Design Driven Development of a Web-Enabled System for Data Mining in Arthroplasty Registry

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Brackium Emendo *(Charm) - Healing spell to mend broken bones.*
[*BRAH-kee-um eh-MEN-doh*]

Harry Potter and the Chamber of Secrets

Abstract

This research was inspired by the work at the Norwegian Arthroplasty Registry, which serves as a national resource for understanding the longevity of implanted prostheses, analyzing risks, and patient outcomes in general. At this moment, they have no online system that would help and enable several user groups to take advantage of the data for clinical, research, and informative purposes.

This thesis has contributed with a high-fidelity prototype of a desktop application named LeddPOR. The system is dedicated to three user groups: patients, physicians, and researchers. The project was completed in collaboration with three other master students, comprising a back-end and front-end development team. Knut Hufthammer and Sølve Ånneland, who provided valuable data mining tasks to be incorporated in the prototype, and Arle Farsund Solheim created visualizations that allow interactive data exploration.

The project followed the User-Centered Design approach, as a method to produce a prototype that would be appreciated by real users. The Design Science Research methodology allowed five iterations, within which prototypes from low- to high fidelity have taken form. The final, fully interactive prototype is intended for physicians, researchers, and patients. There are two dedicated parts; one for hip, and the other for knee. Under those, a number of data mining tasks could be performed at the convenience of the expert user. The sessions can be saved and reviewed according to users' preferences and needs.

The patient part of the system is offering mainly information, but also some resources such as formerly developed applications supporting post-operative care. During this development, we have defined two patient personas, acknowledging their different needs. On the expert side, two personas were created, one for physicians and one for researchers.

Usability testing was conducted with both expert and novice users, which suggested a high success rate. The final System Usability Score (SUS) of 95 points, as well as feedback from evaluation, indicate a potential to develop a product that could be valuable for several user groups.

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1 Introduction

The Norwegian Arthroplasty Register (NAR) was established in 1987 by the Norwegian Orthopedic Association as a measure to handle a series of underperforming hip prosthesis (*The Norwegian Arthroplasty Register Research group*, 2014). Seven years after the establishment, in 1994, the register was extended to include all artificial joints (Havelin et al., 2000). The register receives information on about 85 000 primary arthroplasties of the hip, about 6 000 of the knee, and 1 500 of other joints every year. As of 2019, the Norwegian Arthroplasty Register contains more than 230 000 records on hip replacements and nearly 100 000 records on knee replacements (*Norwegian National Advisory Unit on Arthroplasty and Hip Fractures*, 2021). A varied utilization of arthroplasty registers has led to different positive effects, such as surveillance of implantable medical devices, generation of scientific evidence, as well as cost-savings effects (Delaunay, 2015). However, accessing the data is a tedious task, and the presentation of the data makes it difficult to read and understand for individuals who are not directly involved in research. As a response to these challenges, this thesis explores what methods and design solutions are best suited for a front-end for the register. The research centers around the three main user groups of the Norwegian Arthroplasty register: physicians, researchers, and patients.

Research has shown that user-friendly solutions help utilize data and enabled services not the least by means of web and mobile-based technologies. The Waikato Environment for Knowledge Analysis (WEKA) project proves that a user-friendly interface for data mining can be useful for different applications, domains, and user groups (Srivastava, 2014). This thesis intends to explore possibilities of setting up a web-enabled system that will allow users to work with the arthroplasty register. Appeal to the potential user groups, as well as design solutions, also has to be evaluated.

1.1 Research Questions

- How can front-end development complement back-end development to deliver a user-friendly system for data mining in arthroplasty?
- How can Human-Computer Interaction, in particular, be utilized to support physicians in analyzing data in their daily work and in research?
- How can Human-Computer Interaction, in particular, be utilized to support non-expert

users such as patients to better understand surgical procedures and implants?

- How can this thesis help transform the current state of presenting data from the arthroplasty register to a better and preferred state?

1.2 Collaboration

Part of this research is done in collaboration with three other master's students. Each student provides different contributions to the final outcome, which is a prototypical exploration and outcome analysis tool for a national joint register. Two students have focused on front-end; User Experience, Human-Computer Interaction, and visualization, while the latter have been concentrated on data mining in the knee and hip data. The students focusing on the back-end have provided the front-end students with data for visualization and data mining methods for the prototype.

1.3 Thesis Outline

The following is an outline of the thesis:

Chapter 2: Literature Overview summarizes the literature and related works during this thesis.

Chapter 3: Methods explain the methods and frameworks used in this thesis and their contributions.

Chapter 4: Requirements and Ethical Concerns covers ethical concerns, the target group and participants of this research, as well as the requirements set for the prototype.

Chapter 5: Prototype Development presents the different tools used, and the five design iterations achieved.

Chapter 6: Final Features displays the final functionalities of the high-fidelity prototype of LeddPOR.

Chapter 7: Evaluation sum up the results from evaluations made during iterations.

Chapter 8: Discussion reviews the methods and development process used and answers the research questions.

Chapter 9: Conclusion and Future Work concludes the research with a brief summary and some recommendations about future work.

2 Literature Overview

This chapter will present theoretical topics that are relevant for the research: total hip arthroplasty, total knee arthroplasty, personas in the design development of health technologies, and interface design with older people. In addition, existing tools will be discussed briefly.

2.1 Arthroplasty

Arthroplasty is a specific branch of orthopedics and can be understood as the surgical procedure used to restore the function of a damaged or destroyed joint, mainly in the hip or knee. This is either done by resurfacing or restoring the bones in a joint, or replacing the broken joint with an artificial joint, or prosthesis (*Total hofteprotese, kunstig hofteledd*, 2020). A well-functioning prosthesis can provide the same level of joint mobility as a healthy joint. Total Hip Arthroplasty (THA) and Total Knee Arthroplasty (TKA) are two of the most performed surgeries in arthroplasty. Surgery on the ankle, elbow, shoulder, and fingers have their appearances as well.

There are many reasons behind a joint needing replacement or repairment, but the most common reason is osteoporosis, a degenerative joint disease that weakens bones (*Norwegian National Advisory Unit on Arthroplasty and Hip Fractures*, 2021). Arthrosis, a joint disease caused by wear and tear of a joint, is also a common reason (*Total hofteprotese, kunstig hofteledd*, 2020). The Norwegian Arthroplasty Register receives information on about 85 000 primary arthroplasties of the hip, about 6 000 of the knee, and 1 500 other joints every year. As of 2019, the Norwegian Arthroplasty Register contains more than 230 000 records on hip replacements and nearly 100 000 records on knee replacements (*Norwegian National Advisory Unit on Arthroplasty and Hip Fractures*, 2021).

2.1.1 Total Hip Arthroplasty

Total Hip Arthroplasty is one of the most successful orthopedic procedures that is carried out, with several thousand yearly surgeries in Norway alone (*Norwegian National Advisory Unit on Arthroplasty and Hip Fractures*, 2021). The procedure can restore mobility, relieve pain, and improve the quality of life for patients with hip pain.

An artificial hip consists of a stem that runs down in the femur bone with a "head" on the top, replacing the femoral head. A second part is a hip socket, shaped like a cup to house the head (*Norwegian National Advisory Unit on Arthroplasty and Hip Fractures*, 2021). Variation in materials and design occurs as some prostheses are made for specific situations, but also from progressing research and the development of new, better products (*Norwegian National Advisory Unit on Arthroplasty and Hip Fractures*, 2021). A hip prosthesis is shown in Figure 1.

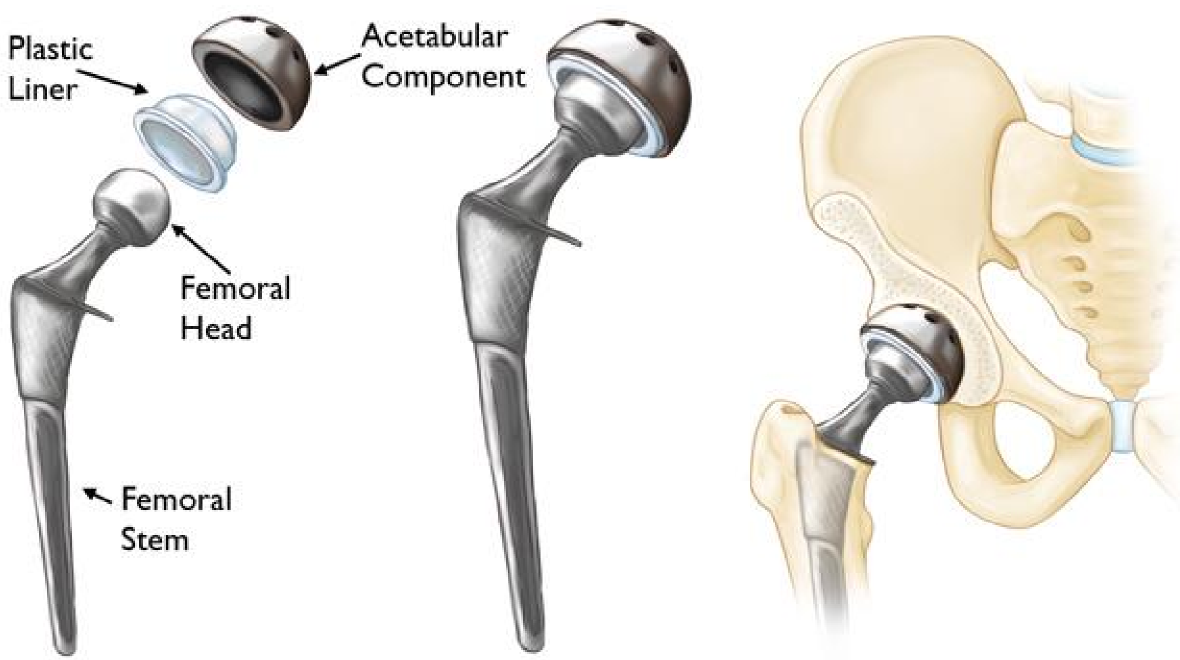


Figure 1: Hip prosthesis (Froan & Fischer, 2020a).

The primary group of patients that needs a hip prosthesis is elderly people, as they are more prone to joint wear or hip fractures. Still, people of all ages have the surgery every year.

2.1.2 Total Knee Arthroplasty

Total Knee Arthroplasty is the second most performed arthroplasty surgery in Norway. An artificial knee consists of a femoral component, a tibial component, and an inter-component. The femoral component is set at the bottom end of the thigh bone and partly encircles it. The inter-component lies between the femoral and tibial components. It often consists of a plastic tray that functions as a bearing surface. The plastic tray is either fixed to a metal component lying on top of the tibial component or directly to the tibia. Depending on the selection of materials and the complexity of the surgery, various cementing techniques are used in the insertion of the different components. Though less common, some surgeries are performed without the use of cement (Aprato et al., 2016). In cemented procedures, one uses bone cement to secure all components into place. Bone cement is biomaterials made by combining a powder and a liquid phase, which can be molded and implanted as a paste and have the ability to solidify once implanted within the body (Ginebra, 2009). Another common cementing technique is the hybrid fixation procedure. Here, only the femoral component is put into place using bone cement (*Knee replacement edition*, 2021). A knee prosthesis is shown in Figure 2.

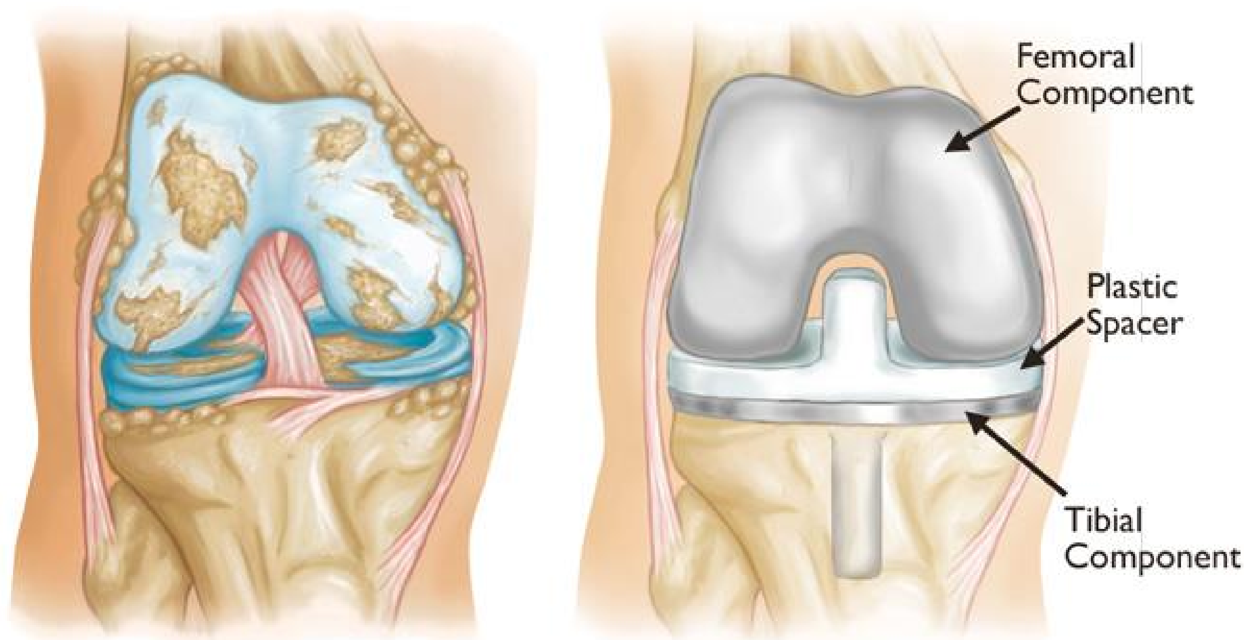


Figure 2: Left: Severe osteoarthritis. Right: Knee prosthesis (Froan & Fischer, 2020b).

2.1.3 Potential Postoperative Complications

There are several complications connected to THA and TKA, the most common being dislocation of the artificial joint. Approximately, This occurs for less than one percent of patients in Norway each year (*Total hofteprotese, kunstig hofteledd*, 2020).

In addition to this, there is a series of other postoperative complications, where the most occurring are (*Risks and Complications of Total Knee Replacement Surgery*, 2021):

- Spontaneous subluxation (incomplete or partial dislocation)
- Infections
- Dislocation
- Implant failure

- Implant fracture
- Leg length discrepancy
- Aseptic loosening
- Osteolysis
- Neurological injuries
- Allergy to metal components
- Loss of motion

Common complications from any surgeries include, but are not limited to, hemorrhage wound infection, deep vein thrombosis (DVT) and pulmonary embolism (PE), urinary retention, and reaction to anesthesia (*After Surgery: Discomforts and Complications*, n.d.).

2.2 Relevant Literature

2.2.1 User Profiles and Personas in Design and Development of Consumer Health Technologies

This paper investigates how user-profiles and personas can be of use in the development of consumer health technologies, with a focus on the aging population and their potential challenges.

Information technology (IT) and challenges in the aging population can somewhat be resolved by designing applications that are senior-friendly (LeRouge, Ma, Sneha, & Tolle, 2011). According to LeRouge et al. (2011), there are multiple needs to be met in order to develop healthcare products that meet the requirements of the aging patient group. They include analyzing and understanding the challenges and requirements of the elderly; studying and implementing methods for making information communication technologies (ICT) accessible to older user groups; modeling and integrating preferences of the elderly population segment into health technologies; and lastly, evaluating the outcomes. A characteristic of the traditional IT design methodology is that the major part of the design decisions is made by designers and/or developers, with limited user participation with a consultative role. Designers and developers tend to be younger adults who are not able to fully understand the needs of an older user group (LeRouge et al., 2011). This can lead to a suboptimal end product, with unsatisfied users.

According to LeRouge et al. (2011), the use of user profiles and personas has not received considerable attention in healthcare informatics research in general, and the development of consumer health technologies in particular. Applications for the older population should consider more user-specific context, physical and cognitive impairments, different motivational factors, and perceptions of self-efficacy.

2.2.2 Interface Design and Engagement with Older People

This paper examines approaches to interface design that led to a successful interactive tutorial for an older user group (Hawthorn, 2007).

Hawthorn (2007) states that one approach to investing more in consciously learning about older people, both in general and in the situation that is being addressed by the design in question. Further, the author argues that there are so many elements to consider when it comes to aging, that they are likely to overload rather than assist a designer. He explains this by stating that knowing about older people's limitations with motor control does not necessarily mean that older people will have difficulty with particular interface features such as menus, scrollbars, or double-clicking. Rather, it helps the designer interpret what has been observed in previous research.

According to Hawthorn (2007), the standard recommendations for user interface design are optimal if they are slightly modified for use with older people. Designers tend to be younger adults who are not fully capable of understanding the older users. It is typical to assume that the user is not unlike the designer; that the user has the same minimum of computer knowledge, a common language, an ability to remember instructions and movement sequences, and the ability to express domain knowledge. Further, the author claims that these assumptions of some similarities are essential in making the design process work. He argues that there are so many aspects to human behavior that to question each aspect would make the process endless (Hawthorn, 2007).

2.3 Related Works

In the following sections, literature is reviewed with respect to the application domain, which concerns arthroplasty, data mining, interface design, and applications directed towards patients. In addition, relevant research is presented in the domain of visualization and Human-Computer Interaction with the Swedish Cancer Register. This thesis is informed by the findings and refers to the main points of interest presented in the publications.

2.3.1 SafeTHA

SafeTHA is a self-reporting tool created to reduce the occurrence of postoperative adverse events after total hip arthroplasty. It enables patients to self-report their current state through answering questions regarding pain, mobility, anxiety, progress, and quality of recovery. SafeTHA also informs the user about various aspects of rehabilitation, such as pain, wound management, known risk factors, and recommended activity level (Krumsvik & Babic, 2017b). Research was also done on creating a learning platform for physicians, patients, and medical students. Besides including clinical patient data, the system wants to include even electronic patient data from self-monitoring. Two different modules were created, one for medical staff and one for patients, both divided into knee and hip areas (Krumsvik & Babic, 2017a).

2.3.2 Norsk Senter for Hofteprotese

Norsk Senter for Hofteprotese is an e-learning platform for patients undergoing hip replacement surgery. It benefits patients by understanding and meeting their information needs, and offers online practical support. In addition to this, it aims to increase patient education and their feeling of safety, as well as improving postoperative rehabilitation. Norsk Senter for Hofteprotese provides information, an exercise guide, and patient self-assessment tools (Carlsen, 2018).

2.3.3 HALE System

HALE is a system for estimating the longevity of a hip prosthesis after THA Longberg (2018). The system explores the use of machine learning techniques on a biomedical dataset motivated by two user groups' needs. The user groups are biomedical engineers who analyze explanted hip arthroplasty prostheses and physicians who work with patients and want to know what the safe and optimal treatment for each patient is (Longberg, 2018).

2.3.4 Mobile Design For Adverse Event Reporting And Pharmacovigilance

This research, conducted by Åserød and Babic (2017a), focuses on the aspect of the patients' safety by designing solutions for reporting of adverse events and pharmacovigilance (Åserød & Babic, 2017a). The proposed user interfaces enable the entry of data specific for adverse events of the knee and hip implants. Besides the patient data, the system supports entry of the event, its classification (serious, non-serious), its follow-up, as well as a connection to the database maintained within the Helse Bergen hospital information system. Safety reports can be initiated and retrieved on request and depending on the adjudication of the event; suspected severe events should be followed up until their resolution. The data entry for safety reporting and pharmacovigilance system is based on the web-based system called WebBISS (Web-based implant search system) (Åserød & Babic, 2017b).

2.3.5 Data Mining in Hip Arthroplasty Data

In this research, Kristoffersen (2019) focuses on developing and evaluating individual patient outcome prediction models based on hip arthroplasty register data. It was assumed arthroplasty had a rich data collection to be explored using data mining methods. This was conducted in two major phases, firstly exploratory data analysis and subsequently predictive modeling made possible by the finding of the exploration phase. To explore the dataset, clustering was utilized to identify similarities and distinctions between groups of patient records. Feature selection and engineering for the predictive models were done on the basis of the data exploration (Kristoffersen, 2019).

2.3.6 Data Mining in Knee Arthroplasty Data

In this research, a set of descriptive and predictive models were developed to explore how data mining in modern health registers can provide useful information to enhance the medical treatment of patients, and to predict the outcome of surgical treatment. In addition, a series of activities needed for effective data mining, such as data selection, data preparation, and result interpretation was completed. In a two-fold assessment of results, standard machine learning metrics were used and conveyed an evaluation with experts from the fields of orthopedic surgery and biomedical engineering.

The results showed that data mining can be used to enlighten crucial aspects of surgical treatment (Iden, 2020). Prediction models were able to forecasts specifications of surgical outcomes in rather fine detail. Although the performance was not developed to full potential, the expert evaluation found the results highly interesting and of clinical importance.

2.3.7 Smart User Interfaces to Cancer Registers

Kanza and Babic (2014) developed several user interfaces for visualizing data mining from cancer registers. The research aims to create more flexible, smart, and easy-to-use interfaces that will assist users working with extracting data from the register (Kanza & Babic, 2015). The final, high-fidelity prototype had an interactive map of Sweden, a graphical presentation of data mining results, a graphical presentation of human anatomy, and code translations. Users could see, for example, incidents of cancer per geographical region by clicking on the selected organ in the body and produce a list of codes for different types of cancers and related organs. Several data mining procedures were implemented in the system (Kanza & Babic, 2014).

3 Methods

This chapter will focus on the material and techniques that were used for this research, along with the methodology that was followed.

3.1 Design Science Research

Design Science research is a framework where the main goal is to create an artifact that serves a human purpose, and that it can be represented in different forms, ranging from software to formal logic (Hevner et al., 2004). Specifically, Design Science Research aims to clarify specific problems to gain an adequate solution to given situations. Even if the solution is proven to be inadequate (Hevner et al., 2004).

The goal of this research was to contribute to the users, with experts or patients, who are making sense of the arthroplasty data. The product is intended for a broad range of users, who intend to work with methods to get answers about surgical outcomes.

The Design Science Research model, depicted in Figure 3, shows the link between two of the main factors in Design Science Research: rigor and relevance. Relevance should offer relevant research to organizations, and professionals who may use the knowledge to solve practical problems. Rigor determines if the research is valid and reliable, and can contribute to knowledge in given areas (Dresch, Lacerda, & Antunes, 2014).

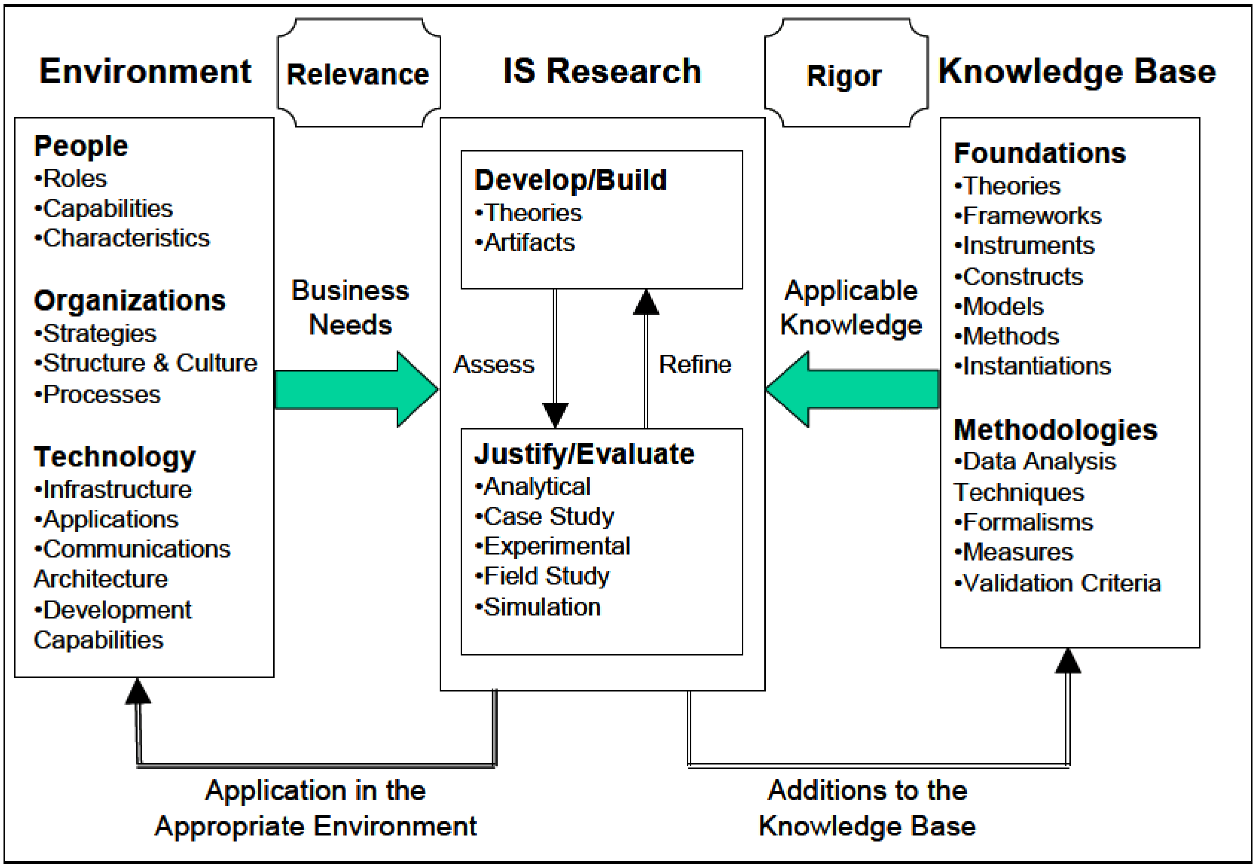


Figure 3: Design Science Research Model (Hevner et al., 2004).

Hevner et al. (2004) suggest seven design criteria or guidelines, as shown below in Table 1. These were created to help and assist researchers, reviewers, editors, and readers to understand the requirements for effective and useful Design Science Research. To be able to succeed with the creation and evaluation of an artifact, it is important to address each guideline in some manner. However, there is no particular order in which they should be applied. By this, Hevner et al. (2004) explains that researchers, reviewers, and editors must use their creative skills and judgment to determine when, where, and how to apply each of the guidelines for their specific research project.

GUIDELINE	DESCRIPTION
Guideline 1: Design as an artifact	Design-science research must produce a viable artifact in the form of a construct, a model, a method, or an instantiation.
Guideline 2: Problem Relevance	The objective of design-science research is to develop technology-based solutions to important and relevant business problems.
Guideline 3: Design Evaluation	The utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods.
Guideline 4: Research Contributions	Effective design-science research must provide clear and verifiable contributions in the areas of the design artifact, design foundations, and/or design methodologies.
Guideline 5: Research Rigor	Design-science research relies upon the application of rigorous methods in both the construction and evaluation of the design artifact.
Guideline 6: Design as a Search Process	The search for an effective artifact requires utilizing available means to reach desired ends while satisfying laws in the problem environment.
Guideline 7: Communication of Research	Design-science research must be presented effectively both to technology-oriented as well as management-oriented audiences.

Table 1: Design Science Research Guidelines (Hevner et al., 2004).

3.1.1 Guideline 1: Design as an Artifact

> *"Design-science research must produce a viable artifact in the form of a construct, a model, a method, or an instantiation."* (Hevner et al., 2004)

The guideline states that one has to create an IT artifact as an instantiation, construct, model or method. An artifact can be defined as a product crafted by a human, or a man-made object (*artifact - definition, examples, related words and more at Wordnik*, n.d.). Hevner et al. (2004) do not include people or elements of organizations in their definition of an IT artifact. In other words, there is more emphasis on the artifact itself, rather than the people using it. IT artifacts are not as independent of people or the organizational and social contexts in which they are used, but as interdependent and co-equal with them in meeting business needs (Hevner et al., 2004). Artifacts constructed during Design Science Research are rarely completed information systems that are used in practice. They are rather innovations that define the different ideas, practices, technical capabilities, and products (Hevner et al., 2004). This research intends to produce an artifact that will serve as an interface between the users of the Norwegian Arthroplasty Register and the register itself.

3.1.2 Guideline 2: Problem Relevance

> *"The objective of design-science research is to develop technology-based solutions to important and relevant business problems."* (Hevner et al., 2004)

This guideline refers to acquiring knowledge and understanding that enable the development and implementation of technology-based solutions to so far unsolved and important business problems as the main objective of research in information systems (Hevner et al., 2004). Currently, there is no graphical user interface for the Norwegian Arthroplasty Register. This is assumed to complicate the use of the register for doctors and researchers. In addition, this makes it near impossible for patients and next of kin to gather any information from the register without consulting a doctor.

3.1.3 Guideline 3: Design Evaluation

> *"The utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods."* (Hevner et al., 2004)

Evaluating is a fundamental part of any research process. In order to properly evaluate an artifact, a definition of appropriate metrics is required, as well as the gathering and analysis of relevant data (Hevner et al., 2004). According to Hevner et al. (2004) IT artifacts can be evaluated in several different terms, such as functionality, completeness, consistency, accuracy, performance, reliability, usability, fit with the organization, and other relevant quality attributes. The different evaluation methods considered for this thesis will be discussed in Section 3.4.

3.1.4 Guideline 4: Research Contributions

> *"Effective design-science research must provide clear and verifiable contributions in the areas of the design artifact, design foundations, and/or design methodologies."* (Hevner et al., 2004)

In order to preserve effective and precise Design Research Research, the project must provide clear contributions in the field of the design artifact, design construction knowledge, and/or design evaluation knowledge. There are three types of research contributions, and at least one is required to be found in a given research project: the design artifact, foundations, and methodologies (Hevner et al., 2004). This research will result in at least one of these contributions. The main goal being the actual artifact, an interactive and high-fidelity prototype.

3.1.5 Guideline 5: Research Rigor

> *"Design-science research relies upon the application of rigorous methods in both the construction and evaluation of the design artifact."* (Hevner et al., 2004)

This guideline addresses the way in which the research is conducted. Design Science Research requires the application of methods in both the construction and evaluation of the artifact. Rigor must be assessed with respect to the generalizability and applicability of the artifact (Hevner et al., 2004). This research will employ several methods to deliver an artifact, in line with relevant literature.

3.1.6 Guideline 6: Design as a Search Process

> *"The search for an effective artifact requires utilizing available means to reach desired ends while satisfying laws in the problem environment."* (Hevner et al., 2004)

Design is essentially the result of a search process that should discover an effective solution to the problem stated. In order to achieve an effective solution through the timeline of the project, one must collect the appropriate knowledge from the application domain, and the solution domain (Hevner et al., 2004). The research of this thesis has been conducted through several iterations in order to consider the relevant literature and conduct evaluation.

3.1.7 Guideline 7: Communication of Research

> *"Design-science research must be presented effectively both to technology-oriented as well as management-oriented audiences."* (Hevner et al., 2004)

The research needs to provide satisfactory information in order for the artifact to be used within a given context. It should enable researchers to take advantage of the artifact and to build upon a growing knowledge base to further develop and evaluate. It is therefore important to explain the process thoroughly to be able to establish a repeatable process for the research project. This lays the foundation for further research by Design Science Researchers (Hevner et al., 2004). The results of this research will be made public through the open-source platform of the University of Bergen, Bora (bora.uib.no).

3.2 Data Gathering

This section will introduce the different data gathering methods used for this research. There are multiple different approaches to data gathering. Therefore, it is important to choose the most suitable techniques in order to achieve the best results. Among multiple different approaches, the methods that were most useful to gather data have been chosen. Sample data were provided from the Norwegian Arthroplasty Register itself. An additional interview was conducted to gather qualitative data. Literature was also reviewed to include published findings relevant to this thesis.

3.2.1 Literature Review

A literature review is a broad analysis of existing literature in the field such as academic papers, articles, reports, and books. Literature reviews aim to provide a summary of relevant findings within the specific domain. This research needed input from the domain of arthroplasty, as well as information technology for which references were gathered using Google Scholar, PubMed, and ACM Digital Library. The findings can be seen in Chapter 2.

3.2.2 Interviews

One can look at interviews as "conversations with purpose" (Sharp et al., 2019). There are four main types of interviews: open-ended/unstructured, structured, semi-structured, and group interviews (also called focus groups). The first three are named based on how much control the interviewer has over the conversation by following a predetermined set of questions. Semi-structured interviews were considered as the most appropriate, since it offers structure but also leaves freedom to the interviewee to express opinions and provide feedback freely.

Semi-structured interviews combine features from structured and unstructured interviews, in that they use both closed and open-ended questions (Sharp et al., 2019). The interviewer has a basic script consisting of predefined questions to ensure that the same topics are covered with all the interviewees. In practice, the interviewer starts with pre-planned questions and then gets the interviewee to say more until there is no new relevant information coming. Using this technique might provide information about topics that could be hard to uncover for non-experts within the field. It is important not to phrase suggestive questions, since this can lead to invalid data and biases (Sharp et al., 2019). Conducting interviews is a good method to gather qualitative data, where one wants to understand the meaning behind the answers on a more detailed level.

This method was used to get a better overall understanding of the topic at hand. As described above, the interviews consisted of predefined questions to be sure to cover the same topic with each participant. Follow-up questions were then asked based on the participants' answers. The participants for the semi-structured interviews were predominantly experts and to some extent patients. The current COVID-19 restrictions have impacted contact with more patients. Instead, they were given a possibility to respond to a questionnaire that covered main topics related to the register and their information needs.

3.2.3 Questionnaires

Questionnaires are a well-established method for gathering demographic data and users' opinions. They are very similar to interviews in that they consist of predefined questions that can be both closed or open-ended (Sharp et al., 2019). One of the key benefits of a questionnaire is that once it is created, it can be distributed to a vast amount of users, which enables collecting a large amount of data during a short period of time (Sharp et al., 2019). This means that you can collect more data than what is possible through interviewing. In addition, you can include people in remote locations, and those who for some reason cannot participate in an interview at a particular time. Questionnaires have the potential to secure a good overview of the groups from which information is acquired (patients, doctors, experts). For this thesis questionnaires were used in order to gather demographic data from the patient-user group.

3.3 Human-Computer Interaction

Human-Computer Interaction (HCI) mainly focuses on the design, evaluation, and implementation of interactive computing systems intended for human use and the study of major occurrences surrounding them (Sharp et al., 2019). Until late in the 1970s, the only people who interacted with computers were information technology professionals and dedicated hobbyists. The emergence of personal computers in the later 1970s changed this, leading to a need for new developments. HCI emerged as a discipline in the early 1980s. The field builds upon many different disciplines, including computer science, sociology, psychology, communication, human factors engineering, industrial engineering, rehabilitation engineering, and many others (Lazar, Feng, & Hochheiser, 2017). Even though the research methods may have originated in other disciplines, they are modified for use in HCI. Since being introduced, HCI has expanded rapidly for four decades, engaging professionals from many other areas and has incorporated diverse concepts and approaches (Caroll, 2013).

3.3.1 User Centered Design

User Centered Design (UCD) is an iterative design process within HCI that focuses on the users and their needs in each phase of the design process (*User Centered Design*, 2020). The users are involved throughout the design process through a variety of research and techniques, to create products that are highly usable and accessible for them.

The basic principles of the UCD process include placing the user at the center of the design, focusing early on users and their tasks, measuring usability empirically, and designing iteratively, whereby a product is designed, evaluated, and modified with real users repeatedly in quick iterations (LeRouge et al., 2011; Ma & LeRouge, 2007).

3.3.2 User Experience

The User Experience (UX) is central in interaction design and HCI. By this, it is meant how a product behaves and is used by people in the real world (Sharp et al., 2019). Nielsen and Norman (2014) define UX as all aspects of the end-users interaction with the company, its services, and its products. One can not design a user experience, instead one can design for the user experience (Sharp et al., 2019). It is critical to focus on delivering a good user experience when developing an interactive product.

Older adults are posed with unique challenges such as limited motor skills and range of motion, affecting the use of computer devices. Further, impaired eyesight affects interaction with interfaces featuring small font size, and reduced speed, memory, and spatial ability affect the learning of software applications (LeRouge et al., 2011). Thus, when designing for an older user group, a deep understanding of the users and a well-constructed conceptual model is crucial for the process.

3.3.3 Interaction Design Life-Cycle

The interaction design life-cycle has four basic activities, including the following: discovering requirements and identifying needs, designing alternatives, prototyping and building an interactive version, and evaluating. The activities should follow an iterative process, which means they should be repeated until the cycle is “satisfied” (Sharp et al., 2019). Or in other words, until all the requirements are implemented in a satisfactory way, and the product is completed.

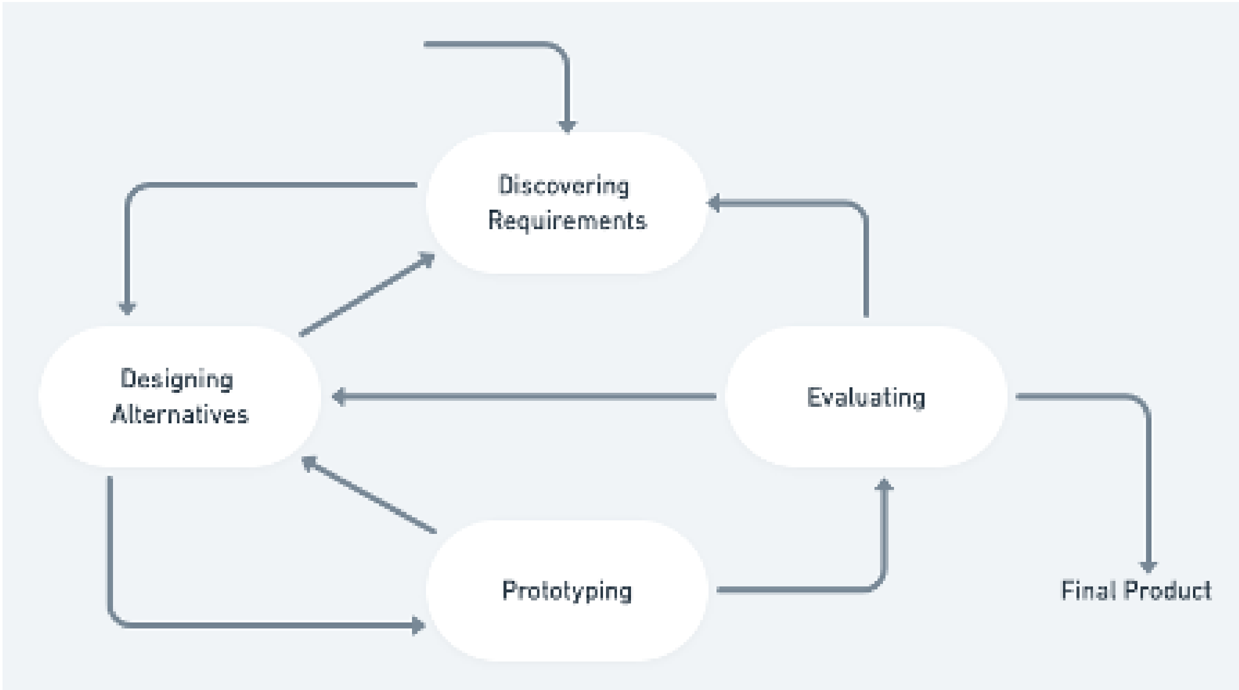


Figure 4: Interaction Design Life-Cycle Model (Sharp et al., 2019).

Discovering Requirements

One must understand and know the target group in order to provide a design that is both supportive and useful. The needs identified during this activity are used as a basis for the products' requirements, which supports the design and development process. Understanding of these needs is obtained through data gathering and analysis (Sharp et al., 2019).

Designing Alternatives

This is the key activity of any design process. Designing alternatives consists of proposing ideas that can meet the requirements. Sharp et al. (2019) suggests dividing this activity into two sub-activities: conceptual design and concrete design. Conceptual design involves how to transform the requirements into a conceptual model. Concrete design entails the details of the product, such as the colors, sounds, images to use, menu design, and icon design (Sharp et al., 2019).

Prototyping

The most effective way for a user to evaluate a product is by creating an interactive version a user can explore. It does not necessarily require a piece of software to prototype. When talking about prototypes, one usually categorizes prototypes in a range from low-fidelity to high-fidelity. A low-fidelity prototype is often a paper-based prototype, which is quick and easy to build, and effective for identifying problems early in the design process. A mid-fidelity prototype is a mixture of correct content and functionalities, but still missing key elements. High-fidelity prototypes are usually more sophisticated, meaning they are more functional and look more like the final version of the design. High-fidelity prototypes do not have to be perfect, but should in some form be interactive (Sharp et al., 2019).

Evaluating

This is the process of determining the usability and acceptability of the product or design. It is measured in terms of usability and user-experience criteria (Sharp et al., 2019).

3.3.4 Design Principles

According to Sharp et al. (2019), design principles are used by interaction designers to aid their thinking when designing for the user experience. These are generalized abstractions that are supposed to direct designers toward thinking about different facets of their design. The principles are a mixture of theory-based knowledge, experience, and common sense. Usually, they are written in a prescriptive manner; suggesting to designers what to provide and what to avoid in an interface. They are not intended to tell the designers how to design their interface but meant to act as triggers to ensure certain features are provided in an interface (Sharp et al., 2019).

The following sections will briefly explain the most common principles: visibility, feedback, constraints, consistency, and affordance.

Visibility

This principle refers to the visualization of different functions for a system. More specifically, a system can have multiple indicators that inform the user about different choices they have in a given situation. For example, the controls in a car that enables the driver (user) to perform different operations are obvious, such as hazard warning lights that inform the user of what can be done (Sharp et al., 2019). In contrast, functions that are out of sight are more difficult to find, and provide a little indication to the user how they should or can be used, for example, devices that have become automated with sensor technology such as faucets. People can experience problems with figuring out how to activate them, thus leading to a frustrating user experience (Sharp et al., 2019). In short, the more visible a function is, the more likely it is that a user will know what to do next.

Feedback

Feedback is related to the concept of visibility. It involves sending back information about what has been done and what has been accomplished, which allows the user to continue with the activity. There are various kinds of feedback available for HCI; audio, tactile, verbal, visual, and combinations of these (Sharp et al., 2019). When feedback is used in the correct way, it can also provide the necessary visibility for user interaction.

Constraints

This refers to restricting the kinds of user interaction that can take place at a given moment. Common in graphical user interfaces is to deactivate certain options in the menu by shading them. This restricts the user to actions only permissible at a certain stage in the activity they are performing (Sharp et al., 2019). Shading functions grey clearly indicates to the user that they are inaccessible. Constraints can prevent the user from selecting an incorrect option, which reduces the chances of making a mistake, which again can lead to a frustrating user experience.

Consistency

Consistency refers to designing interfaces to have corresponding operations and use similar elements for achieving similar tasks. For instance, an operation always using the same input action to select all files, is seen as consistent. On the other hand, inconsistent interfaces allow exceptions to the rule. An example is having the possibility to highlight objects by using the right mouse button, whereas all other operations use the left mouse button (Sharp et al., 2019). A key benefit of a consistent interface is that they are easier to learn and use. Users only have to learn a single operation that is applicable to all objects. Inconsistent interfaces make the user prone to make mistakes.

Affordance

In short, to afford means to “give a clue”. Affordance is a term used to refer to an attribute of an object that enables people to know how to use it. A door handle that requires pulling, or a mouse button that requires pushing, might be seen as a perceptually obvious affordance of physical objects (Sharp et al., 2019).

3.3.5 Usability Goals

Usability refers to how easy it is to learn a product, how effective it is to use, and how enjoyable it is overall from a user's perspective. The usability goals involve optimizing the different interactions people have with interactive products to help them better carry out their activities, whether it is at school, work, or their everyday lives (Sharp et al., 2019). Sharp et al. (2019) describe the six goals as follows:

- Effectiveness refers to how good the product is at doing what it is supposed to do.
- Efficiency refers to how the product supports users in accomplishing their goal/task.
- Safety involves protecting the user from undesirable situations and dangerous conditions.
- Utility refers to the extent to which the product provides the right kind of functionality so that the user can do what they need or want to do.
- Learnability refers to how easy the system is to learn to use. Users should not have to put more effort than absolutely necessary into learning a system.
- Memorability refers to how easy a product is to remember how to use, once the user has learned how to use it.

3.3.6 Conceptual Models

Understanding the problem space well is essential for design teams to be able to conceptualize the design space. Primarily, this involves articulating the proposed system and the user experience. According to Sharp et al. (2019), there are three major benefits of conceptualizing the design space early in the process. First, it enables the design team to ask specific questions about how the conceptual model will be understood by the users. Second, it prevents the team from becoming narrowly focused early on. Lastly, it allows the designers to establish a set of common terms that everyone can understand and agree upon. This reduces the chance of later misunderstandings and confusion. Once all is agreed upon, a conceptual model becomes a shared blueprint for the team to follow during the entire process. It can be used as a basis from which to develop more detailed and concrete aspects of the design for the design team (Sharp et al., 2019). Johnson and Henderson (2002) describes a conceptual model as a "high-level description of how a system is organized and operates". In other words, an outline of what people can do with a product and what concepts are needed to understand how to interact with it.

3.3.7 User Profiles and Personas

Axelsson (2006) defines a user profile as a group of individuals with the same perspective regarding information. A user profile provides a summary describing a collection of users. It is meant to include all the users within a group. It is less detailed than a persona, as it describes general ranges of frequencies of responses (Ma & LeRouge, 2007).

LeRouge et al. (2011) refer to Schwendeman (2006) when presenting common core demographic characteristics captured for a user group of interest. First, they mention the user's prior knowledge and experience. For example, website search proficiency. Second, physical characteristics, if the user is a mobile or stationary worker. Next, they mention cognitive characteristics. By this, they mean the user's preferred learning style. Then there is the social and physical environment; distraction level. Lastly, they mention jobs, tasks, and requirements, in essence, the key tasks for the system.

A persona is a rich description of the typical user for which the design is made. Personas go well beyond demographics, as they are intended to embody the user's mental model (LeRouge et al., 2011). In essence, they make users more human. Understanding who the intended users are is crucial to the success of the design. Personas should include name, age, likeness, occupation, goals, tasks, as well as habits, hobbies and expectations, and other information to provide dimension (Sharp et al., 2019). It is an aid to highlight key goals for the user. Typically developers and designers have a picture for their created persona.

According to Ndiwalana et al. (2005), developing and comparing a set of personas can help designers avoid creating over-generalized user definitions that merely adapt to the system design instead of guiding it. Another benefit the authors mention about personas is that they allow teams to run simulated ad-hoc user evaluations at any point in the design process without having to depend on resource-intensive user evaluations.

Based on the annual report in 2019 from the Norwegian Arthroplasty Register, there is a peak in graphs over hip and knee arthroplasty surgeries around the age 80 (*Norwegian National Advisory Unit on Arthroplasty and Hip Fractures*, 2021). Taking this into consideration, there are additional attributes that can be relevant to describe personas and enhance usability for this case. Retrieved from LeRouge et al. (2011): *existing computer skills and experience, educational level/intellectual abilities/skills of the user, general attitude towards technology, ownership, and use of mobile technologies, attitudes towards specific technology, and learning style.*

Ma and LeRouge (2007) cites Seffah, A., Naghshin, R., and Kline, R. (2003) when asserting that personas can be a useful technique in closing the gap between the intended users' tasks and experiences, and a software engineering tool's functionalities, it has the primary benefit of helping bring focus on not only the user interface design but also the whole software life-cycle, including the identification of functional requirements and marketing. In addition, they promote the development team synergy and communication by providing a shared framework to discuss the end-users and application environment. They can also facilitate creative and explicit design decision-making processes, as well as generating scenarios for future testing and evaluation of the design.

3.3.8 Scenarios

Scenarios are short descriptive stories illustrating how the user interacts with a system. They have a setting, agents or actors who have goals or tasks, and a sequence of actions and events. Scenarios share some of the same attributes as personas, which can be more compelling. According to Grudin and Pruitt (2002), however, scenarios are less effective without personas. Scenarios can, and should, be constructed around personas, but it is important that the personas come first. They are not 'actors' from a scenario, but real people for whom the design is intended.

Scenarios can encourage reflection during the design. They are concrete yet flexible - easily edited, extended, or discarded, and they can be viewed from different perspectives. Grudin and Pruitt (2002) further state that scenarios come with substantial risks and problems. There is often little discussion of the data on which the scenario is constructed, and they are often created to justify a particular feature. If a scenario is not created by an actual person for whom the design is made, it may include unrealistic assumptions. However, well-constructed and realistic scenarios can be the perfect tool for design.

3.3.9 User Stories

User stories are created to define functionalities, offering technical details that could be further programmed. It is written from the user's perspective and is only one sentence (Sharp et al., 2019). It should follow this form:

As a <user category>, I want <feature>, because <goal>.

3.4 Evaluation

This section will introduce different evaluation methods commonly used within HCI research which seem appropriate for this thesis. They are used to comprehensively evaluate systems and prototypes.

3.4.1 Likert Scale

A Likert scale is a simple and intuitive way of measuring variables such as opinions, attitudes, and beliefs. They are often used in order to evaluate the users' satisfaction with a product (Sharp et al., 2019). The Likert scale is a rating system, ranging from 1-5 or ranged by: strongly agree, agree, neutral, disagree, and strongly disagree. When using a Likert scale, the participant is asked to respond to a selection of predefined statements by ticking off the box which is suitable for them (Lazar et al., 2017).

3.4.2 System Usability Scale

The System Usability Scale, or SUS, is a simplistic scale that consists of a ten-question questionnaire (QNR). It offers a quick and accurate way of measuring the usability of a system. The questionnaires are answered with a Likert scale. The following is the ten questions that should be answered in a SUS (*System Usability Scale (SUS)*, n.d.):

1. I think that I would like to use this system frequently.
2. I found the system unnecessarily complex.
3. I thought the system was easy to use.
4. I think that I would need the support of a technical person to be able to use this system.
5. I found the various functions in this system were well integrated.
6. I thought there was too much inconsistency in this system.
7. I would imagine that most people would learn to use this system very quickly.
8. I found the system very cumbersome to use.
9. I felt very confident using the system.
10. I needed to learn a lot of things before I could get going with this system.

The scale is typically used after participants from the intended user group have tried the system that is being evaluated. This is because they should give their immediate response. All the questions must be answered. If the respondent is unsure they should tick the middlebox

(Brooke, 1996). Brooke (1996) explain the scoring of the system, and how it is calculated as:

> *"SUS yields a single number representing a composite measure of the overall usability of the system being studied. Note that scores for individual items are not meaningful on their own. To calculate the SUS score, first sum the score contributions from each item. Each item's score contribution will range from 0 to 5. For items 1,3,5,7, and 9 the score contribution is the scale position minus 1. For items 2,4,6,8 and 10, the contribution 25 is 5 minus the scale position. Multiply the sum of the scores by 2.5 to obtain the overall value of SU. SUS scores have a range of 0 to 100"*

3.4.3 Usability Testing

The main goal in usability testing is to find out whether the product being developed is usable by the intended user group in order to achieve the tasks for which it was designed, as well as whether the users are satisfied with their experience or not. Usability testings are normally done in controlled settings to reduce distractions and remove other potentially disturbing elements from the surroundings (Sharp et al., 2019). Controlled settings can be anywhere from a laboratory to a more casual setting like an office. This allows the designers to have control of what the users do, as well as control the social influences that might impact the user's performance. The users get a set of tasks and are observed and timed while solving them. It is common to record the session while observing, and if possible, log the keys that are being used. The collected data is used to calculate the performance and identify potential errors. Following usability testing, the participants are often interviewed or given a short questionnaire, e.g. SUS. The goal of usability testing is to identify any usability problems, collect quantitative and qualitative data, and determine the participant's satisfaction with the product (*Usability Testing*, n.d.).

3.4.4 Heuristic Evaluation

Heuristic evaluation is an informal method of usability analysis where a number of participants are presented with an interface design and asked to evaluate it. There are several advantages to this evaluation method: it is cheap, intuitive, does not require advanced planning, and it is easy to motivate people to do. The main advantage is that it can be used early and late in the development process (Nielsen & Molich, 1990). Nielsen and Molich (1990) also mentions a disadvantage of the method: sometimes it identifies usability problems without providing straightforward suggestions for how to solve them. In addition, the method is biased by the current mindset of the participants and normally does not generate breakthroughs in the evaluated design. However, it is a good indicator of what you have done and what further needs developing. Further, Nielsen and Molich (1990) recommend having three to five participants to maximize its potential.

When evaluating, there are 10 general principles, or heuristics. The principles one should follow are called heuristics because they are broad rules of thumb and not specific usability guidelines (*10 Usability Heuristics for User Interface Design*, 1994):

1. Visibility of system status.
   The system should always keep users informed about what is going on, through appropriate feedback within a reasonable time.

2. Match between system and the real world.
   The system should speak the users' language, with words, phrases, and concepts familiar to the user, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order.

3. User control and freedom.
   Users often choose system functions by mistake. Therefore the system should support undo and redo functions.

4. Consistency and standards.
   Users should not have to wonder whether different words, situations, or actions mean the same thing.

5. Error prevention.
   Either a careful design which prevents a problem from occurring in the first place or good error messages. At least check for error-prone conditions and present users with a confirmation option before they commit to the action.

6. Recognition rather than recall.
   Minimize the user's memory load by making objects, actions, and options visible. Instructions for use of the system should be visible or easily retrievable whenever appropriate.

7. Flexibility and efficiency of use.
   Accelerators, not seen by the novice user, may often speed up the interaction for the expert user, therefore the system can cater to both inexperienced and experienced users. Allow users to tailor frequent actions.

8. Aesthetic and minimalist design.
   Information rarely needed or that is irrelevant should not be presented in dialogues. Every additional unit of information in a dialogue competes with the relevant information and may diminish their relative visibility.

9. Help users recognize, diagnose, and recover from errors.
   Error messages should be expressed in plain language, not in codes, giving the user a precise indication of what the problem is, and suggest a solution.

10. Help and documentation.
    The best systems can be used without documentation. However, sometimes it may be necessary to provide help and documentation for the user. Any such information should be easy to search, focused on the user's task, and not too large.

3.5 Kanban

Kanban was used for this research through the design stages to easily keep track of the progress. Kanban is an agile development method. Agile development is an iterative, step-by-step development approach that provides a high level of flexibility. In agile development, one divides the project into sub-projects, and the results of each sub-project are tested together with integrated and operational features. In other words, a large project is split into multiple small projects that are related to each other but can also run independently and be completed separately. Agile development is highly collaborative; it is a fast-moving process, and team members hold meetings frequently. Kanban boards are used to visualize the workflow of the team (Al-Baik & Miller, 2014).

4 Requirements and Ethical Concerns

This chapter presents the ethical considerations for this research, as well as the requirements made for the prototype.

4.1 Research Ethics

Proper measures have been taken throughout the research process to ensure that all participants have been treated with respect. By this, it is meant that each participant was informed about their right to confidentiality and anonymity. Each participant was asked to read and sign a consent form before participating.

This research has been approved by the Norwegian Centre for Research Data (Norsk senter for forskningsdata - NSD). The approval can be found in Appendix A. The consent form and interview guides can be found in Appendices B and C, respectively.

4.2 Research Participants

4.2.1 Non-experts

The non-experts who have contributed to this research were requited through personal connections. The group consisted of four participants, two women and two men, who performed usability testing and conducted a SUS. In addition, 49 patients responded to the questionnaire gathering quantitative data.

4.2.2 Experts

Four field experts, three usability experts, and five IT experts contributed to the research, all of whom have degrees or experience within information science or the UX / HCI / Design field. They evaluated the prototypes at various stages using usability testing, Nielsen's Heuristics, and SUS.

4.3 Establishing Requirements

Establishing requirements is not simply creating a list of features one wants; one has to know who the users are and identify and understand their needs. There are two sets of requirements, functional and non-functional requirements. Functional requirements capture what the product should do, while non-functional requirements indicate how the system should behave (Sharp et al., 2019).

The requirements for the prototype were established through conversations with the Norwegian Arthroplasty Register, the patient questionnaire, and reading existing literature. All gave valuable information about what the system should and should not do.

4.3.1 Functional Requirements

The functional requirements describe how the system is supposed to work (Sharp et al., 2019). The functional requirements for the prototype are:

- Inform the user about what type of activities that can be performed
- Present information about risk factors connected to age, sex, height, and body weight
- Present information about different implants
- Present information about the longevity of different implants
- Include a dictionary for patients
- Present statistics for clinicians and researchers
- Allow the user to detect risk factors for THA and TKA analysis
- Allow the user to perform cluster analysis
- Allow the user to generate survival curves

4.3.2 Non-functional Requirements

The non-functional requirements describe how the system should behave, meaning how it should look. It explains its development, as well as the constraints for the system (Sharp et al., 2019). These are the non-functional requirements for the prototype:

- The system must be easy to learn and use
- The system has to be user friendly (easy to use for a wide range of people)
- The system must do what the user expects it to do
- Have a pleasing yet minimalistic design
- The system should work for all browsers

5 Prototype Development

This chapter presents the development process, along with the tools used throughout the research to create the final prototype.

Originally, the prototype was to be created with as much functionality as possible, using HTML, CSS, JavaScript, and libraries such as React.JS. However, due to a delay in data delivery from the register, Adobe XD was chosen to create the high-fidelity prototype instead.

5.1 Development Tools

5.1.1 Xtensio

Xtensio is an online tool to help developers categorize, make and illustrate a persona (*Xtensio*, 2021). The software comes with a couple of pre-made traits of different types of persona, mostly aimed at the industry, but all can be altered to fit a specific case.

5.1.2 Balsamiq Mockup

Balsamiq Mockup is an online prototyping tool for mobile and web platforms. It is a focused low-fidelity user interface wireframing tool that aims to recreate the experience of sketching on paper using a personal computer (*Balsamiq. Rapid, effective and fun wireframing software*, 2021). It lets developers convey their design in more precise detail.

5.1.3 Adobe XD

Adobe XD is a digital prototyping tool for creating interactive solutions for both mobile and web applications, created by Adobe studios. Adobe XD lets designers easily create highly interactive prototypes. Many of its built-in features let the designer draw, shape, and form different features such as buttons and functions (Rae, 2020).

5.1.4 Trello

Trello is a tool for web-based project management. The tool has several uses, such as law office case management, real estate management, and software project management. Trello uses the Kanban model for managing project (*Getting started with Trello*, 2021). It was utilized both for team Kanban and Personal Kanban.

5.2 Iteration Overview

Figure 2 shows an overview of the different iterations during this research in terms of stage of development, methods, and outcome.

Iteration	1	2	3	4	5
Define / Redefine	Define	Redefine	Redefine	Redefine	Redefine
Fidelity	N/A	Low	Low-Mid	Mid-High	High
Method	Literature review and interview with researcher	N/A	Design Principles and QNR with patients	Presentation for experts	N/A
Evaluate	Meeting with NAR	Discussion with team	Discussion with team	SUS and Nielsen's heuristics with field experts and usability experts	Usability test, SUS and Nielsen's heuristics with IT experts and novice users

Table 2: Iteration Overview.

5.2.1 Collaboration - Kanban

This research is partly done in collaboration with three other master students. The team consisted of two students focusing on back-end development and data mining, while two explored front-end aspects such as user-friendliness and visualizations. The back-end and front-end teams worked together closely; by discussing and exploring different ideas, methods, and features throughout the entire thesis.

As mentioned in Section 5.1.4, Trello was used to maintain the Kanban workflow. In total, the team had three Kanban boards; one for back-end, one for front-end, and one for both aspects of the project. The board used for the front-end team can be viewed in Figure 5.

A board consisting of lists containing specific tasks that had to be completed was created. Each task was color-coded with "prototype", "visualization", or both. In addition, each smaller task was color-coded in relation to the corresponding "main" task, e.g. demographic data. Further, we grouped the flow of the items into "To-Do", "Doing", and "Done", and transferred items from one list to another in a consecutive work order.

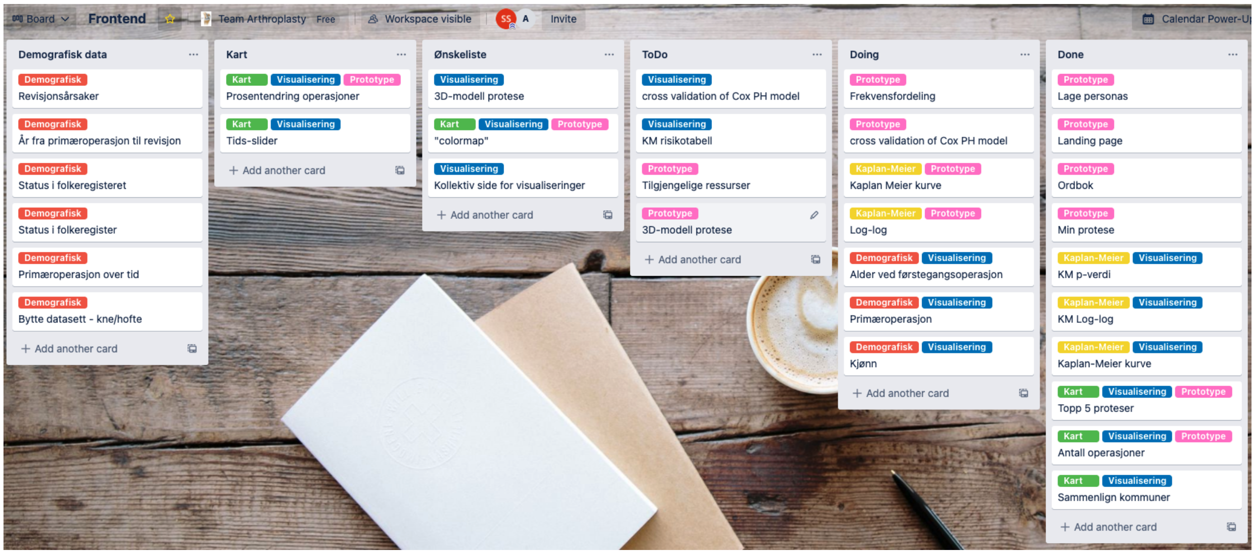


Figure 5: Trello board used by the front-end team.

5.3 First Iteration - Conceptualizing

Iteration one consisted of carrying out a literature review, and proof of concept discussion. As a result, the proposed platform solution was created. The solution is divided into two; one for expert users such as researchers and physicians that lets them utilize the arthroplasty register data in a more efficient way than the register currently allows, and performing data mining with a user-friendly front-end solution. Secondly, the patient aspect gives patients information about their procedures and implants, as well as a dictionary and other potential resources. Both aspects focus on total arthroplasty regarding the knee and hip areas. It is designed for desktop devices.

The first iteration of the prototype development was conducted during the thesis proposal. Three initial personas were created. The initial personas are depicted in Figure 6 and include one physician, one medical student, and one patient. Based on the annual report in 2019 from the Norwegian Arthroplasty Register, there is a peak in graphs over hip and knee arthroplasty surgeries around the age 80 (*Norwegian National Advisory Unit on Arthroplasty and Hip Fractures*, 2021). Taking this into consideration, the patient persona represents an older demographic.

Figure 6: Three initial personas.

5.3.1 Meeting with the Norwegian Arthroplasty Register (NAR)

To assess the feasibility of the proposed platform, a meeting was initiated with two experts in biomedical engineering, one statistician, and a chief surgeon in Orthopedics at the Haukeland University Hospital in Bergen, Norway. The team presented their theses. The presentations were well received, and lead to a lengthy discussion regarding what topics could be explored. The scope of the project was considerably scaled-down, as it was rather abstract at this point. It was decided that the team should focus on two main user groups: an expert group including physicians and researchers, and patients (non-experts). However, the register indicated they were positive to expand the system to a larger audience, e.g. medical students, at a later time. How to arrange interviews and user testing with patients was also discussed, but unfortunately, it became evident in later iterations that this was not feasible due to the COVID-19 pandemic. Instead, a questionnaire was distributed to patients. The questionnaire will be discussed in more detail in Section 5.5.3.

5.3.2 Interview with Researcher

An interview with a biomedical engineer was conducted to gather information regarding the interactivity of the register, and how it is being used today. It was discovered that there are only two ways to access the data: (1) by looking at individual cases, or (2) looking at the annual report. The report presents the data in a standardized way that is commonly used in medical literature. It appeared that this practice serves its purpose, but the problem is that one cannot interact with results, meaning one cannot specify on distinct variables that are not set for the annual reports. For instance, if the report stratifies on sex, one cannot alter it later. This becomes a problem in the cases where one wants to see how a certain variable is affecting the outcome.

5.3.3 Proof of Concept

The literature overview, the meeting with the Arthroplasty Register, and the interview with the biomedical engineer gave a good indication that a desktop application would be a beneficial contribution to the user groups. It was also clear that it would be necessary to make some changes to the established requirements, as well as what would have to be taken into consideration in terms of functionality for physicians and researchers as compared to functionality for patients.

5.3.4 Introducing New Personas

As discussed in Section 3.3.7, the goal of a persona is not to describe real people but to base the persona on a realistic image of people. Two new, more detailed, personas were created for this thesis. Their aim was to help keep the focus on the users and establish a clear picture of their needs through the process. The personas are depicted in Figures 7 and 8, respectively, followed by associated user stories and scenarios.

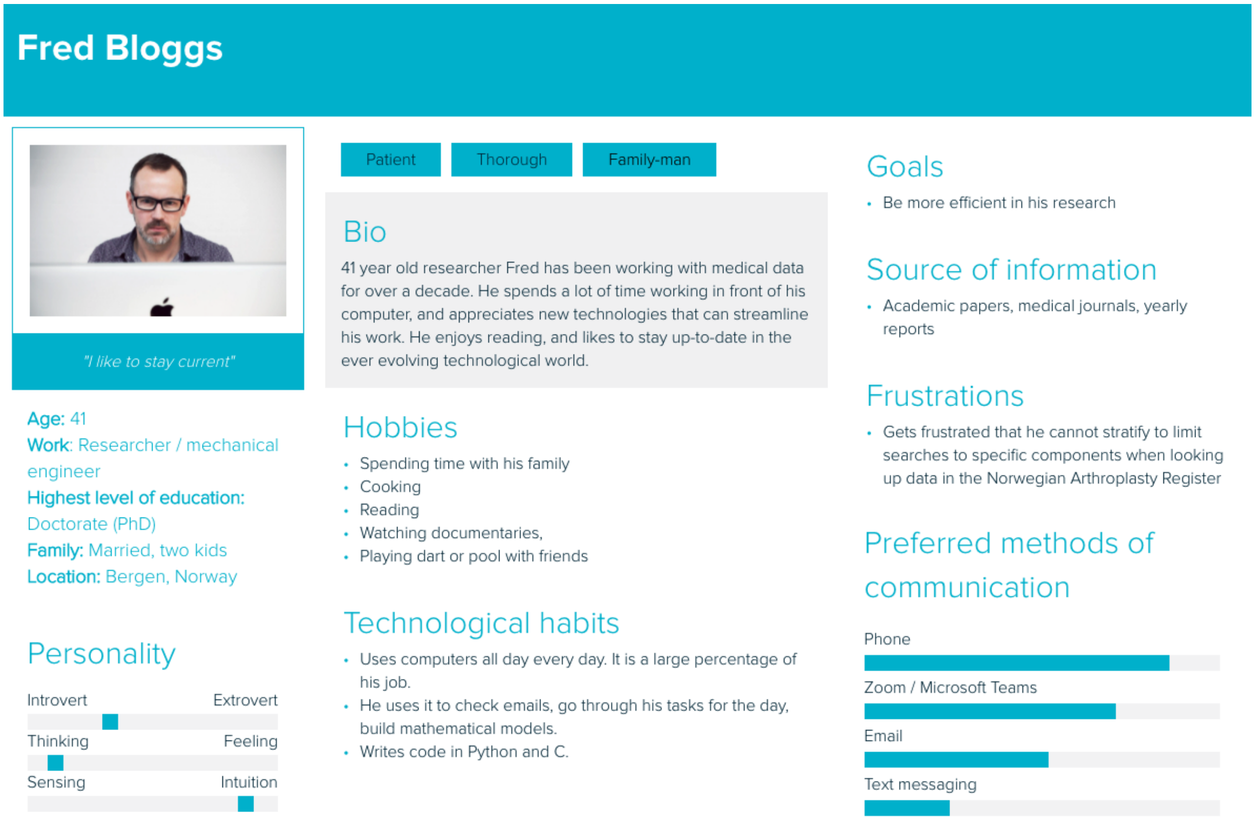


Figure 7: Persona 1: Fred Bloggs.

Fred Bloggs User Stories

- As a researcher, I want to be able to limit searches, because that makes my research more efficient.
- As a researcher, I want to set my own search criteria, because that gives me the exact information I need.

Fred Bloggs Scenario

Fred Bloggs is just finished teaching his kids for the day and is about to start working. He logs into his computer, and checks his email, and reads some news. He then goes through his tasks for the day, and notice he has to look up something in the Norwegian Arthroplasty Register. He navigates to LeddPOR. He wants to limit his search to show the difference between two prostheses. He uses the drop-down menu and selects the two he wants to compare, and he gets the desired result.

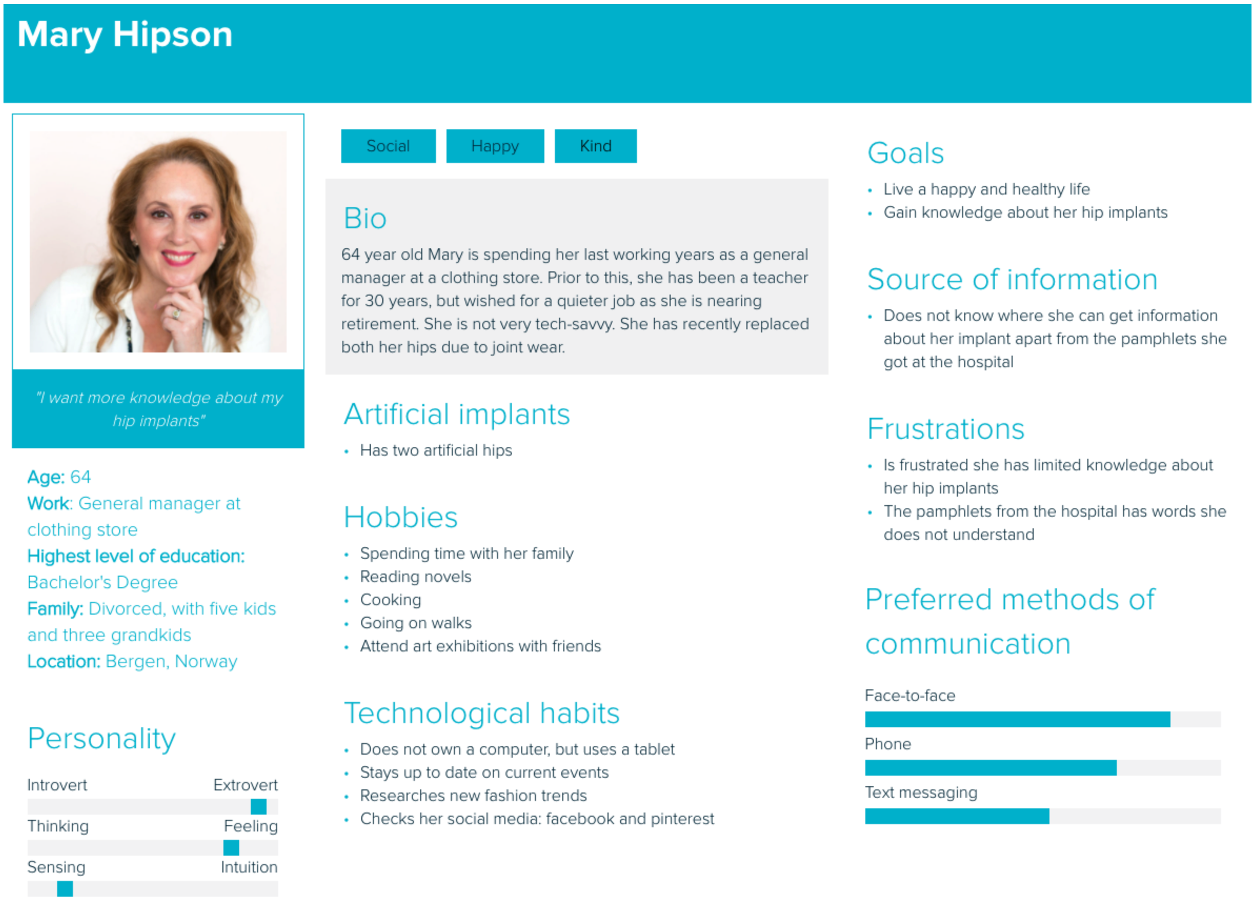


Figure 8: Persona 2: Mary Hipson.

Mary Hipson User Stories

- As a patient, I want to be able to look up information about my implant, because I want to educate myself.
- As a patient, I want easy-to-read visualizations, because I want to understand the information presented to me.

Mary Hipson Scenario

Mary has recently had a double THA and wants to learn more about her new prosthetic hips. She looks at the pamphlets she got from the hospital post-surgery, but has trouble understanding the information because of all the difficult words. She opens her laptop and navigates to the LeddPOR website. She looks up the words she did not understand in the dictionary.

5.4 Second Iteration - Low-fidelity Prototype

A low-fidelity prototype is a visual representation of the basic design of a product. It is not meant to look like the final product and is often used to explore different ideas. Low-fidelity prototypes are often created using simple tools such as pen and paper drawings. This is a very useful method to keep the process simple, reduce cost, and easily modify the prototype to explore different design ideas. These kinds of prototypes usually have a limited set of functions. Their main purpose is to represent them visually, not being able to perform a given function (Sharp et al., 2019).

5.4.1 Sketching

The first version of the application was created with pen and paper, and several sketches were created to explore different ideas and design solutions. Figures 9, 10, and 11 show a selection of final sketches for the prototype. They include a homepage where the user gets general information about hip and knee arthroplasty. Other functionalities in the first prototype include a map of Norway, a dictionary for patients, and a contingency table for physicians and researchers.

The dictionary (Figure 9) is meant to work as an encyclopedia for patients. It contains technical terms from arthroplasty, to make it easier for patients and others with limited knowledge about arthroplasty to improve their knowledge about the topic, as well as navigating the system. The default page of the dictionary contains a list with relevant words accompanied by a suiting and simple description. The dictionary can be filtered by letter.

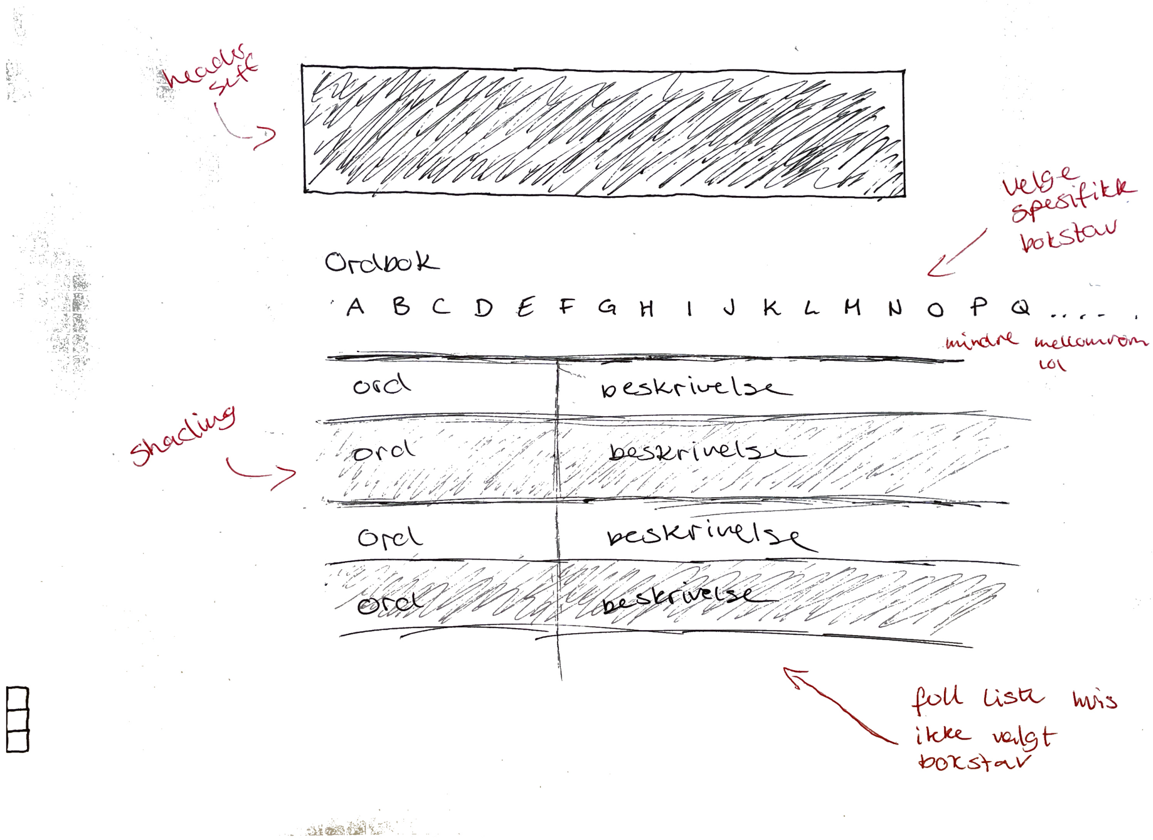


Figure 9: Low-fidelity dictionary.

The map (Figure 10) contains a map of Norway, where users can see various information regarding arthroplasty from the different counties. The content of the map was determined at a later stage (Section 6.5).

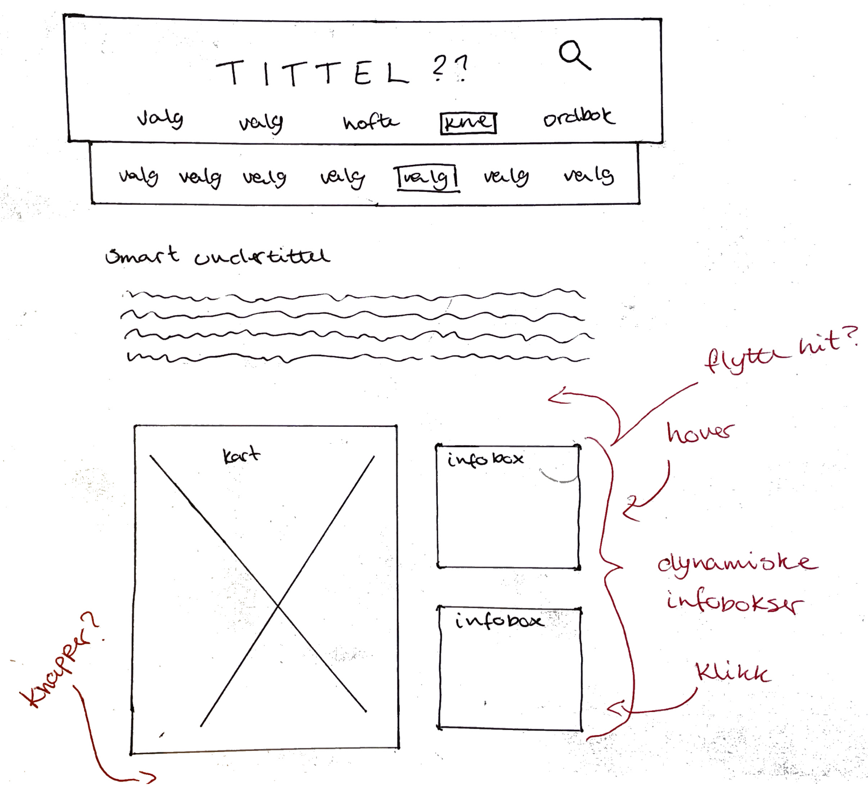


Figure 10: Low-fidelity map.

The contingency table (Figure 11) contains various input fields to create a table with requested values. This page is meant for expert users only. A contingency table is often used to record and analyze the relation between two or more variables. In data mining, they are often used to show what items are presented together

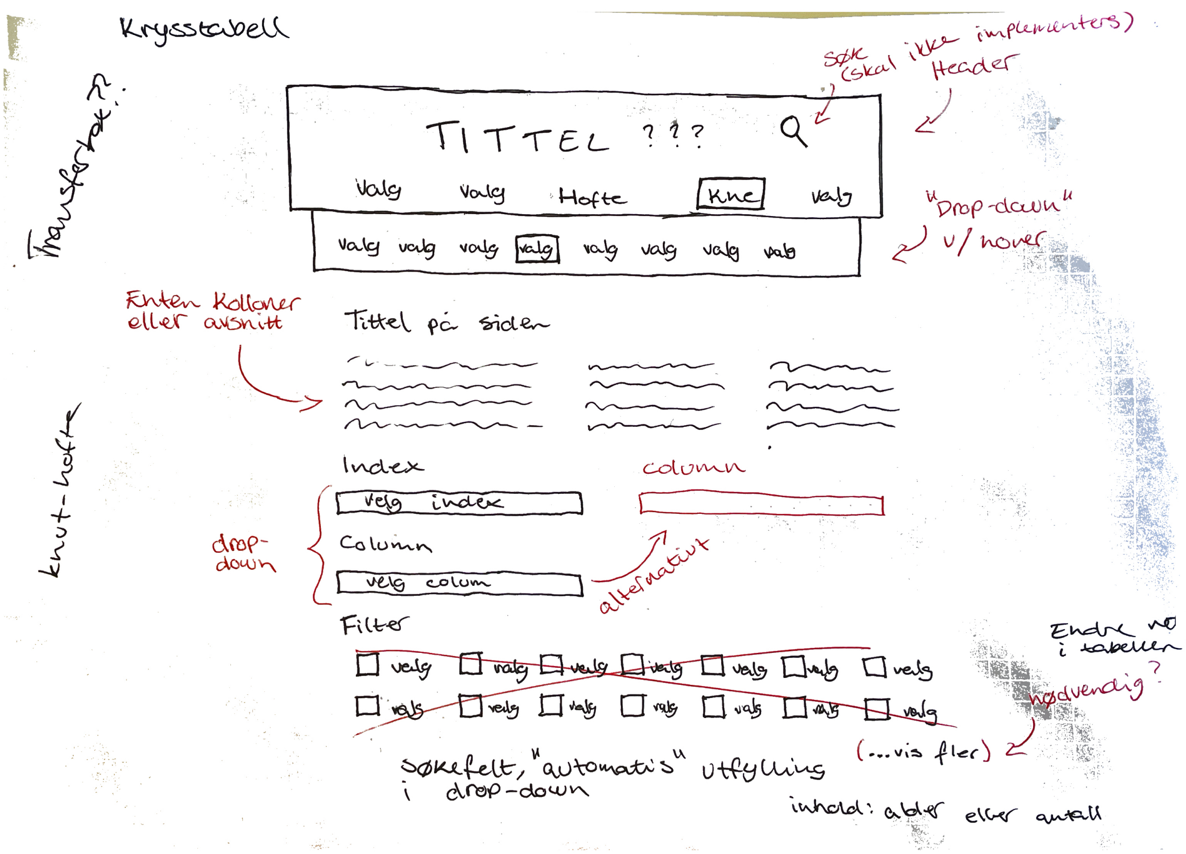


Figure 11: Low-fidelity contingency table.

5.5 Third Iteration - Low / Mid-fidelity Prototype

The third design iteration consisted of redefining and implementing requirements. These were used to create a low/mid-fidelity prototype (wireframe) in Balsamiq Mockup. Before creating wireframes, the design principles were reviewed to make sure they were satisfied in the prototype.

5.5.1 Design Principles

To ensure quality and usability in the current prototype the design principles were reviewed to see if they were well-integrated, or if there were design decisions that needed reconsidering in order to better suit the principles.

Visibility was accomplished by presenting the main functionalities in the header following each page. Less critical functions are "hidden" in a drop-down menu from each of the main functions, to ensure the main functions are more visible.

Feedback was accomplished by adding titles to each page. This enables the user to see where in the system they are located at any given time. The buttons, and other clickable elements, change color when pushed. This provides the user with visible feedback that compliments their action.

Constraints were assessed later in the design process. Constraints are important to ensure the user is not pushing the wrong buttons or unintentionally putting themselves in an unwanted situation.

Consistency was accomplished by reusing design elements. Buttons, title placements, fonts, and colors all have the same design all throughout the system.

Affordance was accomplished by using layouts that are common in desktop applications, such as Helse Bergen (*Helse Bergen*, 2021).

5.5.2 Wireframes

As mentioned in Section 5.1.2, the wireframes were created in Balsamiq Mockup. The prototype had evolved from pen and paper drawings to digital wireframes, classifying it as a low/mid-fidelity prototype. A wireframe is more detailed and closer to an actual product than sketches. The focus was still on a user-friendly layout and functionality. Colors and other definite elements such as icons and graphs will be introduced in the next iteration. The dictionary can be seen in Figure 12, the map in Figure 13, while the contingency table can be seen in Figures 14 and 15. The latter now depicts results. After finishing the prototype, a meeting with the team was held to discuss the results achieved at this stage.

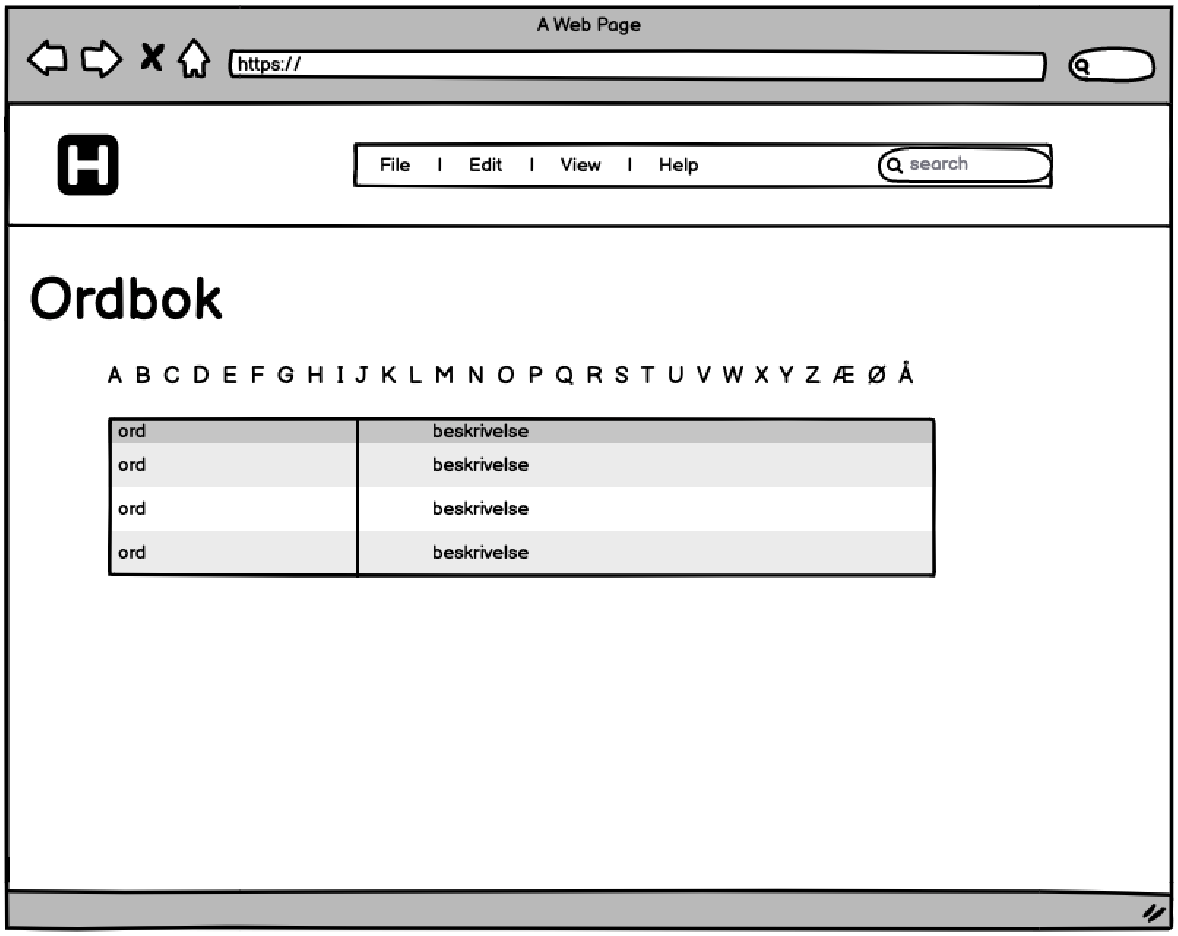


Figure 12: Low/mid-fidelity prototype dictionary.

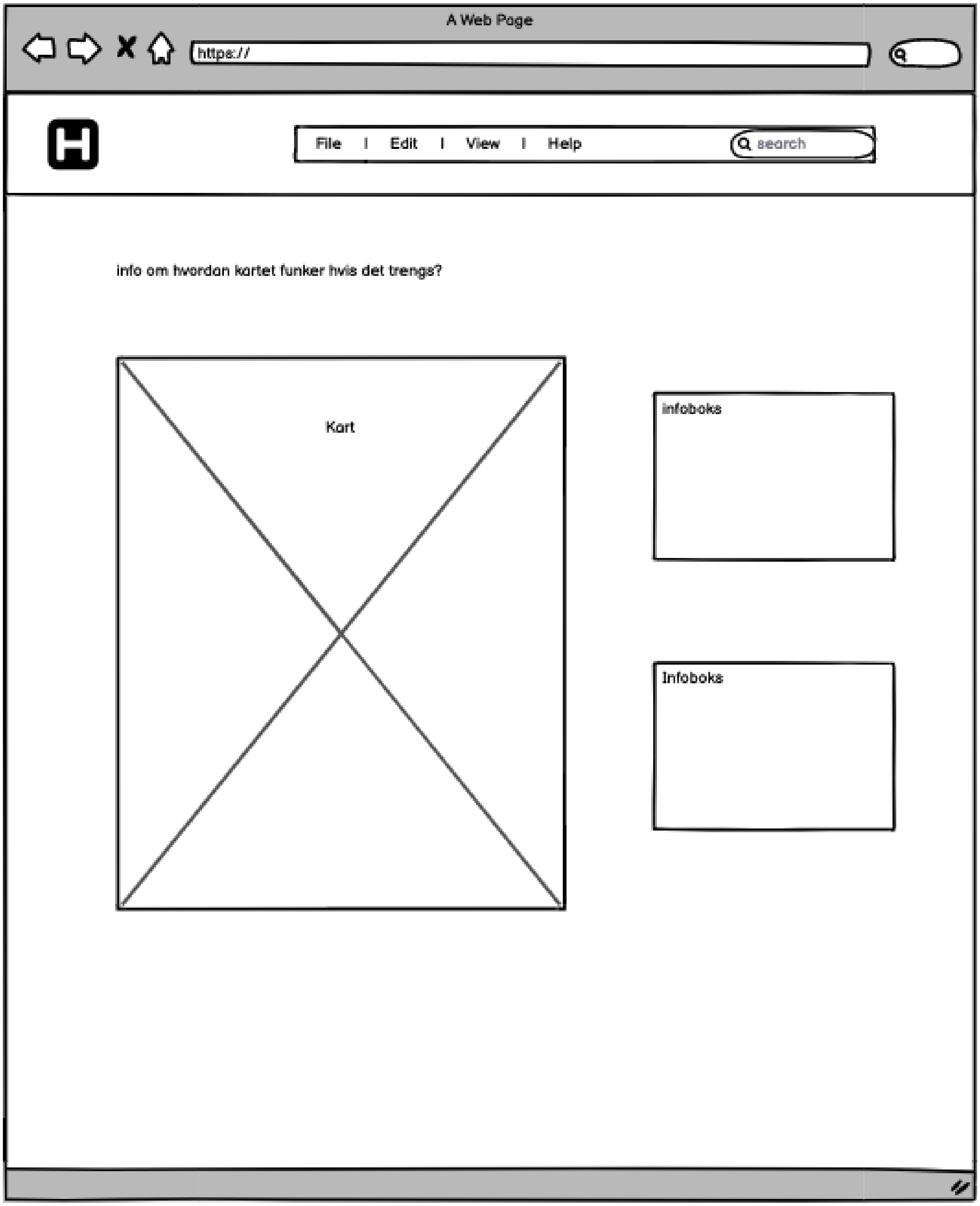


Figure 13: Low/mid-fidelity prototype map.

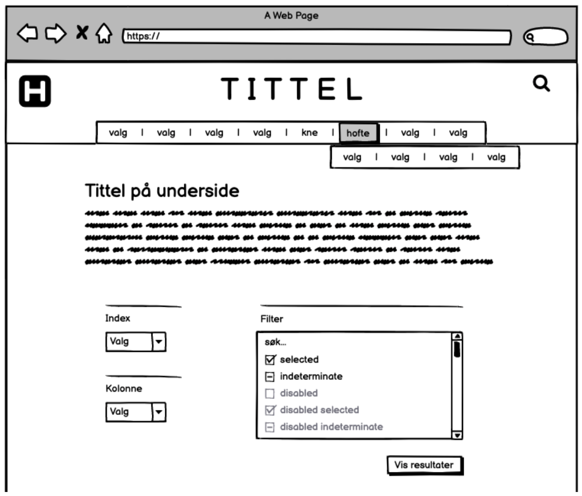


Figure 14: Low/mid-fidelity prototype contingency table input.

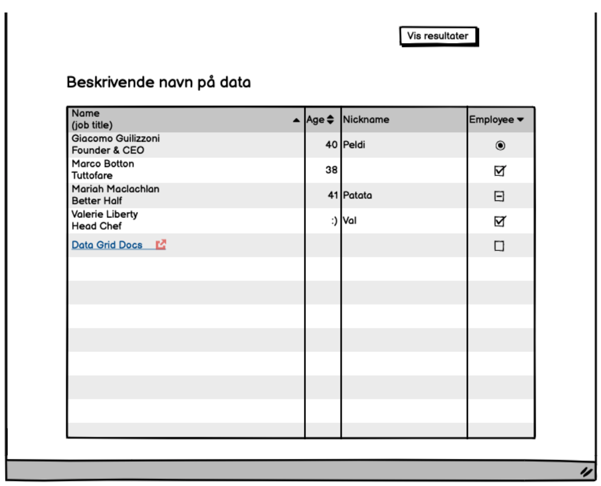


Figure 15: Low/mid-fidelity prototype contingency table results.

5.5.3 Patient Questionnaire

A questionnaire was distributed to patients who have had THA and/or TKA. The aim was to understand state of art and current information needs. 49 patients answered the questionnaire. Results suggested that 18.4% felt they had inadequate knowledge about implants, 57,1% felt they had medium knowledge, while 24,4 % felt they were comfortable with what they knew about implants. 36,7% did not know what implant they had gotten. Patients with less knowledge indicated they wished to become more educated about the topic. The most common response to what information they would like to have access to included information about implants, possible risk factors, relevant data regarding patients with the same implant as them, relevant data regarding patients within the same age group as themselves, and life expectancy of the implant, meaning the longevity. 73,5% were positive to an online dictionary containing words and subject concepts within arthroplasty.

5.6 Fourth Iteration - Mid / High-fidelity Prototype

The third prototype created can be classified as a mid/high-fidelity prototype. A mid-fidelity prototype is a prototype with very limited functionality, but enough functionality to add the ability of navigation and interaction. The prototyping software Adobe XD was utilized to design a prototype in a web-page format. Clickable elements, such as buttons, and text were added. Just like the previous iterations, the prototype was designed for internet browsers such as Google Chrome, Mozilla Firefox or Safari. All the main elements from the earlier prototypes were kept, and some additional elements were added. This was done based on answers from patients in the questionnaire, and discussion with the development team. The main focus in this iteration was to finalize the design elements such as colors, icons and data visualizations. The homepage can be seen in Figure 16 Additional pages for expert users were added, such as a survival rate curve (Figure 17) and Cox Regression (Figure 18).

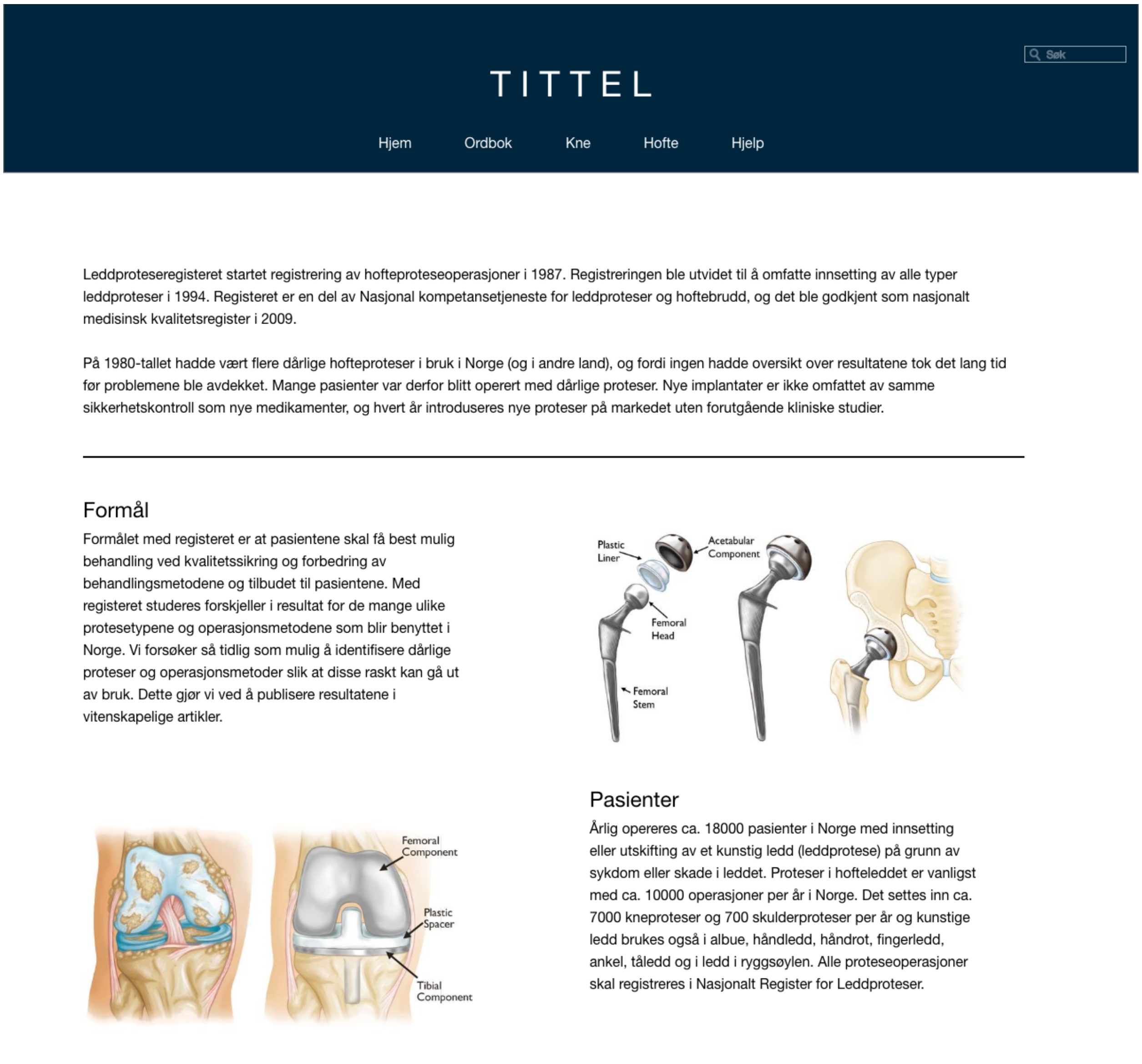


Figure 16: Homepage, mid-fidelity prototype.

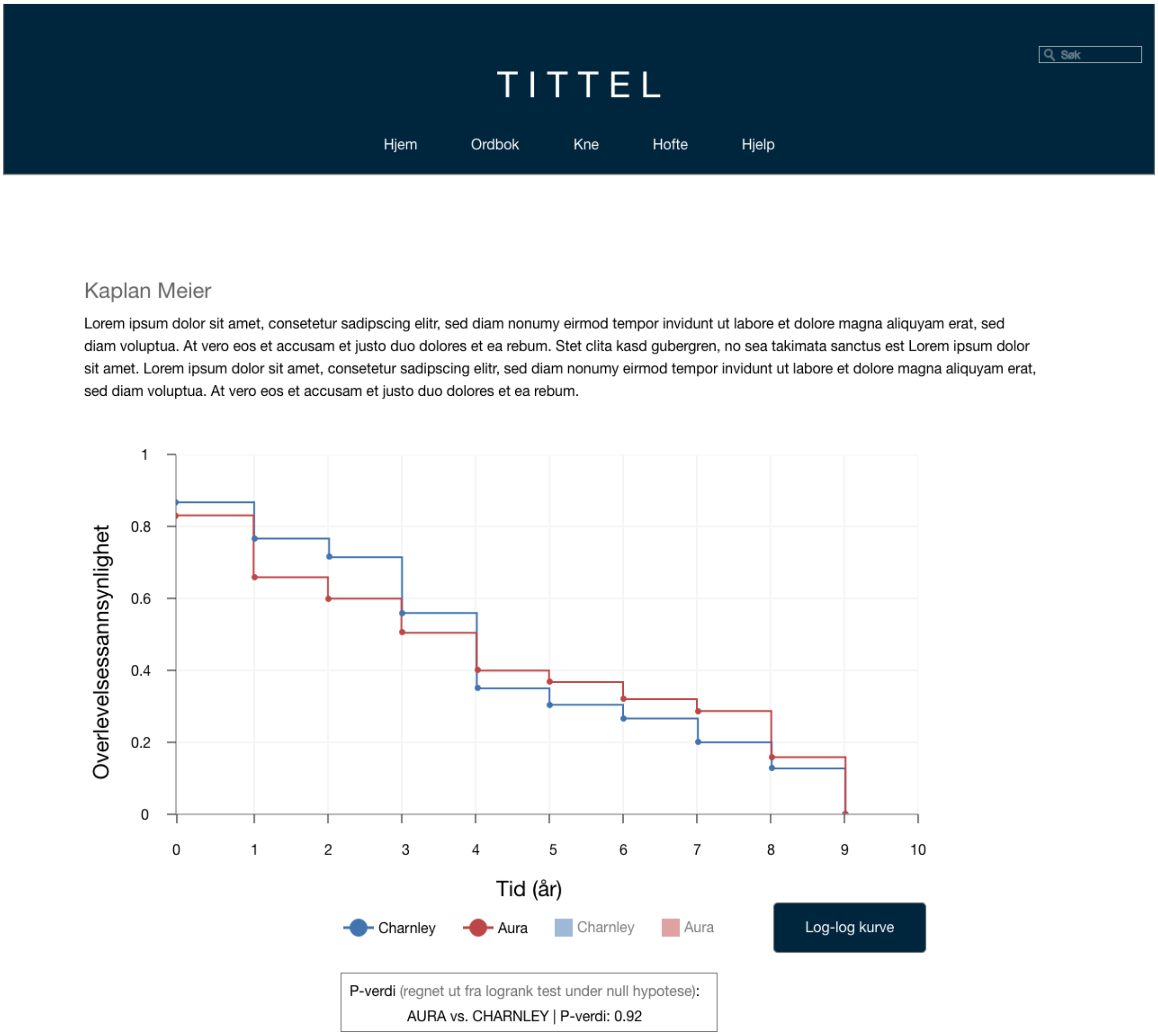


Figure 17: Survival Rate Curve, mid-fidelity prototype.

The Cox regression function (Figure 18) was created in close collaboration with Knut Hufthammer (2021), as he provided the back-end solution for this function. We discussed multiple different ideas and solutions, such as where to put a drop-down menu or checkbox options, based on his personal experiences with Cox Regression models.

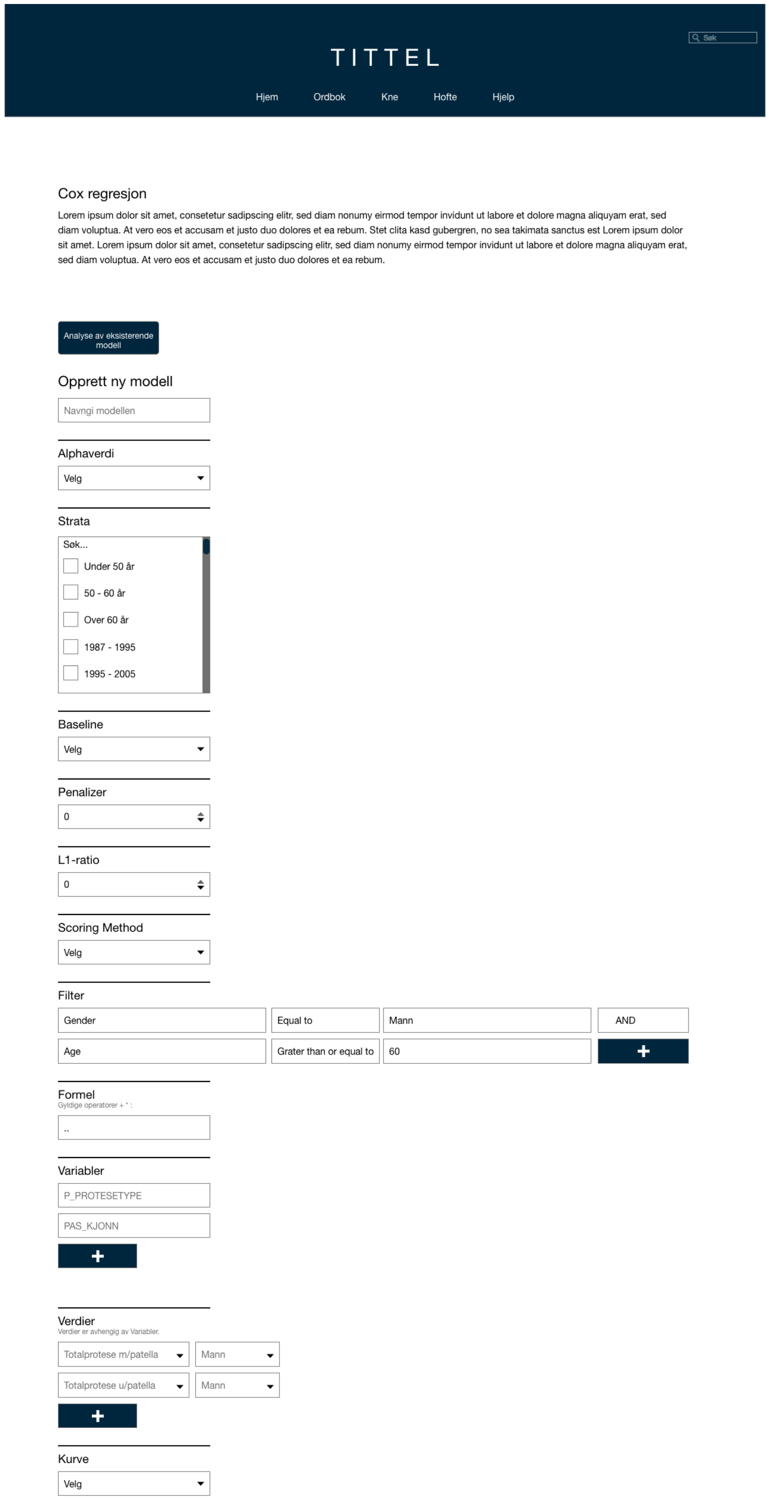


Figure 18: Cox model, mid-fidelity prototype.

5.6.1 Change in Development Plans

This iteration initially started with the intent of implementing the prototype using HTML, CSS, and JavaScript. This was done to some extent, with the map page being fully implemented in close collaboration with Arle Farsund Solheim (2021). However, the data provided to the back-end team was delayed. As a consequence, it was decided to divert to Adobe XD for the front-end development due to time limitations. As a result, there exists a prototype of the map with higher functionality than the map presented in this thesis, which can be viewed in Arle Farsund Solheim's work. It has not been included in this thesis, as changes have been made to the design since this iteration.

5.6.2 Finishing Design Elements

Color Scheme

The color scheme was finalized in the fourth iteration. Input from expert users highly influenced the choice of the color scheme. When data from the medical field, it is important that the users trust the system. To gain the trust of the users, it was decided to choose colors similar to the ones used in Helse Norge's websites. The color scheme is also comfortable for the eyes. The prototype features a white background color and black font. This is to ensure a distinct contrast between the text and background, making the text more visible to increase readability. This is also evident in the button design, with a dark blue color in contrast to white text.

Figure 19: Color scheme for final design.

Font

The font used for the final design is Helvetica Neue. The font was found in the Adobe XD font library. It is a widely used grotesque and sans-serif font, meaning it does not have extended features called "serifs" at the end of strokes. Helvetica Neue is a combination of aesthetic and technical refinements that result in superior design proportions, improved legibility, and an expanded range of uses beyond the original Helvetica typefaces (*Neue Helvetica® Font*

Family Typeface Story, n.d.). The font was used in bigger sizes for headings and subheadings and can be seen in Figure 20.

Figure 20: Helvetica Neue.

Data Visualization

One of the requirements for this iteration was to include different types of visualization which were based on the different kinds of data in the register and analysis of these. It was expected that users could benefit from three main types of visualization, namely scientific visualization, information visualization, and visual analytics (Chou, 2019).

Scientific Visualization

Scientific visualization focuses on the visualization of three-dimensional phenomena, such as architecture, medicine, biological systems, etc. The purpose is to illustrate scientific data graphically, to enable scientists to understand, explain and collect patterns from the data (Chou, 2019).

Information Visualization

This branch of data visualization is the study of "interactive visual representations of abstract data to enhance human cognition". Abstract data can be both digital and non-digital data, e.g. text. Graphics such as trend graphs, flow charts, tree diagrams, and histograms are all examples of graphics transforming abstract data into visual information (Chou, 2019).

Visual Analytics

With the development of scientific- and information visualization, visual analytics has evolved. It has an emphasis on analytical reasoning through an interactive visual interface (Chou, 2019).

Arle Farsund Solheim (2021) provided the data visualizations for the prototype. A selection of graphs can be seen in Figures 21. These particular graphs display the five most common revision causes and the age of the patient during their first surgery, respectively.

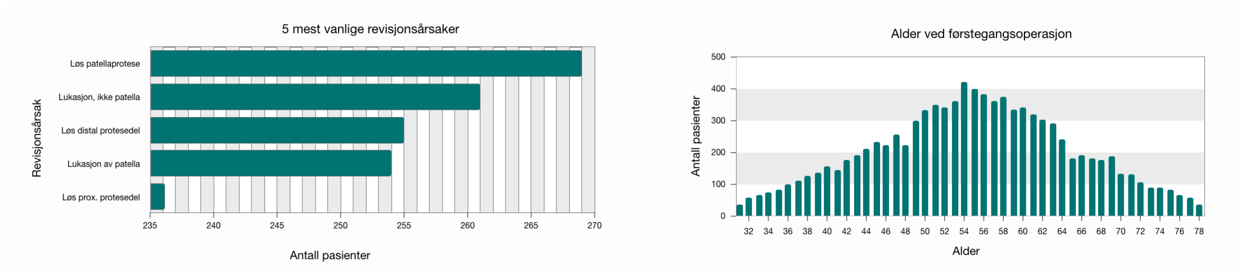


Figure 21: Example visualization. Left: Revision causes. Right: Age during first surgery.

5.6.3 SUS and Nielsen's Heuristics with Field Experts and Usability Experts

Seven participants evaluated the third prototype. The team presented their work to two groups of experts. The presentations were held over video call using Zoom. After the work was presented, the participants could comment or give verbal feedback. Following the presentations, they were given a link to the prototype, so that they could look at it at their own time while filling out a SUS form, and a form containing Nielsen's Heuristics. The participants were explained that the goal of the test was not to test if they understood the content, but rather if it was user-friendly and clear. The participants were told to focus on all elements of the system. The resulting SUS scores ranged from 60 to 90, which corresponds to grades "D" to "B". The SUS will be discussed in more detail in Chapter 7.

5.7 Fifth Iteration - High-fidelity Prototype

In iteration five, a high-fidelity prototype was created in Adobe XD. This would be the final prototype for this thesis. The main modifications in this prototype were based on the feedback and evaluation provided by field experts and usability experts.

5.7.1 Redefining System Outline after Expert Feedback

Based on the feedback from the Heuristic evaluation and SUS, a couple of changes were made to the prototype. Both the field experts and usability experts were in agreement that the functions for researchers and physicians should not be available for the patient group. As one of the participants pointed out, words like survival rate curve can be scary for patients or nervous relatives. This led to a total restructuring of the system, redesigning the header navigation, and implementing a log-in function for expert users, making sure patients do not get access to information not meant for them. Other suggestions were adding icons for both expert and non-expert users, in particular for information and help. One of the participants suggested adding a search function to the dictionary, giving users the opportunity to search for specific words rather than scrolling through a long list of words.

Even though the participants overlooked it, none of the pages specified if they were looking at hip or knee data, so headings to indicate this was also added.

5.7.2 High-fidelity Prototype

The changes suggested in the evaluation were implemented in the last prototype. The expert user functions, which previously were available to patients have been restricted by log-in access. Additional resources for patients were also implemented, such as information about implants and available mobile applications for post-operative care. More details about the final functions and design are described in Chapter 6.

Icons

The icons used in the final design are from Flaticon. Flaticon is a platform with both free and licensed icons (*Flaticon, the largest database of free vector icons*, 2021). Both informative and descriptive icons were added after receiving feedback from experts. The icons used for the design were minimalist. The main criteria for the icons were that they had to be representative of the text. This posed a challenge, as there are different pages for various kinds of graphs. The selected icons can be seen in Figure 22 and 23.

Figure 22: A selection of descriptive icons from Flaticon.

Figure 23: A selection of informative icons from Flaticon.

5.7.3 Usability Testing and SUS with IT Experts and Non-experts

After the final changes were implemented, nine participants evaluated the final prototype. The participants were split into two groups; IT experts and non-experts. The IT experts consisted of three women and two men, while the non-experts consisted of two women and two men. Unlike the usability testing with the previous groups where the prototype was formally presented, these last groups were sent a link to the prototype, seeing it for the first time on their own computers. The details about this are described in Chapter 7.

6 Final Features

This chapter provides an overview of the last high-fidelity prototype and the main functions, selected based on the results of five design iterations.

A total of 43 pages were created to make the prototype as interactive as possible. Figure 24 displays the flow of the system.

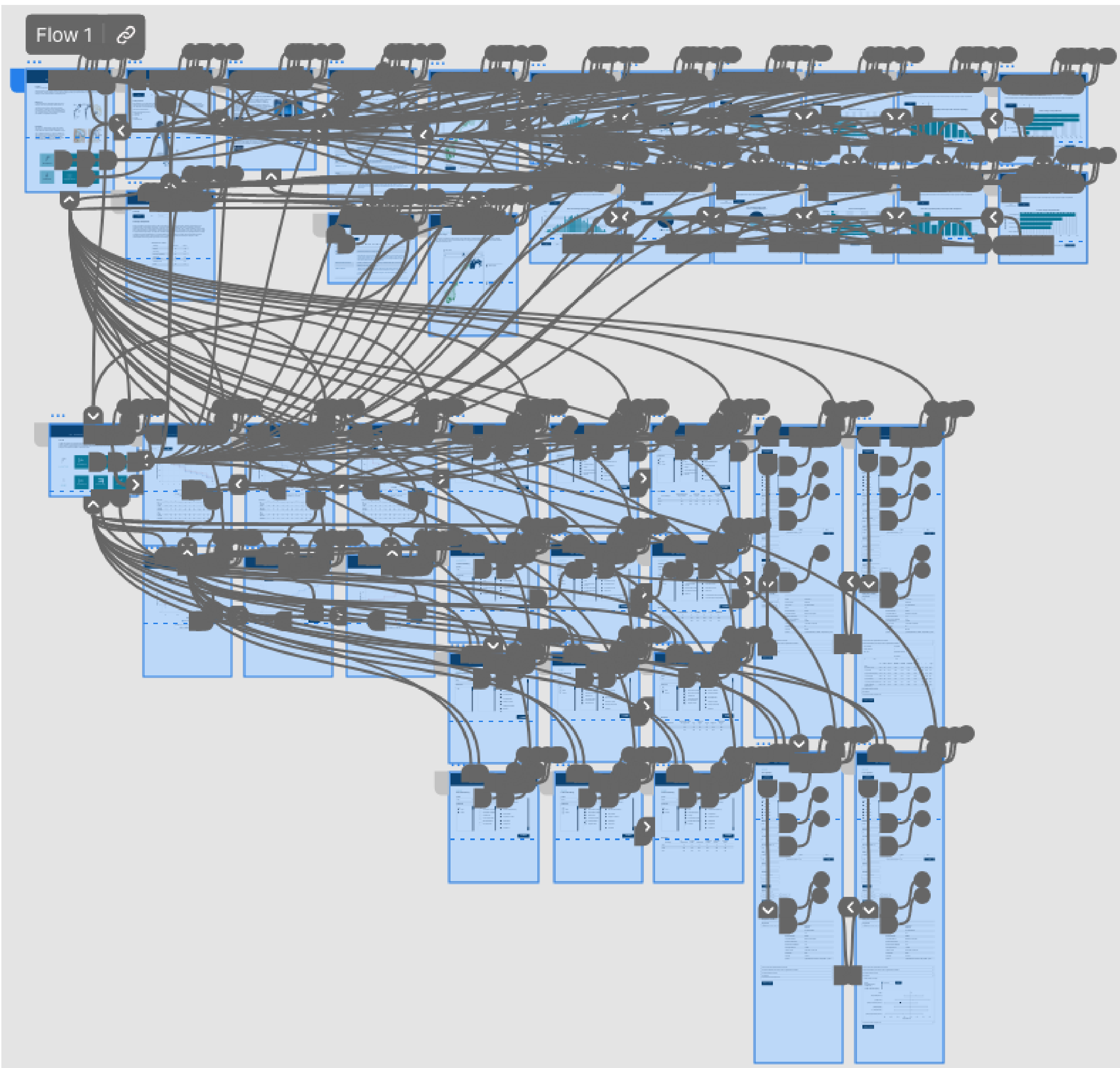


Figure 24: System flow.

6.1 Home

Based on feedback from usability experts, the system was split into two; one for patients and one for expert users like physicians and researchers. Home for experts is shown in Figure 25, while home for patients is shown in Figure 26.

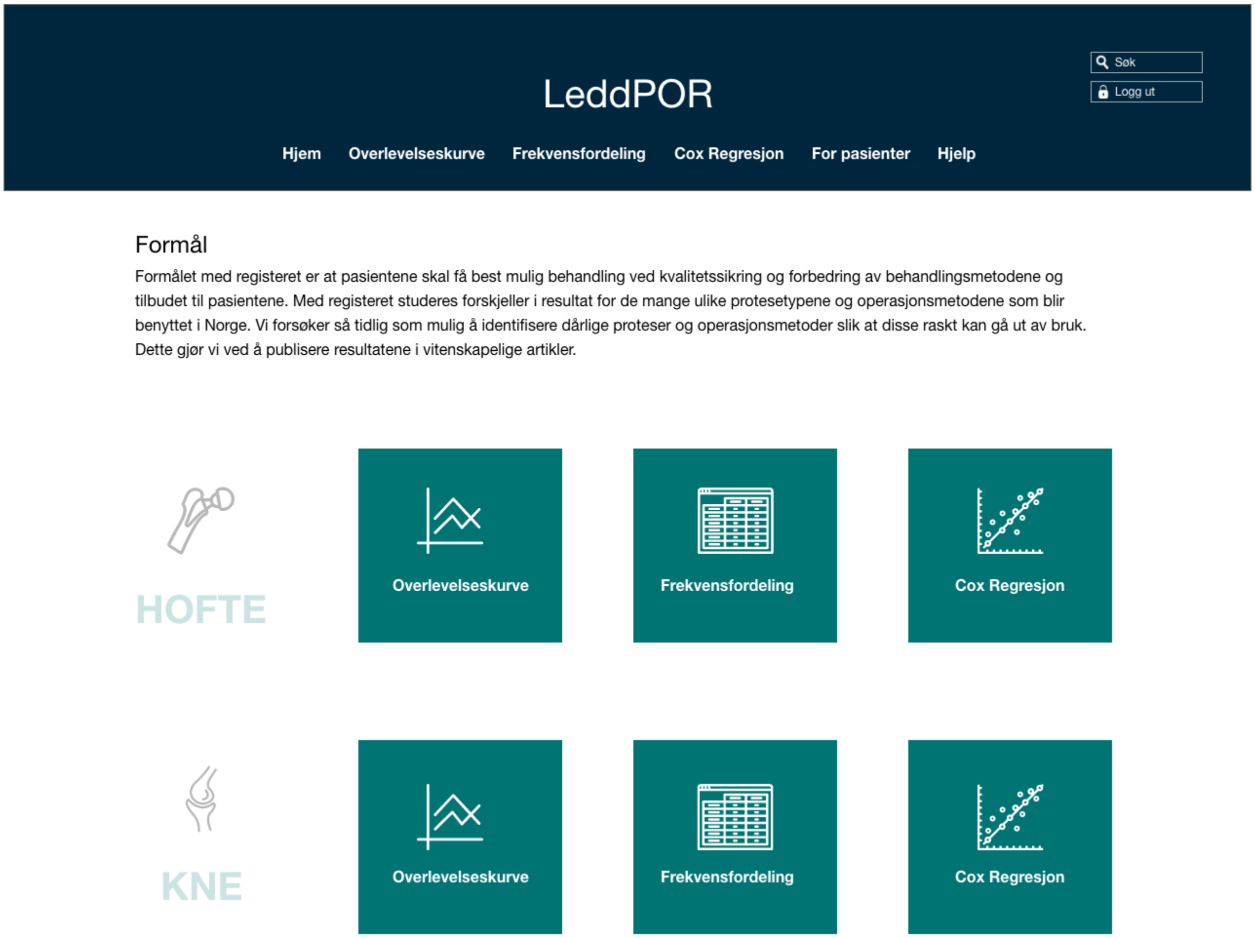


Figure 25: Home for experts.

As doctors and researchers do not need general information about hip and knee implants, they get a short introduction, before being presented with the function choices, divided by hip and knee.

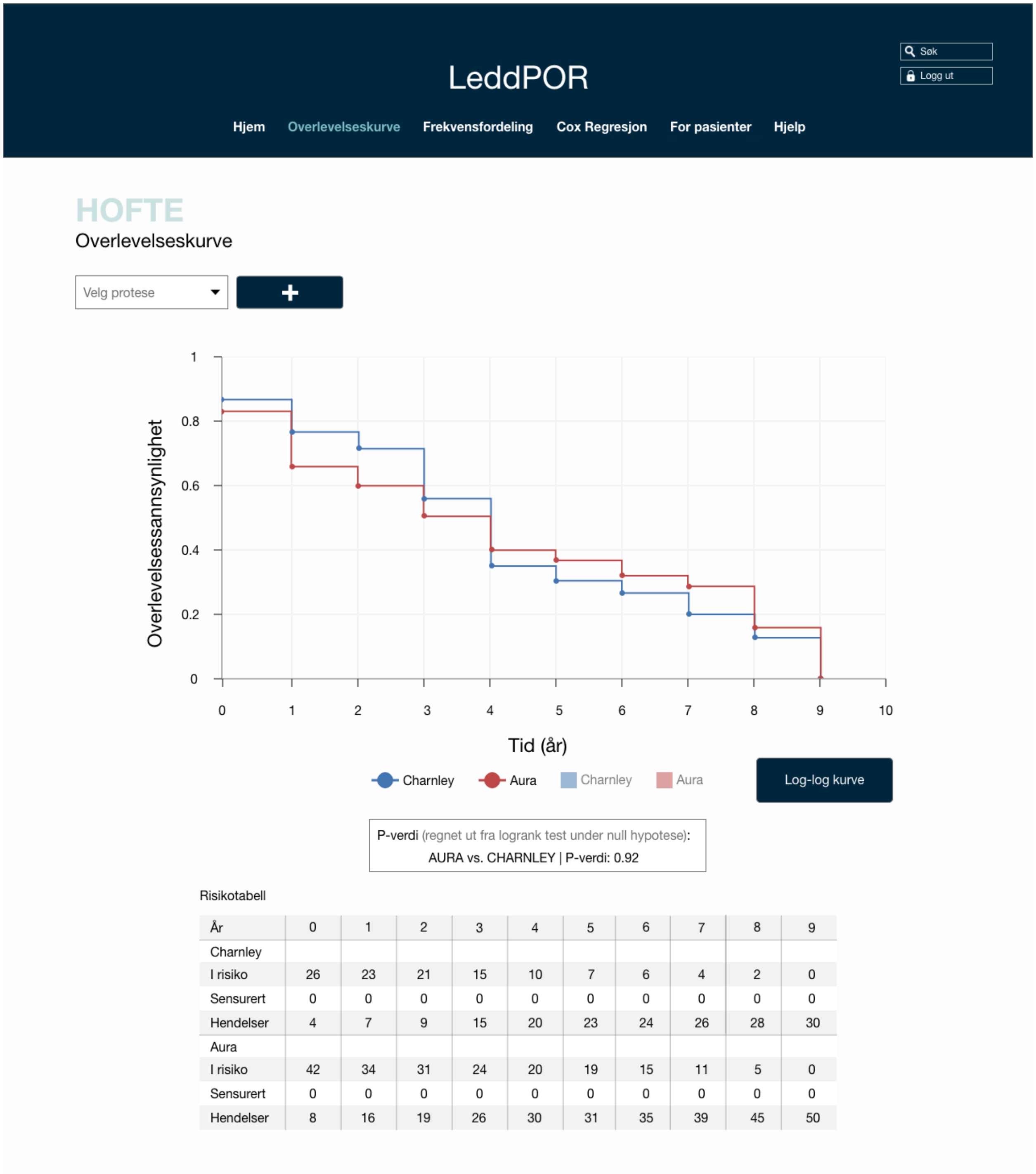
The homepage for patients includes information about the system, what content is available, and how to use it. At the bottom, there is a menu, mimicking the one in the header, so patients do not have to scroll to the top to navigate.

Figure 26: Home for patients.

"Min hofteprotese" and "min kneprotese" have a different background color than the other elements. These functionalities could be further developed to meet patient information needs, which also means that the content has to be carefully crafted, not to confuse users by giving hard to interpret medical information.

6.2 Survival Curve

The survival rate curve lets the user look at the survival probability of different implants, meaning their longevity. Users can select one or more implants from a menu, and compare the longevity. Below the visualization one can see the P-value, accompanied by a risk table. This function is mainly focused on expert users (researchers and physicians), but the questionnaire distributed to patients uncovered that this would also be interesting for them 5.5.3. Hence, this should be considered in future research. The underlying method of the survival curve is Kaplan Meier. The Kaplan Meier method is used to analyze 'time-to-event' data. The outcome in Kaplan Meier analysis often includes all-cause mortality, but could also include other outcomes such as the occurrence of a cardiovascular event (Stel, Dekker, Tripepi, Zoccali, & Jager, 2011).



År	0	1	2	3	4	5	6	7	8	9
Charnley										
I risiko	26	23	21	15	10	7	6	4	2	0
Sensurert	0	0	0	0	0	0	0	0	0	0
Hendelser	4	7	9	15	20	23	24	26	28	30
Aura										
I risiko	42	34	31	24	20	19	15	11	5	0
Sensurert	0	0	0	0	0	0	0	0	0	0
Hendelser	8	16	19	26	30	31	35	39	45	50

Figure 27: Survival Curve / Kaplan Meier.

6.3 Contingency Table

Contingency tables are often used in statistics to summarize the relationship between certain variables and show the frequency count between two variables. Their analysis plays an essential role in gaining insight into the structures of the quantities under consideration and in supporting decision-making. They help find interactions between them. Interdependence of the variables can affect the analyses, so it is important to understand the data distribution, interdependence of variables in order to choose the write method of analysis (Parsian, 2015).

The user can choose index- and column values, followed by what variables to include. In the menu to the right, the user can customize the table further. The results are presented at the bottom of the page.

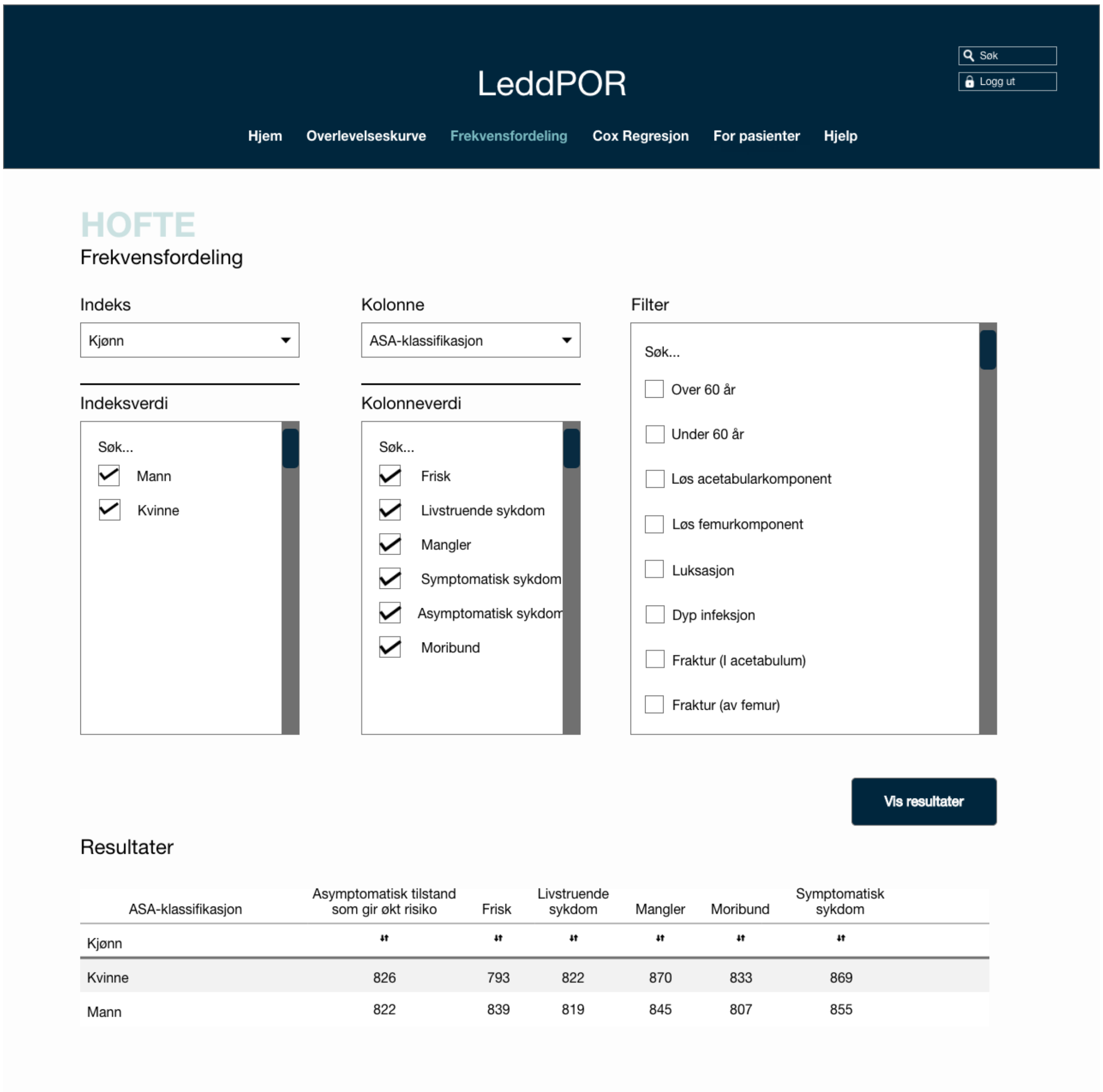


Figure 28: Contingency table with results.

6.4 Cox Proportional Hazard Model

The Cox Regression model (Cox model) is a statistical technique used to explore the relationship between the survival of a patient and several explanatory variables such as sex and implant. One important characteristic of the Cox model is that it estimates relative rather than absolute risk, and it does not assume any knowledge of absolute risk. By definition, Cox models that implement the proportional hazards models are designed for the analysis of the time until an event occurs or the time between events (Parsian, 2015).

The front-end lets the user name the current model, chose fitting parameters, and save the model resulting from the analysis (Figure 29). There is a button at the top, which acts as a shortcut, taking the user straight to analyzing a previously fitted model, where the results are presented (Figure 30). The drop-down menu on the left lets the user chose an existing model. The table on the right presents a summary of the model's fit. Users can then choose what results they want to examine from the summary table.

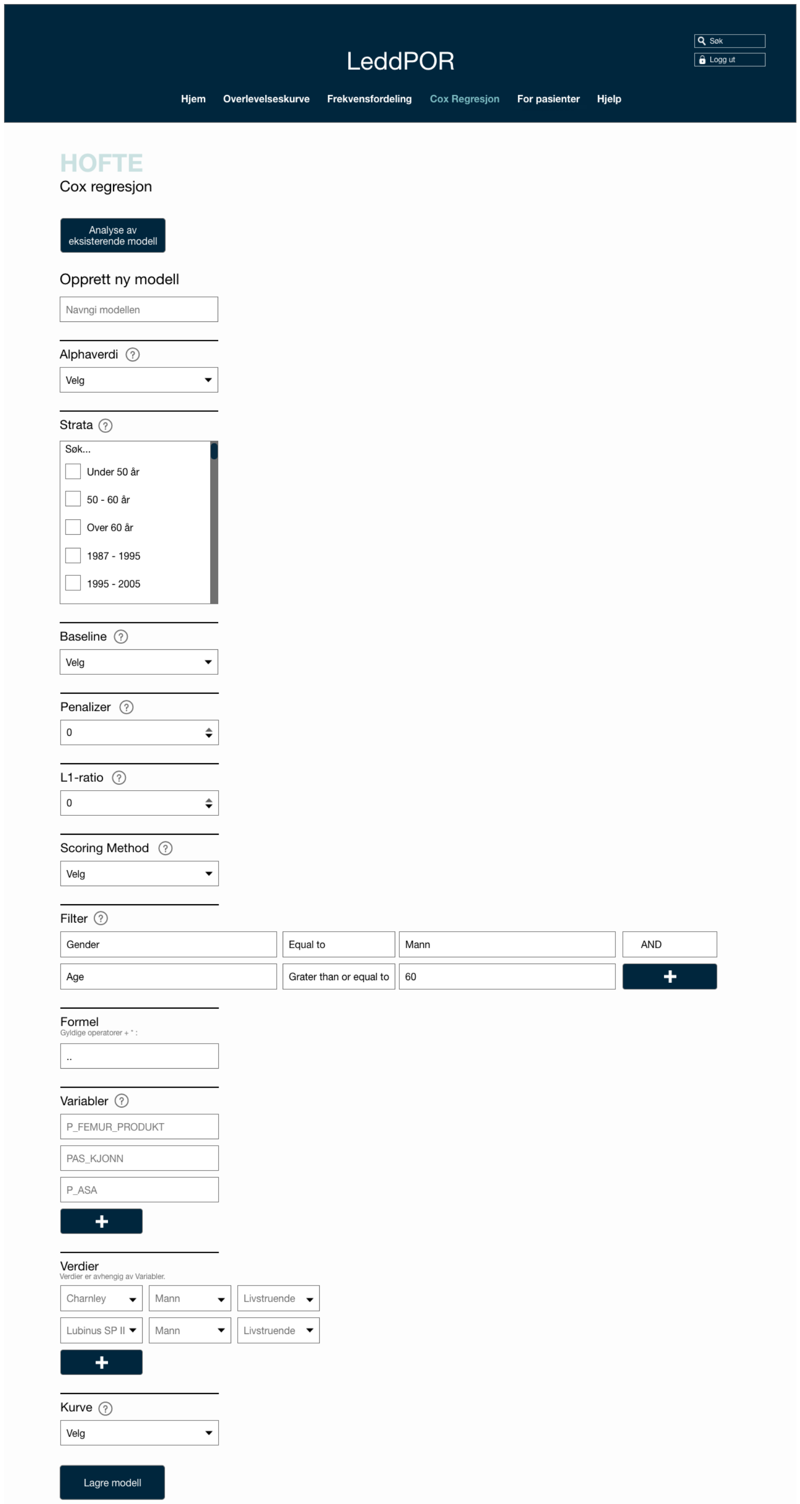


Figure 29: Cox model, fit model.

Analyse av modell

Velg modell

Velg

Model	CoxPHFilter
Duration column	SURVYRS
Event column	ANT_REVISJONER
Strata	null
Baseline estimation	berslow
Computed residuals	residuals not computed
Number of observations	116
Number of events observed	116
Partial log-likelihood	-433.521
Time fit was run	11-05-2021 12:26:30 UTC
Concordance	0.6
Partia AIC	883.042
Formula	P_FEMUR_PRODUKT + ALDER + PAS_KJONN + P_ASA

Predict median and expected lifetime of individuals

Estimated coefficients, hazard ratios, errors and loglikelihood test statistic

null_distribution	chi squared
degrees_freedom	7
test_name	log-likelihood ratio test

		test_statistic	P
0	6.63	0.47	1.09

Variabel	Coef.	Hazard ratio	Standard error	Nedre 95% K.I. for H.R	Øvre 95% K.I. for H.R.	Nedre 95% K.I. for coef.	Øvre 95% K.I. for coef.	z	p	- log2(p)
PAS_KJONN [T.Mann]	0.495	1.640	0.299	-0.090	1.080	0.914	2.945	1.657	0.097	3.359
P_ASA [T.Frisk]	0.364	1.440	0.494	-0.604	1.333	0.547	3.792	0.738	0.461	1.118
P_ASA [T.Livstruende sykdom]	0.190	1.210	0.506	-0.802	1.183	0.448	3.264	0.376	0.707	0.500
P_ASA [T.Mangler]	0.030	1.031	0.463	-0.877	0.937	0.416	2.553	0.065	0.948	0.077
P_ASA [T.Moribund]	0.259	1.296	0.460	-0.641	1.160	0.527	3.189	0.564	0.573	0.804
P_ASA [T.Symptomatisk sykdom]	0.731	2.076	0.490	-0.230	1.691	0.795	5.424	1.491	0.136	2.879
P_FEMUR_PRODUKT [T.Lubinus SP II]	-0.355	0.701	0.305	-0.952	0.243	0.386	1.275	-1.164	0.244	2.033

Plot partial effects on outcome

Plot hazards

Proportional hazard assumption test

Opprett ny modell

Figure 30: Cox model, analysis of existing model.

6.5 Map

The map, shown in Figure 31, is interactive and lets the user look at different statistics in each county of Norway, ranging from 1995 to 2018. As the data set only contains data older than the new counties in Norway, it was decided to use an old map for this visualization. The users can use the slider at the top to change the year they wish to look at and can filter the data between percentage change, top five prostheses, and how many surgeries have been performed, all using the buttons below the map. When one hovers over a county, the data is displayed in a hover-box, as well as in an information box next to the map. When a user clicks on a county, the information is presented in the box beneath the "hover information box", letting the user compare two counties. Figure 31 shows the map after a user has clicked on Finnmark.

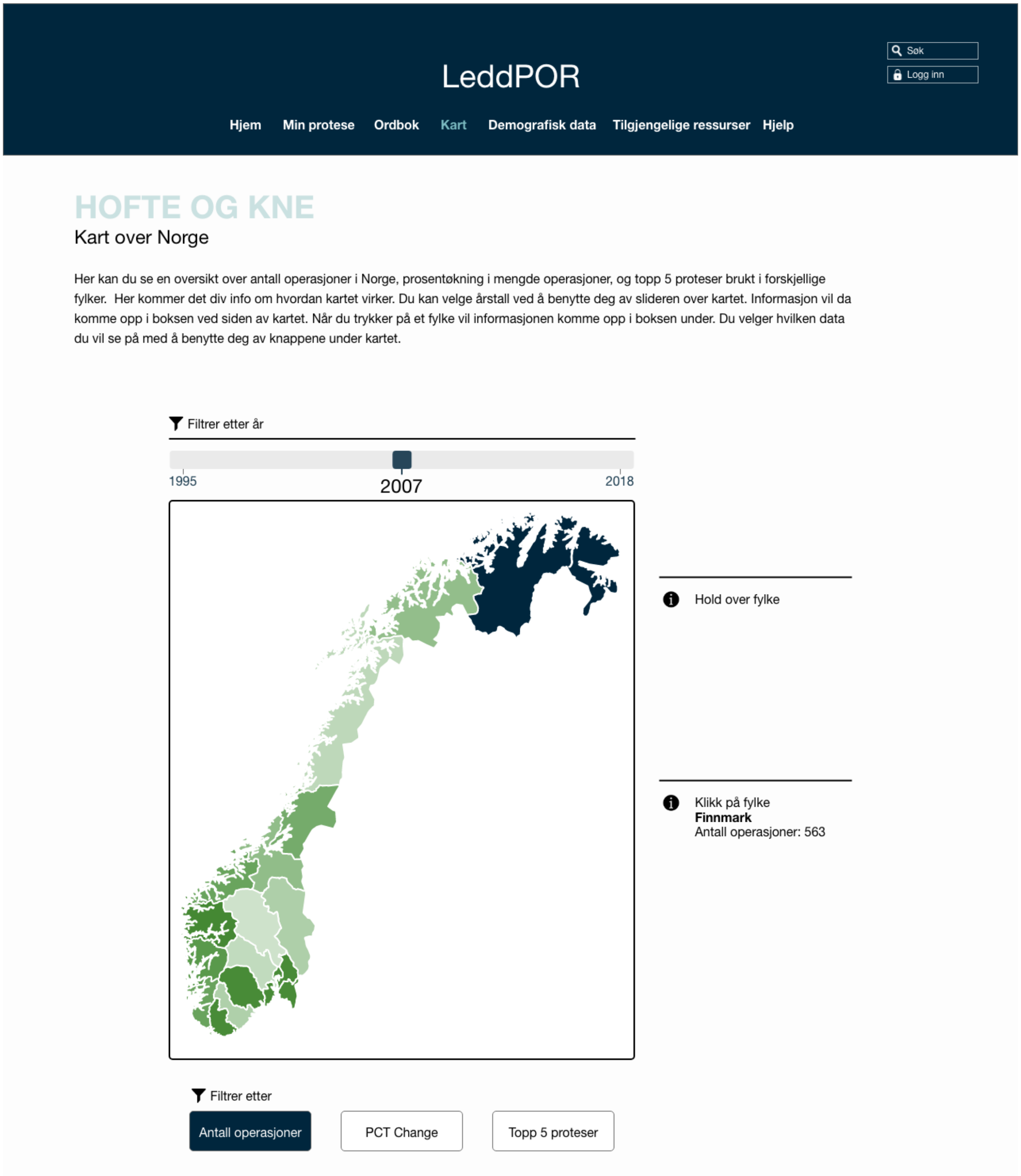


Figure 31: Map results after clicking on Finnmark.

6.6 Dictionary

The dictionary contains difficult words and phrases from arthroplasty. 73,5% answered 'yes' in the questionnaire (Section 5.5.3) when asked if they would use a dictionary if it was available. The features in the dictionary include a search function and the possibility of filtering by letter, as shown in Figure 32.

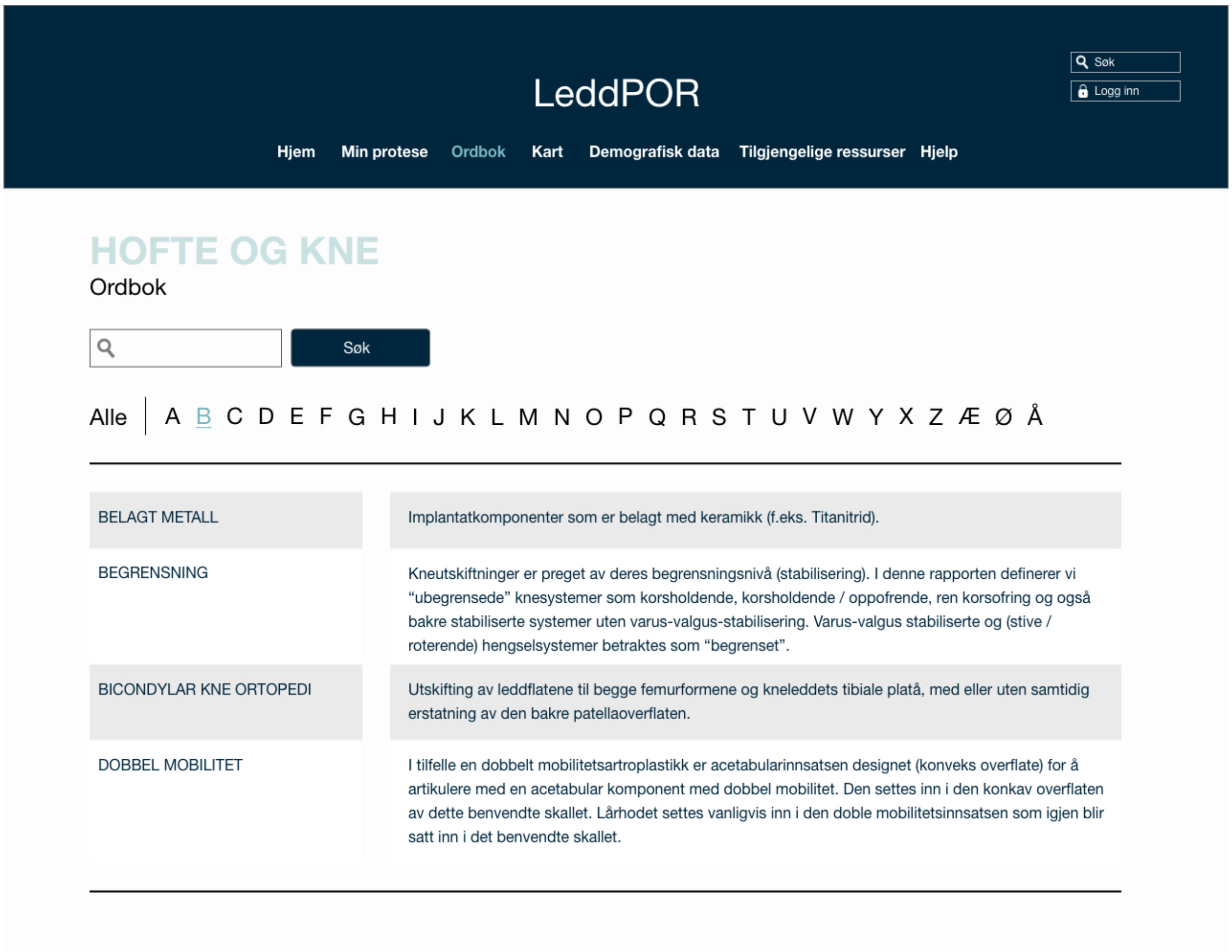


Figure 32: Dictionary filtered by the letter B.

6.7 My Prosthesis

My prosthesis presents general information about implants, and a 3D model of an implant with a hover function to get information about different parts of the implant. From the drop-down menu next to the buttons, information about a specific implant can be found.

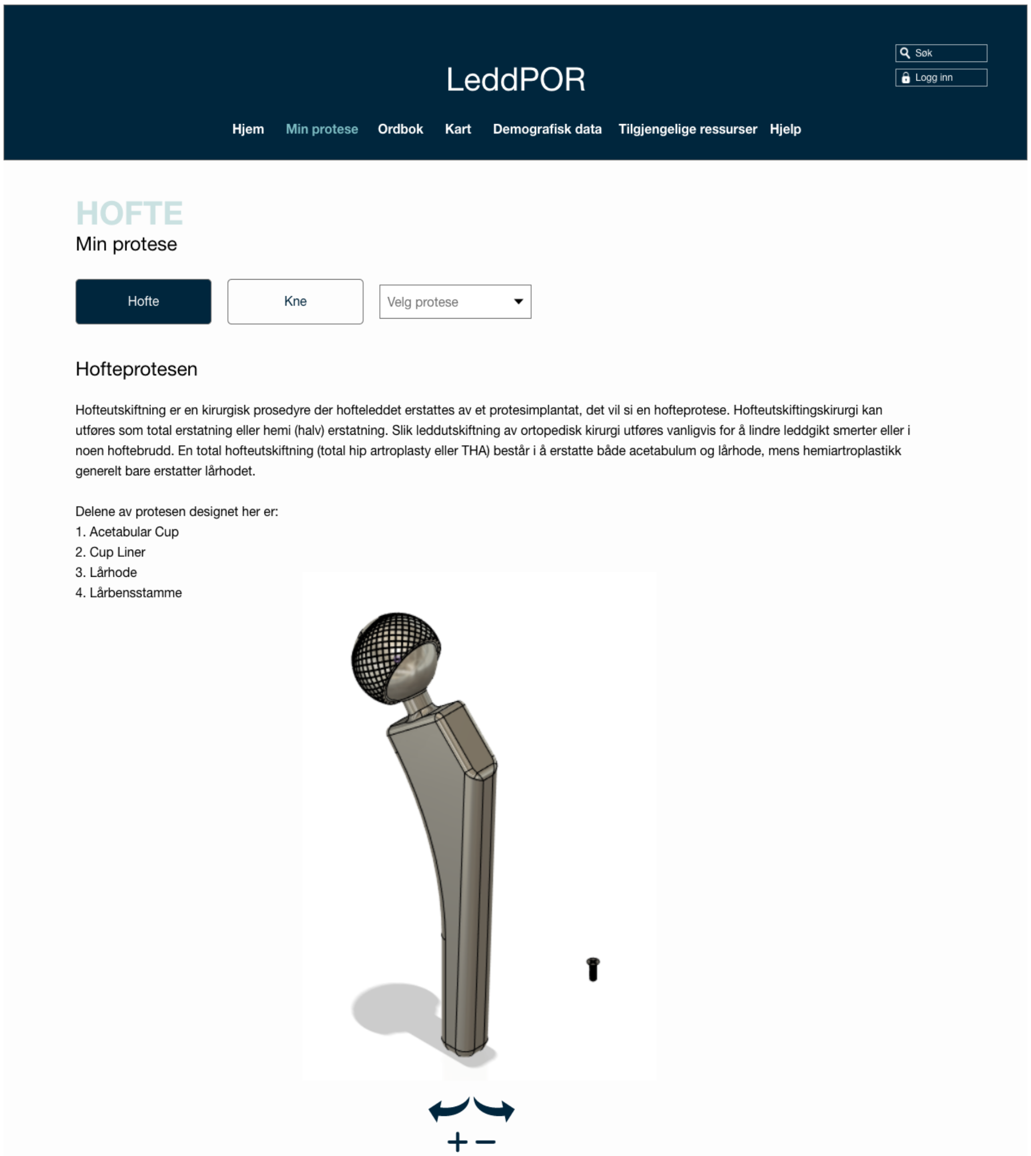


Figure 33: My prosthesis.

6.8 Available Resources

This page displays information about available resources related to hip and knee arthroplasty, mainly mobile applications to help with post-surgery care (Åserød & Babic, 2017b; Krumsvik & Babic, 2017b).

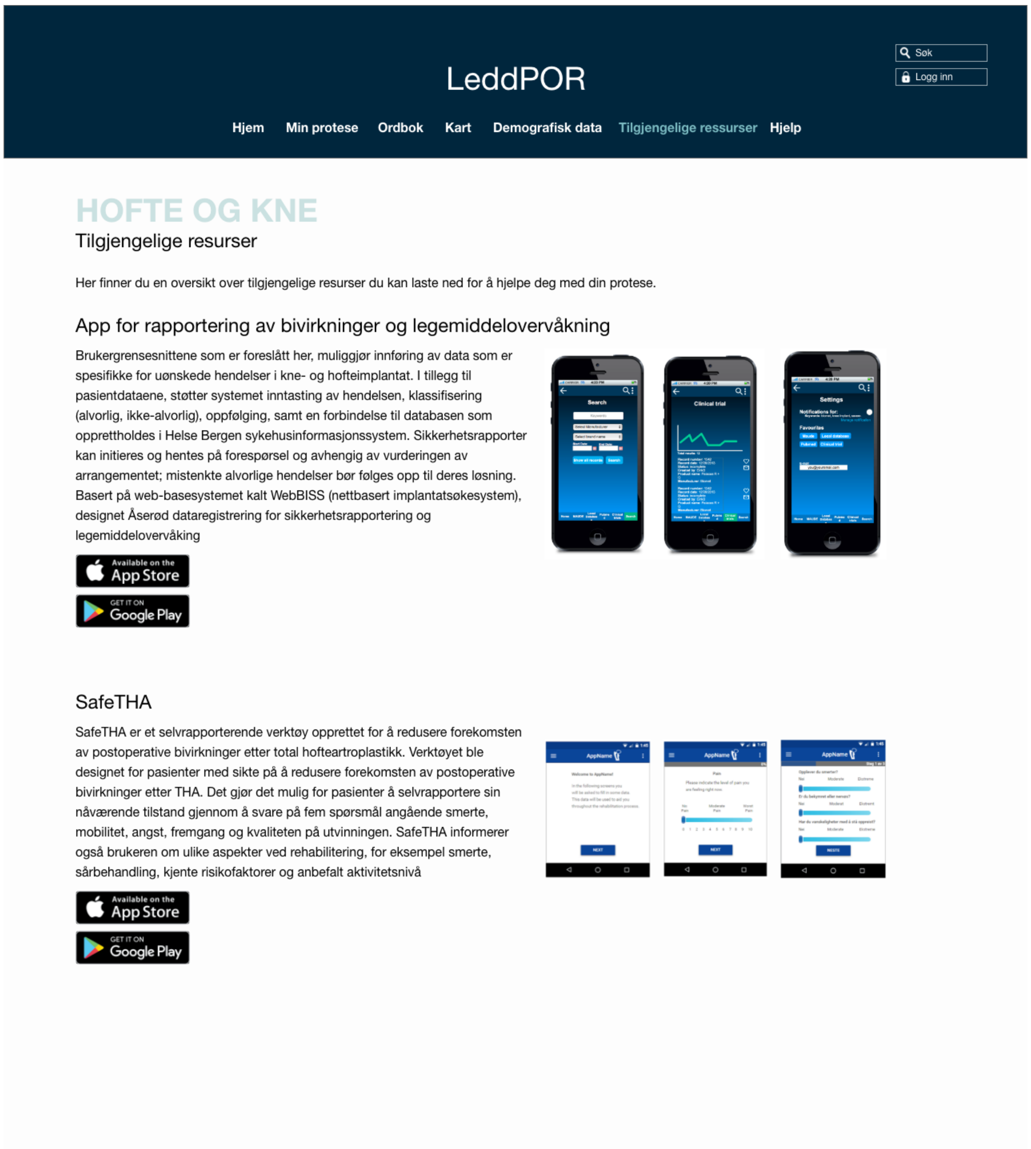


Figure 34: Available resources.

6.9 Demographic Data

Demographic data presents different graphs containing relevant information for patients. The data presented on these pages were chosen based on the answers to the questionnaire. The users can switch between hip and knee for each graph using the buttons in the top left corner, and can easily navigate through the different information with buttons below the graphs. All the graphs contain information on the left axis and bottom axis, reading from left to right. Two different graphs are provided in Figures 35 and 36.

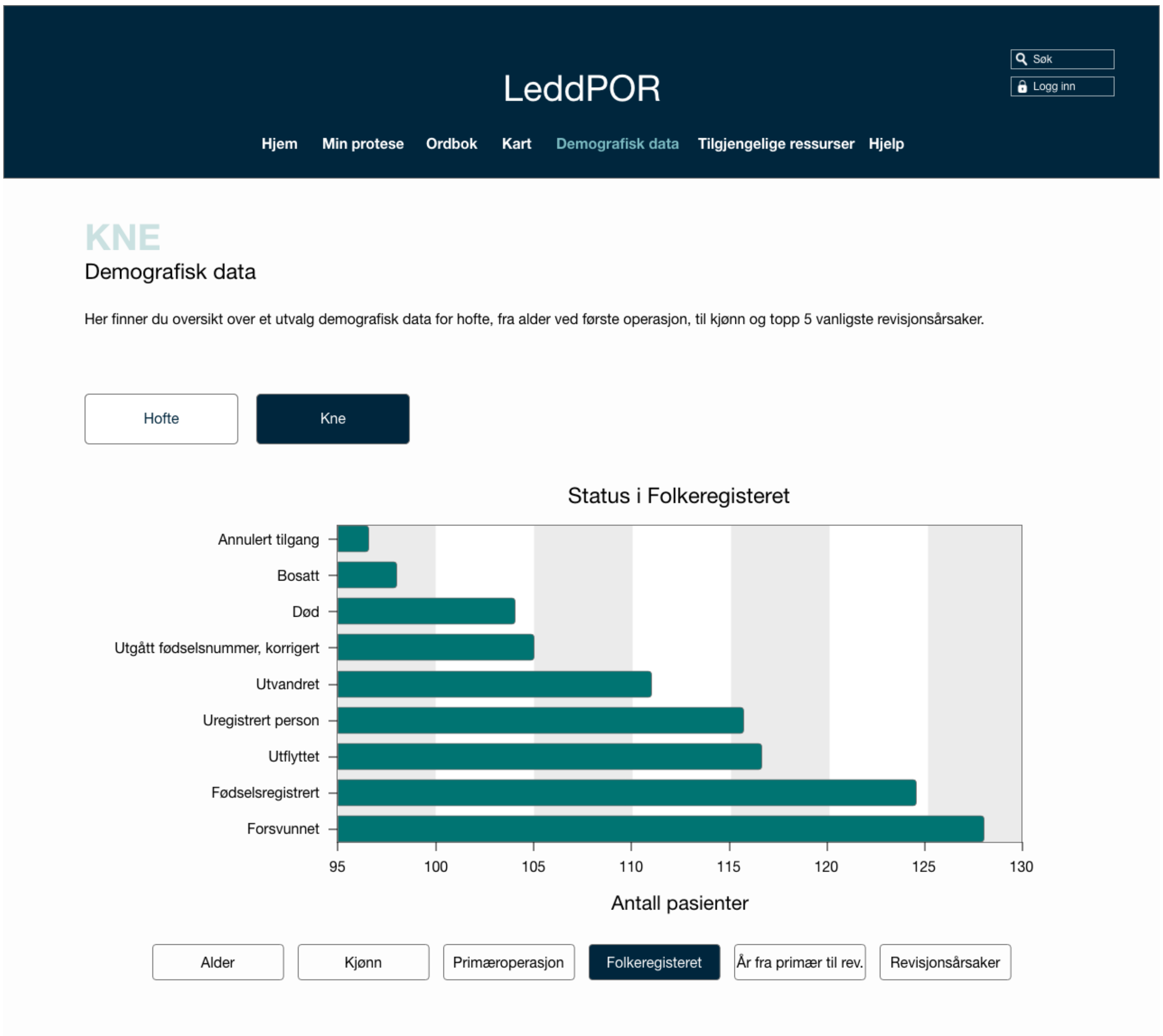


Figure 35: Status in the population register, knee.

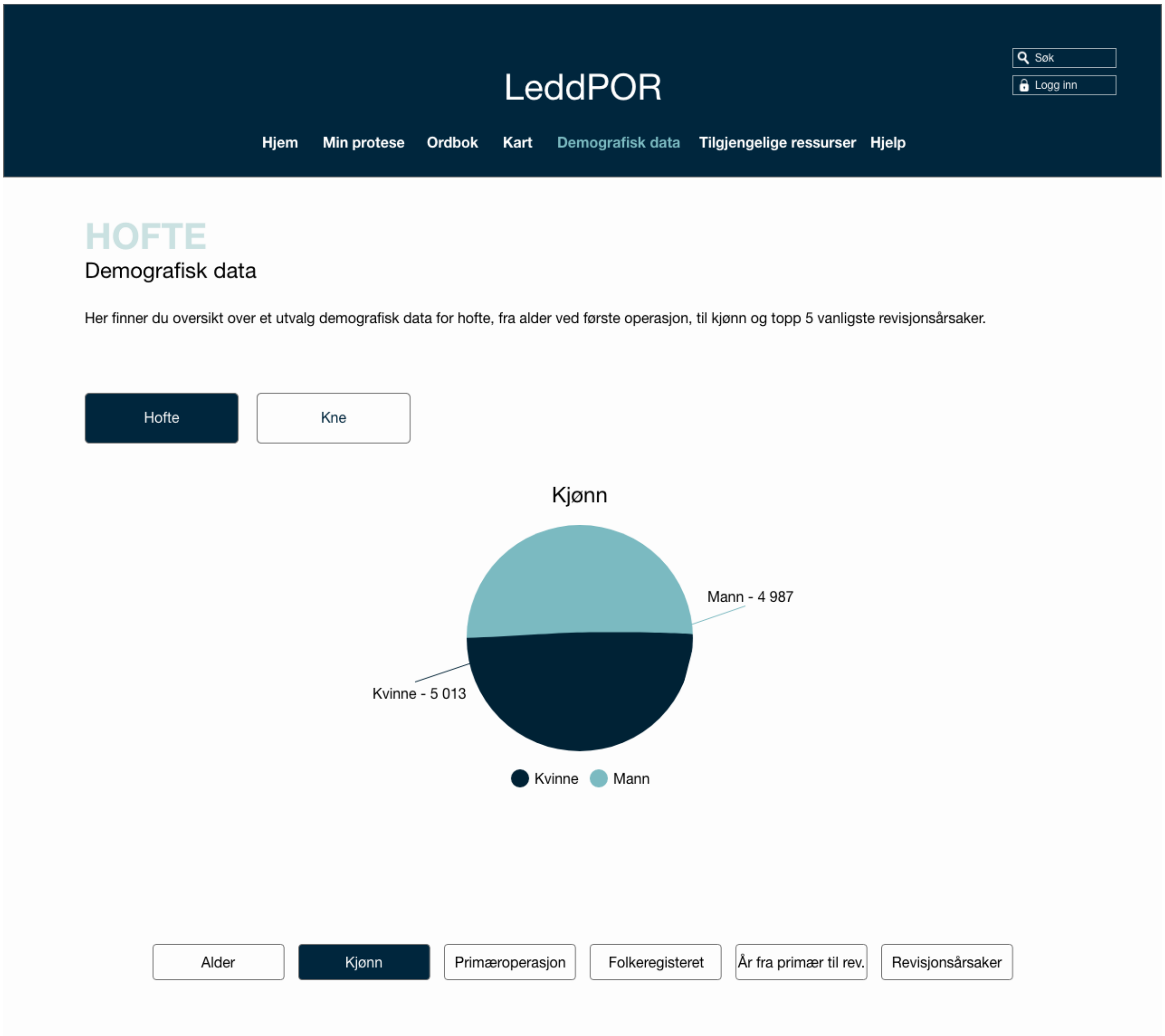


Figure 36: Sex of patients, hip.

7 Evaluation

This chapter will present the results from the evaluation conducted during the design process. The results are gathered from usability testing, SUS, and Nielsen's Heuristics.

7.1 Evaluation Participants

Four different groups were recruited to evaluate the prototype during various iterations. The first group consists of field experts, the second of usability experts working in the industry, the third group of IT experts, and the last of non-experts. The last group was recruited to represent patients, as it was not possible to include actual patients due to the ongoing COVID-19 pandemic. The total number of participants is 16.

7.1.1 Field Experts

The field expert group consists of four people: a well-established researcher with more than ten years of experience who provides deep knowledge about the technical aspects of the system. The remaining three experts provide a younger perspective and are rather new to the field, with less than five years in the field. Table 3 presents a summary of the demographics of the field experts.

Participant ID	Age	Gender	Education Level
P1	41	Male	Ph.D.
P2	26	Male	Master's degree
P3	27	Male	Master's degree
P4	29	Male	Master's degree

Table 3: Group 1: Field experts.

7.1.2 Usability Experts

The usability experts consists of three young people, all with a fresh perspective and with various experience within the field. They have a sharp eye and pay attention to detail, providing important feedback regarding the usability of the system. Table 4 presents a summary of the demographics of the usability experts.

Participant ID	Age	Gender	Education Level
P5	30	Female	Master's degree
P6	28	Male	Master's degree
P7	32	Male	Master's degree

Table 4: Group 2: Usability experts.

7.1.3 IT Experts

The IT experts consist of four master students from the Information Science line at the University of Bergen, and one person with one year as a UX designer with a master's degree in Information Science. They were recruited as IT experts as they have fresh knowledge and experience in evaluating prototypes by participating in subjects such as Interaction Design, System Development, and Human-Computer Interaction. They provided valuable feedback and comments which will be discussed in Section 7.6.6. Table 5 presents a summary of the demographics of the IT experts.

Participant ID	Age	Gender	Education Level
P8	30	Female	Master's Degree
P9	24	Female	Master Student
P10	26	Male	Master Student
P11	27	Male	Master Student
P12	24	Female	Master Student

Table 5: Group 3: IT experts.

7.1.4 Novice Users

A group of novice users (non-experts) were recruited to test the final prototype in order to get an impression of how the general population, without any form of technological background, will experience the system. The age of the participants was generally higher than the ones of other groups which makes them closer to the real patient group. Table 6 presents a summary of the demographics of the last group.

Participant ID	Age	Gender	Education Level
P13	59	Female	Master's Degree
P14	55	Male	Master's Degree
P15	35	Male	Master's Degree
P16	42	Female	Bachelor's Degree

Table 6: Group 4: Novice users.

7.2 System Usability Scale

The prototype was evaluated through a system usability form twice during the design process. Once in the fourth iteration and once in the fifth iteration. The form can be found in Appendix D. The participants filled out the form on their own time and were provided the tasks given for the usability testing (Section 7.3.1) to give them an indication on how to interact with the system. While completing the evaluation, the participants had access to the prototype through an Adobe XD link to test all the functions.

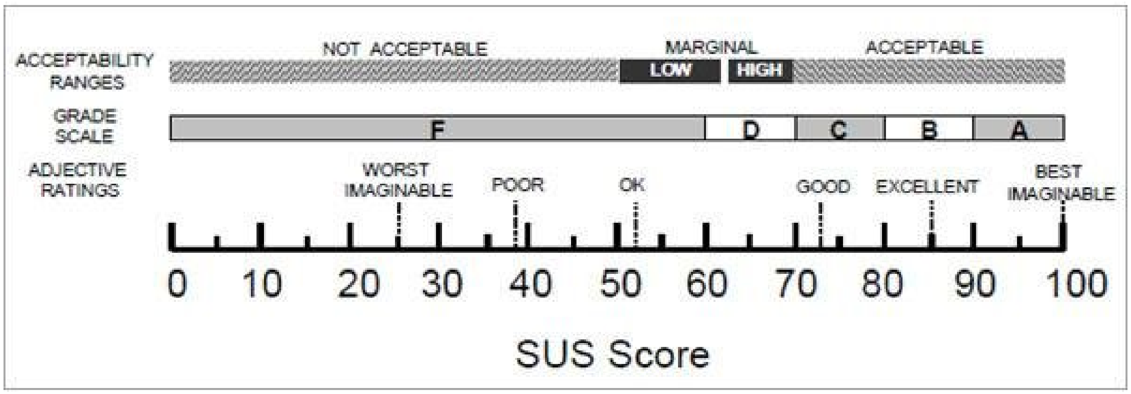


Figure 37: System Usability Score overview (Brooke, 1996).

7.3 Usability Testing

The usability testing was done over video call, meaning all participants completed the evaluation on their private computers. They were provided with a link to the prototype and were asked to share their screen so that their execution could be observed. Usability testing was done with the IT expert group and novice user group in the fifth iteration of the final prototype. In total, nine participants were included in the usability testing. Each participant can be identified with their participant ID shown in Tables 5 and 6, respectively.

7.3.1 Tasks of Evaluation

To be able to evaluate the prototype, each participant had to get familiarized with the system. This was accomplished by giving the participants a set of predetermined tasks that covered some of the key functions. The goal of the usability test was to see how people would interact with the system. During the usability test, the participants were not informed on how to accomplish the tasks. However, they were allowed to ask questions or ask for help if necessary. They were also encouraged to provide comments after each task if they had any troubles completing them.

The tasks for the usability test

1. Look at the survival probability of a prosthesis.
2. At Frekvensfordeling, filter the index by gender and show results.
3. On cox regression, hip, do an analysis of an existing model, look at estimated coefficients.
4. On cox regression, knee, do an analysis of an existing model, look at plot hazards.
5. Filter words by B in the dictionary.
6. Find information about Finnmark.
7. Find the most common causes of revision on the hip.
8. Find information about a specific prosthesis.

7.4 Heuristic Evaluation

Nielsen's Heuristics was the last method used to evaluate the prototype. Again, the field experts and usability experts evaluated the third prototype, while the IT experts evaluated the fourth prototype. The participants were given a form and filled it out while having access to the prototype. The form can be found in Appendix E. They were asked to rate each heuristic in the prototype on a scale from 0 (no issues found) to 4 (usability crisis, crucial to fix before the product is released). The results are presented in Sections 7.5.2 and 7.6.6.

7.5 Evaluation of Third Prototype

7.5.1 SUS with Field Experts and Usability Experts

The first two groups to evaluate the prototype was the field experts and usability experts. They performed the SUS evaluation in the fourth design iteration. Their score ranged from 60 points being the lowest to the highest being 90 points, making the average score of the first two groups 83,5. Above 80,3 is considered "excellent", or the grade "B", in the SUS score overview (Figure 37). Their individual scores can be seen in Figure 38 and 39, respectively.

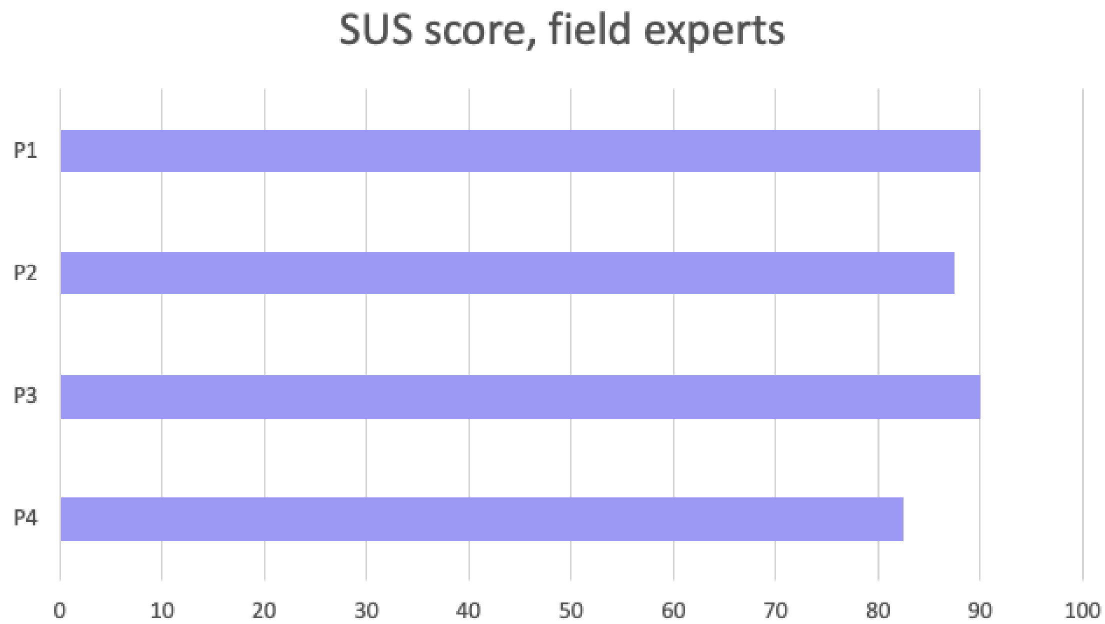


Figure 38: SUS results field experts.

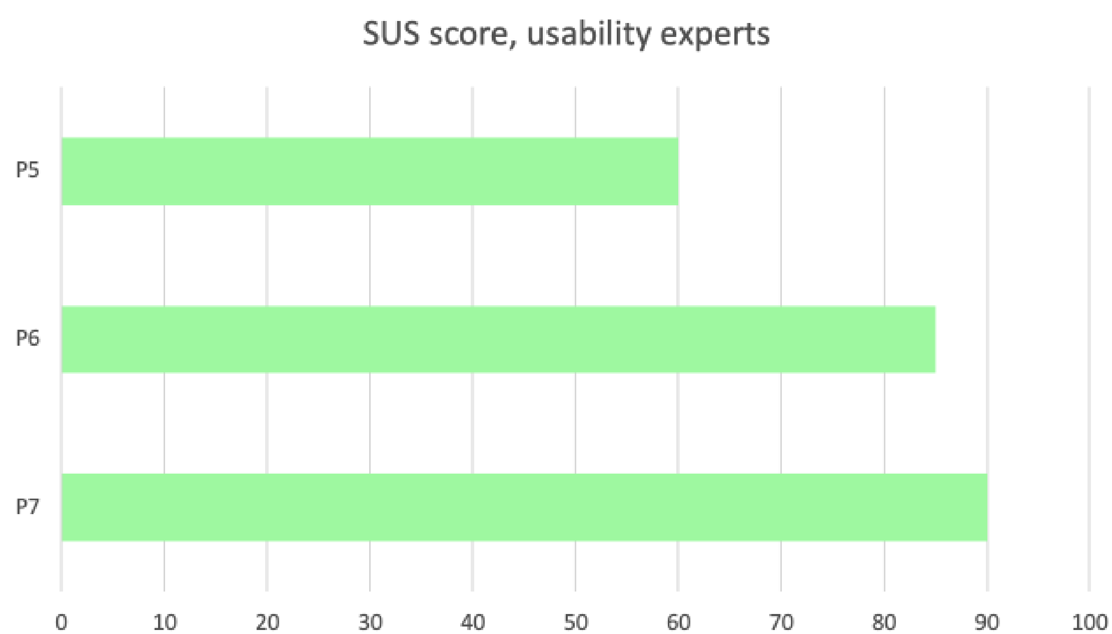


Figure 39: SUS results usability experts.

The field experts were generally satisfied with the system, giving it an average score of 87,5 points. Two out of three usability experts scored the third prototype 85 points and above, which according to Brooke (1996) is considered "excellent" results. However, P5 scored the system a mere 60 points, which is just above "OK", and corresponds to a barely passing grade "D". This lead to the usability experts giving the system an average score of 78,3 points, or grade "C". P5 had many comments for improving the prototype, compared to P6 and P7. They were all taken into consideration when redesigning the final prototype.

7.5.2 Heuristic Evaluation with Field Experts and Usability Experts

The average results of the first evaluation can be seen in Table 7. P1 was not included in the Heuristic evaluation, making the total number of participants to perform the evaluation six.

Heuristic	Average Score
1.Visibility of system status	1
2. Match between system and the real world	0,833
3. User control and freedom	0,667
4. Consistency and standards	0,5
5. Error Prevention	0,333
6. Recognition rather than recall	0,167
7. Flexibility and efficiency of use	0,333
8. Aesthetic and minimalistic design	0,167
9. Help users recognize, diagnose, and recover from errors	0,167
10. Help and documentation	0,667

Table 7: Nielsen's Heuristics results from field and usability experts on third prototype.

The overall results from the evaluation of the third prototype are regarded as good. Still, there were some recommendations for improvement. Feedback and comments from the expert users on each heuristic are summarized in the list below:

1. *Visibility of System Status*
   The users get appropriate feedback, but experts pointed out that it should be made even clearer in the header menu, for example by highlighting the active page.

2. *Match Between System and The Real World*
   The description in the prototype was placeholder-text. Even though it consists of words, concepts, and conventions known to the users, it is still not ideal. This was pointed out by one of the participants.

3. *User Control and Freedom*
   The user is not presented with enough exit points and possibilities to leave unwanted situations. More than one participant wanted a clearer divide for the different user groups.

4. *Consistency and Standard*
   The application was consistent and followed platform conventions.

5. *Error Prevention*
   Even though there was a lack of sufficient error prevention, the feedback did not indicate it. This could be explained by the fact that the evaluation groups were fairly familiar with similar systems.

6. *Recognition Rather Than Recall*
   Objects, actions, and options are visible for the users.

7. *Flexibility and Efficiency of Use*
   The flow of the system makes it easy to use for both experienced and inexperienced users. However, there are not sufficient shortcuts for expert users.

8. *Aesthetic and Minimalist Design*
   The application has a minimalist design; there is no irrelevant and redundant information. Five of six experts agreed the design was aesthetically pleasing.

9. *Help Users Recognize, Diagnose and Recover from Error*
   Error messages were not implemented at this time. However, they would be presented in plain language, with no code, to be easily understandable for the users.

10. *Help and Documentation*
    The application had no help or documentation implemented. One participant suggested adding some guidance on Cox regression, as it is a very technical page.

7.6 Evaluation of Fourth Prototype

7.6.1 Usability Testing with Novice Users

Four novice users conducted usability testing on the fourth prototype. This group got a set of four tasks, consisting of the four last in the list provided in Section 7.3.1. The reasoning for this is that this group was recruited to represent patients, and should only have access to a certain aspect of the system. The goal of the usability test was to find how they would interact with the system, as well as to get an idea of the learnability of the system. The participants had no prior experience with the prototype. The amount of time the participants used can be seen in Figure 40.

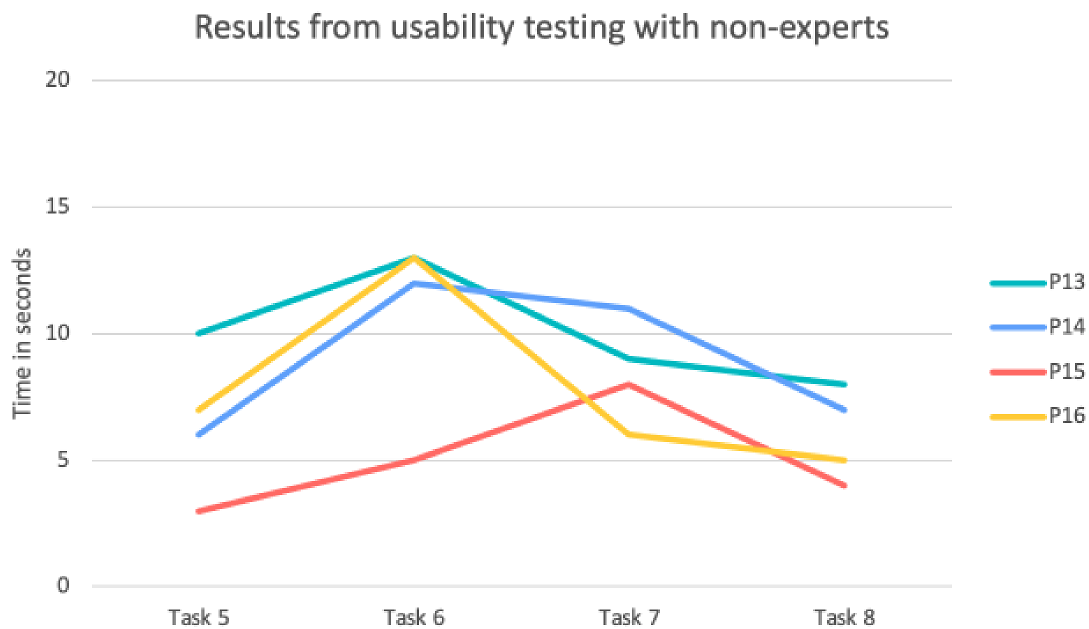


Figure 40: Time used on the four tasks focused on patients.

P16 has a noticeable peak in time on task six. This is due to the fact that she clicked on "Demografisk data" rather than "Kart" when asked to find information about Finnmark. She explained that she thought the information would be located there, given the name. This is a good indication that the menu options could be named differently.

7.6.2 Usability Testing with IT Experts

Five experts conducted a usability test during the same iterations as the novice users. This was to see if there were any major deviations between users considered to be experts and non-experts. They got the same tasks as the novice users, with four additional tasks meant for physicians and researchers. The participants had no prior experience with the prototype. The amount of time the participants used can be seen in Figure 41.

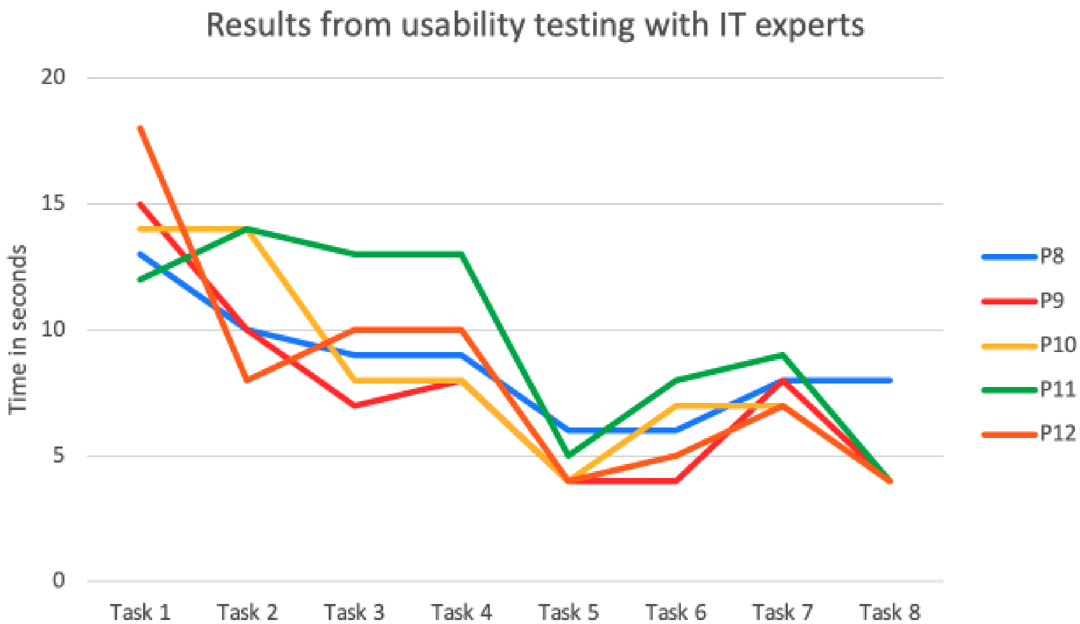


Figure 41: Time used on the eight tasks.

P11 spent slightly longer completing tasks 3 and 4. He was the only participant to manually scroll down to the analysis section of the page, rather than clicking the "shortcut" button which brings the user there automatically, which explained the peak in time compared to the other participants, who all used the button.

7.6.3 Comparing Usability Test Results

When comparing the results in time spent per task, the experts are somewhat faster than the novice users. This can be explained by the fact that the experts have a background in IT, and thus a more structured approach when it comes to problem-solving. The average time used can be seen in Figure 42.

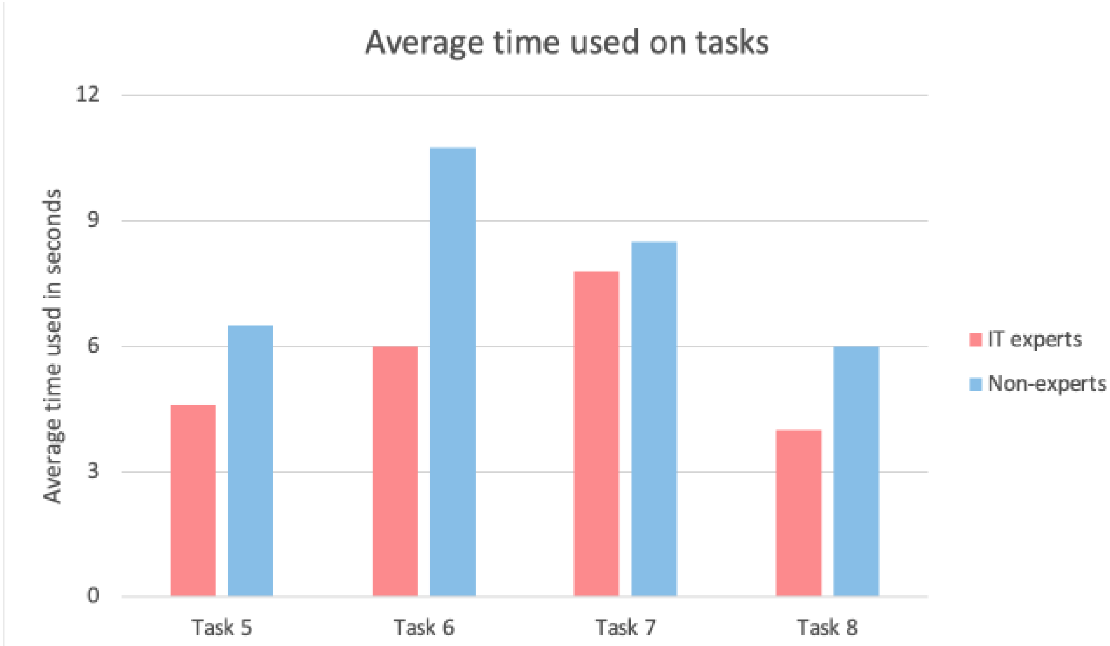


Figure 42: The average time used on the four tasks for experts and novice users.

Overall there was only one considerable difference between the two groups; the novice users spent almost twice as much time on task 6 than the experts. Out of the novice users, three of four explained that they did not think the map would be interactive, while P16 explained she did not know where Finnmark was located on the map. This indicates that it could be easier with labels on the counties. However, in a fully developed system, it would be more clear that the map is interactive, as all counties would be implemented with the hover function.

7.6.4 SUS with IT Experts and Non-experts

Two groups evaluated the fourth prototype, performing a SUS evaluation in the fifth iteration of the design process. Their score ranged from the lowest being 80 points to the highest being 100 points. This makes the average score of the last two groups 92,8, corresponding to grade "A" in the SUS score overview (Figure 37). This is a remarkable increase, even though all were not above "excellent" results. The IT experts gave it an average score of 91 points, while the novice users scored it 95 points average. The individual scores for these groups can be seen in Figures 43 and 44, respectively.

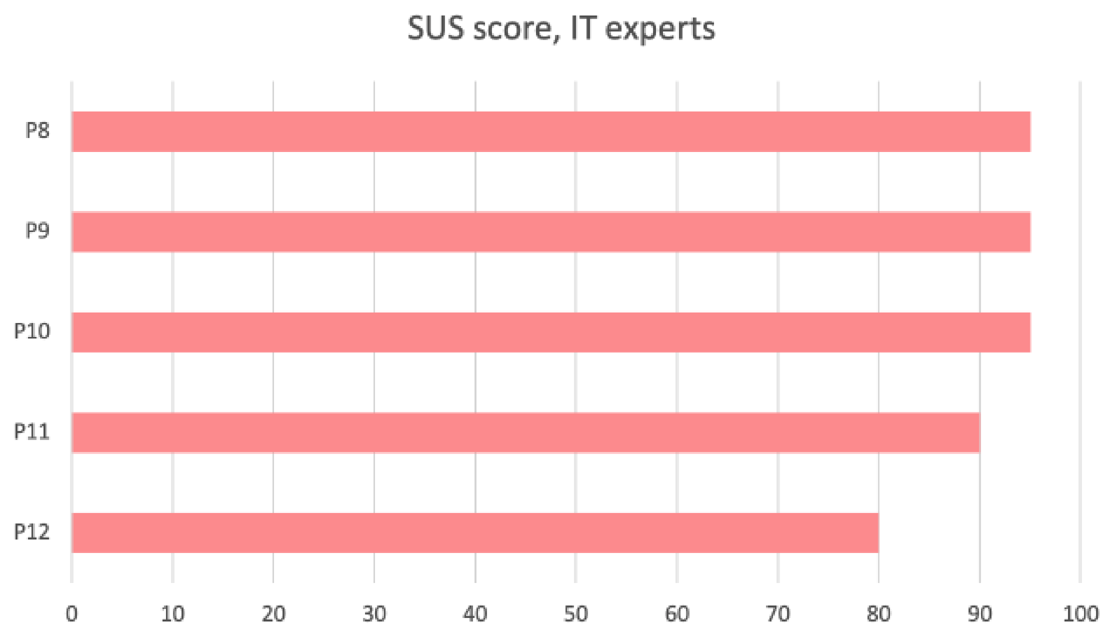


Figure 43: SUS results IT experts.

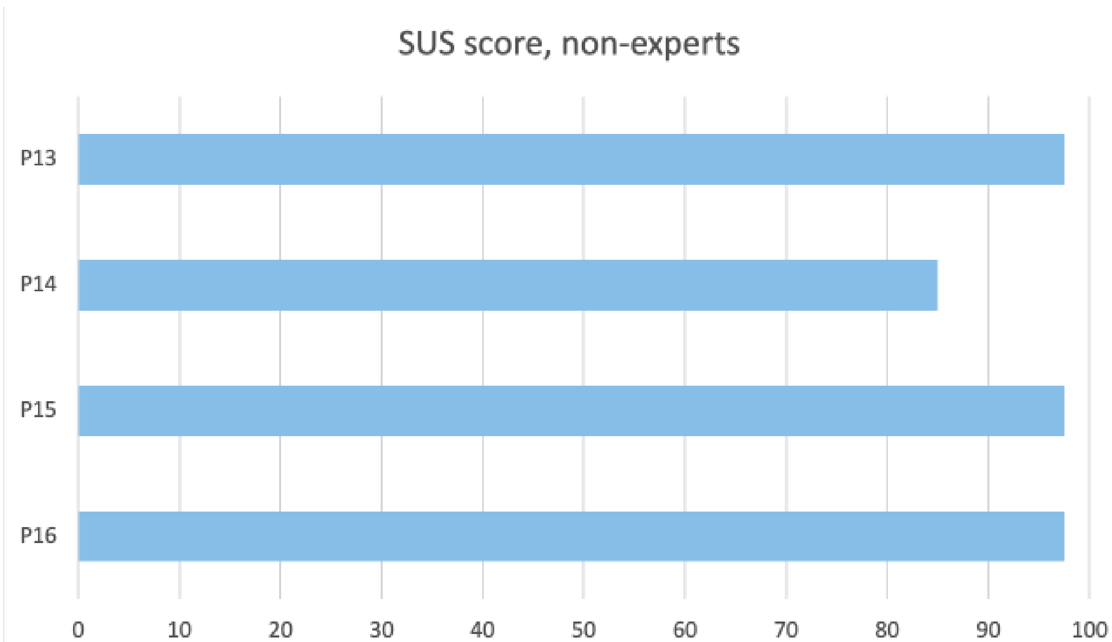


Figure 44: SUS results non-experts.

7.6.5 Comparing and Analyzing SUS Results

A total of 16 participants evaluated the usability of the system. The third prototype scored an average of 83,5 points (grade "B"), and the fourth prototype ended up with a total of 95 points, which corresponds to grade "A". Both scores are above average, with the final score significantly improved.

7.6.6 Heuristic Evaluation with IT Experts

Before the IT experts evaluated the prototype, the comments and feedback from the previous groups were taken into consideration. Everything feasible to fix and implement was fixed. Moreover, the participants of the last group were informed that feedback of the previous evaluation would be included in future work. It is important to note that there was one less person in this group than the prior, meaning the last expert evaluation consisted of a total of five people. The average score of this group can be seen in Table 8.

Heuristic	Average Score
1.Visibility of system status	0,2
2. Match between system and the real world	0
3. User control and freedom	0,6
4. Consistency and standards	0,2
5. Error Prevention	0,6
6. Recognition rather than recall	0
7. Flexibility and efficiency of use	0,2
8. Aesthetic and minimalistic design	0,2
9. Help users recognize, diagnose, and recover from errors	0
10. Help and documentation	0

Table 8: Nielsen's Heuristics results from IT experts on fourth prototype.

The overall results from the evaluation of the last prototype are regarded as excellent. Feedback and comments from the expert users on each heuristic are summarized in the list below:

1. *Visibility of System Status*
   This was satisfying in the last prototype, with the exception of one participant, who thought it should be made even clearer which page was active in the header.

2. *Match Between System and The Real World*
   Satisfactory. One participant suggested links to the dictionary when difficult words appear in the system for future work.

3. *User Control and Freedom*
   The experts specifically noted that the application did not support any undo, redo, or clear functions. It was suggested to implement these in future work.

4. *Consistency and Standard*
   One participant did not like that there was a different color on "my prosthesis" compared to the rest in the menu for patients. One participant did not seem to understand the difference between logged in (expert users) and logged out (patients), as they wanted it to be made even clearer what pages were for patients and what were for expert users.

5. *Error Prevention*
   In addition to the comments received on *3. User Control and Freedom*, it was suggested to include a warning if users tried exiting certain pages (e.g. Cox Regression), before saving sessions.

6. *Recognition Rather Than Recall*
   Satisfactory, no comments from participants.

7. *Flexibility and Efficiency of Use*
   P10 was missing implementations meant for expert users. However, P8 pointed out that by hiding information behind "hint-icons", the system is easier to use for expert users than novice users.

8. *Aesthetic and Minimalist Design*
   Satisfactory to some extent. P8 pointed out that the word grid was somewhat large on the patient's landing page.

9. *Help Users Recognize, Diagnose and Recover from Error*
   Error messages were not implemented at this time. However, they would be presented in plain language, with no code, to be easily understandable for the users.

10. *Help and Documentation*
    The experts suggested implementing a help page. Unfortunately, there was no time for this but should be considered a priority in future work.

8 Discussion

This chapter discusses the high-fidelity prototype, along with the different methods and methodologies utilized in the research. Finally, the research questions are answered.

8.1 Methods

8.1.1 Design Science Research

The Design Science Research framework was used during the whole timeline of the thesis to integrate methods that were applied in the research. The framework has seven clear principles, which made for an efficient way to carry out the research. It was suitable for solving a problem in the medical informatics field. Section 3.1 shows all steps executed leading to the resulting artifact. Design Science Research can be recommended for any real-life and research domain where various experts and methods ought to be considered and involved.

8.1.2 Data Gathering

Literature Review

In the first iteration, a literature review was conducted to gather data and valuable information regarding arthroplasty and designing for specific user groups. It was a great starting method for understanding what sort of theoretical and practical work had to be done. It became clear that there was a need for more specific information for patients, and that there was an opportunity to aid researchers and physicians in their work. The literature review was the foundation of this thesis.

Interview

A semi-structured interview was carried out in iteration one (Section 5.3.2). The method worked well to capture information one cannot find elsewhere. The details provided by the biomedical researcher about the concept and content for the expert side were valuable and contributed greatly to the completion of the prototype. In addition, the meeting with the Norwegian Arthroplasty Register (Section 5.3.1), was of great importance to define the thesis, as the scope of the research was exceedingly abstract and broad prior to this. As experts in the field of Orthopedics, they contributed with meaningful knowledge and gave a sense of clinical utility for the research.

Ideally, interviews with patients would also be carried out in various phases of the development. However, as previously stated, this was not feasible due to the COVID-19 pandemic. Nonetheless, the domain experts were generally positive in regards to the system concept of LeddPor (Chapter 7).

Questionnaire

The questionnaire provided a lot of insightful information from patients in a short amount of time. It was administered to patients in the third design iteration (Section 5.5.3). The feedback was valuable and useful in regards to what functionalities and content should be included in the implementation. The questionnaire included both closed and open-ended questions to allow short comments.

8.1.3 User-Centered Design

The User-Centered Design (UCD) approach was a good process to follow for this application, as it relies on feedback from intended users. Granted, patients should have been more involved in this process. However, the feedback from field experts and novice users contributed greatly to the process and even potentially understanding the patient side (Sections 7.5 and 7.6.1). UCD emphasizes user experience, which was of great significance when designing front-end solutions for such technical methods and practices.

8.1.4 Interaction Design Life-Cycle

As described in Section 3.3.3, the interaction design life-cycle is based on four basic activities: discovering requirements, designing alternatives, prototyping, and evaluating. The life-cycle overlaps with both Design Science Research and UCD. Therefore, it was natural to utilize this method in combination with the others to drive the research forward while also ensuring the quality of the different iterations.

8.1.5 Design Principles

The design principles were applied and reviewed early in the design process to ensure the usability of the system (Section 5.5.1). The principles were important in order to secure an intuitive and user-friendly design that would ensure a good user experience.

8.1.6 Usability Goals

The usability goals, presented in Section 3.3.5, were applied to develop the prototype and proved useful to secure usability. *Effectiveness* and *Efficiency* corresponds with the total SUS score. As shown in Section 7.2, the final average score was 95 points. Thus, one could argue that these goals have been satisfied. The *Safety* is perceived as good. There are no known errors that can enable the user to find themselves in a dangerous or unwanted situation. The prototype demonstrates *Utility* by having essential functionalities. One has to incorporate more support functions for future work. Based on the feedback from both experts and novice users, one can assume the prototype satisfies *Learnability*, as questions 4, 7, and 10 from the system usability scale are directed at how easy the system is to use (Section 3.4.2). *Memorability* is difficult to prove since this goal measures how easy it is for a user to remember the system after a period with no use. However, since learnability is considered high, one can assume that users barely would have any problems using the system after an inactive period.

8.1.7 Evaluation

A total of 16 participants evaluated the system in iterations four and five. Three well-known and established evaluation methods were used in evaluating LeddPOR; Usability testing, System Usability Scale, and Nielsen's Heuristics.

Usability Testing

Usability testing was conducted on both an expert group and a novice user group. The usability testing gave a good indication of whether or not the user interface was intuitive. The expert users were given eight tasks, while the novice users were given the four tasks intended for patients. They all managed to complete the tasks without guidance (Section 7.6). This suggests the system was easy to understand and use.

System Usability Scale (SUS)

SUS is an easy and quick evaluation method suitable for most systems. Field experts and usability experts provided feedback through SUS evaluation in the fourth iteration (Section 5.6.3), while IT experts and the non-expert group performed SUS evaluation in the fifth iteration (Section 5.7.3). Some important issues were highlighted in the first evaluation, and could be fixed in the next iteration. All groups gave a good SUS score.

Nielsen's Heuristics

The last evaluation method used in this thesis was Nielsen's Heuristic. As the heuristics are desktop-centered, this tool was a good choice for evaluating the prototype created. The goal of the evaluation was to discover if there were any potential errors in the prototype. The experts who first evaluated the prototype in iteration four noticed aspects of the system that should be improved, but none of the issues were found critical. The improvements that were feasible to fix were implemented before the next evaluation, and the results show improvement (Sections 7.5.2 and 7.6.6). All ten heuristics were included in the evaluation, even though "help and documentation" were not implemented and thus had no relevance. However, all groups encouraged the implementation of help and documentation at a later time.

Despite the fact that heuristic evaluation is a highly common practice when evaluating a system, there are still some disadvantages to the method. In the particular case of this thesis, experts can be blind to certain aspects that users find essential. Therefore, it would be constructive for the prototype to be tested by actual potential users, specifically patients to ensure that important problems have not gone unnoticed.

8.2 Prototype Development

The prototype was designed and developed through five design iterations. The usage of low- mid- and high-fidelity prototypes proved beneficial for implementing functions and visualizations for evaluation. The prototype was central when receiving feedback, and the higher the fidelity of the prototype, the more suggestions and comments were acquired. In theory, the development had five iterations, but there were in fact, many smaller iterations in between the main iterations, which lead to continuous and constant improvements of the prototype. The smaller iterations were helpful to maintain progress and achieve usability goals. This was especially the case in the team discussions when aspects of the back-end development required input from the front-end. Also, such communication helped to better understanding what development methods entailed, and how the results would be presented to the users. This team communication was often driving these smaller, micro iterations.

The prototype was made in Adobe XD, which means the final artifact is still a prototype and not a fully developed system. Even though the system was tested by various expert groups and a group of novice users, it is recommended to conduct further testing on the artifact, where medical experts and patients are involved.

8.2.1 Limitations

The thesis presents several limitations. Firstly, the prototype should have been an implemented front-end connected to the back-end, and fully functional. A fully interactive prototype would have made the evaluation more accurate. Secondly, the evaluation should have been tested in a more formal and clinical setting. Third, a broader circle of authentic users, such as physicians and patients, should have been included. However, this was not feasible due to the strict rules regarding hospital visits as a result of the COVID-19 pandemic.

8.3 Answering Research Questions

RQ1: *How can front-end development complement back-end development to deliver a user-friendly system for data mining in arthroplasty?*

This thesis is built upon a collaborative exchange between four master students. Planning procedures were done in collaboration; what methods should be included were thoroughly discussed through five iterations. Each iteration was built upon the feedback from the team and experts in various fields. This thesis focused on designing the interface visualization and user experience. It is only through this combination that users could feel comfortable performing data mining and obtain results that would be hard to get without technical background and programming knowledge. Front-end development allows interaction between physicians and researchers, and the system itself. The front-end development provided the back-end team with valuable input regarding what functions would be important to include. Associated work by Knut Hufthammer and Sølve Ånneland address the back-end aspects of the system (Ånneland, 2021; Hufthammer, 2021).

RQ2: *How can Human-Computer Interaction, in particular, be utilized to support physicians in analyzing data in their daily work and in research?*

It is important to note that the prototype created in this thesis does not cover all aspects but in particular those when physicians and researchers turn to understand the risk at hand. The data methods that were implemented are commonly seen in research and practice. The main focus concerns the longevity of the implant and reasons for re-operations for particular patient groups (Chapter 6).

UCD was used during development to make working with statistical procedures as user-friendly as possible. As the researcher pointed out during the interview (Section 5.3.2), there is currently no interactivity while working with the register. The prototype created demonstrates the possibility to stratify data, and looking at specific variables, accompanied by strong visualizations created by Arle Farsund Solheim (Farsund Solheim, 2021). This is described in Section 5.6.2. The effect this would have long term has to be studied, along with how the users utilize the prototype in their everyday work. Currently, data is analyzed in remote mode with help from statisticians and is only presented in annual reports. This makes it very challenging to interact with the register and get quick responses. The data might even be underutilized. HCI solutions could remove these significant barriers. Feedback from expert users has gained positive response (Chapter 7) and could encourage future development of the system. Additional testing has to be performed in the future. Now that a prototype is created, this would be feasible.

RQ3: *How can Human-Computer Interaction, in particular, be utilized to support non-expert users such as patients to better understand surgical procedures and implants?*

The register offers lots of useful data and competence, which is also a national resource that can have great appeal to patients awaiting surgery or healing post-surgery. It is almost expected to have the most important information regarding arthroplasty procedures available to the public, and offer resources to patients. The results from the questionnaire distributed to the patients indicate that there are still unmet information needs, and interest to learn more (Section 5.5.3). The high-fidelity prototype utilizes pictures, presentations of implants, and some developed mobile applications for patients (Chapter 6). More detailed data that needs expert knowledge to interpret is not presented to patients. For example, it might be hard to interpret the results of survival analysis for non-experts (Section 6.2). It might even cause some doubts regarding the surgery. However, based on the results from the user testing and heuristic evaluation, there is information that seems to be well understood by non-experts, which suggests this part of the system could be met with acceptance (Section 7.6).

RQ4: *How can this thesis help transform the current state of presenting data from the arthroplasty register to a better and preferred state?*

Understanding how data mining from the arthroplasty register is currently conducted, and exploring how the data is presented to users is fundamental for this thesis. Within the third iteration of the development process, a questionnaire was sent out to better understand the state of art and current information needs of patients (Section 5.5.3). Results suggested that 18,4% felt they had inadequate knowledge, 57,1% felt they had medium knowledge, while 24,4 % felt they were comfortable with what they knew about implants.

There are enough arguments to think that the work has shown directions and feasibility of developing an interactive interface to the register, which currently has none. An example of what could be done has already been demonstrated. Considering this is a national register, it ought to be explored what appeal the prototype has for physicians and researchers that are working closely to the register, but also those that could have considered using it in the future. The annual meeting of orthopedic surgeons could be one place to present the prototype. Another or future possibility would be to start a dedicated project that would begin with the prototype of this thesis and lead to further development iterations. Since the system offers functionality that is seen in other web-enabled systems working with the data, it could be expected that potential users would give it a chance and develop it further.

A promising example where good interactive systems have been embraced and introduced to clinical wards and research includes WEKA, an open-source data mining system with documented applications in medical domains (Frank, Hall, Trigg, Holmes, & Witten, 2004; Heinemann, 2018; Hosni, Abnane, Idri, Carrillo de Gea, & Fernández Alemán, 2019; Ivanciuc, 2008; *WEKA 3 - data mining with open source machine learning software in java*, 2021).

9 Conclusion and Future Work

The Design Science Research methodology requires some novel artifact of relevance for a problem and of value for intended users. Based on the expert evaluations alone, the results of this research could be deemed as a novel and meaningful contribution to the knowledge base.

This thesis has contributed with a high-fidelity prototype of a desktop application named LeddPOR. The system is dedicated to physicians, researchers, and patients. The back-end development team has provided valuable data mining tasks to be incorporated in the prototype, and another member of the front end-team has created visualizations. Through the current user interface, one could perform data mining procedures such as Kaplan Meier, Cox Regression, and various forms of descriptive statistics. Patient data is at the moment limited to presentation of implants, but also dedicated resources such as mobile applications for post-operative care and safety reporting.

Usability experts performed a SUS evaluation before non-experts, to ensure high quality of artifact before involving novice users in testing. The SUS score graded ”B” of the third prototype indicated that there was still room for improvements. The experts also reviewed Nielsen’s Heuristics to determine how user-friendly the proposed interface was.

The thesis followed the User-Centered Design approach, as a method to produce a prototype that would be appreciated by the intended user groups. The process followed five iterations, where users ideally should have been more involved. However, a group of experts and non-experts contributed greatly in eliciting feedback on the different design solutions. Since part of the high-fidelity prototype is intended for the general population, the design and functions are kept simple.

Final usability testing was conducted on the high-fidelity prototype, by both expert and novice users, and included performing four to eight tasks, which returned with a high success rate. The same goes for the final system usability score which was compared to the grade ”A” (best imaginable) on the SUS score scale.

The prototype provides the foundation for future development of an application that can aid physicians and researchers in their everyday work, as well as improving patient knowledge about procedures and implants.

9.1 Future Work

Future work should firstly include a broader circle of physicians and patients in evaluation. The next step would include technical implementation of the functionalities, for example using the React.JS framework. This would be a necessary step in order to gather feedback and evaluations from intended user groups. New functions might be suggested by either physicians or patients that could influence the system in a good way. This far, proposed features include, but are not limited to; log-in for patients for a more personal experience and customized information based on their implant. With this implemented, one could connect the system to Helsenorge.no. In addition, rehabilitation and other post-operative care could be presented in the system. As for the expert users, the set of data mining tasks can be extended to include additional data analytical methods according to their needs, be it general patient outcomes or aspects of safety and general performance of the implants.

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Appendix

A NSD Approval

NSD NORSK SENTER FOR FORSKNINGSDATA

NSD sin vurdering

Prosjekttittel

Grafisk brukergrensesnitt for norsk register for kne- og hofteproteser

Referansenummer

364254

Registrert

20.10.2020 av Sunniva Blom Stolt-Nielsen - Sunniva.Stolt-Nielsen@uib.no

Behandlingsansvarlig institusjon

Universitetet i Bergen / Det samfunnsvitenskapelige fakultet / Institutt for informasjons- og medievitenskap

Prosjektansvarlig (vitenskapelig ansatt/veileder eller stipendiat)

Ankica Babic, ankica.babic@uib.no, tlf: 4755589139

Type prosjekt

Studentprosjekt, masterstudium

Kontaktinformasjon, student

Sunniva Blom Stolt-Nielsen, nar005@uib.no

Prosjektperiode

15.11.2020 - 15.06.2021

Status

06.11.2020 - Vurdert

Vurdering (1)

06.11.2020 - Vurdert

Det er vår vurdering at behandlingen av personopplysninger i prosjektet vil være i samsvar med personvernlovgivningen så fremt den gjennomføres i tråd med det som er dokumentert i meldeskjemaet den 06.11.2020 med vedlegg, samt i meldingsdialogen mellom innmelder og NSD. Behandlingen kan starte. □ □

MELD VESENTLIGE ENDRINGER □
Dersom det skjer vesentlige endringer i behandlingen av personopplysninger, kan det være nødvendig å melde dette til NSD ved å oppdatere meldeskjemaet. Før du melder inn en endring, oppfordrer vi deg til å lese om hvilke type endringer det er nødvendig å melde: https://nsd.no/personvernombud/meld_prosjekt/meld_endringer.html

Du må vente på svar fra NSD før endringen gjennomføres.

TYPE OPPLYSNINGER OG VARIGHET
☐Prosjektet behandler særlige kategorier av personopplysninger om helse og alminnelige kategorier av personopplysninger frem til 15.06.2021. ☐ ☐

LOVLIG GRUNNLAG ☐
Prosjektet vil innhente samtykke fra de registrerte til behandlingen av personopplysninger. Vår vurdering er at prosjektet legger opp til et samtykke i samsvar med kravene i art. 4 nr. 11 og art. 7, ved at det er en frivillig, spesifikk, informert og utvetydig bekreftelse, som kan dokumenteres, og som den registrerte kan trekke tilbake. ☐ ☐Lovlig grunnlag for behandlingen er dermed den registrertes uttrykkelige samtykke, jf. personvernforordningen art. 6 nr. 1 bokstav a, jf. art. 9 nr. 2 bokstav a, jf. personopplysningsloven § 10, jf. § 9 (2). ☐ ☐

PERSONVERNPRINSIPPER ☐
NSD vurderer at den planlagte behandlingen av personopplysninger vil følge prinsippene i personvernforordningen om: ☐

- lovlighet, rettferdighet og åpenhet (art. 5.1 a), ved at de registrerte får tilfredsstillende informasjon om og samtykker til behandlingen ☐

- formålsbegrensning (art. 5.1 b), ved at personopplysninger samles inn for spesifikke, uttrykkelig angitte og berettigede formål, og ikke viderebehandles til nye uforenlige formål ☐

- dataminimering (art. 5.1 c), ved at det kun behandles opplysninger som er adekvate, relevante og nødvendige for formålet med prosjektet ☐

- lagringsbegrensning (art. 5.1 e), ved at personopplysningene ikke lagres lengre enn nødvendig for å oppfylle formålet ☐ ☐

DE REGISTRERTES RETTIGHETER ☐
Så lenge de registrerte kan identifiseres i datamaterialet vil de ha følgende rettigheter: åpenhet (art. 12), informasjon (art. 13), innsyn (art. 15), retting (art. 16), sletting (art. 17), begrensning (art. 18), underretning (art. 19), dataportabilitet (art. 20).

NSD vurderer at informasjonen som de registrerte vil motta oppfyller lovens krav til form og innhold, jf. art. 12.1 og art. 13. ☐
Vi minner om at hvis en registrert tar kontakt om sine rettigheter, har behandlingsansvarlig institusjon plikt til å svare innen en måned. ☐ ☐

FØLG DIN INSTITUSJONS RETNINGSLINJER
NSD legger til grunn at behandlingen oppfyller kravene i personvernforordningen om riktighet (art. 5.1 d), integritet og konfidensialitet (art. 5.1. f) og sikkerhet (art. 32).

For å forsikre dere om at kravene oppfylles, må dere følge interne retningslinjer og eventuelt rådføre dere med behandlingsansvarlig institusjon.

OPPFØLGING AV PROSJEKTET ☐
NSD vil følge opp ved planlagt avslutning for å avklare om behandlingen av personopplysningene er avsluttet.☐

Lykke til med prosjektet! ☐

Kontaktperson hos NSD: Henrik Netland Svensen
Tlf. Personverntjenester: 55 58 21 17 (tast 1)

B Consent Form

Vil du delta i forskningsprosjektet

"Maskinlæring i norsk register for kne- og hofteproteser"?

Dette er et spørsmål til deg om å delta i et forskningsprosjekt hvor formålet er å lage en portal for analyse og datautvinning av data fra det norske artroplastikk registeret (NAR). I dette skrivet gir vi deg informasjon om målene for prosjektet og hva deltakelse vil innebære for deg.

Formål
Formålet med prosjektet er å utvikle en prototype av en portal hvor brukergrupper slik som ortopeder kan få tilgang til nyttig informasjon om kne og hofteoperasjoner. Hvis prototypen blir god nok, vil det bli utviklet et endelig produkt som tar utgangspunkt i prototypen.

Systemet vil bruke analyse og datautvinning teknikker på registerdata fra det norske artroplastikk registeret. Målet er å skape en plattform med innsikt og analyseredskap for å besvare kliniske spørsmål vedrørende pasienters hofte og/eller kneproteseoperasjon. Forskningsprosjektet vil ha to ulike, men relaterte og til dels overlappende fokus. 1. Et datautvinnings aspekt hvor det vil tas i bruk maskinlæring og andre dataanalyse teknikker for innsikt i data. 2. Et menneske-maskin-interaksjon (HCI) aspekt hvor fokuset ligger på brukergrensesnitt og hvordan en kan presentere analytisk data på en nyttig og intuitiv måte. Noen av spørsmålene vi ønsker å besvare er blant annet: Hva er den estimerte levetiden på protesen? Hvilke faktorer påvirker levetiden av en protese? Hvilke pasientgrupper assosieres med høyere grad av revisjonsoperasjoner? HCI relaterte problemstillinger inkluderer: Hvordan kan designmetoder fra HCI hjelpe med å visualisere data på best mulig måte for forskjellige brukergrupper? Hvordan kan sensitiv medisinsk data bli presentert på en etisk riktig måte? Kan bruk av HCI-metoder og -prinsipper på registerdata hjelpe leger, og forbedre pasientomsorgen?

Forskningsprosjektet består av et samarbeid mellom fire masterstudenter der hver student har ulike oppgaver tilknyttet prosjektet. Studentene har en felles veileder som skal resultere i fire individuelle masteroppgåver.

Hvem er ansvarlig for forskningsprosjektet?
Universitetet i Bergen er ansvarlig for prosjektet.

Hvorfor får du spørsmål om å delta?

Veileder har inngått et samarbeid på forhånd med forskere ved norsk register for leddproteser og ortopeder fra Haukeland Universitetssykehus. Utvalget er aktuelle brukere av det ovennevnte systemet. Som brukergruppe, kan de bidra med kravsetting og utforming av systemet. Som fagkyndig og praktiserende, kan de hjelpe med klinisk forståelse av behandlingen og generell rådføring gjennom forskningsprosjektet.

Hva innebærer det for deg å delta?

Hvis du velger å delta i prosjektet, innebærer det at du stiller til et personlig intervju. Det vil ta deg ca. 30-60 minutter. Intervjuet inneholder spørsmål om dine meninger eller oppfatninger om systemet. Vi ønsker tilbakemeldinger fra fagkyndige for å utvikle prototypen. Metoden vi vil bruke er personlig intervju. Det kan også bli aktuelt med brukertesting under observasjon.

Utvalg 1 (ortopeder), utvalg 2 (forskere), utvalg 3 (pasienter) og utvalg 4 (studenter) vil kunne bli bedt om å delta i et personlig intervju, og brukertesting.

Det er frivillig å delta
Det er frivillig å delta i prosjektet. Hvis du velger å delta, kan du når som helst trekke samtykket tilbake uten å oppgi noen grunn. Alle dine personopplysninger vil da bli slettet. Det vil ikke ha noen negative konsekvenser for deg hvis du ikke vil delta eller senere velger å trekke deg.

Det er ingen avhengighetsforhold for deg som deltaker.

Ditt personvern – hvordan vi oppbevarer og bruker dine opplysninger
Vi vil bare bruke opplysningene om deg til formålene vi har fortalt om i dette skrivet. Vi behandler opplysningene konfidensielt og i samsvar med personvernregelverket.

- Prosjektgruppe og veileder.
- Navnet og kontaktopplysningene dine vil jeg lagre på en kryptert harddisk.

I utgangspunktet vil deltakere ikke kunne gjenkjennes i publikasjon, men kreditering av deltaker kan innfris etter ønske fra deltaker. I tilfelle det blir aktuelt, vil opplysninger som navn og yrke kunne bli gjengitt i publikasjon.

Hva skjer med opplysningene dine når vi avslutter forskningsprosjektet?
Opplysningene anonymiseres når prosjektet avsluttes/oppgaven er godkjent, noe som etter planen skal skje juni 2020. Ved prosjektslutt vil alle personopplysninger bli anonymisert og alle typer opptak (lyd,video) vil bli slettet.

Dine rettigheter
Så lenge du kan identifiseres i datamaterialet, har du rett til:

- innsyn i hvilke personopplysninger som er registrert om deg, og å få utlevert en kopi av opplysningene,
- å få rettet personopplysninger om deg,
- å få slettet personopplysninger om deg, og
- å sende klage til Datatilsynet om behandlingen av dine personopplysninger.

Hva gir oss rett til å behandle personopplysninger om deg?
Vi behandler opplysninger om deg basert på ditt samtykke.

På oppdrag fra Universitetet i Bergen har NSD – Norsk senter for forskningsdata AS vurdert at behandlingen av personopplysninger i dette prosjektet er i samsvar med personvernregelverket.

Hvor kan jeg finne ut mer?

Hvis du har spørsmål til studien, eller ønsker å benytte deg av dine rettigheter, ta kontakt med:

- Prosjektveileder Ankica Babic og/eller Sunniva Stolt-Nielsen (student) ved Universitetet i Bergen.
    - Ankica Babic - Kan nås på epost (Ankica.Babic@uib.no) eller på telefon: +47 55 58 91 39
    - Sunniva Stolt-Nielsen - Kan nås på epost (sunniva.stolt-nielsen@uib.no)

Hvis du har spørsmål knyttet til NSD sin vurdering av prosjektet, kan du ta kontakt med:

- NSD – Norsk senter for forskningsdata AS på epost (personverntjenester@nsd.no) eller på telefon: 55 58 21 17.

Med vennlig hilsen

Ankica Babic (Forsker/veileder)	Sunniva B. Stolt-Nielsen (Student)

Samtykkeerklæring

Jeg har mottatt og forstått informasjon om prosjektet *Maskinlæring i norsk register for kne- og hofteproteser*, og har fått anledning til å stille spørsmål. Jeg samtykker til:

- □ å delta i *personlig intervju*
- □ å delta i *brukertesting (observasjonsstudie)*
- □ *at Sunniva Stolt-Nielsen kan gi opplysninger om meg til prosjektet*
- □ *at opplysninger om meg publiseres slik at jeg kan gjenkjennes gjennom navn, yrke, kjønn, og alder.*

Jeg samtykker til at mine opplysninger behandles frem til prosjektet er avsluttet

----
(Signert av prosjektdeltaker, dato)

C Interview Guide

Intervjuguide

Format: ansikt til ansikt eller digitalt intervju.

Svarregistrering: Lydopptaker, notater.

Hensikten med intervjuet er å først etablerte den faglige bakgrunn hos deltakerne, la deltakerne utforske og tolke resultatene og modellene jeg har utviklet, for deretter å få deltakernes oppfattelse av resultatene og hvorvidt de er aktuelle for fremtidige informasjonssystemer i ortopedi.

Intervju

Varighet rundt 30-60 minutter.

Deltakerne informeres om hva prosjektet går ut på og hva jeg ønsker med intervjuet. Deltakernes teknologiske kompetanse og deres kunnskap rundt artroplastikk og databaser kartlegges.

Personalia

- Hvor gammel er du?
- Hva jobber du som?
    - Stilling / stillingsbeskrivelse?
- Hva er din høyeste utdanning?

Spørsmål:

- Hvilken erfaring har du med teknologi?
    - Vil du si du er datakyndig (kompetent)?
- Hvilken teknologier bruker du på en daglig basis?
- Kan du fortelle om en vanlig dag for deg?
    - (hvor teknologi bli brukt)

- Hvordan vil du beskrive din kompetanse på kne- og hofteproteser?
- Har du kjennskap til informasjonssystemer som predikerer utfall av proteseoperasjoner? Dersom ja, kan du nevne disse?

- Er det vanlig å beregne hva som er årsaken til reoperasjoner for kne- og hofteproteser?
    - Hvordan gjøres dette?
    - Ser du på sammenhenger mellom proteseprodusenter og årsaker til reoperasjoner?

- Pleier du å gjøre vurderinger på kvaliteten på produktene til ulike proteseprodusenter?
- Hvordan gjøres dette?
    - Har du kjennskap til systemer som hjelper med slike vurderinger?

- Hvordan brukes databasene nå?
    - Hvordan ser du på dataen?
    - Hvordan syns du visualiseringen er i dag? Bra/dårlig?
    - Hjelper visualiseringene med forståelsen for dataen?
    - Er det kjente forbedringspunkt for visualiseringene?
- Hvordan syns du det fungerer?
    - Oppstår det noen problemer?
    - Hvis ja, hvordan løses disse?
- Hvilken funksjoner er tilgjengelig for deg nå?
    - Begrense søk, spesifisere søk, osv.
    - Er det noen funksjoner du savner?
- Hva er ditt hovedformål med registeret?
    - forskning, årsrapport eller daglig bruk?
- Hvor ofte kunne du tenkt deg å bruke registeret hvis dataen var tilgjengelig online?
    - Fra tid til annen/en gang i året?

- Utledende spørsmål; har du noe mer å tilføye som ikke har blitt spurt om?

D SUS Form

System Usability Scale

Name: _____
Age: xx
Device: _____
Date: dd/mm/yy

Instructions: For each of the following statements, mark **one** box that best describes your reactions to the system *today*.

	Strongly disagree				**Strongly agree**
1. I think that I would like to use the system frequently					
2. I found the system unnecessarily complex					
3. I thought the system was easy to use					
4. I think I would need assistance to be able to use this system					
5. I found the various functions on the system well integrated					
6. I thought there was too much inconsistency on the system					
7. I would imagine that most people would learn to use the system very quickly					
8. I found the system very cumbersome/awkward to use					
9. I felt very confident using the system					
10. I need to learn to learn a lot of things before I could start using the system					

Please provide more comments about the system:

E Nielsen's Heuristics Form

Nielsen's Heuristic

Name: ______

Age: xx

Device: ______

Date: dd/mm/yy

Severity:

0 – Everything is fine

1 – Cosmetic problem only: need not be fixed unless extra time is available

2 – Minor usability problem: fixing this should be given low priority

3 – Major usability problem: important to fix, should be given high priority

4 – Usability catastrophe: imperative to fix this before product can be released

Heuristic	Severity	Issues	Recommendation
Visibility of system status The system should always keep users informed about what is going on, through appropriate feedback within reasonable time			
Match between system and the real world The system should speak the users' language, with words, phrases and concepts familiar to the user, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order.			
User control and freedom Users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo.			
Consistency and standards Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions.			
Error prevention Even better than good error messages is a careful design which prevents a problem from occurring in the first place. Either eliminate error-prone conditions or check for them and present users with a			

confirmation option before they commit to the action.			
Recognition rather than recall Minimize the user's memory load by making objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate.			
Flexibility and efficiency of use Accelerators -- unseen by the novice user -- may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users. Allow users to tailor frequent actions.			
Aesthetic and minimalist design Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility.			
Help users recognize, diagnose, and recover from errors Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.			
Help and documentation Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large.			