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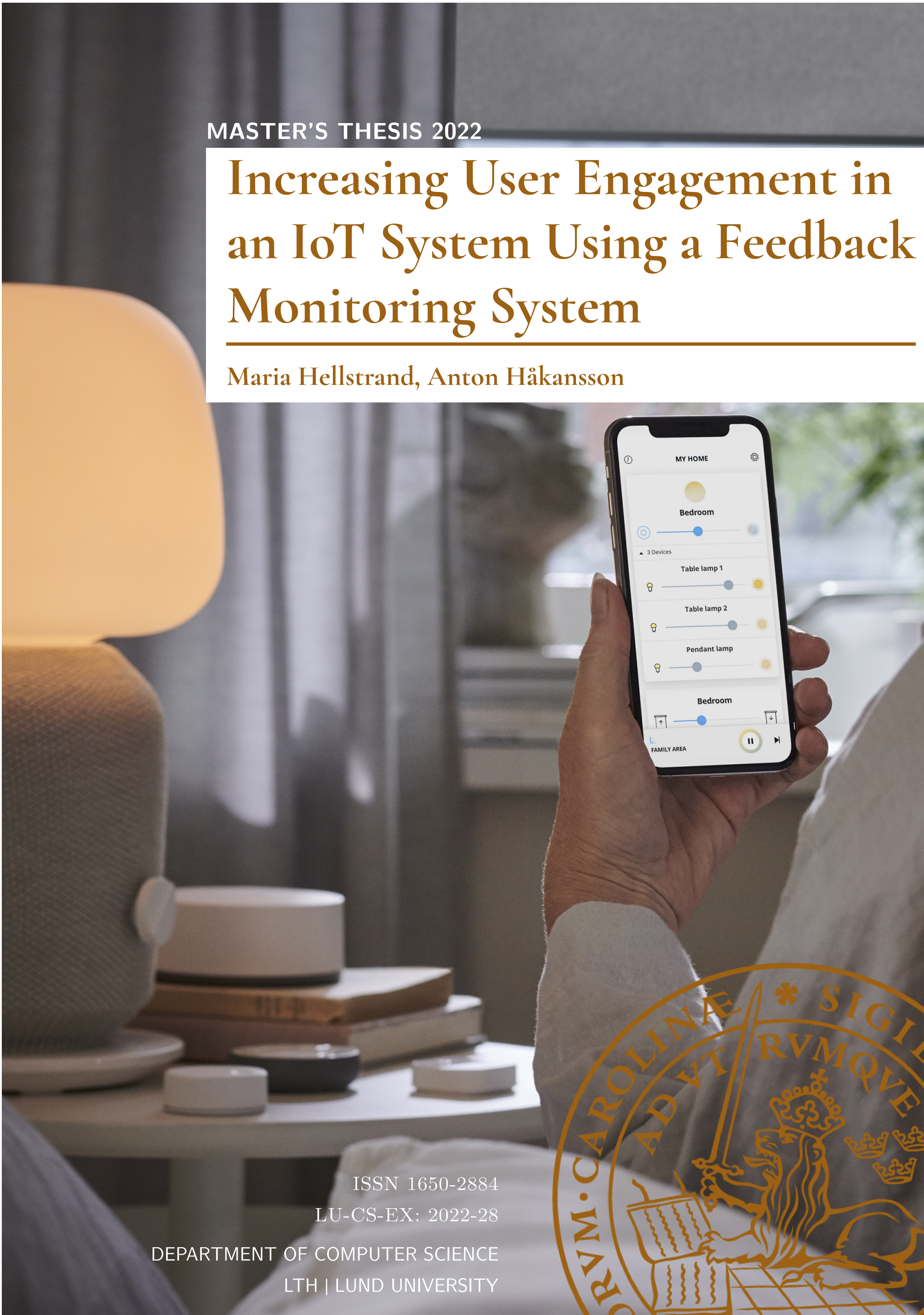
Increasing User Engagement in an IoT System Using a Feedback Monitoring System

Maria Hellstrand, Anton Håkansson



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Hur man genom feedback kan engagera användare att underhålla och monitorera sitt IoT system

Maria Hellstrand, Anton Håkansson

Increasing User Engagement in an IoT System Using a Feedback Monitoring System

(A Master Thesis)

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Abstract

The user base of IoT has increased at a rapid pace and made its way into the everyday life of numerous homes. This puts a high demand on the IoT system in terms of how information is provided to the users since a wide group of people needs to understand and maintain the system.

This thesis investigates what kind of information is relevant and valuable for the users to receive. It can be frustrating to not understand why your system behaves in a certain way. This frustration could be avoided by providing users with the right feedback. It can also be beneficial for users to receive more information about the system and its health. By providing this information to the users, they can become more engaged with using their systems.

Additionally, this thesis examines how information from the system can be collected and stored. Different approaches to acquiring this data are compared and discussed to choose the most feasible solution.

The chosen solution in this thesis solves the stated problem by collecting valuable data from the internal communication channel in the system. The solution consists of two services that provide real-time feedback and an opportunity for the users to diagnose their systems. The results from this thesis show that by providing users with relevant information from their systems, their understanding and engagement with using the system can be increased.

Keywords: Monitoring IoT, Home Smart system, User feedback IoT

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Contents

Chapter 1
Introduction

Internet of Things (IoT) is a concept that has evolved increasingly over the past few years [1]. IoT means essentially that software is integrated into hardware components such that these are possible to interact with. There are several examples of IoT devices in the home environment such as lights, blinds, cameras, and vacuum cleaners which together possess a network of IoT devices. The several use cases for IoT in the home environment are one of the reasons that IoT progressively has made its way into the lives of everyday people. These devices can be controlled from a remote control, voice control, or a graphical user interface, for instance, a web or mobile application.

The performance of IoT systems depends on multiple factors such as internet connection, signal strength, health of the devices, and hardware limitations [2]. This means that the availability and reliability of such a network may be impacted by some of the stated factors. An IoT system contains information about the current state of the devices and about problems that arise within the system. A lot of this information is not accessible to the user, meaning that often the user does not receive much information about the system and its behavior.

It can be frustrating for a user to not understand why a system behaves in a certain way and this frustration can lead to users becoming less interested in using their systems. The data concerning the health status of a system could be favorable for the user to obtain so that the user can both solve and avoid problems that may arise. Errors in the IoT system could potentially be resolved with the right information from the system, or in some cases even avoided. There are also other types of feedback that do not necessarily need to concern problems but could potentially be beneficial for the user's quality of life. Examples of this type of feedback could be beneficial from an environmental, economic, or health perspective. More detailed examples of this could be feedback on energy consumption or air quality in the home environment.

This thesis aims to investigate the problem above and focuses on how the user of an IoT system can understand and monitor the behavior of their systems in a better way, by providing valuable feedback to the users. We will therefore examine the architecture of an IoT system to be able to collect and analyze system data.

1.1 Case Company

The case company for this thesis is IKEA Home Smart. IKEA Home Smart has been a Business Area within IKEA since 2020 and consists of around 140 co-workers. IKEA Home Smart develops smart products to enable a smarter life at home for people around the world. Lights, blinds, speakers, and smart air purifiers are a few examples of smart products developed by IKEA.

1.2 Problem description

The case company has developed an IoT system for the home environment, referred to in this thesis as a Home Smart system. Currently, one of the challenges that the users of this Home Smart system face are the lack of possibilities to monitor the system. The reason is often the lack of feedback that the user receives from their system.

When an owner of a Home Smart system has successfully set up its system the ideal situation is that everything runs smoothly, this is however often not the case. There are multiple errors or unexpected events that can occur and when this happens the user often feels frustrated [3]. This frustration is often based on the fact that the user does not understand why the system does not act correctly, where one problem is the absence of situational information. Enabling the user to receive more information about the system would make the user get a better understanding of the system behavior and why a problem within the system occurred.

To be able to address this problem it is necessary to investigate what kind of information is valuable and relevant for the user to receive. There can be different situations where the user experiences frustration due to not understanding the system. These situations are important to capture since the frustration could be eliminated by sending the right feedback to the user. It will also be important to investigate what information from the system can be beneficial for the user to receive to monitor and understand the system's health in a good way.

When designing the solution we will need to choose an architecture for our design that makes the necessary data easily accessible. Another important problem will therefore be to investigate where in the case company's system the identified data can be found. This thesis addresses these problems and will investigate how a user can become more engaged in the process of monitoring its system by receiving more feedback.

This work will not include legal aspects when collecting and storing data for a Home Smart system. Therefore this should be taken into consideration when applying the results from this work in a production environment.

To make sure that the research does not diverge from the initiating problem, three research questions have been formulated. These research questions will be used as guidelines to make sure that the thesis follows the set goal. By answering these, we can ensure that the thesis solves the initiating problem.

1.2.1 Research questions

The research questions that will be investigated and answered in this thesis are the following:

1. **What kind of information would be valuable to provide to users of a Home Smart system, to become more engaged with monitoring and managing the system's health?**

   1.1 **Which scenarios, that a user can encounter, would be beneficial to receive more/earlier feedback for?**

   1.2 **What device information would be beneficial for the user to receive in order to better monitor the health of the system?**

   To be able to answer **RQ1** in a good way, two sub-questions have been defined. By answering these, the initial question can be answered. **RQ1.1** aims to define in which situations a user should be supported with feedback to better understand the system behavior. **RQ1.2** aims to define what information about the system health could be valuable for the user to receive, and which devices in the system should be included?

   Examples of information that could be valuable are feedback when a device is not responsive or information about which devices that generate the most errors.

2. **What system data about smart devices managed by a Home Smart system should be collected to be able to provide the end-users with the findings from RQ1?**

   This research question aims to investigate what data from the Home Smart system we will need to collect for the user to receive the information found in **RQ1**. This research question will result in answering what data should be collected and why.

   Examples of data that could be found interesting to collect are battery level of devices, firmware version, etc.

3. **What is the most suitable approach to acquire and store the data identified under RQ2 from the devices managed by a Home Smart system?**

   This research question focuses on the aspect of collecting and storing the identified data from **RQ2** and the most suitable way of doing that. There may be several approaches for collecting and storing the identified data. Therefore, we will in this thesis investigate and compare the different approaches while considering what data currently is accessible in the system.

An important part of all research questions will also be to gain knowledge of what kind of solutions currently exist to aid the user in the management of the system health and to analyze why these solutions are not adequate.

1.3 Outline

In this chapter, we presented the thesis and its aim and purpose. In Chapter 2 we will explain the research methodology that has been used in this research and how the chosen methodology aligns with the goals of this thesis. In Chapter 3 the background and related work of this thesis are discussed. The activity of problem conceptualization is explained in Chapter 4 and the chapter ends with the results of conducting this activity. In Chapter 5 the different design choices are described together with the final solution design. Then the results are evaluated in Chapter 6 and the whole thesis is discussed in Chapter 7. The report is finalized with a conclusion in Chapter 8.

Chapter 2
Research Methodology

The goal of this section is to present the research methodology that will be used during this project and provide the reader with a better understanding of the research process.

The decision of research methodology has mainly been based on the fact that we need a method that focuses on problem-solving and supports an iterative process where the solution can be refined. The problem will be approached from a user point of view and a lot of knowledge will be gained through collecting data from the end-users. The solution design will be based on these user insights, though it is not certain this will result in a feasible solution and it will be necessary that the solution can be evaluated and refined when needed. The research methodology that we have chosen to follow that meets these requirements is a design science research method, more specifically the one provided by Runeson et al. [4], visualized in Figure 2.1.

Design science was introduced to reduce the gap between theory and practice [5]. The methodology is oriented towards problem-solving and artifact design. Traditional sciences can have limitations when it comes to studying the creations of new artifacts since traditional sciences are more focused on describing, exploring, and predicting phenomena with each other. The design science research process is therefore aligned with the goals of this project, to design artifacts that solve problems and to evaluate what was designed.

Design science research is based on the same iterative process as in software development where solutions and implementations are developed and evaluated [6]. Design science can be initiated in many different ways and the research process can thereby look different depending on the chosen research method. During our project, we have focused on three main activities that are found to be prevalent in software engineering; *problem conceptualization*, *solution design*, and *empirical validation*. Problem conceptualization aims to explore the specific problem instance or instances, and by this get a better understanding of the core problem and how this can be solved.

Problem conceptualization can not be done in isolation but is strongly connected with the solution design. During these two activities, we will investigate how to answer our research questions and how to find a suitable design for our solution. In this project, the activities of problem conceptualization and solution design will be central, though empirical validation will be important to make sure the designed solution meets the specified requirements. We will validate our results to ensure that the solution solves the core problem. This approach will make it possible for us to refine our solution after validating the results.

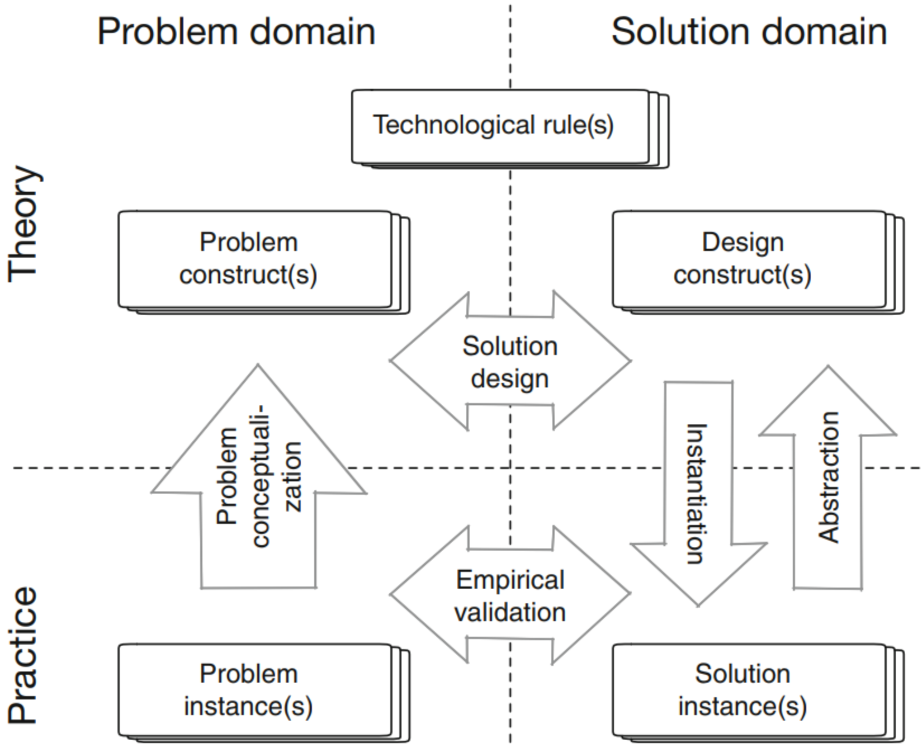

Figure 2.1: "An illustration of the interplay between problem and solution as well as between theory and practice in design science research." by Engström et al. [7]

The process described above can be seen in Figure 2.1. As seen in the figure, problem conceptualization and solution design go hand in hand. During these activities, the technological rules, defined in this thesis as requirements, are formulated and are later used during validation to make sure the solution meets all these requirements. The cyclic process aims to minimize the gap between theory and practice and can with advantage be used for research within software development.

2.1 Problem conceptualization

Problem conceptualization is the first main activity in the design science methodology by Runeson et al. [4]. This activity aims to describe the context of the problem formulated in the research.

At the beginning of the research, our focus will be on describing the problem and investigating what the core problem is. This is an important step since we are going to base our design solution on the insights and knowledge from this activity. The general problem was formulated together with our supervisors at the case company based on their experience with the system. To be able to capture the core problem we will start by performing a case study where we will try to find useful insights. The gathered data from the case study aims to give us valuable insights and help us specify the initial problem.

After conducting the activity of problem conceptualization, the goal is to define requirements for the design. These requirements will be based on the findings when answering **RQ1** and will set the base for how the solution should be designed. The requirements can both be functional and quality since both of these are important when designing a system.

2.1.1 Case study

The case study is an important part of the problem conceptualization activity. The aim of conducting a case study is to collect data that we can use to answer **RQ1**, but also to give us valuable insights for **RQ2** and **RQ3**. Case studies can have different purposes based on what they aim to achieve. This case study was used for exploratory purposes since we wanted to gain new insights and generate ideas based on these insights [8]. There are five major process steps that we followed while performing the case study:

1. Design and plan the case study
2. Preparation for data collection
3. Performing data collection
4. Analysis of the collected data
5. Reporting

We will start by designing and planning the case study since it is important for us to have a plan on how to conduct the case study and describe the aims to be achieved. Conducting a case study is well-suited to what we want to achieve during problem conceptualization since it contains important events such as data collection and data analysis. It is also a well-suited method since a case study is very flexible and data can be collected and analyzed incrementally. This will make it possible to collect more data if needed.

We have found that the best way for us to collect data was to hold interviews with the employees at the case company. By holding interviews with the employees we will be able to ask questions and have a discussion about the internal structure and functionality of the Home Smart System. The interviews will be very valuable since the employees at the case company possess a lot of knowledge from their work experience. This knowledge can hopefully be shared where the employees can give input on how the problem of this thesis can be approached.

Interviews

The goal of the interviews is to gain valuable insights that can be used to conduct appropriate design solutions. The interviews will be semi-structured, meaning that some of the questions will be predetermined while others will not have been defined in advance [9]. This structure will make it possible to ask some questions that can be open for discussion, which is valuable since users' experiences will be discussed and follow-up questions will be important to make sure all information needed is obtained. We will hold one interview with every participant.

When deciding which people to interview we are having in mind that we want people with different roles at the case company. We will choose people with knowledge of different parts of the system to make the collected data as unbiased as possible. It is also important for us to use the interviews as a way of gaining insights into the IoT architecture. These insights can help us get a better understanding of how to answer **RQ3**, since answering **RQ3** requires us to have good knowledge of the Home smart systems architecture and its different elements.

The interview questions will be mainly focused on **RQ1** since we want to gain insights from users of the Home Smart system about what information from the system they feel that they would benefit from receiving. Some people that will be interviewed will have a lot of knowledge about the architecture of the Home Smart system and we will take the chance to ask questions about what data is accessible and where it could be collected. Since we are interviewing people at the case company we will also take the chance to ask some technical questions about how the solution can be structured and designed.

When holding the interviews, the interviewees will be asked to take the role of a user of a Home Smart system. The wish is to gain insights into what kind of feedback the interviewees are interested in receiving from their system. When summarizing the results from the interviews the goal is to gain knowledge that can be used when answering our research questions.

2.1.2 Literature study

In addition to the case study, a literature study will be performed. The literature study will be conducted based on how to perform a literature study according to Thiel **[?]**. The template proposed by the author is organized in the following steps:

- Execute the search based on keywords
- Filter out the relevant papers
- Review abstract for each paper and determine the relevance
- Review the complete paper and determine relevance
- Critical analysis of the results since these are applied in the context of the new research project

Initially, the literature study will be conducted to understand the user's needs in a Home smart system and to find answers for **RQ1**. The data collected from the interviews is the foundation of this, however, the literature study will be used as a complement since there exists previous research on this subject. The findings from these researches can be used to motivate the choices we have made when answering **RQ1**.

Several aspects will be considered when studying the literature such as engagement, trust, customized feedback, and behavior from a user point of view. Therefore the keywords will consist of *user feedback IoT*, *customized feedback IoT*, *user needs Home smart systems*, and *context aware IoT*. Papers based on these keywords will then be selected and processed in the steps proposed by Thiel.

2.2 Solution design

The next main activity within the design science paradigm is solution design. This activity intends to formulate different design proposals for solving the problem and conclude the most suitable based on previously defined requirements.

The design aims to extract and collect the data found when answering **RQ2**. This data will have been identified during the previous case study and when investigating and learning about the Home Smart system's architecture. The identified data should also be stored suitably.

During this activity, a number of design proposals are analyzed and a final solution will be presented. The derived requirements will have been based on the findings from the activity of problem conceptualization and will be used for comparing and analyzing different design solutions during this phase. The comparison between different designs will conclude in the final and most suitable solution to the problem. The result of this activity will be that **RQ3** can be answered.

2.3 Validation

The validity of the research must be established by the evaluation of the problem solution [5]. The solution must meet the required conditions and should demonstrate that it can be used to solve the core problem. The resulting solution does not have to be optimal but should be a feasible solution to the problem [4]. The validation is an important activity to make sure that the resulting solution solves the initial problem. After the activity of validation, it is possible to refine the solution if needed. Design science supports an iterative process where the activities can be done cyclically.

2.3.1 Requirements

From the activity of problem conceptualization, a number of requirements will have been formulated. These requirements aim to describe how the system should work. The system needs to fulfill these requirements for it to be a feasible solution. For each requirement, the solution design will be evaluated and analyzed to make sure the solution fulfills these. The requirements will be evaluated by conducting interviews.

2.3.2 Interviews

Validation will be performed by conducting interviews with people at the case company. The interviews during the validation activity aim to investigate and analyze if the users think the solution meets the defined requirements but also how they experience the designed solution. The interviews will therefore include two main parts. The first part of the interviews will focus on the functionality derived from the solution design and if the interviewees think the functionality fulfills the requirements. During the second part of the interviews, we will ask questions about the experience of the system and the interviewees' thoughts about the solution.

The interview will be semi-structured since we aim to both ask shorter questions, but also need to ask more open questions aiming to open up for discussion.

Chapter 3

Background and Related work

This section aims to provide relevant theory and related work to this thesis. IoT in general is a substantial subject, however, this section intends to describe and explain the most relevant concepts. This will be needed to provide the reader with a basic understanding of the major impact IoT has and will have on our lives and to learn about the concepts that affect users of an IoT system from different perspectives.

3.1 IoT Systems

Internet of Things (IoT) is applied when physical devices are connected to a network, where they can be interacted with [1]. These interactions can be done through actions or readings of sensor values. IoT may be applied to numerous different industries such as healthcare, agriculture, logistics, and the home environment. Devices in an IoT system differ depending on the industry it is applied within, they could for example consist of sensors, lights, or cameras. The devices need to contain a number of components to empower the IoT network, for example, CPU, memory, communication channel, and power source. IoT devices are often controlled through an interface and the most common type of interface is through a smartphone app, in which the user can interact with the devices [10]. The most common implementation of an IoT system is to use a controlling device that handles all the intermediate communications [11]. This device is usually called gateway and it handles communications both between devices and the internet.

There are two fundamental differences in how devices in an IoT system will behave and these two are named sensor and actuator [12]. A sensor is a hardware component that collects data and an actuator is a component that performs an action. These two different types of components can be separated or on the same device.

3.1.1 IoT in the home environment

Smart devices have made their way into everyday people's lives more frequently throughout the recent years [12]. Smart devices for the home environment are widespread with everything from vacuum cleaners to locks which have led to the concept of smart homes. Smart devices increases at a rapid pace which has made this market a billion-dollar industry [13]. These smart devices are integrated into homes to simplify people's lives, for instance with automated actions. There are also benefits of being able to control the devices without the need to physically access them. Interactions with the devices can be through remote control, voice control, or a mobile application.

3.1.2 Data in IoT

Data is an essential part of IoT so that the devices can interact and communicate with each other [1]. Data appears in different aspects such as communication channels, device states, and event changes in the IoT network. This gives the possibility of collecting data for the user since it is needed to understand the state of the devices. However, the data in an IoT system is also beneficial for companies to get insights into different data values the system holds. Companies can use this data for analytical reasons or other purposes that will gain the advantage of the understanding of customer needs. This means that the company is responsible for the data and can decide which data that will be shown to the customer and which data is kept within the company. This does also imply that there are privacy concerns that need to be taken into consideration when collecting and storing the data [14].

3.1.3 Communication channels

The communication channel within an IoT system can be wired or wireless depending on the application, however wireless is the preferable choice in most situations [1]. All the devices in an IoT network need to be able to communicate and understand each other which is the task of a protocol. The number of protocols on the market for IoT devices is countless since there are currently not any standard that encapsulates devices from different manufacturers. An important aspect of the communication is the requirement of encrypted communication channels so that the user always can be comfortable that there is no possibility of a breach within the system.

One communication pattern is of interest in the thesis, which the case company's IoT system applies. This is explained in the next section and aims to provide the reader with the basic theory needed to understand the communication channel in the context of this thesis.

Publish-subscribe pattern

An IoT system needs to have some kind of internal communication between devices and services. One pattern that is frequently used for handling this kind of communication is the publish-subscribe pattern [15]. The publish-subscribe pattern is a model which consists of senders that publish messages on a channel and receivers that subscribes to the topics of interest. There is an intermediate step between the two roles in the communication and this part is called the broker. The broker is responsible for receiving the message from the publisher and then distributing this message to all subscribers that have subscribed to the given topic.

3.2 IoT Users

The many manufacturers of IoT systems have initiated a competition of the customers on the market [16]. Therefore it is often the software in the devices that differentiates the IoT systems which is one of the reasons why the concept of Internet of Behaviours (IoB) has been introduced. IoB is the concept of collecting and processing data to engage the customer for a company's benefit and it is a combination of different research fields, such as psychology, data analytics, and artificial intelligence. There are plenty of examples of this that we interact with daily. One example of this concept is when a video streaming platform suggests movies or TV series based on user patterns and ratings. The ultimate goal is essentially to engage the customer in the streaming service and thereby extend the subscription, which in the end gains more money for the company.

Samhale et al. [2] underline the significance of trust for an IoT system to engage the user. The amount of data in an IoT system may raise concerns regarding privacy and security which is the reason why trust is an important factor. A customer's usual behavior before purchasing an IoT system does often include some invested time in researching the advantages and disadvantages of different systems. This is where the trust and the engagement for the company play an extensive role in the outcome of this decision and the initial engagement in the IoT system. Another challenging part is to maintain the long-term engagement which can be done by multiple different strategies [2]. One strategy is to understand the customer behavior in the IoT system and give insights and feedback to engage the customer.

3.3 Nonfunctional requirements

Nonfunctional requirements, also known as quality attributes of a system, are the soft measurements of a technical system [17]. Compared to functional requirements of a system design, nonfunctional requirements are often not as easily understood but are very important when designing a system since they describe not what a system should do, but how it should do it.

Adams et al. [17] have found that nonfunctional requirements have the following essential characteristics:

- Define a property or quality that the system should have.
- Can be subjective, relative, and interacting.
- Describe how well the systems must operate.
- Are associated with the entire system.

It is important to identify these requirements in an early stage in the development process since it can be very costly to do this later in the systems life cycle. Numerous nonfunctional requirements are relevant for technical systems. Three of these requirements are understandability, usability, and correctness and will be relevant in the context of this thesis. These will be used when designing and implementing the solution in this thesis. These requirements will also be a central part when validating the solution and thereby evaluating how these soft measurements affect the given solution.

In the following three sections the requirements will be described further.

3.3.1 Understandability

Understandability is crucial to consider while designing a system. If it would be difficult for a user to understand the functionality of the solution, it would not serve its purpose. Adams et al. [17] define understandability as *"the ability to comprehend any portion of a system without difficulty"*, from a user's perspective.

The problem defined in this thesis describes the difficulty for a user to understand the Home Smart system's behavior and health. Since the solution aims to solve this problem and provide the user with a better understanding of the system, it will be necessary that the user understand the functionality of the solution and how it should be used. The user will be provided with information and feedback from its system and this information must be given in such a way so the user understands its purpose and why it is given.

3.3.2 Usability

Just like understandability, usability is a requirement that is defined from a user's perspective. It is often divided into five main attributes that provide measurements for usability [17]. The first attribute is learnability which defines the user's ability to learn the system easily. Efficiency is the second attribute and defines the measurement that the user can perform actions, without having to wait for a great amount of time. The third attribute is memorability which is the measurement of how well the user can remember the system and actions within it without the need to relearn everything. The fourth attribute concerns errors in the system, there are two different subjects within this area. The first one concerns that the user should not be able to produce errors in the system. The second subject is that if it after all occurs an error, then the system should remain in a stable state without a crash or similar repercussions. The fifth and last attribute of usability is user satisfaction and a consequence of this defines the user's eagerness of utilizing the system. Results of this metric can vary depending on the user's experience and technological interest. Usability is dependent on all of the stated attributes and factors may have a larger or lesser impact depending on the application and user. Good visualization of the information in the system is a key concept so that the user can understand and utilize the system.

3.3.3 Correctness

Adams et al. [17] define correctness as *"the degree to which a system satisfies its specified design requirements"* and is strongly related to the process of verifying and validating the system. Verification and validation are two different concepts and can be described using the following questions:

- Validation — Is the system doing the right job?
- Verification — Is the system doing the job right?

Just as understandability and usability will be important during the system's design, correctness will be central during the validation phase of the thesis. During the validation phase, the solution will be evaluated based on how well it fulfills the defined requirements, in other words, the solution's correctness will be evaluated. Correctness of a design means that the design is satisfactory and meets the requirements.

Nonfunctional requirements have a great impact on how well a solution does what it is supposed to. Having defined these requirements before designing a solution is important to avoid having to make large changes later in the development process. Understandability and usability are relevant during the design phase and will be valuable to have in mind when designing the solution and will also be used as soft measurements during validation. The definition of correctness is useful during the validation phase in this thesis, and it emphasizes the importance to make sure a solution satisfy defined requirements.

3.4 Challenges and Opportunities in IoT

This section aims to describe the challenges and possibilities for IoT systems. These two subjects will give an idea of how the user can be supported and the challenges of conducting work within IoT that needs to be taken into consideration.

Mennicken et al. [18] have studied challenges and opportunities in IoT. These include both what a user of an IoT system struggle with daily and what a user of such a system finds valuable. One challenge within IoT is the balance of control within the system between users and devices. The user should feel like they possess the control regardless situation. However, work should also be placed on the IoT system to lighten the burden on the user. This balance is challenging to accomplish and obtain for an IoT system. Recommendations, feedback, and automation are examples of things that the IoT system can contribute to the user. One opportunity that Mennicken et al. highlight is to collect data that makes a difference in a user's quality of life. These aspects could be economic, environmental, or health. An example is to collect data related to energy consumption for an IoT user, which can be motivated both from an economic and an environmental perspective. As mentioned previously the reliability aspect of an IoT system needs to be taken into consideration.

Wilson et al. [13] highlight the challenge of reliability within an IoT system and its influence on the user experience. However, reliability is a factor that not necessarily is possible to solve easily since it is affected by multiple factors. Potential factors that can be modified to increase the reliability of a smart home are debugging self-healing systems or administration outside of the household. Moore et al. [19] indicate the challenge of developing IoT systems that will be used by a wide user group. These users can range in numerous different aspects such as age, technological skills, and how often they use their IoT system. A broad target group makes it challenging to meet all different user needs.

Moore et al. [20] have proposed different models for calculating reliability on a device, network, and system level. Reliability at the device level serves its best purpose in the thesis since the user would benefit from understanding each device. These calculations can be done in many different ways, however, a simple calculation would serve its purpose by providing a basic understanding of the system to the user. Lim et al. [21] have conducted an extensive research study regarding how users react when receiving feedback from context-aware systems. The goal was mainly to investigate what kind of feedback novel users would benefit from. The conclusion from the research study was that a user in a technical system would like to know why and why not actions take place. This conclusion is of significant value for us since this describes what kind of information users find meaningful and it confirms that users want to understand why their system behaves in a certain way.

3.5 IoT Monitoring systems

This section aims to give insights into what other work has been done in the field and how the findings from that work can be related and useful in this thesis. Related work was investigated by studying different monitoring approaches for an IoT system. This will give us insights and proposals of different methods to design a feedback and monitoring system. The focus will be on how to design communication channels and feedback processing in a beneficial manner.

Sayad et al. [22] propose an IoT system that monitors multiple machines for a manufacturer so that it is possible to determine when the next maintenance needs to occur. The applied model of the system has been proposed by Medjaher et al. [23]. This model consists of several modules that handle different functionality in the system. These modules can be seen in the list below:

- **Data gathering** - The data gathering module is responsible for collecting data from the system.
- **Data extraction** - Data extraction is the next phase in the system where this module extracts the relevant data needed for monitoring the health of the machines.
- **State assessment** - State assessment is a module that determines whether the state of the machines is stable or in a state of failure.
- **Diagnostics** - Diagnostic of the device is performed if a failure is detected. Then the data from the device needs to be investigated further and find the cause of the issue which the diagnostic module accomplishes.
- **Predictive failure** - This component predicts failures for the devices in the IoT system.
- **Decision making** - The user of the system needs a component that can support and help the user to recognize what action to take based on the outcome from the other modules in the monitoring system. This is precisely what this component is responsible for by giving feedback on the current state and if the user needs to perform a specific action.
- **Interface** - The user of the monitoring system needs an interface that displays the state of the devices and provides support from the decision-making component.

Sayad et al. [22] used a publish-subscribe pattern in the implemented system, where the devices publish their current states on the communication channel. The data gathering module subscribes to these messages and forwards these to the rest of the modules. The user of the system is also able to interact with the machines. This is done by publishing commands as a specific topic, which the devices can subscribe to and listen to. When designing our solution, this architectural design can be used as an inspiration for what kind of modules can be valuable and necessary to include.

Araby et al. [24] have studied IoT systems and architectural approaches. The solution from these authors provides a similar architectural approach as the related work previously described. However, this article gives a higher overview of the system design and the choices related to this. The purpose of the proposed IoT system is to gather real-time data and keep a high quality of crops in the fields. The quality of the crops is calculated with a machine learning algorithm. A farmer would then get notifications if the quality drops and there is a risk of disease on the crops. The following components are used in the implemented system:

- **Publish-subscribe service** - There is a service running on the gateway, responsible for the communication with the devices. This service is called the broker which uses the publish-subscribe pattern described in 3.1.3.
- **Nodes** - These are the devices in the IoT system which give different sensor values depending on the device type. Examples of these values are temperature, humidity, and moisture. The nodes are publishing these values to the communication channel on a dedicated topic.
- **Gateway** - The gateway is integrated on a Raspberry Pi operating on Wi-Fi. It contains a service that subscribes to the topic for the sensor values and saves these to a database in the cloud.
- **Storage** - Storage of the data consists of a MySQL server located in the back-end layer which is in the cloud. The data can be saved and extracted through API endpoints.
- **Data analytic** - The data analytic component processes the relevant data needed to understand the quality of the crops. This component is also located in the cloud.
- **Data visualization** - Data visualization of the data is needed for the end-user to understand the current quality of the crops. This component collects the analyzed data from the database and visualizes this for the user.

The described architectural approach could contribute to this thesis by giving insights into how to design high-level architecture.

Several devices can be connected to the case company's Home smart system. One of these devices is an air purifier which filters out small particles called PM2.5. These particles can be dangerous if a human inhales these in a high concentration for a longer extent. This Thesis has investigated these values further intending to give the user a better understanding of the air quality. Therefore when air quality is mentioned in this paper, it will be based on the values described in the next paragraph.

Shkurti et al. [25] have developed an IoT system that monitors the air quality in classrooms. They have specified index measurements that determine the air quality in a room depending on the PM2.5 level. These are stated as follows, the air quality is excellent if it is between $0 - 10$, good between $10 - 20$, fair between $20 - 25$, poor between $25 - 50$, and above 50 is considered unhealthy. The described ranges could benefit this thesis work to understand the air quality of the home environment for a user that uses the air purifier developed by the case company. The work that they have conducted regarding the index values will support our work when transforming the data from sensor values to relevant information for the user.

Chapter 4
Problem Conceptualization

This chapter will describe the findings after conducting the activity of problem conceptualization. A case study and literature study, presented in subsection 2.1.1 and subsection 2.1.2, were performed during the activity of problem conceptualization with the aim to describe the core problem in this thesis. Additionally, surveys and investigations that have been conducted by the case company, are provided in this chapter. The results from these studies will be presented and we will describe how the insights from the studies can be used to answer our research questions. The outcome from these studies will be summarized and followed up with use cases that are defined according to the results from the different studies.

4.1 Case study

This section will present the performed case study and its findings. The case study is intended to conceptualize the problem in this thesis. As described in 2.1.1, the case study was conducted through interviews. We chose participants ranging from developers to project leaders in the case company. An advantage with these participants is the fact that they are using it on a daily basis, thereby they have great knowledge of the Home Smart system. Another aspect that was considered was to choose participants that covered the majority of the development stack in the case company's Home Smart system. This decision aimed to understand the available data on the different stack levels. The questions for the case study can be seen in Appendix A, where the interviewees were advised to answer the questions from a user perspective if nothing else was told. Participants of the case study coupled with their respective roles in the case company can be seen in Table 4.1.

The aim of the majority of the questions in the case study was to get a better understanding of feedback that would be valuable for an end-user. When using the system there are some unexpected events and errors that can occur within the system. Therefore, it will be important to capture these scenarios to be able to identify what kind of information are of interest to deliver as feedback to the user. Question 8 in the case study intends to give

ID	Role
P1	Developer of the gateway API:s
P2	Developer of the internal structure in the gateway
P3	Software Architect
P4	Mobile Application Developer
P5	User Experience Researcher
P6	Project Leader

Table 4.1: Roles of the participants in the case study

insights into scenarios in which a user experiences difficulties. The results from this question will be guidance when answering **RQ1.1**. Questions 9-11 in the case study are formulated to understand the problem specified in **RQ1.2**. The results from questions 9-11 combined with the previous insights from question 8 will provide answers for **RQ1**. The case study is therefore focused on **RQ1** in general, aiming to specify what information to provide to a user of a Home Smart system.

However, the last question intended to give a general overview of the data that existed on the different stack levels in the architecture of the Home Smart system. This brief introduction to existing data aims to initiate an investigation for **RQ2** and **RQ3**, concerning what data should be collected and where in the internal system this could be done. Since the interviewees possessed different roles at the case company, and thereby had different knowledge of the system architecture, the interviews gave us different perspectives on challenges when acquiring data in the case company's Home Smart system. The main challenge concerned how to gather reliable real-time data. There are multiple channels which the data can be acquired from, but not all of them have the possibility of perceiving all user interactions with the Home Smart system.

From the interviews, we found that the majority of the participants used their Home Smart system on a daily basis. The Home Smart system was not necessarily manufactured by the case company, other Home Smart systems were used as well. Smart light was the device that was mostly used by the participants, followed by smart blinds and speakers. There were several types of information that the interviewees found valuable for a user of a Home Smart system to receive insights. When summarizing the answers we have found that the feedback users found valuable can be divided into two different categories, namely troubleshooting and statistics. The following two sections will describe the findings of these two different classes of feedback.

Troubleshooting

Troubleshooting was the main problem among all interviewees in the case study, where they suffered different problems within their Home Smart system. One specific situation all interviewees struggled with was when devices became unreachable for some reason. The problem could be due to low signal strength or that the device had disappeared from the Home Smart system. The signal strength is dependent on where the gateway is positioned since the signals have to go through the gateway regardless of start and end destination. However, the signal strength is also dependent on the device positioning since they need to be in reach for the gateway. The interviewees described the frustration of not receiving feedback from the system when devices were non-responsive because they were unreachable.

Another challenge that the interviewees struggled with was the general problem when a device does not perform an intended action. There were several different scenarios that the participants struggled with. One example of this problem is when the power source to a light is switched off and a user tries to turn on the light. The user will not receive information concerning why the light could not be turned on, which can lead to frustration.

An additional example of this problem is when the battery of a controller or blind is critically low, resulting in unresponsive devices. The issue can be described as the situation where the user has an expectation of the next state when interacting with a device, but is faced with that this is not performed. This leads to frustration for users when their intentions are not fulfilled, especially when no information is given to the users about the system's behavior. This problem is general in its nature and can therefore be applied to different situations in a Home Smart system.

Statistics

Statistics in a Home Smart system can be collected based on several different aspects. From the interviews, we found that there were mainly three different approaches that could be interesting to implement. The first approach is error-related statistics from the Home Smart system. The majority of the interviewees described their interest in obtaining information about errors in the form of which devices in their Home Smart system have generated these errors and their cause. The interviewees found that it would be of value for them to get statistics regarding the devices that most frequently produce errors in the system. These errors relate to troubleshooting, described previously, in terms of unresponsive devices. It was also valuable to receive possible solutions on how to solve the errors that occur.

Another approach that interested the participants was to acquire detailed statistics on the utilization of the devices in their Home Smart system. Relevant measurements would be to provide statistics of the users' interaction frequency with the devices. However, this type of statistics was concluded by the participants as feedback that is "nice to have" rather than necessary feedback to obtain. Some of the participants indicated that the need for this information could depend on how technically interested a person is, and that the average person most likely would find this kind of feedback superfluous.

The third approach regarding statistics was that the participants could see a potential value in receiving more information from a specific product in the case company's product selection, more specifically an air purifier. The reason why the participants found the information from this device particularly interesting is that it affects the air quality, and thereby the users' well-being. This product is new in the product line which means that the data this product collects, currently is unexplored in several aspects.

4.2 Literature study

The aim of performing a literature study was to get a better understanding of what information a user of a Home Smart system would be interested in receiving. This study was focused on gaining valuable knowledge by investigating what research about feedback in an IoT system that currently exists. The literature study resulted in insights of valuable information from a user point of view, presented in section 3.4, aiming to describe existing challenges in a Home Smart system and what information that would be valuable for the user to obtain. This study described challenges that a user faces and different proposals of information that can be provided to the user.

The main challenge a user struggles with is the unstable reliability of an IoT system which sometimes needs to be compensated with more supportive information for the user. Therefore, the user wants to know why or why not things happen in an IoT system. Another aspect that was found in the literature study was to provide a user of an IoT system with statistics that affect the user's quality of life. Examples of this could be from an economic, environmental, or health aspect. The environmental aspect combined with the economical perspective can be applied to the case company by tracking energy consumption from the devices. However, data related to energy consumption will not be of any high value for the case company's users due to the low impact the devices have on energy consumption. All the devices are low-powered and therefore this measurement will only have a minor impact on the users' quality of life. Energy consumption will therefore not be included in the scope of this thesis. The last aspect concerning statistics for well-being can be applied by collecting data regarding air quality in the home environment.

4.3 Research at the case company

Research has been conducted at the case company that is within the scope of this thesis. There are specifically two sources of information that are of interest which will be presented in the forthcoming sections.

4.3.1 Customer Survey

The case company has performed an unpublished survey answered by users of their Home Smart system with a focus on errors and troubleshooting. Appendix B shows a detailed description of the most relevant questions for this subject from the survey. These will also be presented in the following list where the corresponding answers can be found in Appendix B.

- How often do you and other household members experience issues?
- Where do you usually look for help?
- Do you agree or disagree with the following statements?

The answers to the first question, indicate that a majority of the users face challenges with their system at least once a month. It also shows that there is a minority that rarely faces problems in their Home Smart system. The second question brings up the subject of how these encountered problems are resolved. The answers reveal that a majority of the users look for answers outside of the case company's ecosystem. The most common approach to search for help is to use internet sources that provide more valuable feedback on the problem. Answers to the third question provide substantial information regarding expectations and actions that the user possesses. The survey shows a minority that uses the mobile application as guidance when encountering a problem and that a clear majority emphasizes the importance of understanding the problem and its cause. One challenge that is also revealed through the survey is that 64% strongly disagree with the fact that all household members could fix an issue that arises. A majority of the participants in the survey agree on the fact that there is a potential of receiving help both when a problem arises and to receive guidance pro-actively.

The results from the conducted customer survey at the case company strongly show that there indeed exists a need and wish from the users to receive more system feedback to improve the health of their system. It also shows that customers do experience challenges when encountering issues within the system and that a more responsive system would help the customer to face these issues in a better way.

4.3.2 Customer reviews

On Google Play [26] and App Store [27], where the case company's mobile application can be downloaded, a lot of reviews from users can be found. At the case company, these reviews have been collected and analyzed. When reading these reviews from users, a few problems are often mentioned and should be highlighted. One problem with the system is that a lot of users experience that problems often occur after the gateway or devices have been updated with new firmware. A common issue is that devices disappear from the app and seem to be unreachable. Since a lot of users have experienced issues like this it could be of value for us to include this problem in our research. However, since the problem most likely is related to bugs within the firmware, it will not help the user in any way to provide feedback related to this. Therefore this subject is found to be out of the scope of this thesis.

Other scenarios that arise problems and are repeatedly mentioned in the reviews are issues with non-responsive devices, caused by bad connectivity or low battery level. These problems are interesting for us to include in the research since they most likely can be solved by letting the user receive more feedback from the system and is therefore within the scope of this thesis.

4.4 Summary

After conducting the activity of problem conceptualization we have gained insights into what kind of information is valuable for the user to receive, which answers **RQ1**. These insights are based on the findings from the performed literature study, case study, and research conducted at the case company. Use cases will be specified in this section as answers to **RQ1.1** and **RQ1.2** and these combined will result in the answer for **RQ1**. These use cases can be seen as requirements for the solution and will set the base for how the solution should be designed.

The feedback that users would find most valuable to receive is data related to troubleshooting. From the conducted interviews, it is clear the interviewees found it frustrating when the system behaves in an unexpected way, without understanding why. The results from the literature study confirmed that people do want to know why or why not an action takes place in the system. The research conducted at the case company does also confirm that there is a need and wish from the users to receive more system feedback to improve the system's health. The data we will focus on presenting to the user will therefore be data for detecting problems. By doing this we can give the user an idea of how the problems can be solved. This data should both be provided to the user in real-time and in a proactive way to ensure a high quality of the Home Smart system. A good foundation would be to provide feedback for the most common devices based on the case study, which are lights and blinds.

Other information that is found valuable for the user is two different types of statistics, error frequency and utilization of devices. These statistics are a good complement to the real-time feedback regarding troubleshooting. These two different types of information will support the user to better understand their system, in terms of what devices are mostly used combined with the failure rate for each device. The user can be provided with an adequate overview of the system's health and what the user needs to prioritize when performing maintenance in their system. These statistics will thereby assist the user to be proactive in their system and fix issues in their systems in an early state. However, error frequency may not be enough to understand the exact cause of the issues and therefore it can be helpful for the user to gain statistics regarding failure frequency based on the type of failure.

Additionally, more detailed statistics regarding the air purifier will be given as feedback to the user. This feedback will be in terms of air quality in the home environment so that the user can monitor and have an overview of the current and previous air quality and how it impacts their health. The feedback will be based on the air quality ranges provided by the research presented earlier by Shkurti et al. [25].

Finally, to avoid issues in a Home Smart system, it would be favorable for the user to have the opportunity of diagnosing their system so that it works as intended. If a user would be able to test their system, then the user would receive a better understanding of the current health status in the system. Diagnosing the system would be a suitable approach for the user to detect potential errors and receive feedback about the cause. It would increase user understanding of the system's current health status, by providing the user with the opportunity to diagnose the system.

Accordingly, a number of functional requirements are formulated which aim to describe what requirements exist in the solution design to address the stated problem in this thesis. These functional requirements will be described as use cases, specifying what interactions between user and system need to be included in the design regarding the findings from the conducted activity.

The resulting use cases for **RQ1.1**, capturing situations where errors often occur, are the following:

- **UC1** - A user tries to turn on a light and it does not succeed.
- **UC2** - A user tries to turn off, dim, or change the color of a light and it does not succeed.
- **UC3** - A user tries to move a blind to a specific level and it does not succeed.
- **UC4** - A user presses a remote controller and nothing happens.

UC1 and **UC2** refer to the lights in the case company's Home Smart system which can perform actions such as on, off, dim, and change the color. These can vary depending on the type of the bulb, both for the different lights developed by the case company but also in other Home Smart systems. These use cases are defined for the troubleshooting aspect which was derived from both the interviews and the survey. Lights were the most common device among the interviewees, therefore it is important to capture use cases for these.

The reason why the two use cases are not combined is the fact that they may cause different issues depending on if the light is on or off. The main difference is that if the power switch is switched off and the user tries to turn on the light, nothing would happen and the user's intention would not be fulfilled. If the user instead would try to turn off, dim, or change the color of a light bulb that is already switched off, then it is not supposed to happen anything since the light has to be turned on for these actions to have an effect.

UC3 is for troubleshooting blinds, which is similar to the two previous use cases in terms that a user has an intent with a device and it is not fulfilled. Blinds were also frequently used by the interviewees and therefore this is a use case that could benefit to provide support for the user. Survey question 4 in Appendix B indicates that the most common controller of devices is a remote controller which is the reason why **UC4** has been specified as a use case. This issue could depend on multiple factors. One factor could be that there are issues with the remote controller which cause an error. Another factor could be that the device the remote controller is connected to is not working correctly. Therefore it is beneficial for the user to receive feedback from the system in this scenario to better understand the cause of the issue.

RQ1.2 was defined to get answers about what information the user wants to receive and from which devices. The answer to this is captured in the following use cases:

- **UC5** - A user wants to monitor the air quality in their home.
- **UC6** - A user wants to check that a device works as intended.
- **UC7** - A user wants to be able to view statistics over which devices generate errors, what kind of errors, and how often these happen.

UC5 is based on that the user wants to gain statistics that make an impact on their quality of life. Information regarding air quality is something that affects the everyday living of a user which is the intention for **UC5**. The feedback for air quality can be provided to the user by giving the index measurements, for PM2.5, specified in section 3.5. The air purifier developed by the case company possesses a sensor that gives measurements of PM2.5 which will be used in this use case. The activity of problem conceptualization did also result in that the user should proactively receive feedback, **UC6** aims to cover this aspect by giving the user the possibility of checking the system's health. System health is in this case defined as the condition of the devices and if a user can interact with them without any problems. This use case intends to give the user the possibility of detecting and resolving issues in the Home Smart system at an early stage. The applied devices in this use case will be lights, blinds, and remote controllers based on the arguments stated before regarding usage frequency.

UC7 is a combination of statistics and proactive maintenance in terms that the user can understand their system in a better way by realizing which devices that frequently fail and can thereby take care of issues before they occur again. This could be applied to all devices in the Home Smart system, however, to narrow the scope of this thesis, the same devices as in the previous use case will be applied.

The defined use cases for **RQ1.1** combined with **RQ1.2** are the result for **RQ1**. These use cases will be used as requirements when designing the system and will also be important during the validation phase to make sure that the solution fulfills these requirements.

Chapter 5
The Solution

This chapter presents the resulting solution and its design. The architecture of the solution design is described and motivated.

The design decisions are based on the knowledge gained from learning about the internal structure of the Home Smart system and where in this system the required data can be easily accessed. When designing the solution we have also taken into consideration the previously defined requirements. These requirements determine the most important design choices that the solution needs to fulfill. We will start by describing what data will be collected in the solution and why.

5.1 Data to collect

The previously defined requirements for the solution in section 4.4, formulated as use cases, set the base for what needs to be included in the solution. The use cases describe what the solution needs to contain to solve the initial problem in this thesis. This section will present what data that needs to be gathered for each use case and why this data is necessary to collect.

An example of when a user successfully turns on a light can be seen in Figure 5.1 and unsuccessfully in Figure 5.2. Figure 5.2 shows that there currently are no data provided to the user when the device is unresponsive. This is also the most fundamental part of understanding when an intention is not fulfilled.

Each use case has been analyzed to gain insights into what system data needs to be collected. The result can be seen in Table 5.1 which is the answer for **RQ2**. For some use cases, Table 5.1 also shows the data needed for determining the cause of the issue that is important for troubleshooting. In the remaining part of this section, we will present each use case by describing what data that needs to be extracted from the system for that specific use case.

UC1-UC4, presented in section 4.4, describes the situations where issues often occur and users feel a need of receiving additional feedback from the system. When an error occurs without feedback, users often feel frustrated since their intended action with the system

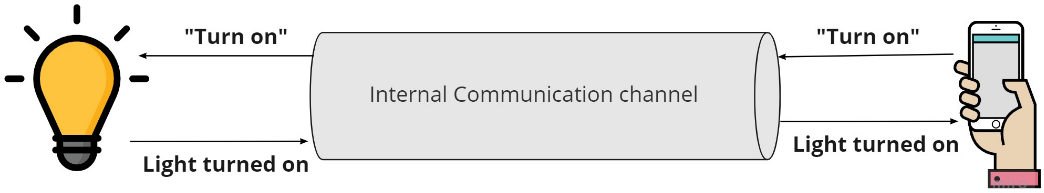

Figure 5.1: The user turns on the light and it succeeds

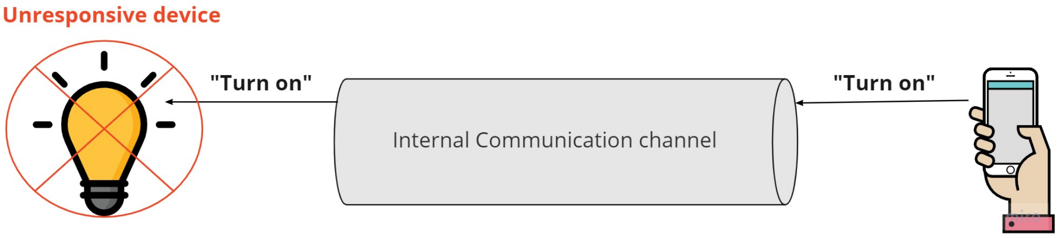

Figure 5.2: The user turns on the light and it fails

was not fulfilled. To avoid this frustration it is important to capture data related to these situations.

UC1 describes the case when a user tries to turn on a light, but an unexpected issue has occurred and thereby affected the outcome negatively. There can be different causes of why the light did not turn on, the light could be unreachable due to, for example, low signal strength. There is also a risk that the user has switched off the power manually with a light switch, which could be another cause of the issue for **UC1**. Therefore it is important to collect data that can determine if a light is reachable or not. Another unexpected event could be that a user tries to turn on a light that was already on, which is not an error but could result in confusion for a user. It is therefore important to check the state of the device, to see if the intended action was already fulfilled. This will be important to check for **UC2**-**UC4** as well, to avoid possible user confusion.

UC2 is similar to **UC1** but the intended action is instead that a user tries to turn off, dim, or change the color of a light device. As for **UC1**, if the light did not turn off, dim, or change color it will be important to collect data that can determine if the light is reachable or not.

Blind is a device where errors often occur. A specific action that can result in issues is when a user tries to move the blinds to a certain level. The data that will be important to collect for **UC3** is the same as for the previous use cases, but with the addition that blinds can be out of battery. The blinds could run out of battery and thereby be impossible to interact with. Therefore if the intended action is not fulfilled, it is necessary to collect data about the battery level of the blinds.

It is possible to connect a remote controller to lights and blinds. **UC4** describes the use case when a user presses the controller and a specific action with a connected device is intended to take place. If the expected event does not occur, it will be important to give feedback to the user on what and why this unexpected event happened. Data that will be important to collect is the state of all connected devices. The cause of issues for the remote controller is partly based on use cases **UC1**-**UC3** since one of the connected devices can fail due to some of the stated issues for these use cases. However, the case could also be that the remote controller is not connected to anything which is favorable to make the user aware of. Another issue that can not be captured in this implementation is if the battery is low on the controller. However, it is not possible to detect this issue since no intents from the user will be displayed on the communication channel.

Another device that was found interesting for the user to receive information about is the air purifier. **UC5** is not related to troubleshooting but is instead focused on the data that can be collected regarding the current state of the air purifier. This data can be very valuable for a user since it contains information regarding the air quality index and the lifetime of the filter integrated into the air purifier. Additionally, the current air quality data is valuable to save and can be used for visualization for statistical purposes.

Other information that was found valuable for users was more data about the current health status of their systems, captured in **UC6**. Data that is important to collect is data regarding which devices that exist in the Home Smart system. This data can be used for testing purposes, for example, it can be valuable to implement functionality so that a user can test if the devices work as intended.

The capabilities of the devices, in other words, what the devices can do, were also found as valuable data. Some lights, for example, have the possibility of changing colors while others do not. Therefore the testing of the system should only be done with the capabilities that the devices can accomplish.

Finally, it is important to save data about the errors that are detected in the system. **UC7** describes the need to save data that can be used and analyzed later on. The cause of errors is valuable to provide to the user for increasing the understandability of a Home Smart system. This gives a better description of how the user can solve the current problem and also how to avoid the same situation in the future.

UC	Data	Error cause
UC1	• Confirm state change	• Power switch off • Unreachable • Current state
UC2	• Confirm state change	• Unreachable • Current state
UC3	• Confirm state change	• Out of battery • Unreachable • Current state
UC4	• Confirm state change for all connected devices	• Devices connected to a remote controller have some of the stated issues in **UC1-UC3** • The controller is not connected to anything
UC5	• Current air quality • Lifetime of filter • Historical data for air quality	———————————————
UC6	• Existing devices in the Home smart system • Capabilities of these devices	• Depending on device type in **UC1-UC4**
UC7	• Historical data for errors in **UC1-UC4**	———————————————

Table 5.1: Collected data for each use case

5.2 Data gathering

In this section, we will present how data is collected and stored in the solution by describing the architecture of the solution design. First, different design solutions will be discussed and lastly, the final solution will be presented and motivated. This final solution concerning data gathering and storage will be the answer for **RQ3**.

The first approach for collecting data that were discussed was to fetch data from the cloud. The case company has an existing solution where they save specific data to a cloud service where the data easily can be analyzed and presented. From this cloud service, it would be possible to extract interesting data. The data is currently used for internal purposes due to privacy issues of logging a system in production. However, if this solution would have been chosen, privacy issues could have been ignored since it is out of the scope of this thesis. In other words, it would have been possible to ignore the issues concerning the logging of user data and build an application to demonstrate what data is possible to collect and how it can be used.

The advantage of fetching data from the cloud is that all data that currently exist in the cloud have been refined extensively since it has passed a lot of different services on its way to the cloud. A major drawback though, is that the data saved to the cloud is limited, meaning that a lot of data are available but not stored. Though it would be possible for us to implement a solution that can upload more data to the cloud, our knowledge in this area is limited and it would take a lot of time just to make sure the data of interest would be possible to extract. Therefore we decided that a cloud-based solution for fetching data would make it difficult to find a way to implement a suitable solution, having both limited knowledge and amount of time for implementation.

The second approach discussed was to use the API-server of the gateway. The gateway possesses APIs and these are the fronts to services outside of the gateway. Data gathering from the API-server would consist of calls to API:s in the gateway where authorization is needed. This solution means that we need to poll from the APIs in this service to be able to retrieve data of interest. The data that this service possesses are snapshots of the current state of all devices in the Home Smart system. An approach for fetching data with help from the API server would make more data easily accessed than with the cloud implementation. Methods to extract data has already have been implemented and there are possibilities to add new methods if needed. The data that the API server possess is in a format that makes it easy to extract and process.

There are both upsides and downsides with a solution based on the usage of the API server of the gateway. One advantage is that data from the API-server has been brushed and therefore there is not a lot of work to do in the extraction phase. However, it is not possible to extract real-time data without rebuilding a major part of the API server which to some extent also deviates from its actual responsibility. Creating our own API server would make it possible to integrate our solution into the current system which might be the preferable choice for the case company since this would add more value to the resulting solution. This solution would though result in additional work in the sense of understanding how the functionality of the current API server works and also how to build and test it. Because of the limited amount of time during this thesis, it was decided that this solution was not possible to implement. Mainly because too much time would be spent on building and implementing the API server.

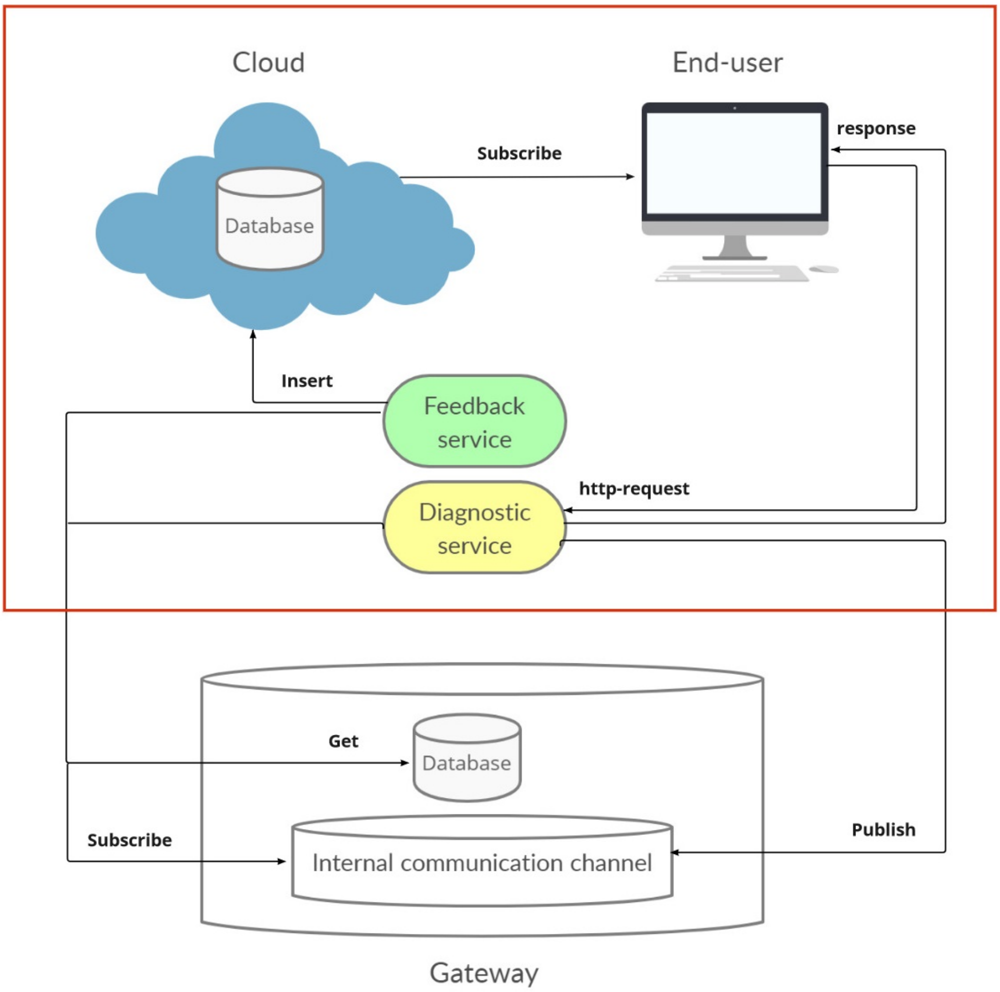

Figure 5.3: Solution design - System Architecture. The components inside the red square are components that have been implemented within this thesis.

The solution that was found most suitable for acquiring data for the stated problem in this thesis, is by gathering data by communicating with the internal communication channel of the gateway in the Home Smart system. The case company uses an internal communication channel between all services that run on the gateway. The internal communication channel and the internal database is integrated parts of the gateway and can be communicated with, which can be seen in Figure 5.3. In the chosen solution, data is gathered by listening to traffic on the internal communication channel combined with the utilization of the internal database on the gateway. This is the answer for **RQ3** regarding the most suitable approach to acquiring data.

The chosen solution makes it possible to interpret all real-time data that concerns traffic between devices and gateway. By subscribing to topics on this internal communication channel it is possible to listen to messages that contain data of interest. The internal database is needed since it is not feasible to understand the initial state of the devices by only connecting and listening to the internal communication channel. Therefore, when the services are started, the current state of the devices needs to be accessed and extracted from the internal database of the gateway. This is achieved by making an HTTP request to get a baseline of the current status in the system. After this, the state of the devices will change depending on the published messages on the internal communication channel.

The decision of gathering data by listening on the internal communication channel was based on the fact that it was possible to both access most data that were of interest, and collect the data in real-time. The implementation of this solution could be done in a reasonable amount of time and would be easy to get started with.

There were multiple factors contributory to our decision, firstly the design is easy to implement since we are not dependent on other factors in the development pipeline. Secondly, which is one of the major factors for this design is the possibility to collect real-time data without having to adjust existing software in the gateway.

The solution has the advantage that a lot of data are already available and easily accessed. Implementing a service that listens on this channel is also quite easily done. A possible disadvantage would be that the solution is not as easily integrated with the current system but would act more as a stand-alone service. Another disadvantage of this approach is that all code needs to be written from scratch. There are however existing solutions in the case company which we can gain inspiration from.

Despite the possible disadvantages, a great advantage is that by choosing this design we can make a lot of decisions on our own. We can thereby ignore issues that are out of the scope of this thesis and focus on extracting data that are valuable for the end-user. Since the aim of this thesis is to conduct research, a stand-alone service is a feasible solution.

5.3 The components

This section will describe the different components of the solution.

The architecture of the solution can be found in Figure 5.3. The high-level architectural approach was inspired by the system design proposed by Araby et al. [24]. The architecture of the solution includes the gateway of the Home Smart system, a database in the cloud, an interface and two implemented services, the feedback service and diagnostic service that communicates with the other components of the system. All components and their importance for the solution design will be further described later on in this section.

5.3.1 Gateway

The gateway is a central part of the Home Smart system since it communicates with all connected devices. The gateway itself contains two important components, the internal communication channel, and a local database. As described previously, the internal communication channel is used in the implementation for subscribing and publishing messages. The local database is also important since it contains data about the current states of the devices in the Home Smart system. These states are extracted in the services during setup to get the initial states of all devices.

5.3.2 Feedback service

The feedback service is responsible for handling real-time data of the Home Smart system. The service aims to support the user to better understand the system's behavior and to provide feedback when an error occurs within the system. This service has used the same architectural approach provided by Araby et al. [24] by having a database between this service and the visualization component for the user.

The model used in the implementation is the model from Medjaher et al. [23] used for dividing the service into multiple modules. Data gathering is firstly performed when starting the service, which consists of making a GET request to the local database in the gateway to recognize the current state of the devices. The real-time data gathering is then achieved by listening to the internal communication channel for the Home Smart system and updating the state of the devices in the database when something has changed within the system.

The next step is data extraction, which incorporates different behavior depending on the topic that is published on the internal communication channel. The feedback service focuses on troubleshooting since this was found to be highly valuable for the users. This is done by mapping a user's intention with the behavior of the system, in other words matching an intention against an actual event in the Home Smart system. Therefore, it is possible to recognize if the intended action was performed and if not, give real-time feedback to the user containing situational information. The service aims to check so that all actions from the user actually take place. This service handles **UC1**-**UC5** and **UC7** which all concern real-time data in a Home Smart system.

An example of when an intended action is not performed is when a light bulb does not turn on when a user presses the button to do so, as specified in **UC1**. In Figure 5.4 can an example of the actions taken in **UC1** be seen. This is where the state assessment comes into place since we need to recognize that the state of a device actually is at the state the user intends it to be. Diagnostics are needed when the state of the device does not live up to the expectations of the user's intent. The diagnostics module within the feedback service will then find the cause of the issue by examining the device which has failed. Every device has specific errors that can occur and the devices need to be examined differently depending on the type according to Table 5.1.

The information about the device is then passed to the decision-making module that gives the user correct feedback depending on the cause of the issue. All actions performed by a user, that are of interest, are saved in the cloud database as historical data. This can be beneficial to have in the decision-making module and make decisions based on historical data. The cloud database also stores historical data regarding generated errors from events in the Home Smart system. These are used for giving insights to the user, by providing statistics about interaction and error frequency.

5.3.3 Diagnostic service

The diagnostic service and feedback service have similar components, but with a considerable difference. Instead of supporting the user in real-time, the diagnostic service aims to help the user to avoid or catch possible issues in an early state. The diagnostic service provides information to the user to give the user a chance to better understand the system and its health. The diagnostic service aims to cover **UC6** by providing a way for the user to test that

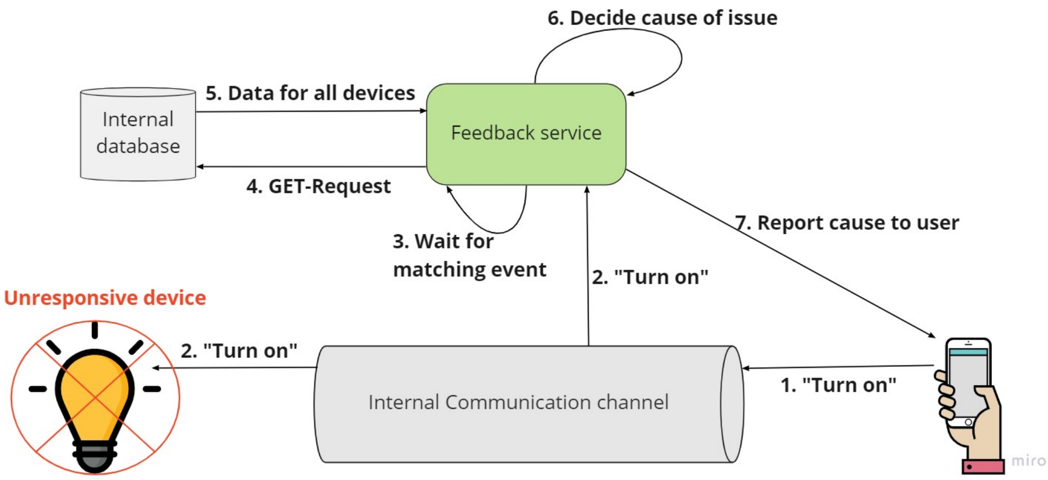

Figure 5.4: The feedback service's actions for **UC1**

all devices work as expected. Thereby a user can be proactive and engaged in the health of their Home Smart system.

A simple use case of the diagnostic service is testing a light bulb in the Home Smart system which can be seen in Figure 5.5. The user can initiate this test from the user interface. The test begins by sending an HTTP request to the diagnostic service, which then performs the test on the device in question. This is done by communicating with the devices by publishing messages on the internal communication channel. The next step in this process is to gather data from the internal communication channel and extract the raw data. The extracted data is then assessed to check that the intentions published from the diagnostic service are fulfilled by examining the state of the device.

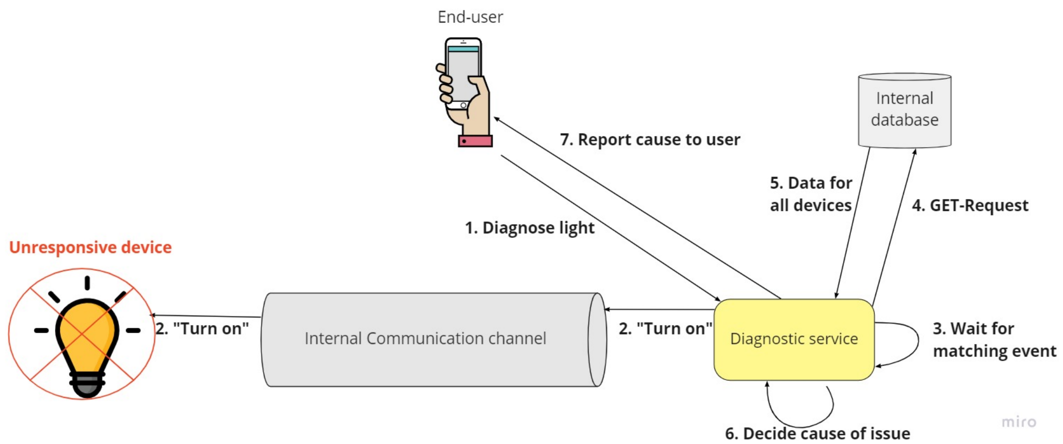

Figure 5.5: The diagnostic service's actions when testing a light bulb

The response to the interface will be different depending on the result of the test. A successful result will return a response to the interface which contains the information about the performed actions and that the test has passed. However, if the result of these actions does not exceed the expectation, a diagnostic check of the device will need to be done. The diagnostics and decision-making will be performed in the same manner as in the feedback service. The outcome from these modules will then be yielded to the user interface, so that the user receives information about problems in the system and why these issues occurred.

The diagnostic service aims to give the user more possibilities to test their system and by this give the user a chance to maintain a high quality of their Home Smart system.

5.3.4 Cloud database

The cloud database is used by the feedback service. The feedback service needs to be able to store data securely and still be possible to access from the user interface. This data is captured in real-time since feedback needs to be provided to the user instantly. The importance of being able to handle real-time data at a rapid pace is a characteristic the database needs to possess. There are two possibilities for the location of the database, locally on the gateway or in the cloud. The advantage of a local database is that the users' data is saved locally where no one outside of the Home Smart system can access it. However, the disadvantage is that the communication to this database would be too complex to insert into the current system architecture which is why we chose the cloud storage approach.

Data representation of the devices in the case company's Home Smart system is complex. When choosing how to store the data several aspects need to be considered. A NoSQL database, which is the database we chose, is known to be flexible and scalable [28]. It stores the data in a similar form as the original objects used in the application which reduces the need for translation of the form the data is stored in and its original form. A NoSQL database would therefore simplify the work effort without having to rearrange the data structure unnecessarily. There are still a lot of database providers that could match these requirements and either of them would suit our case. These stated requirements are an additional answer for **RQ3** concerning the most suitable approach to storing the gathered data.

We chose to use Firebase as a database for storing data collected by the feedback service. Firebase provides security for communication to the database and is easy to access and monitor since it is in the cloud [29]. Firebase has also the characteristic of being able to handle real-time data since the interface has the possibility of subscribing to specific documents in the database which the feedback service can insert into. Lastly, Firebase is a NoSQL database that gives the possibility of replicating the structure of current data in the Home Smart system.

5.3.5 User Interface

The last component is the interface which the user can interact with. The interface connects with the feedback service through the database and the diagnostic service through API endpoints.

The data of interest needed to be visualized in order for us to validate the results effectively. Using an interface makes it easier to validate the results based on how users experience the resulting information. The visualization platform was developed as a web interface, however, the visualized elements could potentially be seen as an integration to the current mobile application that the case company hosts.

Visualization within IoT is a challenging task since the devices incorporate a great deal of information. However, it is not desirable to display all information from a user perspective [30]. Excessive information will lead to complex user interfaces that will frighten the user instead of supporting them. This balance is challenging to obtain without excluding relevant information or displaying too much. This is something to consider carefully in the context of which information the user wants to have and how it will be presented. These decisions need to be considered based on the usability of the interface. There are several attributes for usability, but the main focus will be on learnability and user satisfaction of the interface since these have the most impact on the user experience.

The visualization in the interface is split into multiple sub-pages to enhance learnability. Each sub-page displays relevant information for that specific subject of interest. On one sub-page, the user can see all devices in their Home Smart system and recognize the state of all the devices. On another sub-page, the user can initiate a diagnostic check of a specific device or perform a diagnostic check of all devices in their Home Smart system. Thirdly, one sub-page makes it possible for the user to perceive information about the interaction frequency and failure rate depending on device type and cause of the issue.

The nonfunctional requirement understandability is needed to be taken into consideration. The user should be able to understand what data is displayed and take actions corresponding to this. Fourthly, the user can get more detailed information regarding statistics for the air purifier. These are shown as the current value of air quality and filter time. The user can also perceive historical information regarding air quality patterns depending on the weekday for each hour. Lastly, the user will get notifications of failures in their Home Smart system to be able to troubleshoot the devices. As stated before, the interface has communication with both the database and the diagnostic service to get information for the different data values provided by the services.

Chapter 6

Evaluation

The solution design needs to result in a feasible solution. To make sure the solution is a feasible solution for the problem, a number of requirements were formulated. These requirements aim to map instances of problems and solutions and to transfer knowledge between contexts [4]. After understanding and describing the core problem combined with learning about the Home Smart system's architecture these requirements, defined as use cases, could be formulated. The use cases aim to capture the most important mappings between problems and solutions and to identify and communicate the main values created by this research.

During the literature study, a number of nonfunctional requirements were described. While designing the solution the understandability and usability of the design have been considered. When validating the solution these nonfunctional requirements will be used as soft measurements and they are evaluated based on how well the solution fulfills these requirements.

Both the functional and nonfunctional requirements are important to consider while validating. The validation is performed by conducting interviews and letting the interviewees experience and evaluate the solution design.

6.1 Interviews

The interviews were performed with three of the employees at IKEA Home Smart. We chose people from the previously held interviews since they already had a good idea of the project we had been working on. More specifically we interviewed **P1**, **P2**, and **P4**, see Table 4.1. The interviews were performed by first presenting the implementation to the participants. The implementation was presented by demonstrating the different parts of the solution and how feedback and information are given to the user by interacting with the system. By demonstrating the solution, the interviewees were given a chance to get an understanding of how the solution works and familiarize themselves with the functionality. The questions asked during the interviews can be seen in Appendix C.

After demonstrating the solution, the use cases specified in section 4.4, and data, specified in Table 5.1, were displayed to the interviewees in order for us to validate against the defined use cases and how well the interviewees think the solution meets these. It was also important to ask questions related to the nonfunctional requirements. The solution was evaluated based on what the interviewees thought of the understandability and usability of the solution design.

The majority of the interviewees did agree that more support while using the Home Smart system is beneficial for the user. There are several situations where a user might struggle with the system. The interviewees all felt that the solution for **UC1-UC4** captured the majority of the situations that they have struggled with. Currently, there is minimal support for troubleshooting in the case company's Home Smart system and the participants' general reaction was the solution was a satisfying addition for the user.

According to the participants, there were several advantages to the implementation. The implementation of the use cases **UC1-UC4** was considered very valuable to a user since this functionality makes the user aware that an error has occurred and also gives information about the cause of the issue. Thereby, the user can understand and take action according to this. The participants thought that the collected data in Table 5.1 for **RQ2** covers all data that the system currently supports. Currently, there are no other data that can be collected from the system to get a more precise cause of the issue.

The diagnostic of the devices, which concerns **UC6**, is currently on a separate page in the user interface which the user can navigate to and initiate diagnostic of one or multiple devices. The participants reflected on when to use this and it was concluded that it probably would be used if an error within the system would occur and the user felt the need of debugging the system. However, one participant suggested that the diagnostic service could be a part of the process when a user is adding a device to the Home Smart system. Having this integrated into the onboarding process of a device could then be a proactive check for the user that the system works correctly after adding a device. This would make it possible to capture problems in an early state. Another advantage of this is that the user can understand the capabilities of the device better.

Understandability and usability were also a part of the interviews, where the participants gave their opinions on the user experience. There were several discussions concerning the choices of information and visualization related to these two nonfunctional requirements. The first one was regarding the statistics that displayed error frequency based on devices and error types in **UC7**. This was concluded by some of the participants that it may impact the understandability since this can be too extensive and detailed information. This is similar to **UC5** since this also can be too complex information for the user if the user needs to understand the displayed information and also take actions according to this. The usability was also discussed with the interviewees and how well a potential user would learn and utilize the system. The different parts of the application were easy to get an understanding of according to the participants since it was easy to understand what each use case could contribute to the user. However, statistics for the air purifier made the interface more complex and thereby affected the usability poorly to some extent.

To conclude the findings of the evaluation for the requirements, **UC1-UC4** had the most positive response from the participants. The advantage of understanding why errors occur within the system was the general argument for these use cases from the participants. Testing the system in **UC6** was also a benefit for the user. However, this is not an essential part for a user of a Home Smart system. This type of information could be integrated into other user interactions with the system when there is a need to test that a device works. **UC5** and **UC7** are two satisfactory ways of giving the user a better understanding of interactions with the system and how these are affected. It is important that this type of information is presented in an appealing way to the user so that the user can take decisions directly without first having to understand the information presented. Therefore to increase the understandability and usability this data could instead be used as a base for further implementations of the services that support the users.

6.2 Potential improvements

The interviewees had some suggested improvements for the implementation. Firstly, there were suggestions of support for more device types in the case company's Home Smart system. Speakers were mainly highlighted in this context since these are widely used.

Secondly, the signal strength of a device was an additional point of interest suggested by the interviewees. This data can be valuable for the user since the users of the Home Smart system can have difficulties understanding that the signal strength is the cause of an issue. Often no information is provided to the user to indicate that the signal strength is weak. The participants concluded that adding this data could potentially support the customer when installing the system in terms of where to place the gateway and the devices. It could also benefit our implementation when detecting an error in the system and also when diagnosing the cause of an issue of a problem.

Another potential improvement suggested by the interviewees was to use the data in **UC5** and **UC7**, calculated in the implementation, to give recommendations based on user behavior. Thereby, it would be possible to remove pure visualization of statistics and instead use these to support the user in decision making. An advantage of this is that the complexity of the visualization is decreased. For example, the statistics of the air quality per week and day in **UC5** could instead be replaced with a recommendation of when to turn on the air purifier based on this calculated data. Similar to this, the error frequency data could also be given as recommendations of actions that the user can perform to keep a high quality of the Home Smart system.

The architecture of the implementation was discussed with the participants and one potential improvement concerned the architectural design between the database and the interface. Currently, the information is fetched from the interface, and statistics in the interface are calculated when fetched. These calculations could instead be fetched from an API endpoint where the calculations can be done. The advantage of this solution is that client does not need to perform calculations that can affect the loading times in the interface.

Chapter 7

Discussion

This chapter begins with a general discussion, aiming to describe the challenges and limitations of this thesis. The general discussion is followed by a discussion about the chosen research methodology and ends with a brief discussion about future work.

7.1 General Discussion

The provided solution can be seen as a proof of concept of the findings in this thesis. However, the implementation of the two services described in section 5.3 is a feasible solution for the stated problem but not necessarily the most optimal in terms of a production environment for the case company. To make the solution more integrated with the case company's production environment it would have been possible to integrate the two services on the gateway so that the mobile app could interact with them. Due to the limited time for this thesis, there was not enough time to design a solution that would be integrated with the current system and a stand-alone service was a more suitable approach.

Another aspect that needed to be scoped out of this thesis is the legal aspect of the solution, which is important to consider for a production environment since user data is collected and stored. If the solution would be used in a production environment, then it would be necessary to consider how the data should be saved to not result in any privacy issues. For example, the solution might need to ask for the users' approval when storing and collecting data. Since the solution will mainly be used as a proof of concept and not be used in any production environment, it was possible to scope out legal concerns from this thesis.

The result for **RQ1** can generally be applied to any Home Smart system since the findings can be instantiated regardless of the device type. The use cases that were defined after answering **RQ1** were formulated more specifically for the case company's Home Smart system and for the devices that are included in that system. To be able to test and validate our results it was necessary to define the requirements specifically for the Home Smart system we were using, and therefore the use cases were defined considering the devices and system that was available.

When answering **RQ2**, valuable real-time data was identified and the implemented services in the solution provide the users with this data. The resulting data for **RQ2** can be applied to other projects as well since it is possible to add and remove data based on the context of the implementation. This is similar to the architectural solution, where it is possible to apply the different modules based on the model proposed by Medjaher et al. [23]. The most important thing is that the data gathering module should be able to support real-time data, especially intentions by the user and confirmations that these have been fulfilled.

One threat to the validation of this thesis is that the implementation of the solution has not been used in a production environment on a daily basis. The implementation has only been live during runs in the development and testing stages. However, this is not something that necessarily would have impacted the results from the research questions but could rather have refined or confirmed the results. It could therefore have been valuable to strengthen the results even further by testing the solution in a production environment, but because of the limited time and resources, this was not possible.

7.2 Research Methodology

In this thesis, we have followed the design science research methodology provided by Runeson et al. [4]. Research has been conducted through a literature study and interviews and a feasible solution for the stated problem has been developed.

When conducting the case study, a number of interviews were held with the employees at the case company. One factor that could be a threat to the validity and needs to be considered is that the interviewees all were employees at the case company and not conventional users of the Home Smart system. This means that the interviewees had a lot of technical knowledge and already had a very good understanding of the case company's Home Smart system.

There may be advantages and disadvantages to this. One advantage is that the interviewees know what the system is capable of and have an understanding of information that could be beneficial to expose to the user. Another advantage is that they have seen and tested numerous different scenarios that can arise in the Home Smart system and can transfer this knowledge to us. On the other hand, there is a potential risk that the interviewees are too forgiving of the system since they are the ones that are developing it. Another disadvantage, concerning the development role most interviewees possess, is that they have knowledge about the functionality and the implementation of the Home Smart system and therefore might not feel the same need for additional information in some scenarios that an everyday user would benefit from receiving.

The outcome of the case study was highly dependent on the participants of the interviews. All interviewees were selected for the result to be as unbiased as possible. All participants possessed different roles within the case company and had different knowledge of the system. This increases the validity of the case study. The validity could have been further increased if we had held interviews with more conventional users of the Home Smart system as well. Unfortunately, we did not have this possibility but instead referred to a survey that had been conducted at the case company. The participants in this survey were all conventional users, though quite technically interested, and by referring to this survey the validity of this research can be further increased.

The interviews were held with six different people and resulted in valuable insights. The validity of the result from these interviews could also be increased if the interviews had been held with a larger number of people. Though, for the scope of this thesis, the interviews gave us enough knowledge and insights to be able to answer our research questions feasibly.

Something that increases the validity of this thesis is the previous work and current research that has been presented. By referring to previous work that relates to this thesis and current research that confirms the hypothesis, the rigor can be increased.

7.3 Future work

Since this thesis has been conducted at a case company the IoT system that has been analyzed has been the one the case company has developed. This can be seen as a limitation since we have been dependent on the case company's system and the functionality that it supports. For example, there might be additional information that would be beneficial for a user to receive, which the case company's Home Smart system currently does not support.

One example of additional information is signal strength. Low signal strength is a factor that could affect the overall performance of a Home Smart system and lead to frustration for the user. It would have been interesting to see if this could help the user to structure their Home Smart system in a better way and understand how the positioning of the devices affects the system's performance. Unfortunately, this was not supported in the current system at the case company. If this research would be developed further, the signal strength would be very valuable to extract and present to the user.

In future work, it would also be interesting to take the collected data and develop a recommendation service for the user. This service could for example recommend when to turn on a device at a specific time when a user often performs this action. Recommendations could also include multiple user data and make predictions according to this.

Another area, that especially the diagnostic service could be used for, is software testing. The implemented services could help during testing of the case company's Home Smart system, for example when manually testing the system. By using the service, it would be possible to perform testing with physical products but in a remote location. The current architecture of the diagnostic service supports integration with this type of system since it has an API endpoint that any service could call and test a specific device.

Chapter 8
Conclusion

This thesis has investigated what information a user of a Home Smart system would like to receive. The conducted work consisted of studying what challenges a user of a Home Smart system faces and what information could be presented so that the user can understand the system in a better way. The thesis was structured by defining three research questions, which aimed to investigate what information from a user's perspective should be presented. This information was then translated into functional requirements specified as use cases. The use cases were used when investigating what data that was necessary to collect when designing the solution. Lastly, an implementation for collecting and storing the data was developed and evaluated.

We believe that all three research questions we originally formulated have been answered. **RQ1** was answered by conducting interviews and a literature study. The answers for **RQ1** resulted in valuable insights into the challenges that exist when a user is interacting with a Home Smart system. Often the problem is the user's lack of understanding of the system's behavior. From the conducted research two main approaches for increasing the user's understanding and engagement with the system were found. The first approach relates to troubleshooting. The users experience a need for support when an error occurs within the system and information on how the error can be solved. Secondly, it was found that statistics, especially statistics that make an impact on the user's life, would be beneficial to receive.

Another type of information that was found valuable was information that could help the user with being more proactive in their Home Smart system. From the research, it was concluded that the user should have the possibility of checking that the system works as intended. These results were derived into additional use cases for the case company's Home Smart system.

The interviews also gave us knowledge that we used when answering **RQ2** and **RQ3** since the interviewees possessed a good knowledge of the Home Smart system and its internal structure. After defining a number of use cases we were able to answer **RQ2** about what data from the system we needed to collect. Data that was found valuable was data about the devices and their states, for example, battery level and if the device is reachable or not.

The use cases that were defined specified what needed to be included in the solution for it to solve the initial problem. When investigating and answering **RQ3**, this gave us insights into how the solution should be structured for it to collect the found data from **RQ2**.

RQ3 resulted in a data-gathering system that has a close connection to all interactions and events within the Home Smart system. The solution that was implemented in this thesis collects data by listening to the internal communication channel combined with the internal database in the Home Smart system. The solution provides feedback to the user when a user's intended action with the system does not succeed. The most suitable approach to storing the data is to store it in the cloud to provide easy access to the data.

When evaluating the solution it was found that information regarding troubleshooting and additional information about the system and its health, increases the user's understanding of the system. Statistics that impact a user's quality of life are also valuable for a user to receive. However, these statistics must be presented in such a way that the user can take decisions correctly without the need to understand minor details.

The results from this research could be applied to other Home Smart systems than the one used in this thesis. The information and feedback from **RQ1** are relevant for any Home Smart system and the collection of data can be done according to the results from **RQ3**.

This research could be developed further by implementing functionality so that relevant recommendations can be given to the users regarding how they can utilize their systems more sufficiently. It is also possible to collect more relevant data that is needed to determine issues that occur within the system and the cause of these. Since collecting and storing user data is very sensitive and there exist a lot of privacy issues, the findings of this research can be seen as proof of concepts rather than something that can be used in production.

The research in this thesis has shown that users of a Home Smart system do experience an increased understanding of their Home Smart system by receiving more feedback related to troubleshooting. It has also shown that more information about the system and its health increases their engagement with using the system.

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Appendices

Appendix A
Interview Questions

1. What is your name?
2. What is your responsibility within the IKEA Home Smart team?
3. How long have you worked at IKEA Home Smart?
4. Are you a consultant or employee at IKEA Home Smart?
5. Are you in possession of an IoT system in your home environment?
6. What devices do you use in your system?
7. How often do you use them?
8. After the initialization of your IKEA Home Smart system, have you experienced any difficulties?
9. To avoid encountering problems within your system. What information would you, from a customer point of view, be interested in gaining from your IKEA Home Smart system?
10. Would there be any positive feedback that you would be interested in receiving from your system?
11. What feedback would make you more engaged in the utilization of your system?
12. With knowledge from your work within Home Smart, do you have any suggestions of data that could be valuable from a customer perspective and wherein the system architecture does this exist?

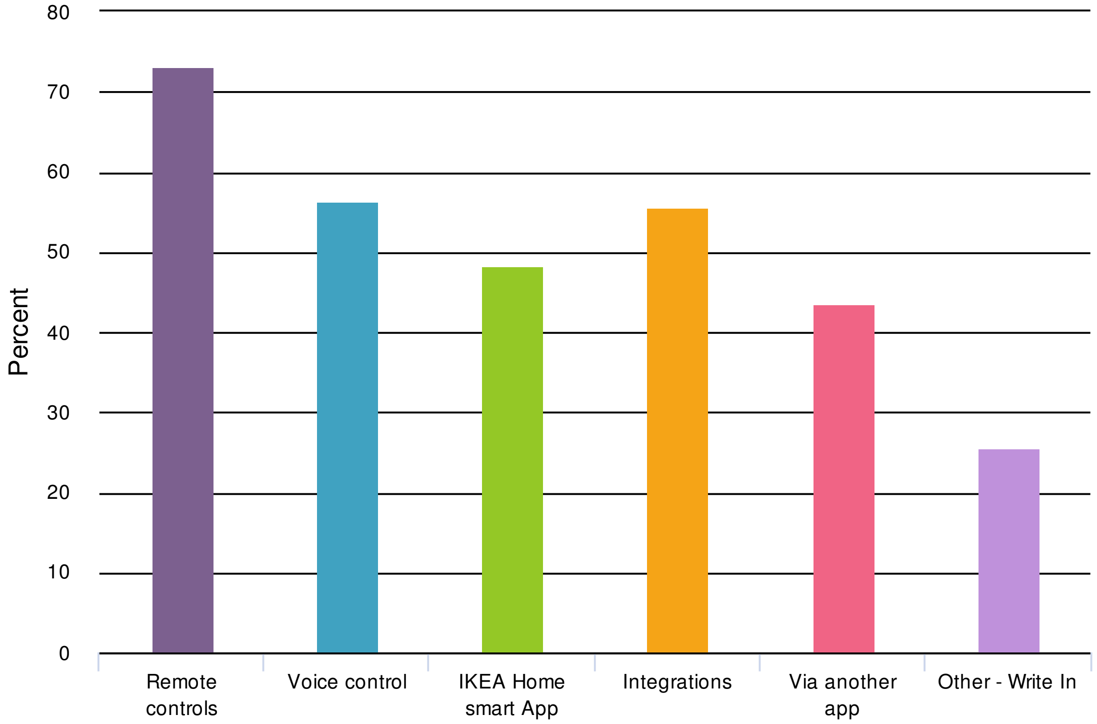
Appendix B
Survey Questions

Report for IKEA Home smart Help & Support

Response Counts

Completion Rate:	**100%**	
	Complete	149
		Totals: 149

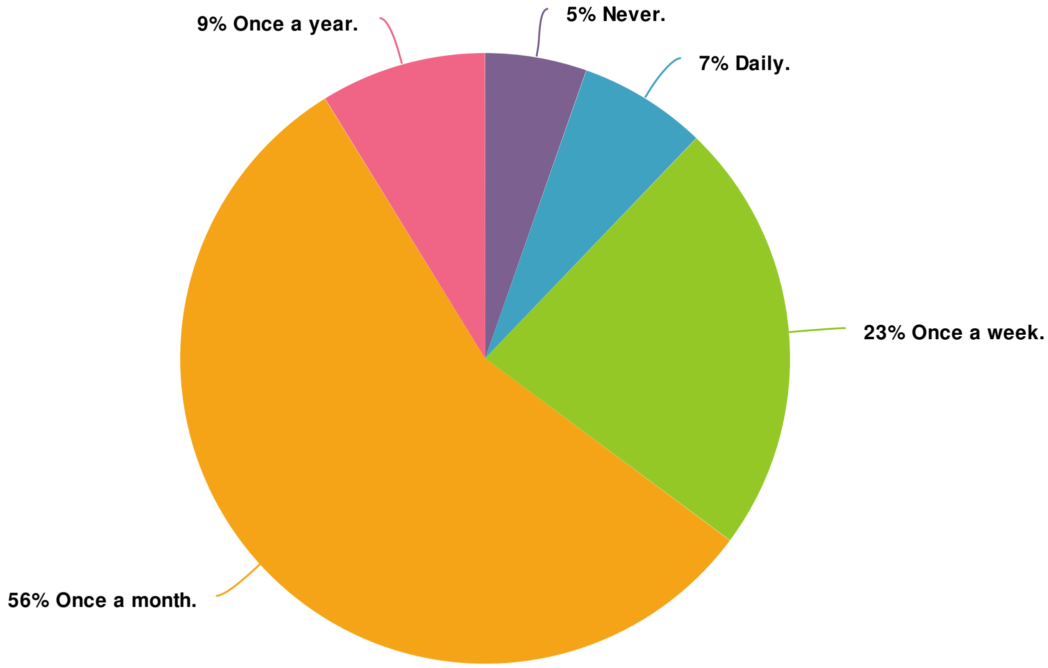
4. How do you control your smart home?



Value	Percent	Responses
Remote controls	73.2%	109
Voice control	56.4%	84
IKEA Home smart App	48.3%	72
Integrations	55.7%	83
Via another app	43.6%	65
Other - Write In	25.5%	38

Other - Write In	Count
Home Assistant	10
Home Assistant	2
HomeKit	2
HomeKit	2
Totals	38

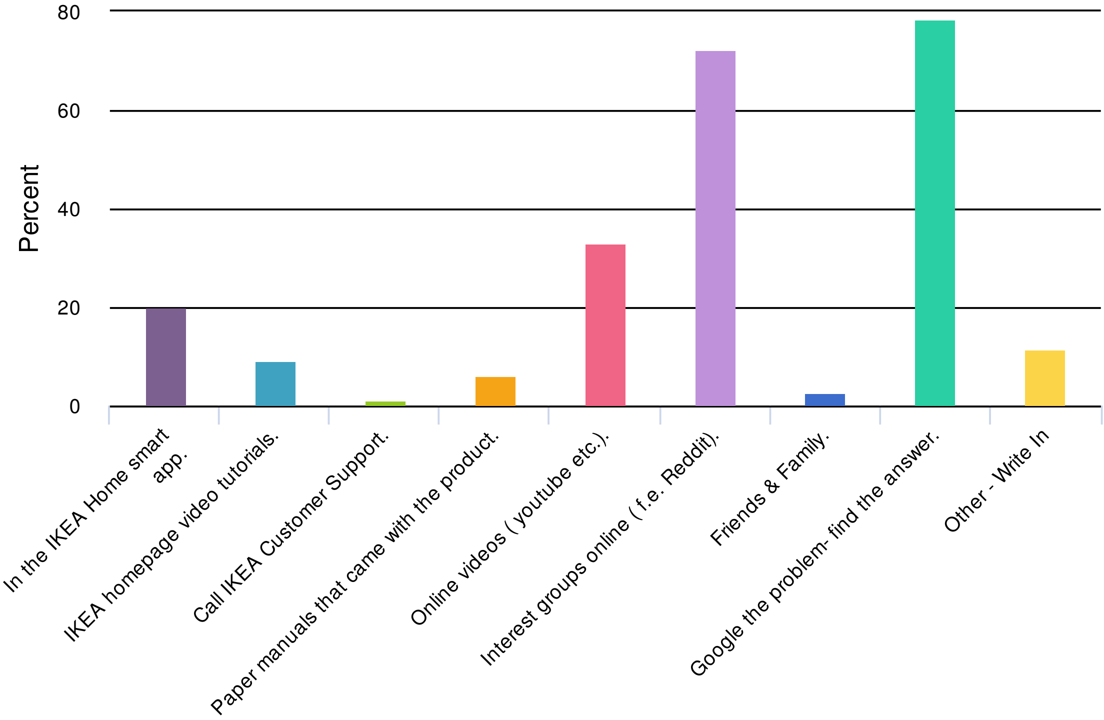
8. How often do you and other household members experience issues?



Value		Percent	Responses
Never.		5.4%	8
Daily.		6.8%	10
Once a week.		23.0%	34
Once a month.		56.1%	83
Once a year.		8.8%	13

Totals: 148

10. Where do you usually look for help?



Value	Percent	Responses
In the IKEA Home smart app.	20.1%	30
IKEA homepage video tutorials.	9.4%	14
Call IKEA Customer Support.	1.3%	2
Paper manuals that came with the product.	6.0%	9
Online videos (youtube etc.).	32.9%	49
Interest groups online (f.e. Reddit).	72.5%	108
Friends & Family.	2.7%	4
Google the problem- find the answer.	78.5%	117
Other - Write In	11.4%	17

11. Do you agree or disagree with the following statements?

	Fully Agree	Agree	Disagree	Strongly disagree	I do not know..	Responses
When encountering an issue, the in app guidance helps me solve it. Count Row %	2 1.3%	22 14.8%	48 32.2%	42 28.2%	35 23.5%	149
To fix it, it is important to understand why the hiccup happened. Count Row %	78 52.3%	56 37.6%	10 6.7%	2 1.3%	3 2.0%	149
Fixing an issue is easy. Count Row %	1 0.7%	60 40.3%	62 41.6%	14 9.4%	12 8.1%	149
Everyone in my home could fix the issue. Count Row %	4 2.7%	19 12.8%	48 32.4%	64 43.2%	13 8.8%	148
I inform myself on how the products work before I buy them. Count Row %	90 60.4%	51 34.2%	6 4.0%	2 1.3%	0 0.0%	149
I spend too much time maintaining the IKEA Home smart system. Count Row %	18 12.2%	46 31.1%	57 38.5%	23 15.5%	4 2.7%	148
Sometimes I can not be bothered to fix the issue right away. Count Row %	36 24.3%	74 50.0%	29 19.6%	6 4.1%	3 2.0%	148

Appendix C
Validation Interview Questions

1. Do you think that the provided information would help the user to understand their system better? Why or why not?
2. Would you like to use it in your Home smart system in the home environment? How often?
3. Do you think that members of your household would benefit from the provided information?
4. Are there any other errors that could arise that you would like to receive information from that are not covered in this implementation?
5. Would there be any other information that you would like to get from the Home smart system that is not displayed in the application?
6. How easy is the application to utilize?
7. Is it clear what each sub-page is used for and what you can do?
8. Do you think that the information is too complex or is it a good balance for the user?
9. Would you like to get additional explanations for the visualized data?
10. Do you think that the purpose of the information is clear?

EXAMENSARBETE Increasing user engagement in an IoT-system using a feedback monitoring system
STUDENTER Maria Hellstrand, Anton Håkansson
HANDLEDARE Masoumeh Taromirad (LTH), Iraj Entezarjou (Inter IKEA), Laszlo Urszuly (Inter IKEA)
EXAMINATOR Alma Orucevic-Alagic (LTH)

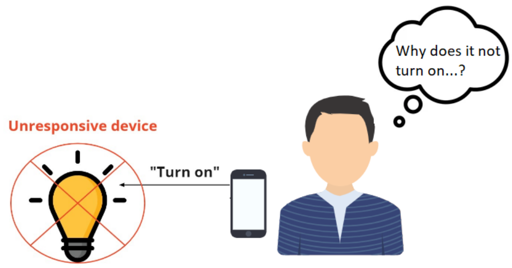
Hur man genom feedback kan engagera användare att underhålla och monitorera sitt IoT-system

POPULÄRVETENSKAPLIG SAMMANFATTNING **Maria Hellstrand, Anton Håkansson**

Problem med att förstå varför ditt smarta hem beter sig på ett visst sätt? Varför inte lampan tänds när du försöker sätta på den? Efter att ha installerat smarta produkter i sitt hem är förhoppningen att allt ska fungera utan problem, tyvärr är detta oftast inte fallet för många användare. Värdefull feedback från systemet kan göra att användare förstår och kan underhålla sitt smarta hem på ett bättre sätt.

Smarta hem har ökat dramatiskt i popularitet de senaste åren vilket ställer högre krav på systemen gällande förståelse och möjligheter. Ett problem som många användare stöter på är att systemet beter sig på ett oväntat sätt eller att ett fel uppstår. Detta ofta utan att ge någon feedback till användaren. Den bristande feedbacken från systemen skapar frustration hos användarna då de ofta inte förstår de bakomliggande orsakerna till varför problem uppstår. Denna frustration kan leda till att användare blir mindre benägna att använda sina system. För att användare ska kunna bli mer engagerade i att använda sina smarta hem och få en ökad förståelse för sitt system och dess beteende krävs mer information och feedback.

Vi har i detta examensarbete utvecklat en applikation som ger användare direkt feedback i situationer där mer support kan behövas. Denna feedback fokuserar på att hjälpa användaren när fel uppstår i systemet och ge förslag på hur felet kan lösas. Applikationen möjliggör också att användare kan diagnostisera sina enheter och därmed göra användaren mer proaktiv i underhållningen av sitt system. Denna diagnostisering testar enheterna så att de fungerar korrekt och ger feedback på om något gått fel under testningen.



Resultatet från examensarbetet visar att det finns en stor efterfrågan av denna typ av feedback från slutanvändaren. Det är dock viktigt att presentera informationen på ett enkelt sätt som gör att användaren förstår hur den ska agera utifrån den givna informationen. Fokus ska ligga på vad användaren kan göra för att förhindra eller lösa problemet, snarare än själva problemet i sig.