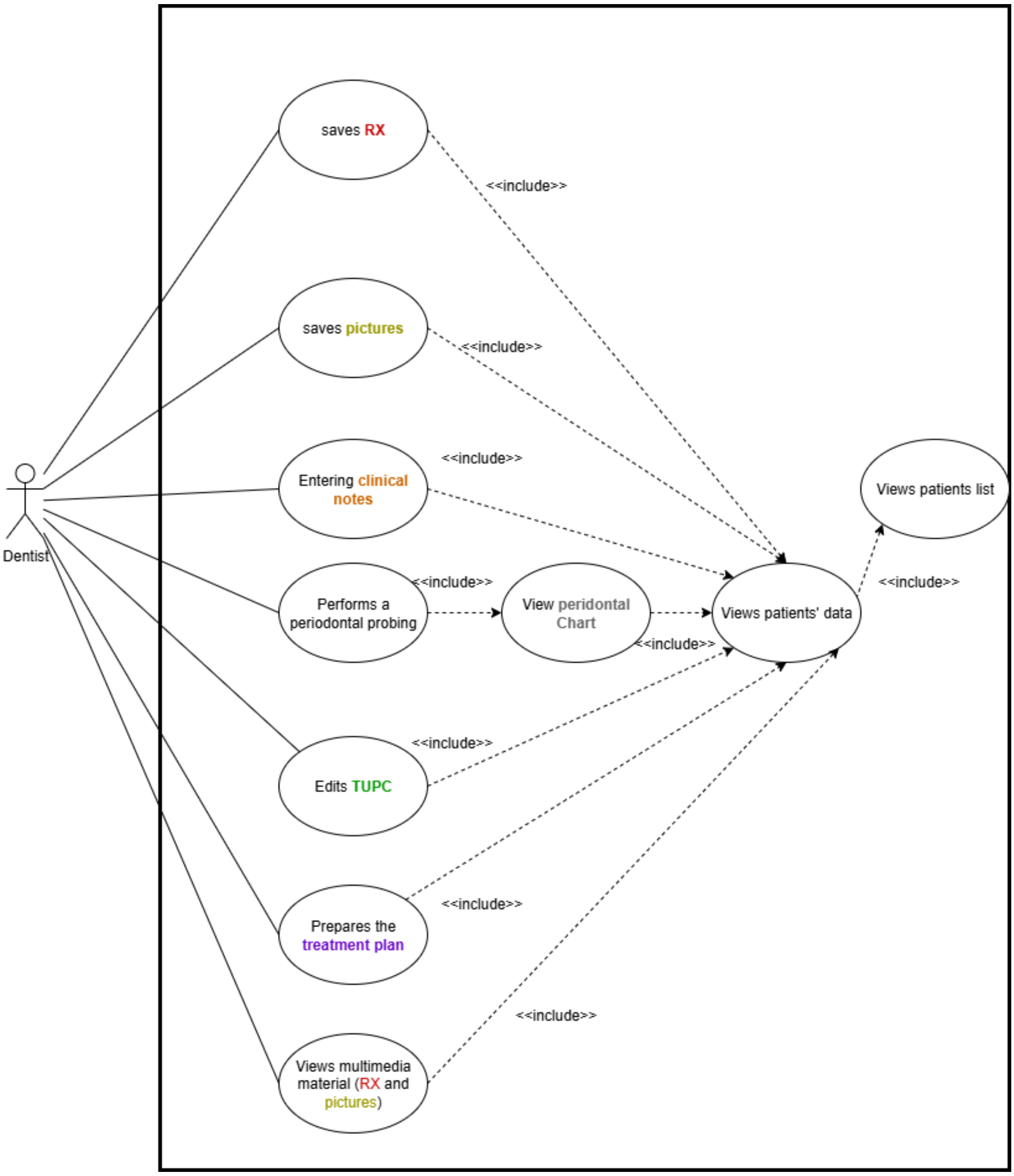

Figure 3.5: Initial Use Case Diagram

Once the initial Use Case Diagram had been created, the principal system requirements were elicited and cataloged as a PowerPoint presentation. PowerPoint was chosen because it provides an easy method of producing clear and readable summaries of the requirements that could be easily consulted and discussed with my assistant and the clinicians involved in the project. The objective was to produce the content as the starting point for a systematic validation phase, where feedback could be gathered, recommendations for change could be suggested, and consensus could be preserved over the functionalities that were going to be implemented.

However, as the subsequent chapters make clear, this phase of validation never occurred. The lack of direct communication with the clinicians thus left the prerequisites remaining at the starting documentation level, lacking the back-and-forth feedback that would have guaranteed their usefulness toward practical clinical practices.

Here, the requirements are presented.
The software must:

- Provide the possibility to log in with username and password.
- Provide a list of patients, with the ability to add, delete, and modify patient information.
- Allow the visualization of patient information once a patient has been selected.
- Allow, for each patient, the storage and consultation of multimedia material such as photographs, radiographs, and panoramic images.
- Include a section for the treatment plan for each patient.
- Include a section for the TUPC (Turin University Periodontal Chart) for each patient.
- Provide the periodontal chart for each patient, with the following functionalities:
  - Insertion, consultation, and modification of clinical values for each site of each tooth (KT, PPD, Rec, CAL, BoP, Plaque, Mobility, Furcation V, Furcation P, Type).
  - Automatic calculation of clinical indices and generation of a graph visually representing the extent of periodontitis for each tooth.
- Ensure the secure storage and backup of patient data in compliance with privacy regulations (e.g., GDPR).
- Generate reports or slides for the presentation of clinical cases, based on the stored data.

Requirements Modeling Details

The next step I undertook, according to my role, was the development of the interface prototypes and the activity diagrams. These two design artifacts are intimately connected: the interfaces are the visual layer of the system, and the activity diagrams are the control logic, explaining the behavior and reactions of the system under user input. In such a sense, the activity diagrams make clear the relationship and the transition between the different interfaces, such that user input is transformed into appropriate system reactions.

Furthermore, as the interface and activity diagrams were being constructed, the Use Case Diagram was updated incrementally. This was inevitable because an activity diagram maps one-to-one across the use cases. Formalizing the flows of the activities made increasingly clear which use cases were relevant, which were prerequisites for other use cases, and what the relations of inclusion should be.

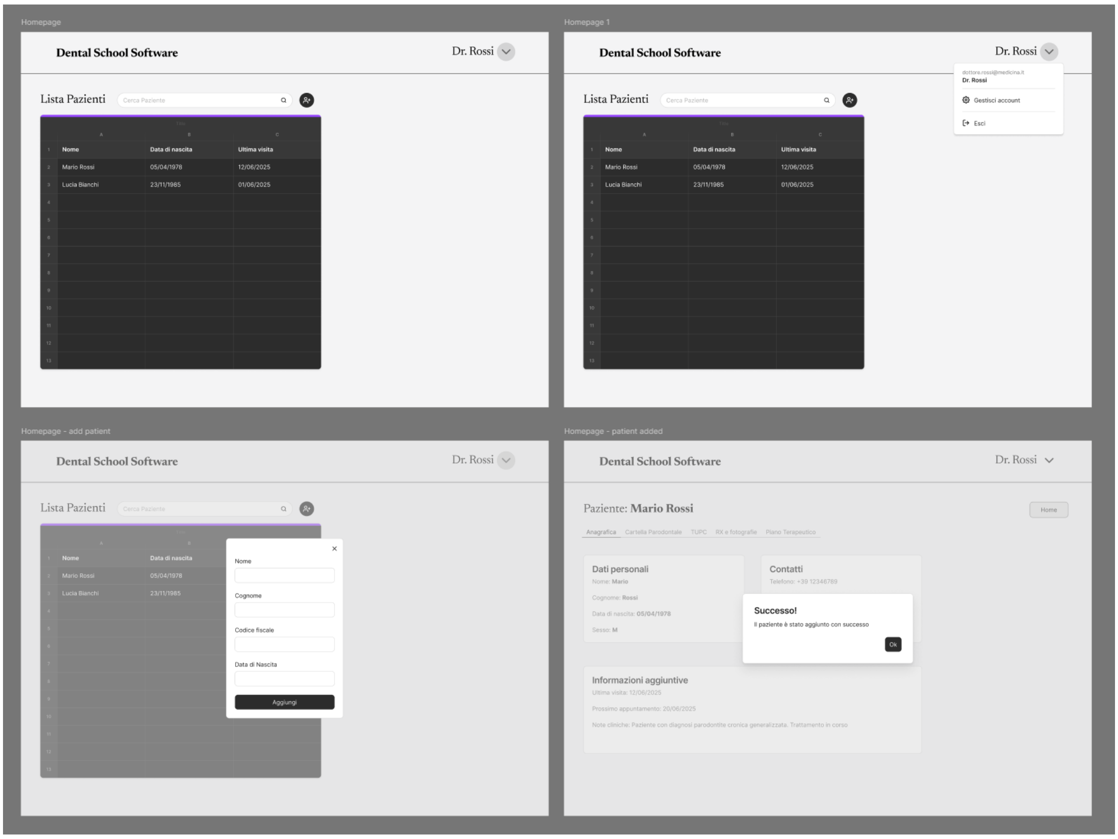

Figure 3.6: Interfaces for the Homepage

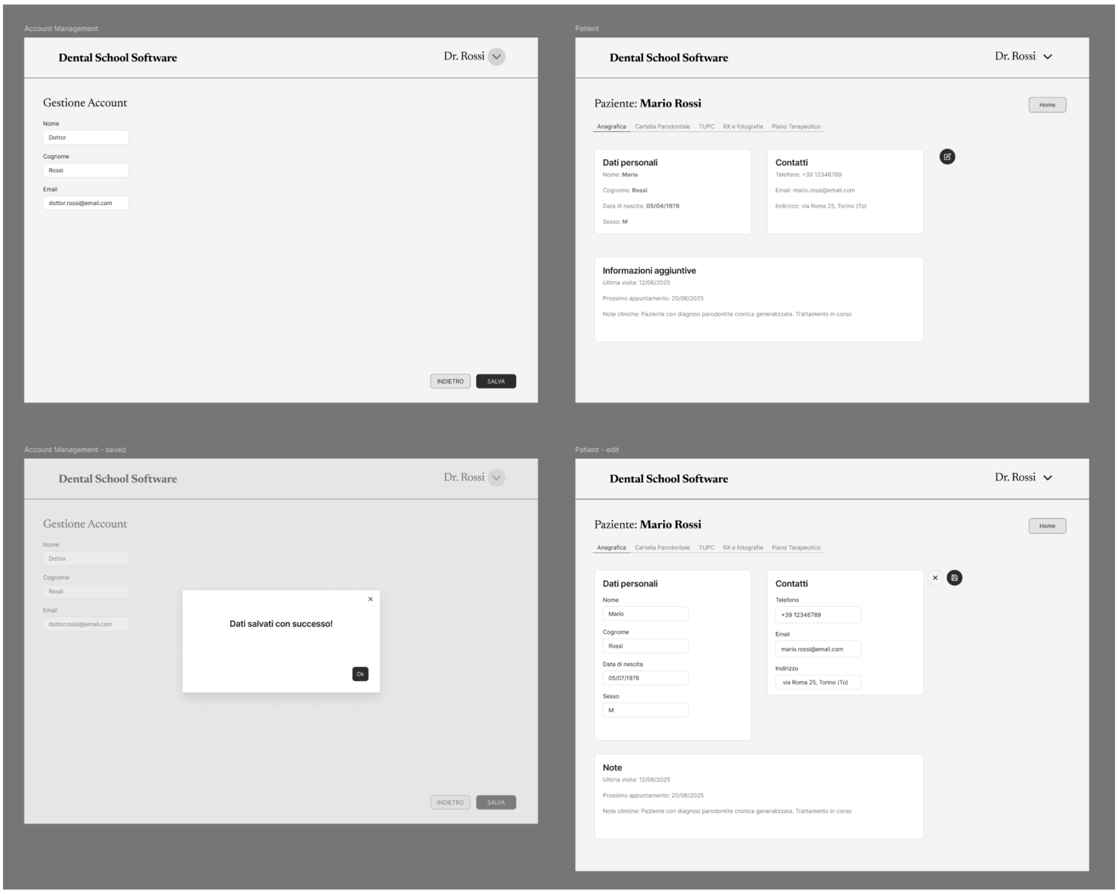

Figure 3.7: Interfaces for Account Management and Patient

In the final version of the Use Case Diagram, the only use case related directly to the actor (the Dentist/Assistant) is the use case for the "Homepage Management", and it includes the following use cases:

- Account Management
- Clinical Notes Entry
- Therapeutic Plan Drafting
- Patient Management
- The last of these, Patient Management, is itself a composite use case that includes:
- Periodontal Chart Management

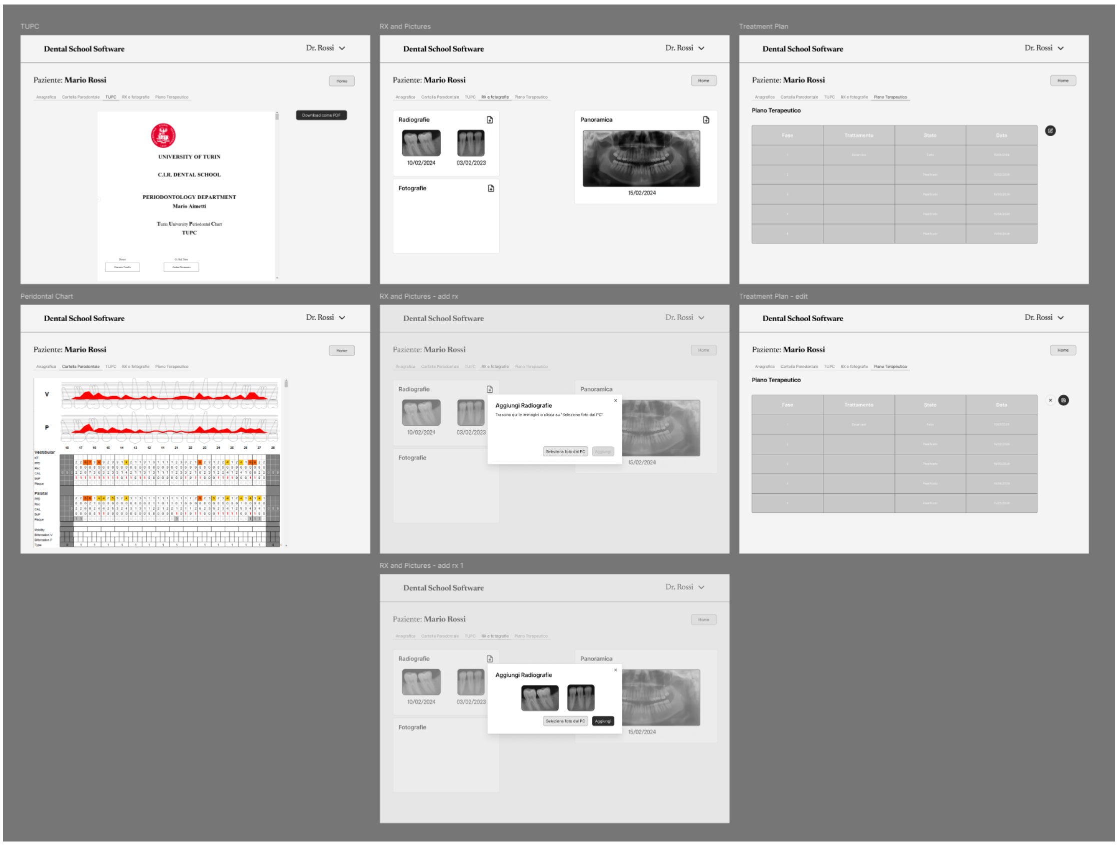

Figure 3.8: Interfaces for RX, TUPC, Peridontal Chart and Treatment Plan

- TUPC Management
- Multimedia Records Management (radiographs, photographs, etc.)

These relations and hierarchical inclusions are all clearly illustrated in the final diagram.

Arranging the use cases within this hierarchical manner became a key design decision. In setting up the top-level use case as the "Homepage Management", all interaction was thus automatically concentrated through one entry point, mirroring the clinician's real workflow within practice. This served to maintain the system as both modular and user-friendly, whilst at the same time mirroring the clinical logic of viewing patient information and therapeutic data. It enabled the following mapping of the use cases onto separate interfaces and activity diagrams, and helped make the design more understandable and suitable for future redefinition.

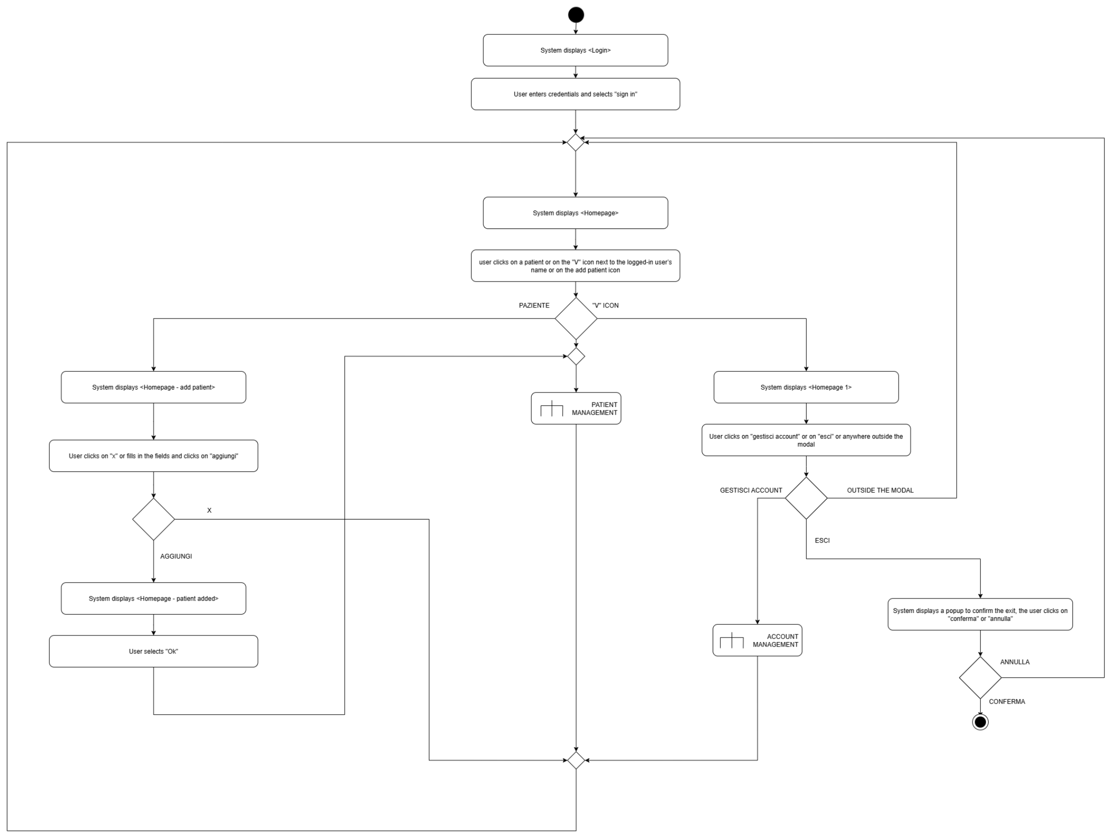

Figure 3.9: Homepage Management Activity Diagram

After completing these previous activities, the next step was the modeling of the entities. Each one of the significant entities within the system was identified and defined in terms of its attributes. Each entity was given a unique identifier as its key attribute, and one or more auxiliary identifiers that associated it with linked entities within the system. This provided for coherence within the data model and convenience in tracing relationships.

Special care was taken for the representation of the oral structures that are the core of the periodontal field. The entities for the mouth, teeth, and their respective sites had to be represented with great precision, as they serve as the foundation for storing periodontal variables. Each tooth was represented both as a whole unit and decomposed at the level of its respective sites. The decomposition was required to handle the clinical reality of periodontal probing, where each site generates autonomous data points that together end up defining the general condition of the dentition.

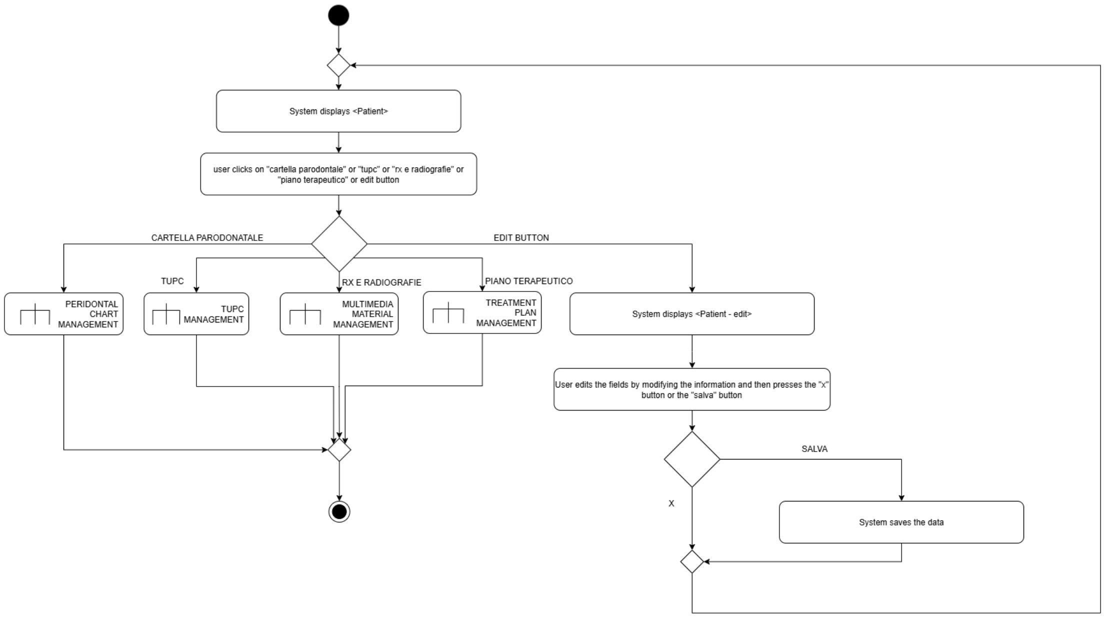

Figure 3.10: Patient Management Activity Diagram

3.3.3 Challenges Faced

The first challenge I encountered in this project was that I was immediately required to get accustomed to a totally different professional field: dentistry, and, more narrowly, periodontal practice. This was a completely new domain for me to get familiar with. This is because I come from a computer engineering background. So, at first, little was known to me of the field's specialized vocabulary, workflows, and variables. This meant making a concerted effort to close the distance between my technical and medical knowledge required for proper modeling of processes and designing a workable software solution.

The learning curve was steep. Periodontology entails a wide range of concepts, not just diagnostic techniques such as measuring probing depth, but also planning for care, recording patient data, and the use of designated forms and classification. I had to understand all of these topics and meanings in order to be able to analyze and design software that would better meet the requirements of clinical professionals.

The field visit to the dental center was essential in addressing that problem. The observation of actual procedures and flow, hearing clinicians' commentaries, and experiencing the environment directly allowed me to gather essential information otherwise not available. It was on that visit that I got to witness how theory translated to day-to-day practice, from the documentation on the periodontal chart

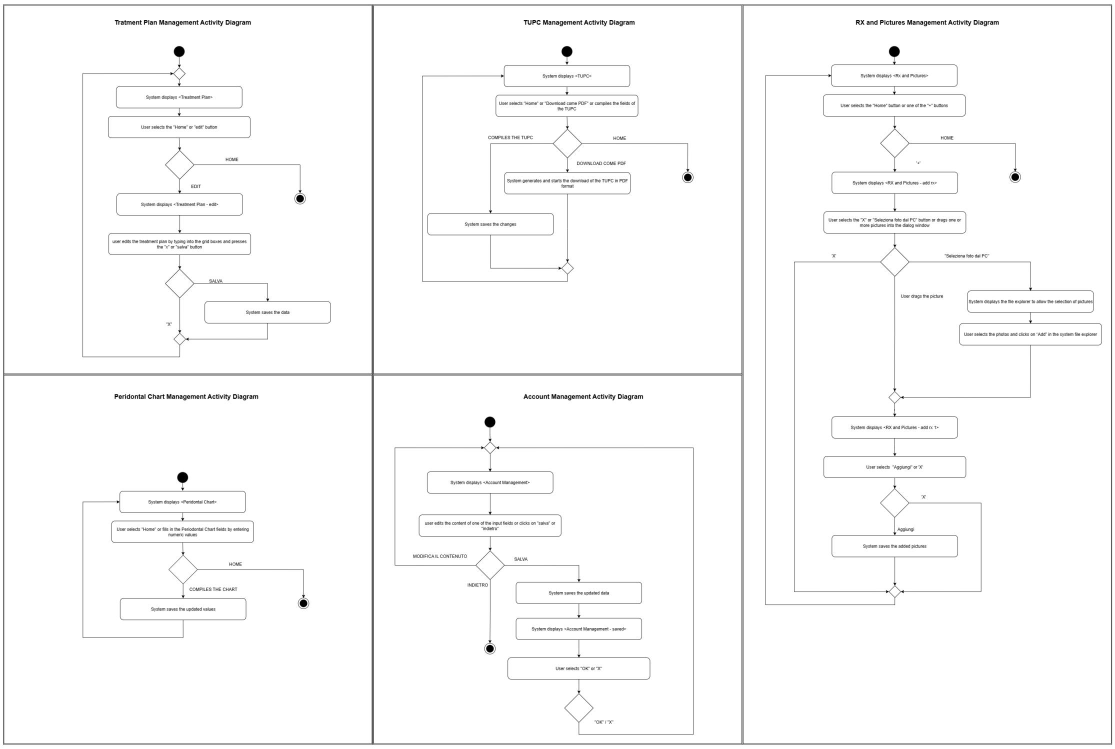

Figure 3.11: Other Activity Diagrams

to how assistants and doctors communicated their roles. To be doubly sure that nothing crucial was missed, I re-read and re-interpreted the notes gathered on this visit. The notes served as a central point for cross-reference during the design and modeling stage, such that at each stage, I could check twice that terms, variables, and procedures were understood correctly and were being correctly applied. This reflective stage was crucial due to the likelihood that misunderstandings at the requirement level would easily have created faults or inefficiencies in the system design.

Another important challenge that I encountered was expressing the periodontal probing activity in terms of workflow diagrams. Periodontal probing is a very complex and detailed clinical procedure, yet at the same time, a recursive and repeating activity that is extremely difficult to represent in a diagram without generating a proliferation of unnecessary loops and excessive visual clutter. Transforming such a process into a formal representation required a careful balance between formality and readability.

The difficulty arises out of the nature of periodontal data collection. For each one of the study variables, such as probing depth, clinical attachment level, or bleeding

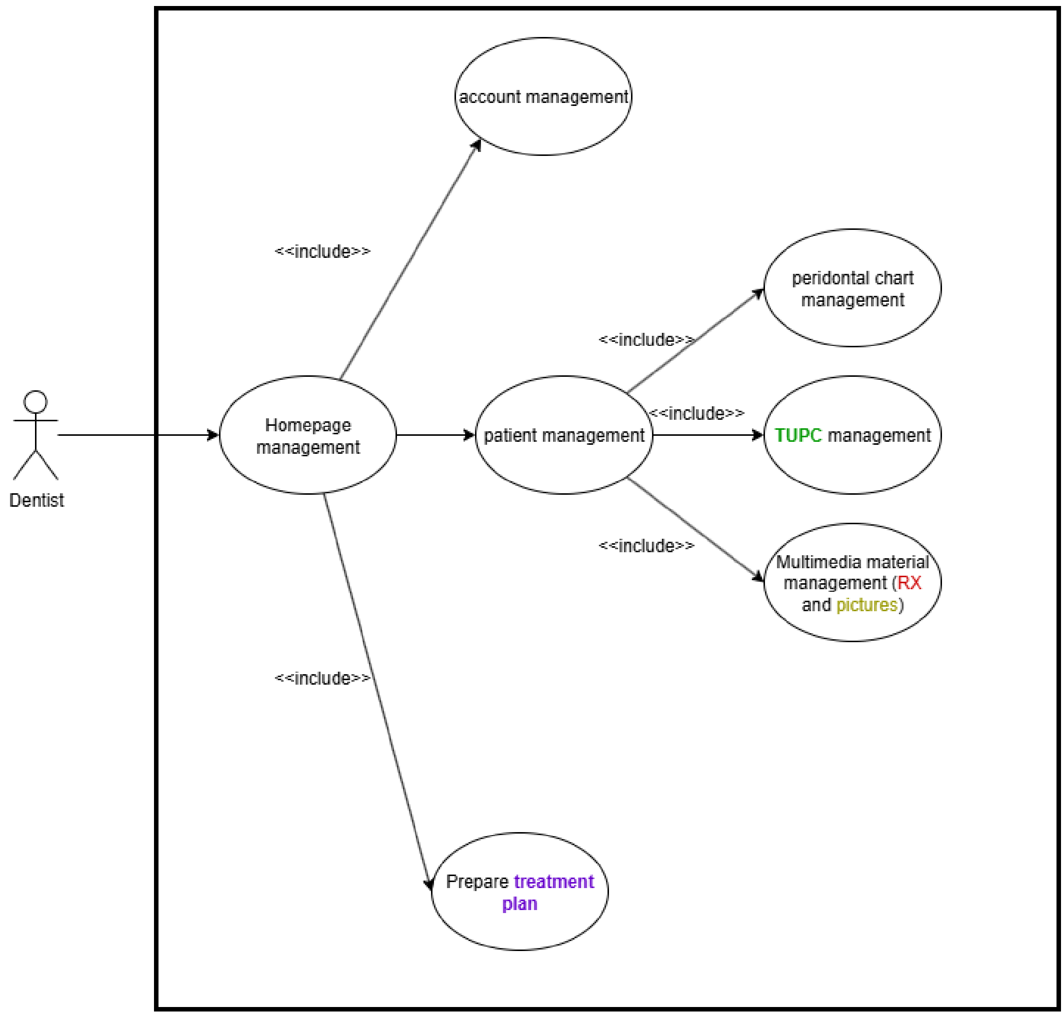

Figure 3.12: Final Use Case Diagram

on probing, the measurements must be recorded for each and every one of the teeth, and for three different sites within each one of the teeth. The measurements are on both the vestibular (outside) and the palatal/lingual (inside), according to the location within the mouth of the respective tooth. The entire procedure must also be conducted for both the upper and lower arches, thus essentially doubling the degree of repetition. The end-product is a huge number of repeated operations that make it extremely difficult to design a diagram true to the clinical experience without descending into confusion extremely difficult.

The decision on how best to model this flow was thus anything but simple. On

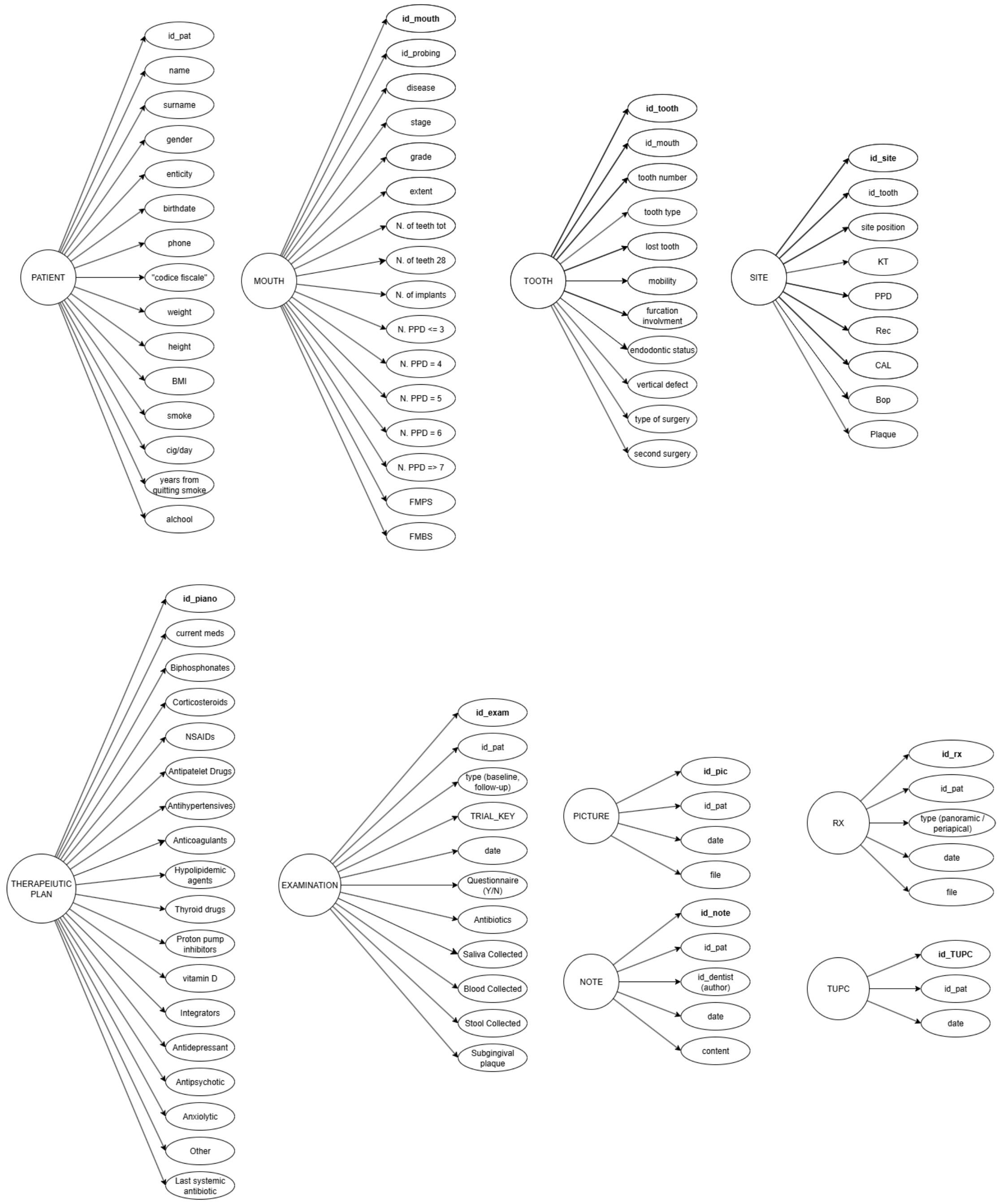

Figure 3.13: Main Entities

the one hand, there was the need to be faithful to the clinical procedure, without simplifying too much the cyclical and repeated nature of the measurements. On the other hand, the diagram should be kept at a level that is easily understandable, without flooding a large number of nested loops and repeated activities, and branches. The compromise that was finally adopted balanced the use of loops and parallel activities and tried to find a balance between completeness and clarity.

Parallel activities were added to illustrate the freedom that is afforded to the clinician while carrying out the probing action. In reality, the dentist is under no obligation to start measurements from one particular arch: they may choose at will to begin with the upper or lower one, according to inclination or patient situation. This freedom is required to be represented in the diagram, demonstrating alternate routes that end up being the same in terms of the complete probing result. Therefore, the end workflow diagram incorporated parallel sections that branched and re-united, and useless loops were avoided by combining the recursive activities into a single larger one.

This modeling experience taught me the importance of abstraction in modeling extremely highly repetitive medical procedures. Instead of modeling each and every iteration in extreme detail, one was constrained to develop a diagrammatic solution that highlighted the underlying logic and variability in the procedure and was able to retain conceptual clarity.

Another major challenge that fell to me while on the project was constructing the interface prototypes. The chosen software was Figma, a software extremely popular within the design community, yet software that was unknown to me. The ultimate result was that additional time was required to get accustomed to its workflow and design paradigm, something completely foreign to the development suite that was known to me. Most notably, trouble was experienced applying components: while indeed many pre-fabricated items did exist, tweaking and shaping them for the project's unique requirements wasn't so immediate and involved judicious experimentation.

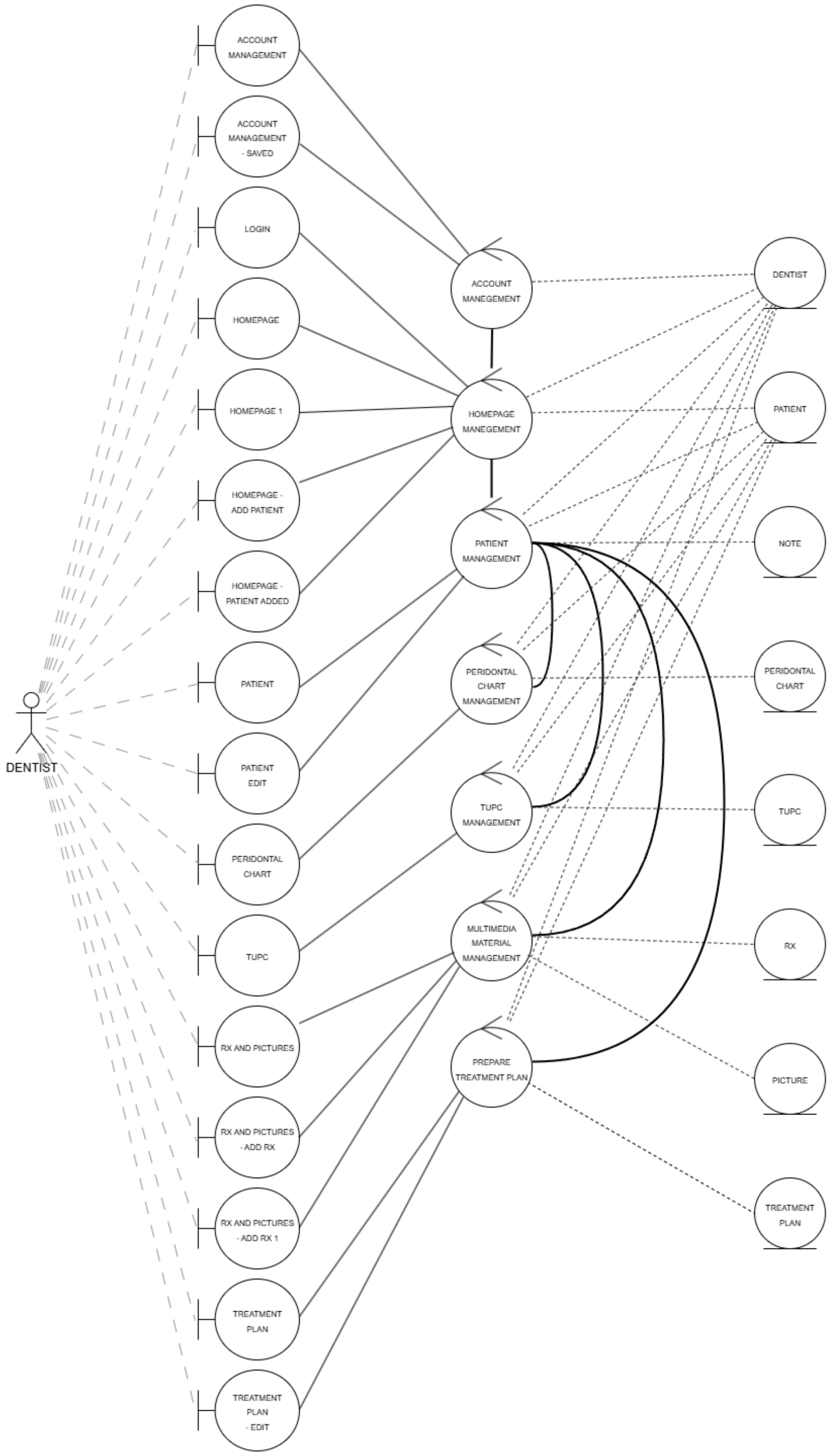

Figure 3.14: Communication Diagram

Chapter 4

Conclusions

In this last chapter, the key points of the thesis are highlighted again. Looking back and consolidating its achievements, successes, challenges encountered, and lessons learned. It provides evidence on the implementation of process modeling, requirement elicitation, and design steps in medical software development, and proposes improvements that could be added. Moreover, it points out the limitations of the current method and presents possible future enhancements. The intention is to provide an equitable criticism of the work performed and the possible implications for healthcare organizations and clinical practice.

4.1 Summary of the Work

This thesis embarked on the development of a medical software system that originated from the need to collect data for an experimental periodontal protocol. But despite this initial need, it was designed both to support this accurate data collection for the protocol and to facilitate the daily workflow of clinicians. Coming from a Computer engineering background, from the very beginning, my role was that of a mediator between two distinct but interconnected domains. These domains are the highly specialized environment of periodontology, with its specific clinical needs and procedures, and the structured methodologies of software engineering.

The first challenge I faced was becoming familiar with the clinical context. Which was almost completely new for me. Dentistry, periodontology in particular, generally has a very specialized vocabulary that is not easily understood by someone who is not familiar with that field. I found it difficult to come to terms with this vocabulary at first because many of the definitions and procedures had no analogs in my prior studies. However, through the on-site observation I made at the Dental School of the University of Turin, I was able to overcome this first obstacle. By observing the patient's visit and procedures such as periodontal probing (*sondaggio parodontale*), and by taking copious notes on what I saw and heard, I was eventually able to keep up with clinical discussions and translate them into structured data. This immersion stage wasn't merely a matter of learning words, but of understanding how they applied to real tasks and workflows.

Based on this, I then proceeded to process modeling, one of the most fundamental and time-consuming tasks of my work. My role was to model the clinical workflows in a correct manner. This activity was done by determining their actors, activities, data flows, and outcomes. I didn't do this in a single session or straightforward approach. Instead, I did so in a systematic and recursive way, beginning with preliminary drafts and refining them in an iterative cycle of feedback and revision. The feedback I received from my assistant during this period was extremely useful, as it highlighted areas of misinterpretation and encouraged me to question my own assumptions. Each iteration cycle moved the models closer towards the real clinical workflow, and I was instructed in the importance of patience and perseverance for accuracy.

In order to illustrate the workflows in detail, I employed the three diagram types analyzed in more detail in Chapter 2. Firstly, for each process, I created a Synopsis Diagram that allowed me to represent the context of the processes. By explicating the actors, data involved, trigger event, and results. The Workflow Diagram, based on Petri nets, provided the means for modeling the order of activity, decision points, and potential parallelism between the activities. The Swim Lane Diagram helped me demonstrate the duties of different actors at different times, clearly showing what each actor does at each stage of the process. Thus, entering more into the details of the workflows. The interaction among these three perspectives was effective, as it both structurally and dynamically supported the workflow. Creating and working on these diagrams was my own task, and I applied a lot of effort to produce them in a way that models reality as closely as possible.

Once the process modeling reached a satisfactory level, I proceeded to requirement elicitation. I was tasked with finding the requirements for the new system and collecting them in a format that is suitable for a presentation. This involved identifying the main users of the system, the data that would be required to capture or generate, and the functionality to support research and clinical practice. A PowerPoint document was produced as the output of this phase. This not only documented the outcomes but also served as a template for the design phase. And this format is suitable for an easy requirements presentation, discussion, and validation. In this case, I was not only able to draw on my background in software engineering, but also on the foundation I had gained from elective courses in Medical Software Programming. These proved to be particularly valuable, having acquainted me with concepts of safety, reliability, and usability of medical systems, and enabling me to address the challenges of applying engineering approaches in a medical context.

This was followed by the system design and development phase. My responsibility was to convert the accepted requirements into real models that would guide future implementation, including drawing use case diagrams to formalize the system and user interaction, creating interface prototypes to visualize the application during use, and designing activity diagrams to outline the expected system behavior. To establish a sound basis for data management, I developed entity–relationship models, while communication diagrams were used to model the logical interfaces between the different components of the system. Each of these deliverables was my immediate responsibility, and each required not only technical competence but also the ability to ensure congruence with the clinical realities observed earlier.

Throughout the project, I acted as a bridge between the technical and clinical communities. Even if my main role was one of producing diagrams and documents, I had to consider all aspects. Constantly translating requirements, disambiguating, and ensuring that solutions proposed weren't merely clinically applicable but also technically feasible. This required flexibility: at times, I had to wade through the details of periodontal terminology and procedures; at others, I had to step back and formally apply modeling techniques with rigor.

My contribution, in total, covered the entire work cycle: from the initial observation and familiarization with the clinical setting, through process modeling and validation, requirement elicitation, to system design. The outcome of this process was a set of models that together form the design of a digital platform capable of being both a research tool for periodontitis procedures and a means of supporting the daily tasks of dentists and students. The experience also reaffirmed the importance of interdisciplinarity: even though I was coming from a software engineering perspective, I was able to navigate the medical field effectively as a result of both my academic training and on-ground learning. This thesis thus demonstrates how healthcare can be addressed using formal software engineering techniques, and how the role of the individual researcher—as a go-between between fields—is central to the success of such endeavors.

4.2 Key Achievements and Results

The main results of this thesis can be traced to the use of formal software engineering principles in the clinical domain of periodontology. By the strict use of process modeling and requirement elicitation, it was feasible to lay the foundation for a medical software system that would be able to assist research protocols along with daily dental practice. The following list presents the key achievements that were obtained from the effort of this thesis project:

- Accurate and Comprehensive Process Modeling: Synopsis, Workflow, and Swim Lane Diagram were produced, capturing the periodontal workflow. This was achieved through on-site observation, interview, and iterative feedback. Although these diagrams mainly document the process, they also facilitate communication between technical and clinical stakeholders and provide a solid base for further developments.

- Merging Clinical Knowledge and Technical Approaches. One of the biggest successes was to understand and overcome the challenge of specialized terminology and clinical procedures. Through observing and documenting a real-life scenario, studying it, and getting it documented, I succeeded in mapping domain-specific expertise into technical software models without compromising on precision.

- Systematic Requirements Elicitation. I derived from validated process models the main users, associated data flows, and key functionalities required. I condensed the results into a requirements report that both constituted the regulatory documentation and acted as a working guidebook for system development.

- System Design. Based on the requirements, I designed a comprehensive set of design artifacts such as use case diagrams, activity diagrams, entity–relationship models, communication diagrams, and interface prototypes. All these outputs taken together provide an integrated plan for the medical software system, combining clinical necessity with technical feasibility.

- Blueprint for Future Development. Although implementation was not the primary focus of this thesis, the models and diagrams established lay a good foundation for future software development. This system has been analysed and designed with extensibility and flexibility in mind. In this way, it can be adapted for application in other clinical contexts beyond periodontology.

These technical results are the key achievement of this project. But this thesis also demonstrated the personal ability of interdisciplinary adaptability. Coming from a software engineering background, I was capable of bridging the complexities of medical terminology and practice through self-study and preparation provided by the course in Medical Software Programming. This double competence allowed me to act as an intermediary between clinicians and technical frameworks, a role that was central in the realization of the project's objectives.

The final achievement is therefore double: one, a set of proven models and needs that can be utilized to steer the development of a dental practice management digital platform; and two, that software engineering's structured methodologies can be applied successfully in healthcare, provided proper communication and understanding between paradigms are ensured.

4.3 Limitations of the Project

In this report, different project limitations have been recognized. The majority of such limitations can be traced back to a lack of communication, the availability of the clinical context, and the project scope itself. It is known that the limitations determined are critical because they highlight where the future projects can be improved upon or extended.

- Limited communication with assistant: Following the process modeling stage, communication with my assistant dropped because of her transfer to another institution. This established a break in the feedback, thus removing the iterative validation aspect that had been essential throughout the first project phases.

- Minimal clinical interaction. Other than the initial visit to the Dental School, I never actually did get the chance again to sit down routinely with clinicians and dentists and verify and reverify the process models or refine the requirements. In such a manner, the models were thus consistently tested and confirmed more through individual interpretation and isolated feedback, as opposed to iterative interaction with a panel of stakeholders.

- Restricted access to real workflows. Descriptions were borrowed from just one small sample of clinical practice, such that a few of the differences in the workflow might not be represented. More exposure to more than one department or more cases would've enriched the models and enabled more generalizability.

- Lack of implementation testing. The focus of the scope for this thesis only went as far as process modeling, elicitation of requirements, and system design. Since there was no implemented prototype tested within an actual clinical environment, it is impossible to ascertain the full extent of the integration of the proposed system within day-to-day operational usage or quantify its practical effect upon efficiency and quality of data.

- Interdisciplinary complexity. Finally, the project's inherently interdisciplinary nature—involving dentistry, periodontology, and software engineering—caused difficulty on its own merits. Although I managed to overcome the hurdle of learning specialist language, the lack of continuous interaction with the experts made it more difficult the process of converting clinical needs into detailed specs.

4.4 Future Developments

For the medical software project designed for this thesis, there are numerous development and growth possibilities. At least three serious directions for development and concentration should be developed and taken:

- Ongoing validation with clinicians. Efforts for the future need to be focused on arranging more sessions with periodontists and dentists for the purpose of extensively validating the process models and sharpening them until they receive clinical endorsement. As good as the needs and diagrams produced thus far are, practitioner input through more direct engagement is needed for the purpose of verifying that the system correctly models the workflows under observation and can be relied upon as an instrument aid within everyday practice.

- Refining the interfaces and diagrams. Another point of improvement relates to the interfaces and activity diagrams developed throughout the system development process. Future iterations will be performed under close collaboration with clinicians, whose feedback will directly inform the changes. In such a manner, the application can be tailored toward their actual needs, and usability can be paired with the possibility of applying it instantly within the clinical setting.

- System development and implementation. The next crucial step is the system software development itself. This entails the selection of the most appropriate development technologies, paying special attention to interoperability with the already existing systems, the protection of the sensitive biomedical information, and scalability for extension into the future. The development should be carried out under a systematic approach, ideally agile and iterative, for the potential of ongoing feedback and improvements as the system evolves.

Other developments could be the extension of the platform to other regions of dental specialties, so the system may become a more general tool in the complex world of dentistry. What could make the software even more useful is the incorporation into hospital systems and electronic medical records. Finally, emphasis should be placed on the usability and training aspects such that dentists and students can comfortably use the platform with minimal learning needs.

These directions combined lay out a road map for being able to take the models and designs of this thesis and transform them into a clinically evaluated, fully implemented, and extensible software system. The system would not only accommodate research protocols in periodontology but also the day-to-day needs of dental practice, with compliance with medical software standards and data protection directives.

4.5 Final Thoughts

It has been challenging but rewarding working on this thesis. It gave me the chance to tap into and explore a completely new domain for me. One of dentistry and periodontology, which is challenging but definitely interesting. I had the opportunity to gain enough knowledge to define processes and create a software system of clinical relevance. I also had the new opportunity to apply the methodologies learned in my studies to a practical healthcare setting.

Reflecting on this experience, I believe the biggest contribution that I can make is to act as a bridge between the clinical and technical worlds. While my academic roots are in computer engineering, the previous course I attended in medical software programming and visiting the Dental School first-hand gave me the ability to speak clinicians' languages, understand their workflows, and portray them formally. This dual perspective, clinical and technical, was a critical asset throughout the project.

In addition to the development of correct diagrams and requirements, I was able to foresee implementation and usability issues. Rather than viewing medical processes as flow-like abstractions, I had the opportunity to see the real practicalities of what clinicians encounter. Thanks to this, I could shape solutions that could possibly integrate into their regular practice. This likely has improved the quality of the models and made the project not completely theoretical, but based on real needs.

The experience also highlighted the importance of communication, validation, and interdisciplinarity. In this project, the communication with the clinician had been limited to a single encounter, but I understand how important ongoing feedback is in optimizing a system to address actual-world requirements.

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