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Understanding the complexity of error detection in smart homes

Why smart home users lose control and how to get it back

Master's thesis, May 2016

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Summary

This study was started in order to analyze the causes of users' diminished control when using smart home technology and to suggest solutions for giving control back to the users. A case study was conducted in a Norwegian care home for the elderly, Hill Care+, and the malfunctions in the heating system was chosen as the case to be studied.

During the reconstruction of the history of the case, a complex web of actors and stakeholders and control system in Hill Care+ was revealed. A problem which seemed simple on the apartment level turned out to be a large-scale malfunction which required a comprehensive investigation, examining the underlying heating infrastructure of Hill Care+. Such complexity in the case required a framework to address both Human-Computer Interaction (HCI) and infrastructure matters. Thus, the concepts and the framework of Edwards et al. [14] which addresses infrastructure problems in HCI were employed in order to detect what challenges the heating infrastructure caused for users in maintaining control over the smart home technologies, and to figure out how to address them in the four layers of infrastructure in Hill Care+.

The power smart home users have to control smart home technologies is diminished because of constrained technological possibilities, interjected abstractions reflected on the applications built on top of the infrastructure, and unmediated interactions when the infrastructure of smart homes malfunctions. The framework by Edwards et al. provided a systematic way to address three identified challenges on four layers of different engagement levels. The most recommended solution is to take the user experience and usability into consideration early in the design process, by reflecting them in the requirement specification and make use of them more proactively in the production and evaluation process. User participation is also essential to align the user needs and the system functionalities, because such alignment would contribute to give the users control over the smart home technologies. Good surface design and a good conceptual model would also assist them to maintain control.

Acknowledgement

This master thesis is written based on field work in a Norwegian care home for seven months. I would like to thank all those who have participated in my study, even during their busiest period of time. Without their detailed account and support for additional information it would have been even more challenging to understand the case.

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1 Introduction

1.1 Motivation

1.1.1 My smart lighting system at home

When my husband and I moved into our current apartment, there was a simple smart lighting system (Figure 1) installed by the previous owners. It is a system which controls the lights by setting different modes, for instance if vacation mode is set the lights at home would be turned on in the evening. There is a control panel with a screen mounted on the wall, as in figure 1, where we can program various lighting settings, and the lighting can also be controlled by a remote control.

Figure 1. The smart home technology at home

Out of excitement we navigated and pressed the menus on the control panel, but there was no reaction and nothing happened. Strangely, the remote control could dim or turn the lights on and off by pressing the numbered buttons and the up/down buttons on it. We figured out, after pressing all the buttons on the remote control, that each number is programmed to control localized lights. We guessed that the control panel might be able to change the current settings to suit our preference. In the beginning, we thought that it was not responding because we did not use it properly or that there might be some steps that we overlooked. However, after all the available settings and menus were explored it became more obvious that it did not work because of technical issues. Since the remote control was still working and there are manual switches for each light mounted on the wall, as seen in Figure 2, to override the pre-programmed settings, we have ignored the control panel without fixing it for three years. It was sometimes annoying for me because I often forgot which switch is programmed for the lights in which zone of the apartment.

Figure 2. The remote control and the manual switches

I finally decided to try to figure out how to repair the control panel in order to adapt the current lighting settings, and searched for the user manual for the system on the Internet. On the website of the vendor of this system, however, I could not find a user manual for end users or any information on troubleshooting. On the frequently asked questions page it said:

> *Can I program the system myself?*
>
> *The electrician configures and documents functions that control lighting, heating, security, etc. Adjustments, such as to temperature, or light levels, can easily be done by you.*[1]

[1] "FAQ,," xComfort, accessed April 24, 2016.
http://www.xcomfort.com/faq.html

After an extended search, I finally found a user manual from a search engine made by another company which seemed to be related to this system. However, this user manual was not helpful. I followed the steps from the user manual to configure the settings, but the menus did not carry out the operations that they were supposed to. I found another instruction made for the installers, but it seemed highly advanced and I did not want to risk making any mistakes which might make the current lighting settings to stop working.

After these attempts, making changes appeared to be beyond our control and highly dependent on experts. What I wanted was merely to adapt the current settings so that it better suited our logic and preference, but numerous steps were required, including checking the type of product, finding the contact person, and detecting what exactly was not working in order to report the malfunction more precisely. The control panel apparently hid an underlying structure which entailed a web of experts and vendors I needed to contact and different levels of system control. This underlying structure seemed to be a complex infrastructure. It might also be quite expensive to repair it if the service period is expired. The control panel is still mounted on the wall without being used, since the day we moved in more than two years ago, and it merely shows the temperature of the living room.

Smart home technologies are supposed to benefit residents, making everyday life simpler and more comfortable. However, when they do not meet the expectations of the residents or are not entirely functional, this makes the residents feel frustrated and powerless because they partially lose control over their home. As in the case of my lighting control system, I cannot fully control it but have to accept the current setting as it is. My power of control diminished because of this 'smart' lighting system and this motivated me to think about why we as users of the smart home technology lose control, especially in an error situation, and what we can do to have better control over the smart home technology.

1.1.2 Unused smart home control

There is another situation which shows how smart home technologies diminish the power of the residents to control them. Christiansen and Andersen [8] conducted a study as a follow up study to one initiated by Kanstrup and Christiansen [21], where three couples were offered an installation of a smart home control system on a small scale in their new apartment. However, only two households participated in the interviews and they did not take advantage of the offered smart home control system for eight years. One household was still confused about which switch to press to turn on which lights, and the other household was uncertain about malfunctions even though they had not tried to program the system. Christiansen and Andersen speculate that the smart home controls were not fully utilized because they diminished the power of control that the users had over their home. The frustrations when using the smart home technology are apparent in the quoted user voices:

"Even though I have lived here for many years by now, I still find myself running around and pushing the wrong buttons, … And what bothers me is that one never knows whether it is on or off … it's very annoying" (Household 1) [8] page 44

"Well, it is amazing, that we after eight years don't know how to turn on the light in the hallway" (Household 3) [8] page 44

In their analysis, what these users want regarding this smart home technology is to control it. The users want to be in control of their environment by independently configuring the behavior of the technology to suit their preference and taking actions when required. They want to adjust dimming and switching the light at home instead of automating it. To take necessary actions, however, the users first need to understand some of the logic behind the operation, and then have the power to negotiate or change the logic or the rule underlying the functionalities. This is indicated in the user's voice:

"I was here at the time where they programmed our light. … But I have in any case made a systematic, where okay, the first switch is controlling this light and … In that sense there is logic. And it is important as well, that the people who install the units, have thought through the logics… But I find that it is very nice to stroll around and then push that one, 'now there will be light' by pushing this…" (Household3) [8] page 45

I find this study by Christiansen and Andersen interesting in two ways. Firstly, the experiences of the two households are very similar to mine when using the smart lighting system at home. They still press the wrong buttons to turn the lights on and off at home, feeling annoyed as I also did. Secondly, though it is not confirmed yet, both household 3 in the study and me suspect that there is a malfunction in the system. The only difference is that I attempted to re-program the system and household 3 did not.

As illustrated in my smart lighting system and the study conducted by Christiansen and Andersen [8], the users of smart home technologies are not in full control over the technology at home. Smart homes are designed to improve the residents' quality of living. The question is, however, to which degree we do have control when using this automated smart home technology.

1.1.3 Being in control over the technology at home or not

Technology is becoming more automated and it is regarded as one of the most efficient solutions. The complexity of technology is well hidden under automation as long as it is built on a reliable and robust system [33]. However, it reveals itself when there is a malfunction. Users who have already got used to the automated technology become helpless and powerless because of the lack of control over the system.

The concept of levels of automation presented by Cummings [10] is helpful to understand the balance of automation and human control in the system. In these levels of automation, full automation is 10, where the computer decides everything and acts autonomously, ignoring the human. Cummings maintains that a higher level of automation is appropriate for tasks that do not require flexibility and have a low probability of failure. The smart home technologies which conduct rather redundant and repetitive tasks might be suitable for a high level of automation, but then there is very little room for flexibility, which is essential in private homes, such as for fine adjustment of lighting settings in various contexts. I regard my smart lighting system as having level 5 of automation, where the computer executes a suggestion if the human approves. Despite the medium level of automation, as a user of the smart home technology, I feel my power of control diminished.

Automation level	**Automation Description**
1	The computer offers no assistance: human must take all decision and actions.
…	…
5	executes that suggestion if the human approves, or
…	…
10	The computer decides everything and acts autonomously, ignoring the human.

Table 1. Levels of Automation by Cummings [10]

The core concept inherent in the following definitions of ‘control’ from numerous dictionaries is a power to change something or someone according to what the controller wants.

The act or fact of controlling; power to direct or regulate; ability to use effectively[2]

The act of restricting, limiting or managing something; a method of doing this[3]

The ability or power to decide or strongly influence the particular way in which something will happen or someone will behave, or the condition of having such ability or power[4]

The fact that I could not change my home as I wish might be one of the reasons why I felt my power of control over the smart home technology diminished, as the households in the study by Christiansen and Andersen [8] did. As inferred from the two situations, it is assumed that the higher the level of automation is, the weaker the users’ power of control could become, as the users delegate more of the decision-making process to the machine, thus preventing the users from making changes as they want. As technology develops, smart home technologies will become more advanced and more automated. In this trend, it will be interesting to study the user control when using smart home technology, focusing on when user power is diminished and how to maintain it.

In the context of using smart home technologies, being in control indicates that users can decide the behavior of the technologies so that they function as the users prefer. To influence the system behavior, it is crucial to comprehend what is going on by understanding the design intentions and the system functionalities and being aware of possible options in order to independently take necessary actions to change the home into a preferable situation. If the users are dependent on experts such as technicians or installers every time they need to make changes at home, this cannot be seen as having control over the smart home technology. In other words, being in control refers to understanding the system and being independent when using the smart home technology.

[2] "Control," Collins English Dictionary, accessed April 24, 2016. http://www.collinsdictionary.com/dictionary/american/control
[3] "Control," Oxford Learner’s Dictionary, accessed April 24, 2016. http://www.oxfordlearnersdictionaries.com/definition/english/control_1?q=control
[4] "Control," Cambridge Dictionaries Online, accessed April 24, 2016. http://dictionary.cambridge.org/dictionary/english/control

1.1.4 Smart home for the elderly

The smart home technology implemented in residences for elderly or physically challenged people is prone to be more automated and centralized so that residents are not often required to interact with the technology. However, as demonstrated in my situation and the study by Christiansen and Andersen [8], the power of control over smart home technologies is more likely to decrease when the level of automation increases. The purpose of smart home technology is not merely freeing the residents from all the chores and routines. It is also helping them to address their needs by using advanced tools so that they can independently manage daily tasks [5]. Instead of being dependent on a few super users to manage the smart home technologies implemented, all the users of smart home technologies should be able to take advantage of the technologies to increase their autonomy at home.

With this concern regarding the diminished power of control over highly automated smart home technology in mind, I visited a Norwegian care home for the elderly, Hill Care+[5], where various smart home technologies are implemented in the apartments. Hill Care+ hosts 91 apartments and is one of the Care+[6] buildings built upon the Care+ concept. Care+ is a locally used concept created to provide the elderly with better housing in a large municipality in Norway. What distinguishes Care+ apartment from other nursing or care homes is that they are equipped with smart home technology. Care+ buildings are serviced 24 hours a day and seven days a week and usually host 50-100 apartments in the building.

Hill Care+ has been a pilot project for the municipality so that the experience from Hill Care+ can be carried over to other upcoming Care+ projects[7] to improve them. It was opened in autumn 2012 and had been operational for three years by the time I was looking for a field site to conduct research. The residents and employees of Hill Care+ have been living with smart home technologies for three years and this made Hill Care+ a promising field site to find a case to study user control over smart home technologies. It was also advantageous that the residents and the employees of Hill Care+ are relatively comfortable with people who observe and ask about their use of the smart home technologies implemented in the apartments, as many researchers and experts in smart home technology and Human-Computer Interaction have already been there to study the use of the smart home technologies.

[5] The name has been changed for anonymity.
[6] "Omsorg+" in Norwegian
[7] There are 599 Care+ apartments in seven districts in the municipality as of February 2016. By 2026, the municipality plans facilitating a total of 2,000 Care+ apartments.

In a meeting with the director of Hill Care+, she explained how various actors were using the smart home technologies implemented and mentioned an issue concerning the heating in Hill Care+. Not long after its opening in September 2012, some residents had already started to report that they felt cold in their apartments. Since then the actors and stakeholders of Hill Care+ have been working on the issue of insufficient heating in some apartments, but it took almost two years to troubleshoot. It was still an on-going issue, but she informed me that the responsible stakeholder was taking actions to correct the detected errors as of September 2015.

This case of insufficient heating in Hill Care+ seemed interesting because the case is directly related to the users' diminished or lost control over the technology. The residents of Hill Care+ were not able to significantly change the situation even though they felt cold in the apartment. The heating itself might appear irrelevant to smart home technology, but the heating system is definitely a part of the smart home technologies in Hill Care+. The smart home technologies are built upon the physical heating infrastructure and are also a part of this heating infrastructure, providing the users with a set of methods to interact through in order to eventually control the heating system. The long-term troubleshooting indicated the complexity of this case. The process of troubleshooting must have unfolded a web of numerous actors and stakeholders involved in the heating malfunction case, and a layered control system in the smart home technology. Because of the presumed complexity hidden in the underlying structure of infrastructure, this is a similar process, although on a larger scale, to the one that I did not dare to initiate by myself; to adapt the settings of my smart lighting system and fix the suspected malfunctions. I assumed that the study of this heating case would be helpful for understanding the causes of users' diminished control over smart home technologies and for finding ways to enhance and maintain control, as it shares some context with my smart lighting system at home, such as malfunctions and a complex underlying structure which can be referred to as an infrastructure.

1.2 Research question

There are some well-designed systems which allow the users to manage the smart home without being confused, but the users are often overwhelmed by the complexity of the smart home technologies, especially when there are malfunctions. For rich affordances in life, we need and seek advanced functions of technology, which results in complexity. It is inevitable because advanced technology and our life require it. Such complexity as one of the features of advanced technology, however, should be dealt with so that users can have control over the technology.

The diminished power of control becomes more apparent, and the complexity of smart home technology reveals more of itself in the process of troubleshooting. It is evident that future homes will be equipped with more and more advanced technology for efficient energy use, promotion of comfort and security of the residents. In this current trend, it is crucial that the residents do not lose control over their own home. Being in control, inferred from my smart lighting system and the study of Christiansen and Andersen [8] illustrated in the previous sections, indicates that the users can understand the capabilities of the technology implemented, find out possible actions to take and have the power to negotiate or change the logic or rules underlying of the functionalities. As smart home technology advances its complexity will increase, but this should be dealt with so that the users still maintain control over it.

The research question of this study is why the users, primarily residents of smart homes, lose control over the smart home technology, and how the users can take back control. To seek answers to the research question, it is essential to acquire a deep understanding of a situation where the users feel their power of control over the smart home technology diminished or lost. Therefore, this study will be based on the field work in Hill Care+. The malfunctions in the heating system of Hill Care+, and the diminished user control over the smart home technologies which manage this heating system will be investigated in this case study. The causes of the diminished or lost power of control will be examined by studying the process of troubleshooting in the heating case. When the causes are identified and analyzed they could become a source for finding actions to give the users control over the smart home technology.

More specifically, the research questions of this study are as follows:

- Why do smart home users lose control of their home, especially in the case of malfunctions?
- What actions can be taken for users to take back control over the smart home technology?

1.3 Chapter overview

Chapter 2 will provide an introduction to smart home technology, illustrate smart home technologies implemented in Hill care+ and an overview of previous studies in order to find the position of this research in the context of related work.

Chapter 3 will present several concepts and the framework adopted in this study and explains the relevance of using them in the analysis and discussion of the case in this study.

Chapter 4 will account for the type of methodology and the methods employed in the study to describe how the field work and the analysis were conducted.

Chapter 5 is a preliminary description of the case to provide a full context of the case. This chapter thus presents an overview of the actors and stakeholders who are closely concerned with the case.

Chapter 6 will describe the case in detail. After the general description and the timeline of the case will be presented, the accounts provided from the perspectives of each actor and stakeholder will follow.

Chapter 7 will detect three challenges the heating infrastructure imposed on the users when shaping a feeling of control over the smart home technology.

Chapter 8 will address the three challenges detected in the previous chapter on each layer of the infrastructure in Hill Care+.

Chapter 9 will illustrate more concrete actions to be taken by presenting the design mockups which reflect the layer analysis from the previous chapter.

Chapter 10 will sum up the study with its contribution and suggestions for future research.

2 Background

2.1 Smart home technology

Many buildings newly built or recently renovated are ‘smart’. What makes homes and buildings smart? Harper [19] maintains that what makes homes and buildings smart is the interactive technologies that they contain. Aldrich [1] extends Harper’s definition by additionally stating the purpose of smart homes:

> *A residence equipped with computing and information technology which anticipates and responds to the needs of the occupants, working to promote their comfort, convenience, security and entertainment through the management of technology within the home and connection to the world beyond. [1] page 17*

A smart home is, technically speaking, a residence where such interactive digital technologies are implemented. As technology advances, the scope of the definition of smart home technology is also expanding. Gann et al. [17] identify numerous areas, as shown in Table 2, where smart homes can improve residents’ quality of life, meeting their needs and helping them to achieve greater autonomy so that they can live longer independently at home.

The areas where smart homes can contribute to improving quality of life [17]
• Safety • Security • Convenience and usability • Control of domestic appliances • Energy and environment management • New forms of entertainment • Business, home networking and learning applications • Home services such as shopping, medical and care provision

Table 2. Areas where smart homes can enhance residents’ quality of life

According to the Ministry of Social Affairs and Health Care in Norway [23, 24], smart home technology is a collective term for information and communication technology applied to homes:

> *…in homes various components are communicating through a local network. … Smart home technology enables an automated communication with the external world by telephone (or mobile) or*

through the Internet, sending messages or alarms to one or more recipients. ... [24] page 8 (translated from Norwegian)

The focus of this definition lies on connectivity and automation. Demiris and Hensel [11] add another aspect of smart home technology as being integrated into the infrastructure of home.

The technology is integrated into the infrastructure of the residence and does not in principle require training of or operation by the resident, distinguishing thereby smart home applications from stand-alone units that can be used in the home setting and need to be operated by the end users. [11] page 33

The examples of technologies implemented in smart homes are presented in Table 3, and they have mainly two key application areas; one being internal environmental control and the other being home security, safety and emergency aid. Internal environmental control involves control of heating, ventilation and air conditioning (HVAC), and monitoring of these so that they meet the requirements of the residents. Sensors, alarms and various user interfaces provide aid for home security and in an emergency situation at home. Triggers such as buttons or GPS based location indicators are also types of advanced sensors which assist in summoning help at home.

Examples of smart home technologies [17]	
Internal infrastructure: control and communications	**Wired or 'bus' systems** • Power line • Fiber optic **Wireless 'signaling' systems** • Infra-red • Radio
Interactive systems and external connectivity	• Interactive-digital TV • Digital radio • Telephone • Intelligent meters (power line and radio) • Warden call systems
Internal appliances, terminals, and equipment	**User interfaces** • Television • Door entry system • Pressure switches • Control panels **Monitors and detectors** • Thermostats • Smoke detectors • Alarms

	• Contact sensors
	Controllable electric-powered devices and systems
	• Electric switches • Lighting • Ventilation equipment • Entertainment equipment • Security systems • Heating systems

Table 3. Examples of smart home technologies (page 49, summarized)

2.2 Smart home technologies in Hill Care+

The smart home technology is implemented in all apartments in Hill Care+. The purpose of the installation of smart home technology in Hill Care+ is to provide the residents with comfortable housing, easy regulation of apartments as well as a higher degree of security. Additionally, it aims at effective energy consumption.

The heating is adjusted through two thermostats: one in the living room and the other one in the bedroom. When a window is open, the temperature falls to 10 °C. As a safety measure to avoid frost damage, when it gets colder than 10 °C the alarm goes off. During night time, the window sensors only affect the temperature in the room where the window is open, but during daytime, the temperature in the whole apartment will be decreased. The heating cables in the floor of the bathroom keep a constant temperature of 23 °C and the floor heating in the bathroom can be turned off by the switch on the wall.

The lights in the living room, bedroom and bathroom are automatically switched on and off by motion detectors. That is, when its sensor detects motion it is turned on, and if no motion is detected for a certain period of time, the light is turned off automatically. In the bedroom, there is a switch the resident can set to either day or night mode. When the night mode is set, dimmed light is turned on when motion is detected. Other lights are implemented in the floor, from near the bed to the bathroom. They are switched on at night when motion is detected to guide the residents to the bathroom and prevent them from falling down in the darkness. The automatic light sensor can be overridden by a manual switch on the wall.

The stove alarm[8] is implemented over the cooktop. When it detects any danger which can cause a fire, the alarm goes off. The power supply to the cooktop is then shut down, and it starts to beep very loudly. The alarm can be turned off by using a special magnet kept in the fuse box. Also, a power supply timer is implemented in the kitchen so that kitchen appliances will not be left with the power on for a long time.

The water sensors[9] are placed both in the bathroom and the kitchen to avoid flood if an accident should happen. If moisture above a certain level is detected the alarm then goes off and the supply of water is stopped.

All these numerous components and technical installations are connected to a central system which communicates with and manages them through the user-facing interface. This central system which intelligently operates and controls the building is commonly known as Building Automation System (BAS)[10], and the whole building and the apartments of Hill Care+ are controlled centrally by BAS.

2.3 Related work

Christiansen and Andersen [8] address in their study that difficulties in using and controlling the smart home technologies might have been caused by the lack of understanding of the design intentions and the system functionalities, and the mismatch between the logic of users and the behavior of systems. The automated smart devices and environments have freed users from engaging with complex technology directly. However, this can sometimes result in people getting caught out and frustrated, especially when the technology stops working [37]. Randall [35] points out that the lack of feedback could confuse the users when controlling the devices.

Such user experience challenges have been studied in the context of home networking, one of the core properties of smart homes which enable them to be connected. Grinter et al. [18] identified challenges that households had in coordination, set up and maintenance of home networks. Chetty et al. [7] examined the relationship between home networking and the house itself, extending the work of Grinter et al. by focusing centrally on the infrastructure which supports and enables home networking. They broadened the scope of the research on

[8] "Komfyrvakt" in Norwegian
[9] "Vannføler" or "Vannalarm" in Norwegian
[10] "Sentralstyrt driftsanlegg (SD-anlegg)" in Norweigian

the networked home by examining technology, services and stakeholders who administer and support them and by exploring the relationship between home networking and home infrastructure. Shehan and Edwards [38] suggest that engagement by the Human-Computer Interaction (HCI) community could contribute to overcoming the user experience challenges in the design of home networking technologies. However, the layers of underlying infrastructure, not designed with the human aspects taken fully into consideration, could inhibit HCI endeavors to create a positive user experience. Focusing the dependency of HCI on the infrastructure and the tension between them, Edwards et al. [14] identify the general challenges the infrastructure causes in shaping the user experience, and then present four approaches to address these challenges in HCI. Their approaches share a basis with the analysis of Rodden and Benford [36], built upon the framework of Brand [5].

The framework of Brand presents six shearing layers -*Stuff, Space plan, Services, Skin, Structure and Site*- which compose buildings. Rodden and Benford apply those layers to analyze whether the development of interactive digital devices for domestic space complies with the changing process of buildings that Brand presents. Edwards et al. also apply a layered framework to primarily the digital infrastructure, sharing the focus of Rodden and Benford on closely interwoven levels of buildings and the importance of underlying structure. The framework of Edward et al., however, does not directly employ Brand's six layers, but present four new approaches - *Surface, Interface, Intermediate* and *Deep* - which seem to be adapted from Brand's layers to apply better to the digital infrastructure. I will present more about the relationships and development of those frameworks in section 3.3.1.

Recognizing the importance of deep engagement with the infrastructure in order to overcome the limits of underlying infrastructure, as Edwards et al. argue, the *Homework* project [29] recreates the underlying infrastructure to provide the users with greater access and control for managing it. The Homework project re-examined the protocols and architecture of the domestic settings and incorporated these requirements within the infrastructure to assist the inhabitants to better manage and control their home network. They pushed interactions deeper into the infrastructure by increasing the number of possible interactions and enhancing the interactivity of the elements in the infrastructure previously invisible to users. Compared to the previous works which attempted to merely expose the underlying infrastructure to the users with a better visualization, presuming that the underlying infrastructure is unchangeable, the Homework project sought to overcome the limits of the underlying infrastructure by reshaping it.

While the Homework project analyzed the infrastructure challenges based on the end user needs emergent from ethnographic studies on households, the infrastructure challenges in my research will be identified based on a case study which entails perspectives of various stakeholders. Considering that there are numerous actors involved in infrastructure, including various perspectives could contribute to extending the scope of challenges imposed on both ends users and super users. The Homework project and my research both acknowledge the importance of a more fundamental engagement with the underlying infrastructure to allow users a more enhanced control, but the Homework project did not adopt the four approaches by Edwards et al. to address the identified infrastructure challenges in the process of reshaping the underlying structure. My research will, however, employ the four approaches to contribute to providing a way to analyze and find the solutions in cases where infrastructure challenges have considerable impacts on HCI concerns. This aims to show that the application of the concepts and the framework to similar cases could assist the design of underlying systems for the user experience.

My case study is about malfunctions in a smart home, which is rather commonly observed and diminishes the power of control that residents have. Among numerous works concerning smart home and smart home technology, I have not found any research in the exact same context as mine, an error situation in smart homes with a focus on users' control over smart home technology. Budaiwi [6] designed a 'thermal-comfort' questionnaire to assist preliminary assessment of space thermal conditions in buildings where complex Heating, Ventilation and Air Conditioning (HVAC) systems are implemented. However, his study was conducted primarily to support the investigation and problem solving by super users of the building, such as building operators or facility managers. His study does not focus on neither smart homes, smart home technology nor end users such as residents. This study thus hopes to contribute to providing a systematical approach to the examination of an error situation in smart homes, and design implications for positive user experiences which help the users to get enhanced control over smart home technologies.

3 Theory

3.1 Design for a user experience

The focus of the research question in my study lies on user control. I will attempt to uncover why users lose control over the technology and discuss possible actions to give them back control. Feeling of control is an emotion and a part of the user experience. It is thus important to understand the definition of the user experience and the concepts used to design for such user experiences in this study. The concepts introduced in this section will function as a basis for the evaluation and analysis of current design solutions in Hill Care+ which diminished users' power of control, and the discussion for improved design or possible actions to be taken to give the users the feeling of control back.

3.1.1 User experience

The overall impression and the emotions the users remember about the interaction with the technology form the basis of the user experience. Negative emotions such as confusion, frustration and anger, or positive emotions such as a feeling of control and mastery, satisfaction and pride [32], are all examples of the user experience users might feel after interacting with smart home technology. Hassenzahl and Tractinsky [20] define user experience as:

> *User experience (UX) is about technology that fulfills more than just instrumental needs in a way that acknowledges its use as a subjective, situated, complex and dynamic encounter. UX is a consequence of a user's internal state (predispositions, expectations, needs, motivation, mood, etc.), the characteristics of the designed system (e.g. complexity, purpose, usability, functionality, etc.) and the context (or the environment) within which the interaction occurs (e.g. organizational/social setting, meaningfulness of the activity, voluntariness of use, etc.). Obviously, this creates innumerable design and experience opportunities. [20] page 95*

The user experience is a subjective concept and is concerned with numerous subjective qualities. The nature of the user experience is multifaceted [37], as observed in the definition of Hassenzahl and Tractinsky. To design for a pleasant user experience, numerous aspects of the user experience need to be taken into consideration. Among them, design principles and the usability attributes will be used as a set of concepts to evaluate the designs for the user experiences in this study.

3.1.2 Design principles

Sharp et al. [37] describe the most common five design principles used for designing the user experience. *Feedback* is a well-known principle which indicates that products should provide information about performed actions and possible further actions, informing the users about what is going on. Feedback is closely related to *visibility*. The more visible the products are, the more likely the users are to recognize and anticipate what to do with them. In order to enable the users to avoid making mistakes and guide them to interact in a proper way, the concept of *constraints* is used for restricting certain ways of interaction. When interfaces provide the users with similar ways to perform similar tasks, the users can learn the interfaces fast because of the *consistency* found in the various interfaces. The users also learn how to use products by their *affordance*. The clues given by the attributes of objects can assist the users to make sense of how to interact with them.

Norman [32] adds several principles to the previously presented ones. After he first introduced the concept of affordance, it has been used when describing the design process of making the relationship between the object and the required action visible, which is not what affordance originally refers to. Norman maintains that *signifiers* should be used instead in a case where designers want to communicate what actions are available from products. He introduces *mapping* as an effective way to design for indicating the connection between two different sets of things. A natural mapping, for instance a layout of the control which imitates the spatial organization of physical objects to be controlled, could be useful for the users to map the connection between the control and the objects.

Among the design principles, he underscores that a *conceptual model* is the most important one to provide the users with true understanding. It is a mental model which represents peoples' understanding of how things work. The conceptual model does not have to be accurate and precise as long as it supports the use. As it is usually constructed from the experience of the perceived structure it could be wrong, which might lead to inappropriate use.

Commonly referred design principles [32, 37]
• Feedback • Visibility • Constraints • Affordance - *Signifiers* • Mapping • Conceptual model

Table 4. A summary of commonly referred design principles

3.1.3 Usability goals

The Human-Computer Interaction (HCI) community was historically concerned primarily with usability, but now it is more concerned with understanding, designing for, and evaluating a wider range of user experience [37]. Norman and Nielsen [34] also maintain that the user experience is an even broader concept compared to usability. Usability is one of many aspects which could influence the quality of the user experience. It is commonly taken into account in the design of user interfaces (UI), which is a crucial part of the design, as it has a significant impact on the total user experience.

Usability is concerned with how well users can make use of the product and it is applied to all aspects of a system, including installation, usage and maintenance, optimizing the interactions users have with the system [37]. Nielsen [30] defines usability as a quality attribute that assesses how easy the UI is to use. Five attributes determine the usability of a user interface.

Additionally, he stresses that utility is another equally important key attribute which determines whether a system is useful. Utility is concerned with whether the functionality of the system can accomplish tasks. Although the system is easy to use, if it does not do what users want the system is not useful.

Five usability attributes by Nielsen [31]
• How easy is it for users to accomplish tasks? (Learnability) • How quick can users perform tasks? (Efficiency) • How easy is it for users to reestablish proficiency? (Memorability) • How many errors do users make and how severe are they? (Errors) • How pleasant is it to use? (Satisfaction)

Table 5. Five usability attributes

3.2 Smart home as an infrastructure

My case is about an error situation in a smart home. The field site, Hill Care+, is not a single smart home, but an apartment building composed of 91 smart apartments. Compared to singular smart homes, Hill Care+ entails a broader scale of smart home technologies, actors and stakeholders. Smart homes like Hill Care+ are not merely a network of heterogeneous smart devices, but an assembly of people, services and technology. In smart homes humans and non-humans are intertwined, including intangible entities such as policies, technological push, gender division of labor and governance regimes (new public management like the Care+ concept) [15]. Such socio-technical aspects of smart homes enable them to be referred to as a relatively small-scale infrastructure.

Infrastructure is an extensive term which describes any underlying system or structure in the background that supports other organizations or society [14]. Karasti et al. [22] explain the notion of infrastructure, on the conceptualization developed by Star and Ruhleder [41], as a multifaceted concept referring to interrelated technical, social and organizational arrangements involving hardware and software technologies, standards, procedures, practices and policies together with digital configurations in support of human communication and capabilities. However, I will focus primarily on the technical aspects of infrastructure in Hill Care+ in this study.

Technical infrastructure is twofold in my case; digital and physical. The digital infrastructure is one or more system-level software layers, such as operating systems, toolkits, frameworks, services, protocols and standards [13, 14], which provide new technical capabilities for other software. The physical infrastructure includes all hardware technologies, such as technical installations and services, including cables, pipes and electricity, in the building connected to the digital infrastructure.

Star and Ruhleder present several characteristics of infrastructure describing its social and technical properties. The most relevant features that outline the technical infrastructure of Hill Care+ are as follows:

- Embeddedness

  The infrastructure is *embedded* in other structures and technologies. Users do not see the infrastructure itself, aside from physical devices, when it is fully functional.

- Transparency

Infrastructure is *transparent* during normal use, invisibly supporting other types of work which runs or operates upon it.

- Becomes visible upon breakdown

This invisible infrastructure becomes *visible upon breakdown*. When the technology malfunctions, the users must make sense of and interact directly with the technologies to correct them. In this troubleshooting process, when the users configure and change the behavior of technologies, the infrastructure becomes visible.

- Is fixed in modular increments, not all at once or globally

When the infrastructure breaks, it is *fixed in modular increments, not all at once or globally*. As infrastructure is large, layered and complex, the repair of infrastructure takes time and involves various systems inside the infrastructure. It might require adjustment and negotiation with people involved in different layers of the infrastructure.

An understanding of the characteristics of smart home infrastructure could support analysis of the heating malfunction case, which will require examining of the infrastructure of Hill Care+. In this study, however, the domains of organization and society in the infrastructure will not be discussed much, with the primary focus being on the domain of technology and its use. However, social aspects and their complexity in the infrastructure of Hill Care+ in the heating case were naturally revealed during the study of the heating malfunction case. I will return to this by presenting the case from the perspectives of actors and stakeholders in Chapter 6.

3.2.1 Facets of the infrastructure problem

In order to detect the causes which diminished users' control over smart home technologies in the heating malfunction case, I will employ the three general ways the infrastructure influences the shaping of user experiences suggested by Edwards et al. [14].

Firstly, *constrained possibilities* indicate that certain user experiences become completely excluded or limited because of the design choices made by the infrastructure. Allowed experiences are dependent on the technical capabilities that the infrastructure provides.

Secondly, *interjected abstractions* refer to the conceptualized technical capabilities exposed to the users. The users can construct a conceptual model by interacting with those interjected abstractions in the applications in the infrastructure.

Lastly, *unmediated interactions* happen when there is no mediating application between the users and the infrastructure. This can occur when the infrastructure malfunctions and is revealed to the users, urging them to directly interact with the infrastructure.

In addition to the three general infrastructure challenges that Edwards et al. present, Leitner et al. [26] point out another challenge which the infrastructure of the smart home could cause.

Smart homes consist of numerous components and multiple devices. Although each single device provides positive user experiences, the composite of heterogeneous components could cause an unknown effect. Leitner et al. maintain that different aspects of interaction that each device provides would influence the entire interaction, combined with the human factors, causing *interaction effect*. The interaction effect will be helpful for understanding how various implemented smart technologies influence each other, especially in the analysis of the heating case on the infrastructure level.

3.3 Framework

In order to analyze the heating malfunction case in this study, a framework which addresses the domains of both HCI and infrastructure is necessary. The user control which shapes the user experience and, conversely, a part of the user experience, should be considered in the use context, the smart home infrastructure. In order to conduct a holistic research which combines those two different domains, the framework of Edwards et al. [14] will be employed in the analysis and the discussion of the case. Their framework addresses infrastructure problems in HCI, focusing on the dependency of HCI on the infrastructure and the tension between them.

3.3.1 Development of the framework

The framework of Edward et al. [14] is built upon the previous work by Brand [5] and Rodden and Benford [36]. In the framework by Brand there are six layers which comprise a building; listed from outside to inside, *Site, Skin, Structure, Services, Space Plan and Stuff*.

Site is the geographical location and it lasts longer than buildings. *Structure* refers to the building itself, the foundation and load-bearing elements of the building. *Skin* is the exterior surfaces of the buildings. What makes the building work are the *Services,* such as communications, wiring and plumbing, which are embedded in the Structure. The interior layout, where walls, ceilings floors and doors go, is affected by the *Space Plan*. All the artifacts that occupy the space, for instance furniture, appliances and decorations, are referred to as *Stuff*. All the layers have different rates of change which might thus risk the building to be torn apart as it evolves.

The layers suggested by Brand provide Rodden and Benford with a basis for the analysis of domestic environments, regarding the development of interactive digital devices for domestic use. In their analysis, they maintain that it is important to expand the scope of the research so as to study the real context where the interactive domestic devices are to be placed. Chetty et al. [7] assert that Rodden and Benford have made home infrastructure and interactions between the technical and physical visible by outlining diverse stakeholders involved and activities related to each layer.

3.3.2 The layers of engagement in infrastructure

Similar to the work by Rodden and Benford [36], Edwards et al. [14] also adopt a layered analysis built upon the work by Brand, in order to address the infrastructure problems in HCI. Edwards et al. present four new layers of infrastructure and outline on each layer the process managed and the activities required for addressing the identified infrastructure challenges, in order to contribute to design for positive user experiences. The four layers are as follows:

Surface approach has its focus on superficial layers which users interact with and face the most. It attempts to protect users from challenges caused by infrastructure.

Interface approach is concerned with the applications which support the infrastructure. It aims to improve the mapping between conceptual models of users and system functions.

Intermediate approach attempts to provide new flexible infrastructure technologies, to deliver an improved user experience by designing a novel type of applications. This is a more proactive approach compared to *surface* and *interface* layer, as it seeks to make changes closer to the infrastructure. However, their capabilities are restricted by even more fundamental infrastructure layers.

Deep approach endeavors to affect the infrastructure itself, which requires the engagement of systems specialists who design infrastructure. It is a more fundamental approach compared to others presented above, as it can contribute to overcoming infrastructure problems in HCI. Boundary objects, which will be presented in the following section, are proposed as a concept to employ for cooperation between multidisciplinary groups on the deep level

Figure 3 illustrates how the four approaches by Edwards et al. are related to the shearing layers by Brand. The four layers (left in figure 3) do not exactly overlap with Brand's layers (right in figure 3), as the four approaches are oriented towards the digital infrastructure. The relation, for instance between the *intermediate* and *deep* layer and outer layers, *skin, structure and site*, is not clear. However, the illustration might help to visualize connections between two sets of layers.

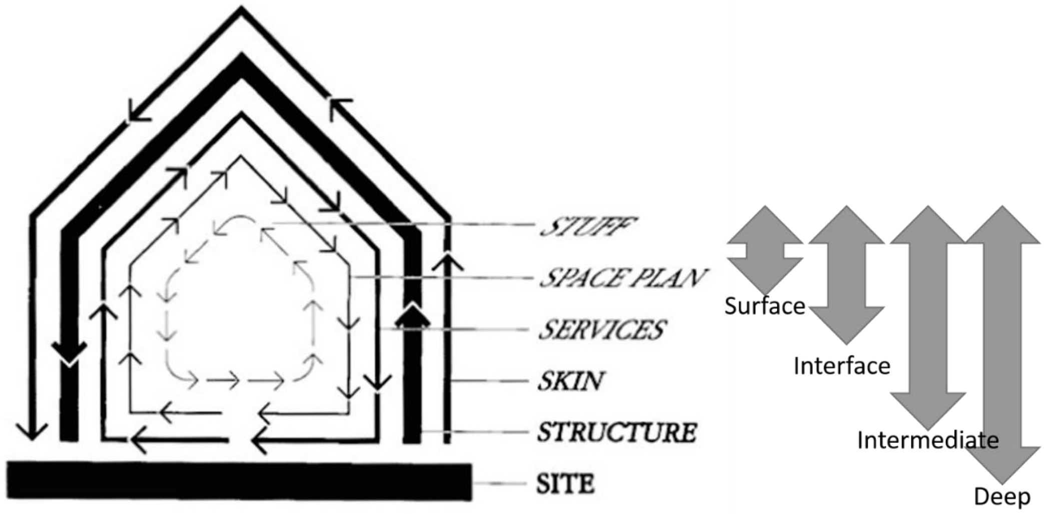

Figure 3. The mapping between the layers by Brand [5] and the approaches by Edwards et al. [14]

Boundary object

Boundary objects are objects flexibly interpreted to adapt to the local needs but robust enough to maintain the identity which would commonly be understood by various communities. The term *Boundary objects* was coined by Star [4] and is the concept suggested as one of the concrete solutions when addressing the infrastructure problem on the *deep* layer in the framework. The boundary object is useful at the organizational level, such as the deep layer, where the experts from multidisciplinary groups need to cooperate. Boundary objects allow different groups to work together without consensus because they can be used to balance and manage different categories and meanings when there are divergent viewpoints. In other words, it is important to create and manage boundary objects in order to build coherence among diverse communities of practice. They are the basis for conversation and action and become a communicative device across intersecting communities.

4 Research methods

4.1 Case study

This research was conducted as a case study which examined a single case in depth, aimed at understanding an error situation in the smart home and the resulting diminished user power to control the smart home technologies, as well as proposing steps to enhance the user control. The pre-study was started in January 2015 with research on general smart home technologies, and the field work was undertaken for seven months, from September 2015 to March 2016. A three-year-old building constructed with integrated smart home technology, Hill Care+, was chosen as a field site. It is a residential care home for the elderly, built in compliance with the Care+ concept[11]. There are 91 apartments and all of them are equipped with a set of various smart home technologies.

4.1.1 The goal of the case study

This study was conducted with the hope of providing readers with applicability [27] so that they gain vicarious experience from the case study and upon these experiences re-examine and reconstruct the phenomena of their interest. A rigorous qualitative case study is useful to understand and describe a phenomenon by examining individuals and organizations through their interventions, relationships, communities or programs [44] so that they can deconstruct and reconstruct various phenomena [2].

4.1.2 The type of case study

Not all the houses equipped with smart home technologies are as complicated as Hill Care+, which entails numerous actors and stakeholders, and a highly advanced control system. However, an in-depth study of this particular and unique case of heating malfunction in Hill Care+ could hopefully contribute to acquiring a sound understanding of the relationship between user control and the infrastructure of smart homes, which could then be reflected in the design of future smart homes.

[11] Care+ is a concept made by one major municipality in Norway. The elderly over 67 years old can apply for renting an apartment of Care+ building where the service personnel is available 24 hours a day and seven days a week.

The type of case study on the heating malfunctions in Hill Care+ is both intrinsic and instrumental identified by Stake [39]. Stake explains that in the intrinsic case study, researchers have a genuine interest in the case itself. An intrinsic case study is conducted not because the case represents other cases, but because it has its particular traits and problems. Thus, the purpose of the intrinsic study is neither to understand a generic phenomenon nor to build a theory. Instrumental case study, however, aims at achieving more than merely understanding a particular case. The case itself thus becomes of secondary interest and plays a supportive role to help researchers accomplish another goal out of external interest [2].

I find the heating malfunction case of Hill Care+ interesting because of its particular problems, revealed during the process of troubleshooting. Although this heating case does not represent other cases because of its own context, an in-depth study of this case can facilitate the understanding of diminished user control over smart home technologies, and help to provide design implications for more positive user experiences, enhancing the user control over smart home technologies.

In this study, a single case was chosen. What made the case unique compared to others was a complex troubleshooting process, in which it took more than two years to identify the causes of errors. During the error detection process numerous problems were detected and each problem involved different actors and stakeholders. Although the case is singular, its complexity was observed on a broad scale in the infrastructure of Hill Care+, which placed the case in a unique and rather extreme situation and thus required a holistic single case study [44].

4.2 The context of study

Even though the case chosen in this study is singular, it is highly complex because the study cannot ignore the contexts embedded and situated in the case. Stake [40] emphasizes that the examination of these complexities is necessary to make the relationships intertwined among them more understandable. The contexts of interest in this study are social, ethical and economical.

The Care+ concept is an important residential format both for the municipality and the elderly citizens in the social context. The elderly population is increasing and so are the demands for care services and nursing and care homes. However, the budget to provide all the required services and to hire personnel is limited. It is, therefore, crucial to take advantage of technology to help the elderly be independent in their residences or a residential care home such as the Care+ buildings.

The residents in Care+ are elderly people over 67 years old, as well as citizens with special needs under the age of 67 in the municipality who also qualify for renting a Care+ apartment. The age of the residents in Hill Care+ indicates that their health condition could easily be affected by the indoor climate. The heating case is thus sensitive because cold indoor temperatures could negatively influence especially the residents who have a more vulnerable health condition. Considering the age of the user group, the actors and stakeholders of Hill Care+ should take it seriously.

The municipality offers a set of standardized requirement specifications to be fulfilled in construction of Care+ buildings, but the contractors can specify them in detail. In this specifying process the financial aspect plays a significant role. It is the municipality which makes the concept and administrates carrying it out, but the investment to construct the building is made from the Norwegian State Housing Bank[12]. The budget should be enough to fulfill all the requirements of Care+, which entails both the construction of building and the procurement of all the technological installments. The budget is usually not large enough to procure the most advanced or the best technology available in the market. Even if the budget allows the purchase of state-of-art smart home technology in the market this does not automatically guarantee the user satisfaction. In this sense, it is not easy to make a decision on how big investment to make on smart home technology and foresee the long-term gains.

4.3 Data collection

4.3.1 Interview

Hill Care+ is managed by the caretakers, who are always available and assist the residents in the building. A non-profit organization owns and operates Hill Care+, but the building was built by a construction company engaged by the non-profit organization. Hill Care+ is constructed upon the Care+ concept, made by a Norwegian municipality. I will provide a more detailed description of the actors and stakeholders involved in the case of Hill Care+ in

[12] “Husbanken” in Norwegian

Chapter 5. The data was primarily collected from interviews with actors and stakeholders of Hill Care+ who are closely involved with the heating malfunction case, and with some experts on smart home technology. The interviewees were the director and a caretaker of Hill Care+, a technology manager and a technology consultant in the operations team of the non-profit organization which owns and rents out the building to the municipality, a manager in the service department and a technology integrator from the construction company which built Hill Care+, and an advisory consultant in the municipality who works with Care+ projects. In order to enhance my understanding of current smart home technology and its use in the market, I interviewed a designer in a company which specializes in smart home appliances and a building automation technology expert in a consulting company. Nine interviews were conducted in this study, and the interviews took place at the workplaces of the interviewees, or on Skype if they were working in a distant city. The interviews lasted for at least one hour or maximum one and a half hour.

Additional data was collected by email communication after the interviews. Before the interviews started, the interviewees were informed of the study and signed the consent form. Some interviewees requested a list of questions in advance, but otherwise, the interviews were semi-constructed. All the interviews were audio recorded and transcribed. The analysis of the interviews was conducted mainly from transcripts of the interviews.

Even though the interviews were aimed at obtaining factual data on the error detection and troubleshooting process, the data from the interviews were combined with the interpretations of interviewees regarding the actions and events which took place and the views of themselves and other stakeholders [43]. This sometimes resulted in different perspectives and interpretations on the same event. It was also challenging to reconstruct the event because of incomplete information arising from a lack of memory since not all the steps taken were documented and three years had already passed by the time the research was conducted.

In addition to the formal interviews, informal conversations were held with the residents of Hill Care+. The conversations have been organized in the lobby of Hill Care+ in a casual setting or under a social event. The issue of the conversations was the use of smart home technology in the apartment and the conversations were not audio-recorded but the keywords and the part of the conversation were noted afterward.

4.3.2 Direct observation

After the interviews, subsequent observations were conducted and they were helpful to understand the work practices. The observation was usually combined with the interviews and not planned beforehand. The interviewees of the operation team demonstrated their work practice using the Building Automation System (BAS) after the interview. During the demonstration they gave additional explanations of the systems and shared their experiences with using them. The observed systems confirmed what the interviewees described, for instance how dissimilar interfaces the underlying applications of the BAS had, which was one of the biggest challenges the interviewees mentioned. During the interview with the caretaker of Hill Care+ she received several alarm messages, so I could come up to the apartments where the alarm went off together with the caretaker and observed how she managed the situation and how the residents reacted to the alarm. After the interview she also demonstrated how the caretakers utilize the BAS, and she explained how they use it to manage the alarms and to check the status of apartments. After a short and informal interview with one resident of Hill Care+, she showed me her apartment. I did not observe how she used the thermostat but she made some comments when I asked if she had used the thermostat "It is not my thing, it is Christine's (the name of one of the caretakers[my note])"

4.3.3 Documentation and archival records

Documentation and archival records are useful to understand past and current practices and use of existing software tools [25]. From the archival records of a software tool used for administration of maintenance tasks of Hill care+, I attempted to find any patterns among frequently requested maintenance tasks registered. The information book and the orientation checklist for new residents gave insight into the prioritized information to be provided to the new residents. The documentation that specified functional requirements that Hill Care+ should fulfill during construction were examined in order to understand what requirements were regarded as minimum and how detailed they were described. The user manual for the thermostat contributed to provide a more exact understanding of available functions that the implemented thermostat offers.

4.3.4 Challenges

It was highly challenging to gather the data because the collected data should be complete and precise in order to reconstruct the story of the heating malfunction case in this study. As there were numerous actors and stakeholders involved and all of them had different responsibilities regarding the detected malfunctions, an interview with one single actor could not provide a whole story of the heating case. When there were questions unanswered by the interviewee because they were not their domain or responsibility, I asked him or her to point to the relevant person. In this way the interviews were sequentially planned to collect all the pieces of information to reconstruct the entire troubleshooting process. However, not all the information was available. Since this was still an ongoing case at the time of my study, and a rather large repair was in the process of carried out, some actors were careful about sharing some sensitive information, for instance the scale of the malfunction which would be used in estimating the size of expenses to be paid. After seven interviews with the actors and the stakeholders I attempted to place the gathered information in chronological order to make a timeline with the dates of each significant event, and my timeline was confirmed in e-mail communication with the interviewees. The timeline will be presented in Chapter 6.

4.4 Analysis and interpretation

4.4.1 Subjectivity

The question of subjectivity and bias is what researchers should be aware of during the whole process of the study. It is applied not only to case studies and other qualitative methods, but also to quantitative research methods. However, as mentioned above, the goal of this study is to explore the current situation and gain knowledge of it. Flyvbjerg [16] contends that the proximity to reality and the learning process constitute the most advanced form of understanding. That is, when researchers place themselves within the context of being studied they can learn more about the case, closer to the reality and the viewpoints and behavior of the actors and stakeholders.

The primary data source for my case study is the interviews with the actors and stakeholders directly or closely related to the case. The raw data from the interviews is subjective, as all the interviewees gave an account of the processes and actions from their perspective combined with their feelings and interpretations of the situation. Thus, the stories told in the interviews were their versions of the events reconstructed, understood and acted out [9] from their viewpoint. This subjectivity, however, became a resource for a deeper understanding and a means to figure out what has really happened, reflecting the contexts where the interviewees were placed.

In order to avoid mere subjectivity this study adopted the principles that Crang and Cook [9] proposed to achieve rigorous subjectivity.

Firstly, the study was theoretically sampled by accessing people directly involved with the case so that they could offer quality information on the case. Secondly, the study was semi-saturated. The three interviews with the operation team of the non-profit organization[13] were undertaken with two people simultaneously so that the various discourses of the event could be picked up, modified and shared through the conversation between the two interviewees. It was helpful that two people were present at the interview, as they could recall the memory together and give a shared account of the event, which could be regarded as semi-saturation for the elaboration of the event. Lastly, I attempted to make the study theoretically adequate by finding the relevance of my study to other similar works. However, I could not find any similar case of malfunctions in smart homes on a large-scale, focusing on subsequent reduced user control over the smart home technologies, so it was challenging to explore any possible tensions or commonalities between different perspectives on the diminished user control over smart home technologies when they malfunction.

4.4.2 Triangulation

Messick [28] maintained that the author is responsible for the validity of the readers' interpretations. The credibility of the case study is acquired by triangulation of the descriptions and interpretations throughout the study [40]. Triangulation can be achieved when multiple perceptions are used in the interpretation of meaning. It is crucial to identify various ways to see the case as it would help acquire a diversity of perceptions. The use of multiple sources can provide corroborating evidence which can clarify and verify the interpretation of data [25]. Multiple data sources can thus help to overcome the concerns of quality raised by the use of the single source.

[13] The non-profit organization owns and operates Hill Care+. They are renting the whole building to the municipality and the municipality is again renting out the apartments to the elderly citizens. I will return to this in Chapter 5.

In this study, I started data collection with interviews with the actors and stakeholders. They have provided useful but limited data because of different domains of responsibilities regarding the case. On the same events, they had different perspectives and understandings, which resulted in various interpretations. Even though their perceptions were initially based on the same fact, they sometimes had different views because of the social and economic contexts they as actors and stakeholders were situated in. This enabled a partial triangulation because the interviewees sometimes provided the same or different views on the same event. However, they tried to remain as neutral as possible as it was still an ongoing case. It was not easy for them to remember all the steps they have done, thus it was necessary to find documentation which logged all the processes during troubleshooting and verify the data from the interviews. However, most of the communication during the troubleshooting took place verbally when they were on the site or by emails. It was thus challenging to find any documentation which provided an overview of the whole process.

However, the investigation of the artifacts and the demonstration of the systems used in the field site – the interface of the building management system, thermostats, radiators and room temperature – helped to verify the described malfunction and confirmed the statements made in interviews, which increased the validity of data acquired from the interviews. A combination of interviews along with direct observation of the field site enhanced the understanding of the heating malfunction case.

4.4.3 Methods of analysis and interpretation

It is vital to establish credibility of the data presented in this study. The presented data is the proximity of reality and the analyzed data is my interpretation of participants' interpretation. Thus, it is crucial to provide in detail the process of analysis through the issues and how to come to the conclusion.

The data was partially analyzed already during the data collection. After every interview the data was sorted and categorized in order to collect the missing information for reconstructing the whole story of the heating case, and compare the accounts from various actors and stakeholders, whether there was any part of the story which was not clearly elaborated. This formal stage of analysis aimed at reconfiguration of data in the early process to facilitate later data analysis [25].

General strategy

Yin [44] proposes two general strategies for analyzing the data to help the investigator to conduct a successful analysis of the data in the study. He maintains that the best preparation for conducting a case study analysis is to have a general analytic strategy. As this study did not have strong theoretical propositions regarding the issue, the general strategy chosen for this study was to develop a basic descriptive framework of the case and begin with that. It is an alternative strategy when theoretical propositions are absent. The analysis of the data in this study started with a detailed description of the case. The framework used in the description consists of providing a detailed explanation of each actor and stakeholder involved in the case in each section, regarding who they are, what they have done concerning the case, what challenges they had, and what they needed to improve the case situation. It aimed at describing the complexity of the case by providing various perspectives and actions taken by each actor and stakeholder to handle the heating issue. This descriptive approach helped to identify the causal links between the source of user experience challenges and the consequences which is the case itself, the malfunctions and the long and complicated error detection and troubleshooting process.

Open coding techniques

Even though this study does not have the purpose of generating theory, I employed open coding techniques by Strauss and Corbin [42] , used to conduct grounded theory research. Open coding techniques allow a close examination of data by conceptualizing and categorizing phenomena reflected in them, and the techniques are clear and executable for analyzing a large amount of text-based data [25]. The data collected during the field work was primarily from the interviews, so I had an extensive amount of text-based data, in the form of transcripts of the interviews. Thus it was necessary to utilize a set of techniques which enables a systematic but thorough examination of data in order to build a sound basis for further analysis and discussion of the heating malfunction case.

Firstly, I began by analyzing the interview transcriptions line-by-line. The text was analyzed in order to find and identify the patterns, opinions, behaviors, or other issues interesting and meaningful in relation to the heating case. The similar events, actions and parts of events were highlighted and different colors were used to indicate various phenomena. The marked parts varied from a single word to a whole sentence. From the marked data, interesting instances were given a name in order to label and describe the phenomenon reflected in the data.

Secondly, the conceptual labels generated in the previous step were grouped so that they entail similar contents and thus develop a category. All the concepts were written on a separate sheet of paper to obtain a good overview of the invented concepts, avoid making overlapping ones, and thus reduce the number of units of concepts.

Lastly, I wrote down all the similar concepts in one column and named them to represent the phenomenon the concepts commonly indicate. After the category was given a name, its properties were explored to develop a deeper understanding of each category.

Through the open coding process, I could disassemble various accounts of the interviewees and integrate them again into one holistic resource which built a foundation for further analysis and discussion of the heating case.

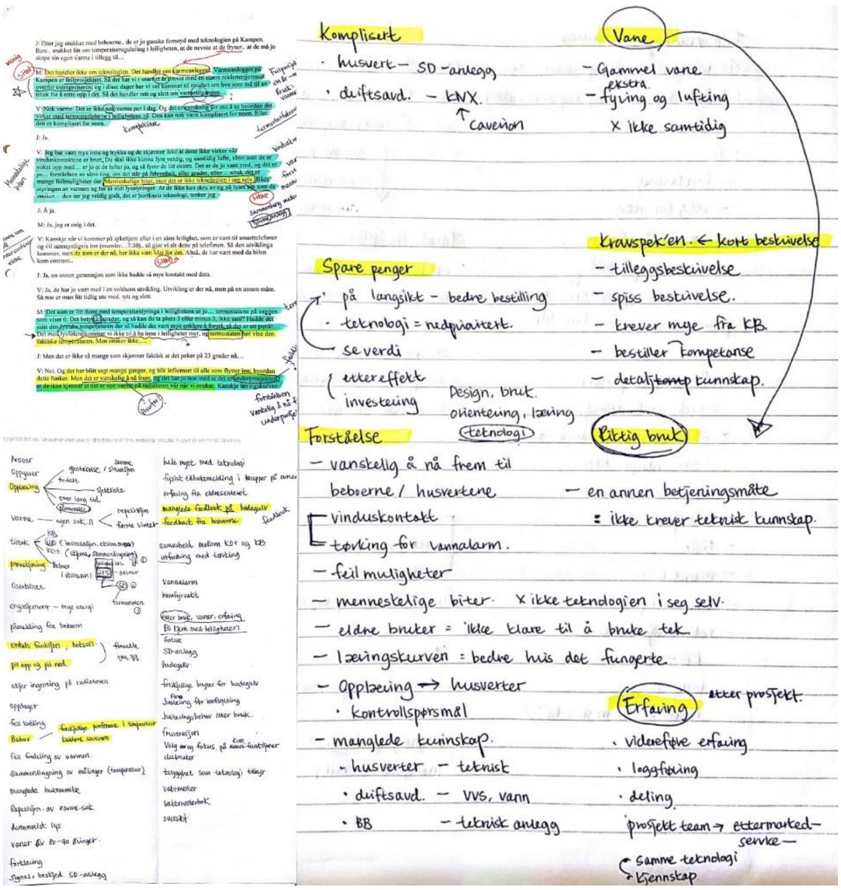

Figure 4. The coding process.

Labeling (left top), Grouping (left down), Categorizing(right)

4.5 Ethics

The case focused on the malfunction of the heating infrastructure in Hill Care+. This indicated that the exposure of full description of the actors and stakeholders could risk their social or professional status and make them feel embarrassed. It was thus agreed with the interviewees that real names would not be used in the study. Accordingly, all the names of the actors and stakeholders in this study were changed for anonymity. Before the interviews started the interviewees were informed about the study and signed the consent form. In the consent form it was also specified that all the data will be deleted completely after the study was finished. Furthermore, the participants have received drafts of the write-up to have a voice on how they were presented and confirm that the description of the case was written correctly. The interviewed advisory consultant in the municipality replied with several comments on the description of smart home technologies in Hill Care+ and the responsibility of the municipality. Her comments were applied to more precisely specify the technologies equipped and clarify the relationships between stakeholders in Hill Care+.

5 Field description

This chapter will provide detailed descriptions of the actors and stakeholders involved in the heating malfunction case in Hill care+ necessary to understand the full context of the case, which will be presented in the next chapter. The descriptions in this chapter are based on the empirical work conducted for seven months from September 2015 to March 2016.

5.1 Actors and stakeholders

There are numerous actors and stakeholders involved in the construction and management of smart homes, and they all have different goals and interests. Stakeholders are architects, housing corporations, project developers, electricians, builders, caretakers, service suppliers, product suppliers, consulting agencies, insurance companies, building managers, building technicians and residents [3].

This section, however, will present only the key actors and stakeholders who are directly related to and affected by the heating malfunction case.

The following sections will describe the profiles, responsibilities and roles of the most relevant actors and stakeholders (Figure 5) in the case from Hill Care+. The order in which they are presented is not related to their importance, but to their chronological sequence of engagement. Thus, the reason the municipality comes first is because they initiated the Care+ concept. The non-profit organization comes after because it was they who signed the contract to construct Hill Care+ and rented out the whole building, including the apartments, to the municipality. The municipality then rents out the apartments to senior citizens over 67 years old living in the municipality. Senior citizens who have special needs because of documented physical or psychological conditions can also apply for renting a Care+ apartment, even if they are not over 67 years old.

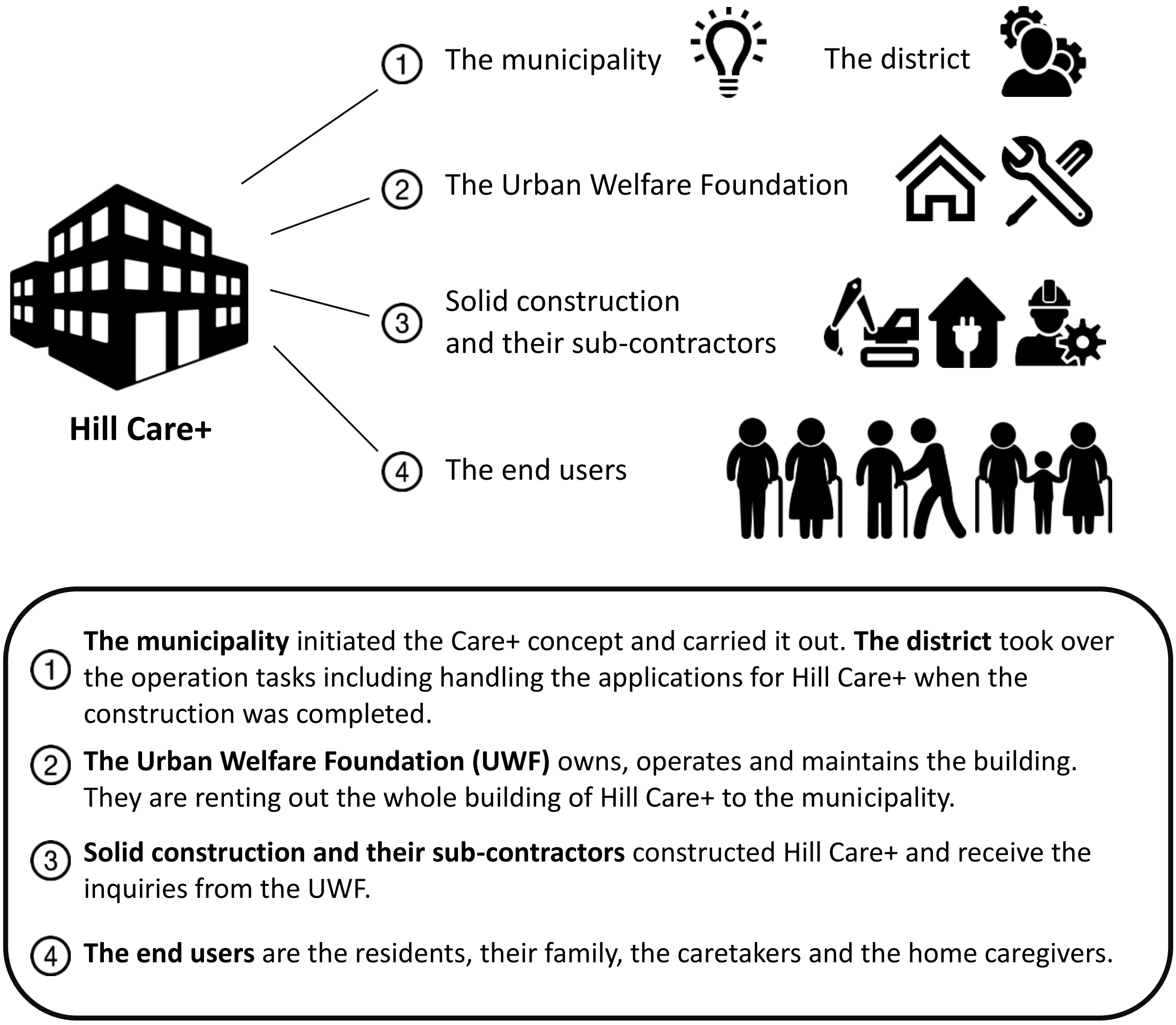

Figure 5. Actors and stakeholders[14]

5.1.1 Municipality[15]

After the council of the municipality, decided how many Care+ building would be built in the municipality the process of Care+ was initiated by both the municipality and the districts[16] inside the municipality. The municipality has created the Care+ concept, the requirement specification and the request for tender, announced the competition, called for bids, evaluated and accepted them. The owners of the land or the old buildings which requires renovation,

[14] Icon made by Freepik and Vectors Market from www.flaticon.com
[15] "Kommune" in Norwegian
[16] "Bydel" in Norwegian

such as non-profit organizations or municipal enterprises[17], can construct Care+ buildings in cooperation with either the municipality or the district inside the municipality.

When a contract is signed with the non-profit organizations, the municipality follows the whole construction process along with the district where the Care+ building will be located. The district plays a more active role when the contract partner is a municipal enterprise. The municipality has the responsibility for the procurement when the owner of the land is a non-profit organization. If there is already a building on the land, there will be an evaluation as to whether the building will be renovated or a new building will be constructed. When construction work is required, the non-profit organization takes responsibility for the construction process. Once construction is complete and the municipality officially takes over the building, the district is in charge of operational tasks. Their tasks are, for instance, receiving applications and assigning the apartments to the applicants in the municipality, and arranging the social services for the residents of Care+.

In 2008, the municipality signed a contract with several non-profit organizations and one private actor for construction and management of Care+ buildings. One of them, the Urban Welfare Foundation (UWF)[18], who owned the land and the old nursing home[19], signed a contract to partially demolish the old nursing home building, renovate it and additionally construct a new building to be connected to the old building. They would rent out the whole building to the municipality for 20+10+10[20] years in addition to operation and maintenance of the building for 4+4 years. The regulations limit the maximum contract period of the rent and the service to 40 and 8 years respectively.

5.1.2 The Urban Welfare Foundation

The owner of Hill Care+ is the Urban Welfare Foundation (UWF), a non-profit organization, and they currently operate Hill Care+. The UWF cooperates broadly with the public health and social sector, and Care+ projects are one of their work domains.

The UWF had designated a design and build contractor[21] to construct Hill Care+ before they signed a contract with the municipality. The design and build contractor, Solid construction[22],

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17 "Kommunale foretak" in Norwegian
18 The name has been changed for anonymity.
19 "Sykehjem" in Norwegian
20 "+10" indicates that it is optional.
21 "Totalentreprise" in Norwegian

who would construct Hill Care+, in turn engaged sub-contractors for technical installations. The UWF has concretized the specifications of Care+ apartments made by the municipality, with assistance from consultants. These are the minimum functional requirements to be fulfilled, thus the UWF should concretize them with more details to ensure the quality.

The operation team[23] utilizes a Building Automation System (BAS) to operate and manage the building of Hill Care+. The BAS is their primary tool for providing an overview of the status of the building, not only on the apartment level but also on the infrastructure level. It presents operational status of the heating, ventilation and water supply etc. on the infrastructure level, and the temperature of each room and the status of various alarms on the apartment level.

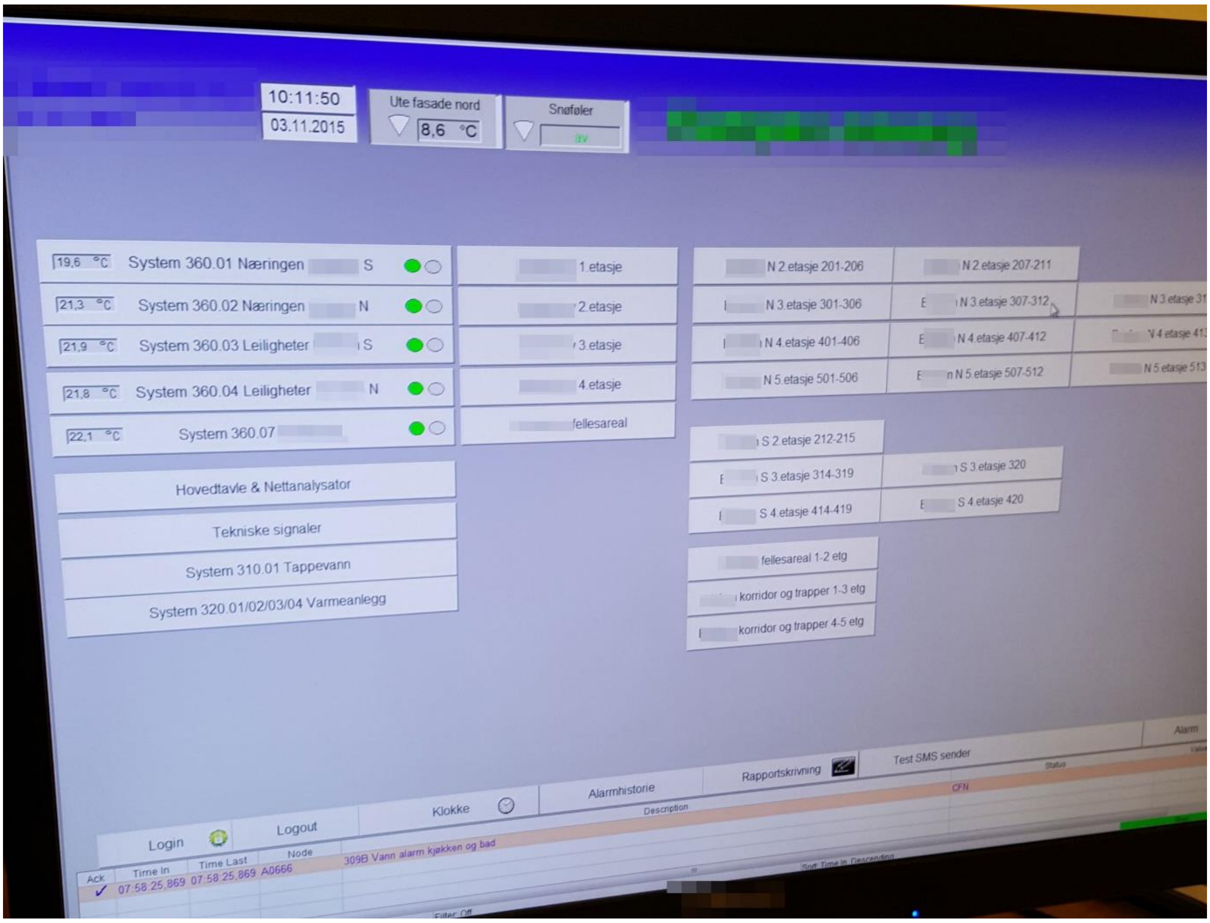

Figure 6. The graphic user interface of the Building Automation System in Hill Care+

The operation team and the caretakers in Hill Care+ use an additional program which administrates the maintenance tasks. Once the caretakers register an inquiry, the operation team reads it and turns it into a task to perform. The inquiry is handled when the operation

[22] The name has been changed for anonymity.
[23] "Driftsavdeling" in Norwegian

team comes to Hill Care+, and it is archived when it is fixed. Apart from the inquiries registered by the caretakers, the operation team logs preventive maintenance and corrective tasks. There is a total of 2,127 log entries, including all types of tasks, stored since the operation team started to use this program in January 2013[24].

5.1.3 Solid construction

A large construction company, Solid construction, was awarded the contract to construct Hill Care+ from the client, the UWF. They are a single contractor with the UWF, which means that Solid construction is a single entity whom the UWF contacts directly regarding concerns about the building of Hill Care+. Apart from the contract with the UWF they independently engage sub-contractors to deliver technical installations to the building.

Solid construction must ensure that the buildings and all the technical installations fulfill all the requirements specified by the municipality and the UWF. Their goal is to deliver a complete building which performs what the client required and described. Solid construction is experienced in construction, but the interviewed technology integrator[25] mentioned that they find implementation of technical installations in buildings challenging since it is not their most competent domain. Building automation is becoming more common and the demands of the clients on technology to be installed in new buildings are increasing. Since Solid construction purchases around 70% of the services, this requires close cooperation between Solid construction and the engineers from the sub-contractors. It is crucial for them to ensure that all the required functions are included in the production in the early phase by maintaining a close dialog with the sub-contractors.

The service department of Solid construction receives inquiries to correct defects in the buildings from the client. Normally, the guarantee period is five years, and it is contractual. To retain objectivity through the entire claim process, they encourage the clients to make the communication official by keeping a record of the whole process. The clients are encouraged to send a form filled out with information regarding the defects in the building. Once a claim case is opened, the service department starts to log what the claim case concerns, what actions have been taken and the status in an Excel sheet. In the future, they plan to utilize a new software to streamline this logging process between themselves and the client. When the

[24] Hill Care+ opened in September 2012
[25] He works with ensuring diverse technological installments in the building are connected and coordinated.

claim is made by the client, the service department examines the content of the claim themselves, as there is usually not sufficient information about the claim provided by the client, before they forward it to the sub-contractor.

5.1.4 Sub-contractor

There are numerous sub-contractors who delivered technical installations to Solid construction. They were engaged by Solid construction and signed a contract with them. This indicates that the sub-contractors and Solid construction who engaged them, are responsible for any defects or consequences of all the deliverables in Hill Care+ during the service guarantee period. The sub-contractors produced the components and installations of the Hill Care+ building according to the requirements from Solid construction. A sub-contractor could be a single company or a cluster which consists of several companies. A large technical installation usually has a complex structure made up of numerous components. Thus, the structure of the sub-contractors could be complicated, depending on the complexity of the installations to be delivered and the number of elements which require special expertise.

When there is a need for repair or a claim on the performance of the products, the UWF reports the issue to Solid construction. Solid construction then forwards the claims to the sub-contractors who delivered the parts in question. The process of reporting defects and repairs in Hill Care+ should strictly follow the contractual relationships between stakeholders. The UWF and sub-contractors who delivered technical parts in Hill Care+, for instance, have no contractual relationship, thus the operation team in the UWF must speak to Solid construction concerning any facility or technical issues in Hill Care+.

5.1.5 Caretakers

General roles and responsibilities

Hill Care+ is serviced by caretakers 24 hours a day, seven days a week. They are available either in the reception or their office near the reception. The common use of the word caretaker might lead to a misunderstanding, but the caretakers in Hill Care+ are merely managing the building, they do not provide healthcare services to the residents. However, they are the main point of contact for the residents in Hill Care+. The caretakers know the residents well, and the residents feel comfortable contacting them for various inquiries. The homecare service, practical assistance and the home nursing service is provided and arranged by the municipality and the district where Hill Care+ is located. It is sometimes not clear to what extent the caretakers should assist the residents, however, and it is also part of their responsibility to evaluate the capacity of the resident to carry out the inquiry on their own and advise or assist them partially or fully if required. Also, they coordinate all the assistance for the residents and the social events in the building.

The caretakers of Hill Care+ are required to have a certain level of technological competence, enough to handle the numerous alarms triggered by the sensors of the smart home technology installed. However, it does not mean that they should be experts in managing the smart home technology. Their main technological task is to turn off and reset the alarm warnings that appear on the interface of the BAS (Figure 7) after they have checked the corresponding apartment and handled the situation. There are many occasions of false alarms, thus, they give the residents instructions about how to avoid triggering a false alarm. They are frequently asked about the various sensors installed in the apartment or the tablet-PC that all the residents are provided with.

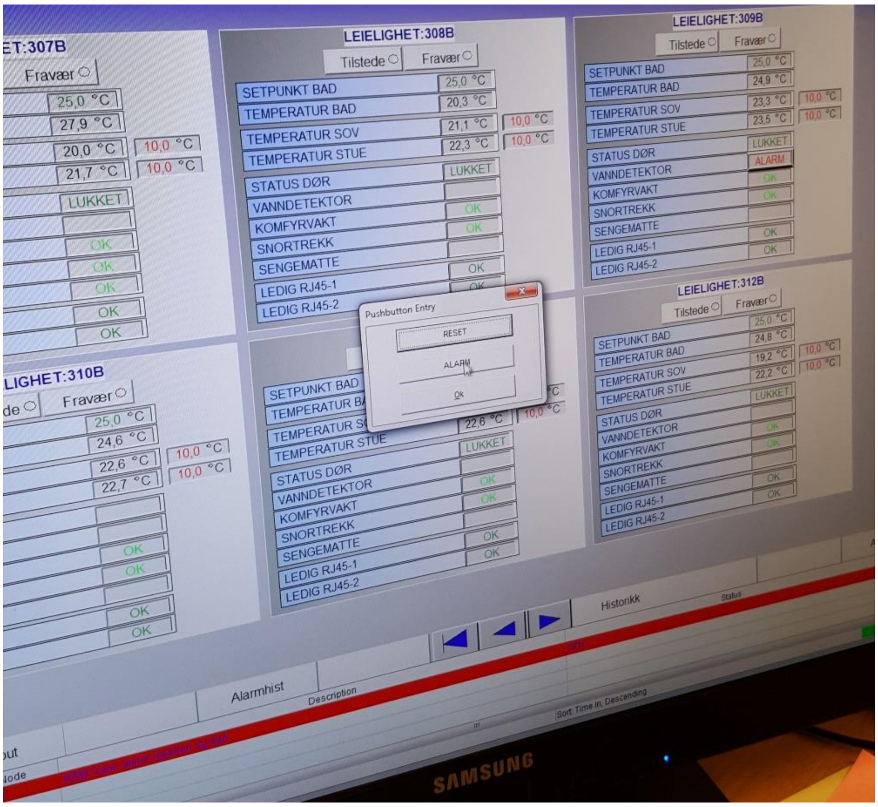

Figure 7. The flood guard alarm was set off and a warning appeared with a red strip in the system.

Orientation process

When a new resident moves into Hill Care+ the caretakers inform him or her about the apartment with simple instructions about the sensors, and provide them with a residence guidebook[26] which contains comprehensive information about Hill Care+, including simple explanations about each type of smart home technology in the apartment. They have a checklist of themes about which the new residents should be informed. The interviewed caretaker mentioned, however, that new residents struggle with retaining all the information delivered in the first meeting with the caretaker. This is because the sensors and alarms are located in different places in the apartment, and they all have different interfaces to relate to along with a set of prohibited behaviors to avoid false alarms. Some of the examples are flood and stove guard in the apartment. Too much water on the bathroom floor will cut the water supply and putting a hot frying pan on an unused cooktop will set the stove guard off. It is highly overwhelming for the elderly residents, who are not the most active technology users, to build a good overview of a variety of alarms and sensors at once.

Even though the new resident did not have many questions in the first meeting with the caretaker, not only newcomers but also the residents who have lived in Hill Care+ for one or two years, mistakenly trigger false alarms from time to time – for instance, the stove alarm or flood guard alarm in the bedroom. Contrary to the stove alarm which beeps very loudly, many residents do not notice that the flood guard alarm has been triggered until they need water, since it simply cuts the water supply. When the caretaker shows up at their front door and asks them what has happened it is not uncommon that the residents have no idea what is going on. After triggering the false stove alarm once or twice, the startled residents learn how to use the cooktop in an appropriate way, since it beeps very loudly. After trial and error, they learn and get a better understanding of the technology installed in the apartment, how they work and how they should be used. That is why the caretakers maintain that it is a long-term process of learning.

Report of malfunction

Whenever the residents come to the reception and ask for repairs or maintenance of their apartment, one of the caretakers first comes up to their apartment and checks whether the

[26] "Beboerperm" in Norwegian

caretaker can handle it by herself. If the situation cannot be handled by the caretakers, they write down the details of the request in a book where all the caretakers log maintenance inquiries. Then one of the caretakers, usually the same person, later registers all the log entries from the book to the maintenance program (Figure 8). This program administers the building maintenance and is used by both the caretakers and the operations team in the UWF. The operation team checks the maintenance inquiries registered in the program, turns them into work tasks, and go through them, in cooperation with the caretakers, when they come to Hill Care+.

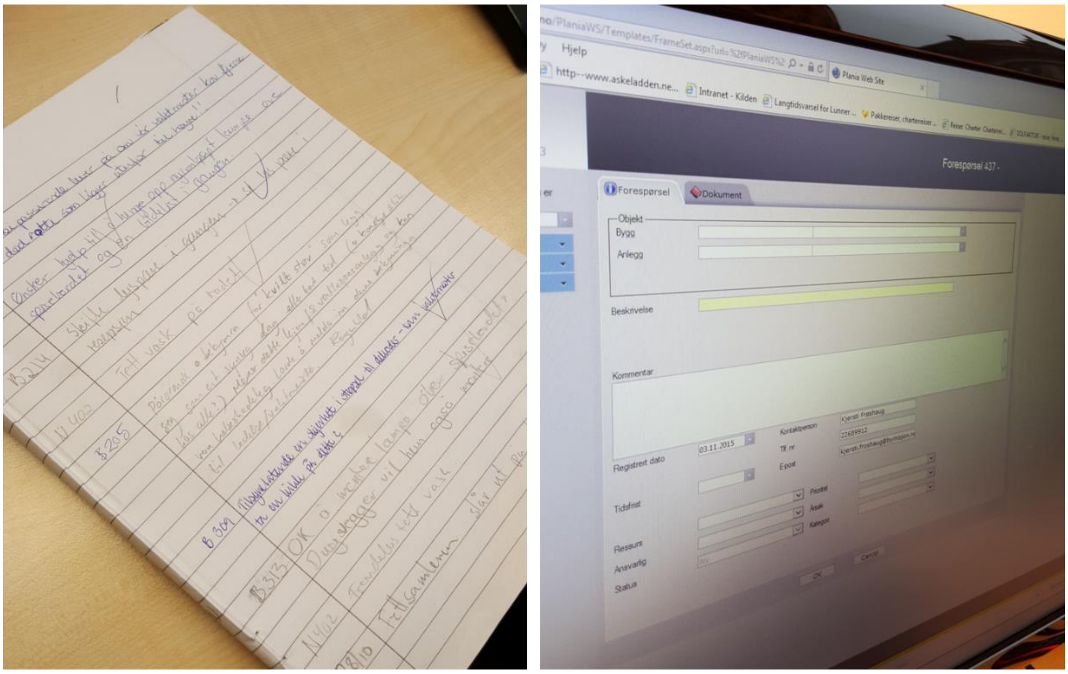

Figure 8. Registration of maintenance inquiries in the book (left) and in the administration program (right)

5.1.6 End users

Profiles of the residents

The minimum age to apply for a Care+ apartment is 67, with exceptions made for people under 67 with documented physical or psychological special needs. However, most of the residents in Hill Care+ are over 67 years old, and they have a need for adapted apartments because of their vulnerable health condition. Their needs are mostly caused by their reduced motor skills, but they can manage most of their daily life tasks by themselves and take advantage of social activities provided in the Care+ building.

Some residents are comfortable with using the tablet-PC[27] and being surrounded by sensors, but other residents are indifferent to any technological components in the apartment and the building. Thus, it is challenging to generalize the average technology competence of residents in Hill Care+.

The home caregivers[28] and the families of the residents are also end users of Hill Care+. It is required for them to be aware of the sensors and alarms in the apartment when they assist with the house chores, such as cleaning or cooking. When the families of residents stay overnight in Hill Care+, they are also told about the various sensors, for instance the automatic light switches. However, it is still the residents who utilize the smart home technology in the apartments the most.

The sensors and alarms implemented in the apartments in Hill Care+ are new features the residents in Hill Care+ have to relate to. They are informed about the smart home technology installed in the apartment from the caretakers when they move in, but it is not easy to absorb every detail within a short period of time. As long as all the components are used in a proper way and the alarms are not mistakenly activated they are almost unnoticeable. However, if they are utilized in an inappropriate way the consequence sometimes could be startling for the resident, such as the alarm which goes off with a very loud beeping sound, and if this happens frequently it becomes annoying for them. The alarm is one of the most crucial functions in the Care+ buildings in case an accident happens. However, if they cannot control the smart home technologies in the apartment, which leads to frequent false alarms, this could frustrate the residents and hinder them from feeling at home rather than in a care institution.

Use examples in everyday life

Some residents might think that it is convenient that the lights turn on and off automatically when they sense movement, while others might think that it is annoying that they cannot manipulate the lights on their own. The light sensor is so sensitive that if the resident makes a rather significant movement while sleeping, the light is turned on automatically and stays lit for a while. Because of that, some residents covered the light sensor with aluminum foil to get back control over the lights. The satisfaction with automatic light switches depends on

[27] A tablet-PC is provided to every resident in Hill Care+. It is a part of the welfare-technology implemented in Hill Care+.
[28] "Hjemmetjeneste" in Norwegian

personal preference along with their health condition, because if they are relying on a wheelchair or walker, it could be more convenient to have automatic light switches, as they will not have to go to the switches to turn them on.

The stove alarm, on the contrary, has a strict set of safety codes. If the residents violate any of them, the alarm goes off and beeps so loudly that it could scare them. If residents use a smaller pot than the size of the cooktop, the heat or the smoke from exposed part of the cooktop could cause the alarm go off. Even though it is very simple to stop the alarm by putting the magnet on it, if they do not know how to do that or where to find the magnet they just have to wait until the caretaker comes up and helps them turn it off. Whenever an alarm goes off, a message is sent to the mobile phone of the caretakers, and then one of them comes up and handles the situation. What scares some residents, according to the interviewed caretaker, is that the beeping sound is so loud that they sometimes misunderstand that the alarm goes off in the whole building, even though the alarm is only local. As they do not know how the alarm system operates in the house, they often misunderstand that the caretakers are coming up because they have heard the alarm even on the first floor.

The flood guard frequently sets the alarm off when the home caregivers clean the bathroom by spilling too much water on the floor. The alarm does not make any sound, but the water supply is cut off. Then the caregiver has to come down to the reception or one of the caretakers must come up to the apartment and check the situation. They advise the home caregivers and the residents that the floor must be completely dried up before the water sensor can be reset and the water comes back.

6 Presentation of the heating malfunction case

This chapter will describe the heating malfunction case in detail. The general account of the case will be given first and then accounts of the case in the perspectives of each actor and stakeholder will follow. The accounts are primarily based on the interviews with the stakeholders. In order to obtain a thorough understanding of the case situation, this research reconstructed the history of the heating case based on various accounts from each actor and stakeholder of Hill Care+.

In each section of the actors and stakeholders it will be presented how they recognized the case, what challenges they had, and what action they took. As in the previous chapter the order presenting the actors and stakeholders is in the chronological sequence of engagement. Since the case was initiated by the resident reporting to the caretakers that they felt cold in the apartment, the presentation of the case starts with the account from the residents. After that comes the account of the caretakers describing what efforts they made in cooperation with the operation team in the UWF. It is the operation team of the UWF who spent the most time with troubleshooting, thus their process of troubleshooting will be explained rather longer than other sections. The next section is about how Solid construction handled this case and what final actions they took to correct the problems in this case. Lastly, the perspective of one advisory consultant in the municipality on this case will be recounted.

6.1 Case description

Even though Hill Care+ was technically the most advanced Care+ building in the municipality with integrated smart home and welfare technology, some residents had already complained that it was not warm enough in the apartment from the very first winter in 2012. The residents of Hill Care+ are mostly senior citizens over 67 years old, which means that their health condition can be easily affected by the indoor temperature if they stay cold. The vulnerability of this user group made this case sensitive, and immediate actions should be taken.

In an attempt to detect the source of the malfunction, a comprehensive examination was carried out for an extended period. The caretakers, who spend the most time in the building and understand the residents best, started to adjust the temperature of the apartments reported as cold. According to the interviews with the caretaker and the operation team, the elderly residents struggled at the beginning of understanding how the heating operates, because the method for heating regulation in Hill Care+ was different compared to what they were used to. However, this was not the fundamental cause of this malfunction. After the caretakers checked the status of thermostats and measured the actual temperatures of the apartments reported as cold, the operation team in the UWF started to examine the case on a deeper level and with a broader scope.

The operation team had begun to scrutinize components behind the wall, which are supposed to be invisible when they are in proper functioning. They checked out the communication and the performances of the components. With no malfunction discovered in the elements on the apartment level except for some small connection errors, they went deeper into the level of the applications which control the components. Lastly, they checked the heating effect and concluded in December 2014 that the heating installation was not properly dimensioned and regulated during the construction process. The UWF engaged a third party in February 2015 and they submitted a report on the effect of the heating installation in Hill Care+ in March the same year.

Solid construction received significant claims from the UWF in December 2014. The UWF submitted minor claims in the first year and the first year inspection but large-scale claims, including the one on the heating installation, were not discussed with Solid construction beforehand. Solid construction was not involved in the troubleshooting process in 2014 until the UWF filed the claim cases. After Solid construction had received the claim on the heating installation, they forwarded it to the responsible sub-contractor and required them to give account for the claim and repair the claimed defects. However, no concrete actions were carried out by the sub-contractor for six months. Solid construction could not leave the case unhandled anymore, thus they engaged a new sub-contractor to amend the heating installation in Hill Care+. In autumn 2015, the new sub-contractor replaced small radiators and pumps and regulated them properly again. I will provide a more detailed description of the heating malfunction case in the following sections. Figure 9 presents a timeline of the case with important events specified.

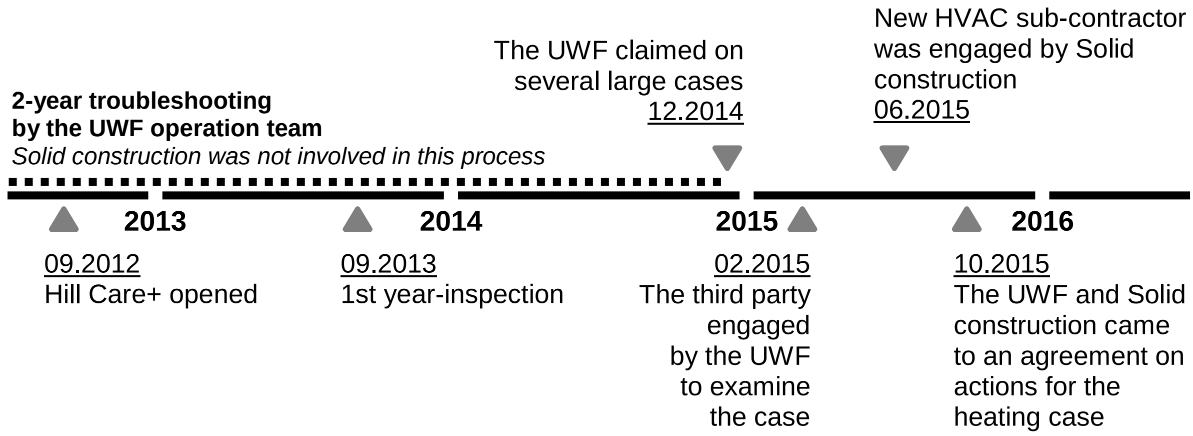

Figure 9. Timeline of the case on the malfunction in the heating system

6.2 The layers of complexity

6.2.1 End users

The users directly involved in and affected by this case are the residents. The home caregivers can also help the residents adjust the temperature on the thermostat, but they mainly provide home care services and do not stay long in the apartment. The family of the residents might have helped them to address the issue to the stakeholders including the caretakers but they do not live in Hill Care+. Hence, it can be regarded that the case was initiated by the residents when they reported to the caretakers that they felt cold in the apartment already during the first winter, in 2012. Since it was reported not long after the opening, other actors and stakeholders of Hill Care+ have been aware that there are some apartments not getting enough heating and taking this issue seriously from the beginning.

Confusing thermostats

One resident in Hill Care+ told me that it was as cold in her apartment as outside during the summer of 2015. During that summer it was colder than usual. Her apartment is not located in a place where the sunlight shines in directly, so it might cause her apartment to be colder than other apartments. When I visited her apartment at the beginning of December 2015 (it was -7°C outside on that day), she told me that she did not feel cold but that it was not comfortably warm in the living room in her apartment. Because she did not want the bedroom to become too warm, she usually opened the window in the bedroom.

Every resident has different preferences when it comes to comfortable temperature, thus each apartment is equipped with two thermostats, one in the living room and the other in the bedroom, on which they can increase or decrease temperature from the standard one set by the BAS. The temperature is increased if the button with the triangle sign pointing up is pressed (Figure 10) and decreased if the button with the triangle sign pointing down is pressed. There are, however, some challenges here to regulate the temperature.

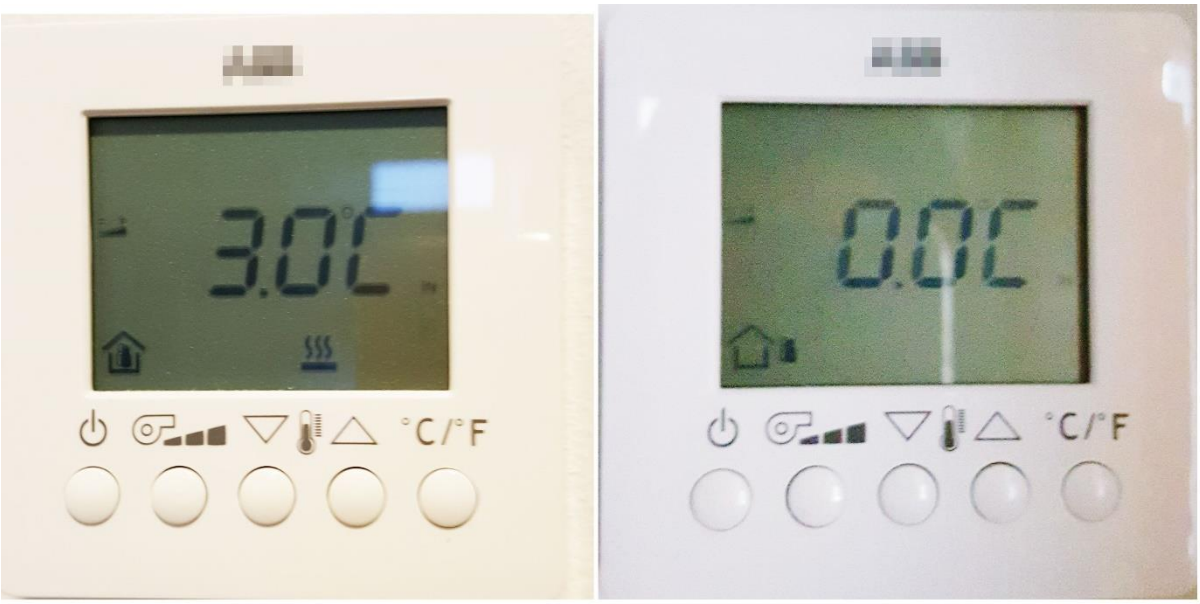

Figure 10. Two thermostats in the apartment of the interviewed resident.

One in the living room (left), the other one in the bedroom (right)

Firstly, the number on the thermostat does not indicate the actual temperature in either the living room or the bathroom. It shows a number between -3.0 and (+) 3.0, which is the difference between the altered and standard temperature. The standard temperature is set to be 21°C in the living room and 19°C in the bedroom. When it is set to the standard temperature, the thermostat will show 0.0 on the screen. If the resident has increased the temperature by three degrees, 3.0 will be indicated on the screen. To understand the meaning of the numbers on the thermostat, the residents should first know the standard temperatures for each room.

Secondly, there is no clear feedback after the adjustment of temperature. It is not intuitive for the residents to know what happens after the actions are performed on the thermostat unless they recognize the symbols which appear on the screen of the thermostat. One way for them to find out whether the thermostat is in function is to check whether the radiator gets warmer or colder after the adjustment of temperature. However, it takes time for the radiator to get heated up or cooled down. It is not realistic to check the radiator constantly and the changes in the temperature of the radiator cannot be reliably detected by simply touching the radiator at regular intervals. After all, the thermostat displays the current status through the symbols on the screen: one in the bottom left corner with the figure of and the other one above the thermometer symbol, with a figure resembling steam (the left thermostat in Figure 10). They imply ongoing operations, but do not provide the residents with clear feedback on what operation is ongoing. Unless the residents know what all the different symbols indicate, the feedback given through the symbols is not intuitive to understand.

Heating installation is not in proper operation

The critical issue in this case was that the heating system in the building was not working properly, at least until the summer of 2015. The proper actions were being taken in November 2015. Both the lack of clear feedback from the thermostat and the malfunction of the heating installation added confusion to not only the resident but also to other actors of Hill Care+.

It was frustrating especially for the residents who are used to directly adjusting the temperature with a valve switch attached to the radiator. The operation team in the UWF indicated that the old habits the residents brought from their previous residences might complicate this heating case. Most of the residents used to open the window with the radiator on in their former home. However, in Hill Care+ the radiator does not work if the windows are open, and the temperature of the whole apartment will fall. During the night, only the room where the windows are opened will be affected. If the temperature falls below 10 °C, the alarm goes off. Both the old habits of the residents and the unclear feedback from thermostats, which merely display numbers from -3 to +3, resulted in improper use of the heating system in the apartments. The deficiencies of the heating installation, combined with the incorrect use by the residents, worsened the heating problem. The residents remained confused in the apartment without much control over the heating system.

The residents' control over the regulation of temperature in their apartment had significantly diminished. One resident I interviewed told me that she did not dare to touch the thermostat as it is not her domain, but the caretakers'. The only action the residents did take was to report about the cold apartments to the caretakers. The responsible sub-contractor provided Hill Care+ with extra portable heaters for the residents who needed them. However, the interviewed resident told me that, even though it is free to use, she was careful about using the extra heater because she might need to pay a large electricity bill[29].

6.2.2 Caretakers

The heating in the apartment has been an issue for the caretakers since the first winter, in 2012. The thermostats seemed to function well in some apartments but not in others. The caretakers tested the thermostats in the cold apartments. Even though they adjusted the temperature +/- 3 degrees, nothing happened in the radiator. Since they were aware of what the number on the thermostat indicates, they expected that the temperature would increase by three degrees when the thermostat shows (+) 3.0 in the living room, but the radiator did not seem to get warm.

Firstly, they discovered that some thermostats were connected to the wrong room. Because of this, when they adjusted the temperature in the living room the radiator in the bedroom became warm. After they had given notice to electricians about this, the connection was corrected so that the thermostats would be connected to the corresponding rooms. It did not, however, solve the problem. Secondly, they made a form and wrote down the measured temperature twice, first before they changed the temperature and again three hours after that, and compared them to the numbers shown on the thermostats and the interface of the BAS. It did not, however, give any clear indication as to where the problem lay.

They have also tried out other several ways to find out the source of the malfunction, starting from checking the buttons on the thermostat to measuring the temperatures in different places and settings. However, the source of the error was not detected. In this troubleshooting process, they worked closely with the operation team of the UWF.

[29] The residents of Hill Care+ are paying the electricity bill after individual use.

6.2.3 Operation team in the UWF

Checking the electronic components

The operation team inspected the case on a broader scale than the caretakers did. Concerning their tasks, operation and maintenance of the building, it was important to discover what caused the problem before reporting it further to the main contractor, Solid construction. After they had been informed of cold apartments, they started by checking electronic components in one of the reported apartments to see whether all of them were in operation and if they were able to communicate each other. The signal communication between the thermostat, actuator[30], and the radiator was checked, and it was confirmed that the actuator functioned well in reaction to signals from the thermostat. Since the performance of all the electronic components was not in question, they adjusted the amount of water which flows into the radiator in an attempt to increase the volume of heating and tried to distribute the heating evenly in the building. The heating from one of the apartments not reported as cold before, for instance, was distributed to the one reported as cold. After several days, however, an apartment never reported as cold started not to get enough heating.

Checking the BAS

In addition to examination of heating installations, the operation team followed up the BAS (Figure 11) to figure out if there were any malfunctions in the system. The BAS provided them with an overview of which apartment needed more heating so that they could distribute the heating from the apartments regarded as warm to the ones reported as cold. The BAS was not, however, a sufficient tool for the operation team to detect where the exact cause lay since it merely shows the current status of operation and the measurements, not the source of error. Thus, the operation team had to check other underlying programs, which control each component whether they return values read to the BAS.

[30] Actuator is a component which acts upon the received signals. In the heating system, it receives the signal from the thermostat to operate the radiator.

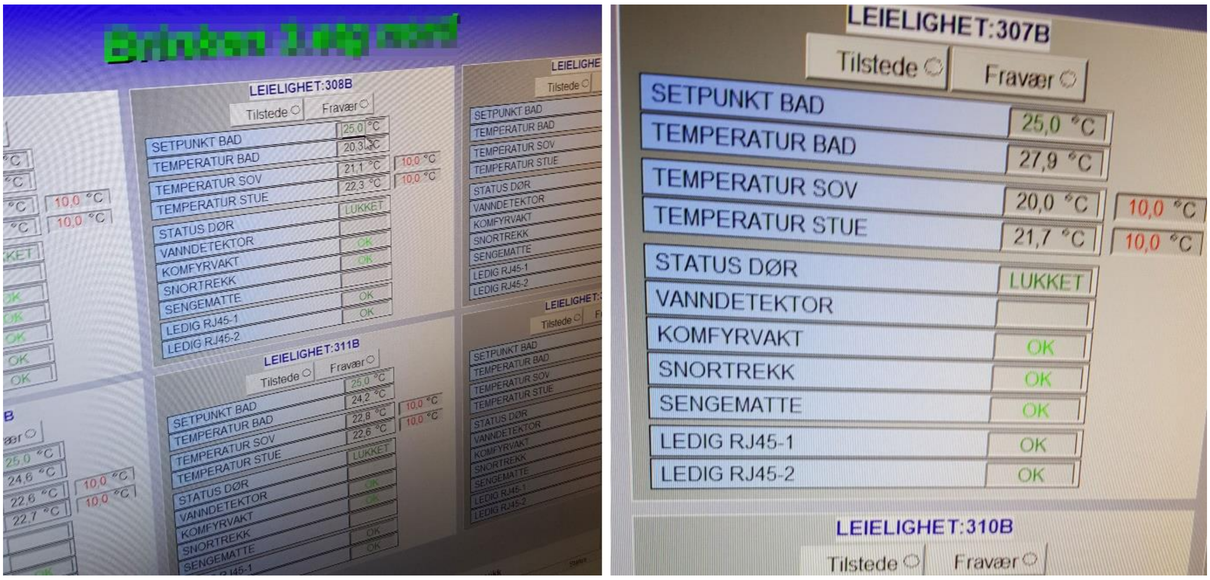

Figure 11. The information presented in the BAS[31].

KNX, a top underlying system

The top layer of the underlying systems, right beneath the BAS in the control system of Hill Care+, is the KNX[32]. It is where all the raw data from heterogeneous components in Hill Care+ is gathered and interpreted so that they can communicate in one common language. Then it sends them to the BAS so that they can be presented in a more user-friendly way on the user-facing interface. The interface of the KNX is highly technical and text-based. The operation team emphasized that it is not their responsibility to go deep into the KNX-level since it is an underlying system and supposed to function invisibly. However, as the heating system did not work properly and the components and the system on the surface level were functioning properly, the operation team needed to request access to the KNX to investigate the source of malfunction on a deeper level. During the troubleshooting, they accidentally found additional problems which would not have been found unless they had acquired access to the KNX.

Before the operation team started to look into the KNX, they assumed that all the values presented in the BAS were correct. In order to confirm that the correct value is retrieved from

[31] The information presented is, from the top, the set temperature of the bathroom floor, the current temperature of the bathroom floor, the temperature in the bedroom, in the living room, the status of the door (open or closed), the flood guard, the stove guard, various sensors implemented near the bedroom.
[32] KNX is a standard which enables all the components in smart home to communicate in one common language.

the KNX and sent to the BAS, they compared the raw data in the KNX and the data presented in the BAS. However, they found about 20 cases of mismatched values. This resulted in the wrong temperature for some of the apartments being presented in the BAS, because it was retrieving some values from the wrong addresses in the KNX. They reported this to the responsible engineer so that the BAS could receive and present the correct values from the accurate address in the KNX.

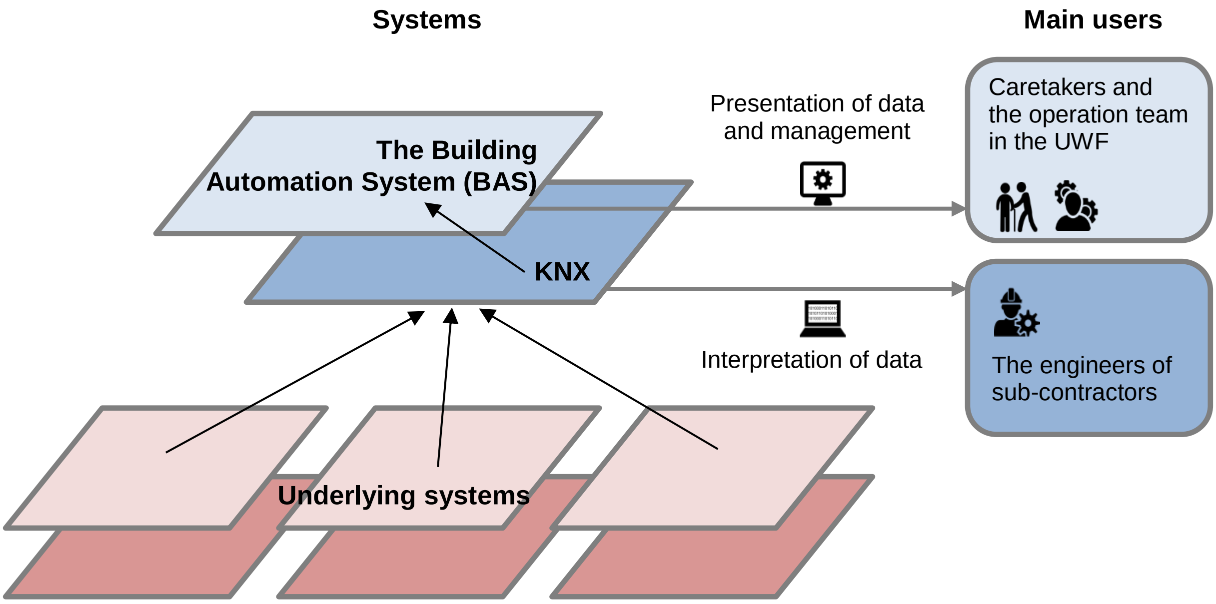

Figure 12. The structure of the systems in Hill Care+[33]

Complexity of the numerous underlying systems

It was challenging for the operation team to check the various programs as they were produced by different vendors, which also meant that each program had different responsible engineers. In the most complicated cases, the troubleshooting of applications must be conducted by the various engineers who delivered each application. If, for instance, an error was detected in the BAS by the operation team it would be reported to the BAS engineer. If the error might be caused by the KNX, it would then be forwarded to the KNX engineer. If the error is not caused by the KNX it would be sent even further to another corresponding engineer who delivered the underlying application. As such it could become a time and resource demanding process to detect the source of the error because of the several layers of applications which constitute the infrastructure of Hill Care+.

[33] Icon made by Freepik from www.flaticon.com

The KNX engineer evaluated the control system of Hill Care+ as highly complicated. Even though there was one single error detected in the BAS, it might have been initiated from one of the underlying applications which lie deep down, causing other subsequent errors before it reached the BAS. In such layered infrastructure the error detection process could be highly challenging, as the original error is not visible and might have arisen several layers down.

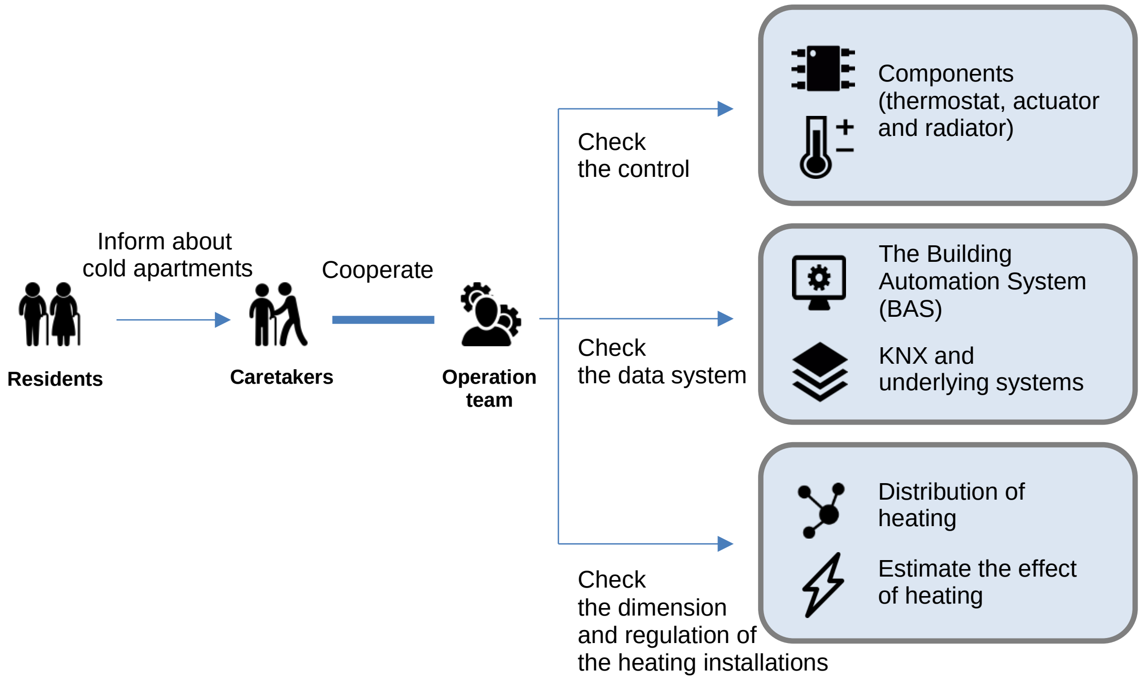

Figure 13. The summary of the troubleshooting process[34]

Result

After an extended examination in cooperation with engineers and technicians, the UWF have decided in December 2014 that the error resulted from the incorrect estimation of heating volume during the planning process and the wrong regulation of heating distribution. They filed claims on its repair to Solid construction on 31st of December 2014. The UWF engaged a third-party, a research organization that has a department specialized in building research, to examine the case in February 2015. They measured the effect of the radiators installed in Hill Care+ and submitted a report. Since Hill Care+ was opened in September 2012, it took

[34] Icon made by Freepik from www.flaticon.com

over two years to come to the conclusion that the whole heating installation was incorrectly dimensioned and improperly regulated. In short, the cause of malfunction in the heating infrastructure in Hill Care+ was that there was not enough heating. That is, the total amount of water to cover the whole building was not sufficient, and was thus causing the distribution of heating to be challenging. The difficulty with distributing the heating might have resulted from having small pumps that were too weak to distribute the hot water through the building and apartments, but this is my reckoning inferred from the information that the small pumps were replaced by bigger ones as part of the repairs of the heating installation. The UWF and Solid construction came to an agreement about what actions to take to fix the heating installation in autumn 2015. More about measures taken to repair the heating installation will be described in the section about Solid construction.

Claim case vs. Maintenance case

The troubleshooting process for the operation team was highly challenging because the fundamental cause of the problem was hardly visible and not easily detectable. Without assistance from the engineer and technician of the sub-contractor, it could have taken far longer to detect the source of the problem. However, the operation team was supposed first to report the case to Solid construction and involve them in the troubleshooting process. If the case had been handled and closed successfully, however, the case might have been regarded as a maintenance case, which implies that the UWF should take the expenses for the case. Without being involved in the entire troubleshooting process it is also challenging for Solid construction to acquire a good overview of the process to determine the scope and the scale of the claims.

The operation team referred to a recent case which they had to handle immediately because of security concerns. In the perspective of the operation team it resulted from a defect in the components, thus it is a claim case. However, it could be regarded as a maintenance case in the perspective of Solid construction, as the problem was solved relatively easily within a short time period. In any claims case there is a discussion between the UWF and Solid construction about who is responsible for handling the situation, and according to both parties, the lines between a claims case and a regular maintenance case is not always clear. This is a critical issue which decides who will bear the expenses required to handle the claim case.

6.2.4 The service department in Solid construction

The service department in Solid construction is not the same team as the one who participated in the construction of Hill Care+. They register the claims from the clients and handle them. If the claims are resulted from defects of the installations in the building they forward them to the responsible sub-contractors. It is common to have a five-year guarantee contract with the client, the owner of the building. In the case of Hill Care+, Solid construction has not been informed about any major concerns from the UWF until December 2014 when they filed numerous large claims including the one regarding the heating installation. There were some claims reported from the UWF before 2014, but the scope of those was smaller compared to the claims made in 2014. Solid construction was not involved in the troubleshooting process until December 2014 and they were informed afterward that in the troubleshooting process, the UWF cooperated with the engineers and the technicians of the sub-contractors who were not in a contractual relation with the UWF. In the perspective of the operation team in the UWF, however, it was necessary to detect the source of the error before reporting the case to Solid construction.

After the report from the research group engaged by the UWF had been submitted, Solid construction required the sub-contractor who delivered the heating installation to investigate and give an account of the malfunction and make suggestions for the actions to take. However, the sub-contractor could neither provide them with proper accounts nor propose necessary actions. After six months without a concrete solution, Solid construction could not wait any longer. The families of residents and the UWF had begun to urge Solid construction to take necessary actions as soon as possible. Therefore, Solid construction had to engage an entirely new sub-contractor to correct the heating installation in summer 2015. As a result, around 20 small radiators were replaced by bigger ones to increase the heating capacity and small pumps were also replaced by bigger ones and re-regulated properly in autumn 2015.

6.2.5 Sub-contractor

In the process of investigation of the software applications, the operation team cooperated closely with the KNX engineer from the sub-contractor who delivered it. The engineer provided the operation team with a set of elimination methods to be used in the troubleshooting process of the applications. The method could be used to ensure that there is no malfunction in the KNX system, before the operation team could proceed to the next level.

The examination of the KNX system was essential because it is the system which enables all the connected components to communicate with each other in one standardized language. The elimination methods that the KNX-engineer presented are as follows:

The elimination method for troubleshooting of KNX
1. Check if the electronic component has power 2. If so, restart the component after cutting the power 3. Scan the components using the programming tool, ETS4, which allocates all the elements an address through which they can be connected to the KNX-network. 4. If the components are not scanned, restart the component 5. Check if there is any malfunction in the application of ETS4. 6. Look through the application of the component and check what other components are connected. 7. The error could be caused by other tools which do not have an address inside the KNX, but are still controlled by and communicate with the KNX-system.

Table 6. A set of elimination methods used for the troubleshooting of the KNX-system

6.2.6 Municipality

The municipality was not directly involved in the troubleshooting process. However, one advisory consultant who works with the Care+ concept shared how she viewed the heating case in Hill Care+.

The central heating system in Hill Care+ functions well with regards to efficient energy consumption. However, it did not take the characteristics of the residents into consideration. Hill Care+ is an apartment building for the elderly. Their reduced bodily functions and lack of activities make them feel cold more easily during the cold period, which usually lasts from September to May in Norway. The central heating is an economical way to operate the building for energy saving, but it does not guarantee that the regulated indoor temperature provides the elderly residents with enough heating. She questioned whether the allowed range of temperature regulation, currently three degrees, is sufficient for the elderly residents who supposedly have bigger demands for increasing the temperature. There should have been thorough consideration and reflection during the design process about how to balance the two relatively conflicting functions of the smart home; energy saving and a higher degree of flexibility which might result in increased energy consumption.

The advisory consultant pointed out that there are a couple of challenges to address this issue. Firstly, it is not simple to decide on ideal temperature which can satisfy every resident in the building. The temperature which provides comfort might vary for every individual. It is also in question who will decide the standard temperature in the BAS of the building. Secondly, it requires a larger budget to procure a system which allows more flexible individual regulation in a central heating system. A fine-tuned temperature regulation which satisfies individual demands, but at the same time does not exceed the allowed heating capacity might require a sophisticated control of the entire installation.

7 Analysis of the problem area

Bierhoff, et al. [3] emphasize that the goal of designing smart home technology should be giving control to residents over their home and technology, which empowers them and increases their autonomy However, the case of Hill Care+ demonstrated how little control the users had over the smart home technology when it did not function properly, because of the challenges that the infrastructure of the heating control imposed on shaping the user experience. This was revealed in the troubleshooting process as described in the previous chapter.

This chapter will discuss why the users of Hill Care+ became powerless, especially when the smart home did not work, by using the three ways Edwards et al. [14] propose how technical infrastructures influence user experience: constrained possibilities, interjected abstractions and unmediated interaction. They focus on the tension between the user experience and underlying infrastructure and the dependency of user-centered design on the existing technological infrastructures. The case chosen in this study demonstrated that it was essential to expand the scope of analysis by including the underlying infrastructure of the smart home technology beyond the surfaces where the interaction is the most visible. This is because examination of issues exposed only on the surface level would not be enough to fully understand the complexity of error situations and eventually find the cause of malfunctions in the case. The term ‘users’ in the following sections refer to the residents, the caretakers and the operation team in the UWF. As presented in the preceding chapters, the residents are end users and the caretakers and the operation team are super users. The operation team has, however, more technical competence than the caretakers to engage with the infrastructure on the deep level.

7.1 The causes of diminished control over the smart home technology

The reasons for the error in this heating malfunction case, an improperly dimensioned and regulated heating installation, might seem irrelevant to diminished control over smart home technology, which is the research topic in this study.

Above all, it is essential to understand that the heating installation is a part of the smart home technology. The heating installation is one of the infrastructures on which various smart home technologies of Hill Care+ are built, and the thermostat and the BAS are the digital part of the heating infrastructure. It is the smart home technology which mediates between the users and the infrastructure in Hill Care+. Thus, the analysis of the infrastructure problems which influence the shaping of user experiences can provide insights into the causes of diminished control over the smart home technology by closely examining what challenges the heating infrastructure imposed on the users' control over the smart home in Hill Care+.

7.1.1 Constrained possibilities

Constrained possibilities indicate limited user experiences resulted from the technical capabilities of an infrastructure. Design choices made by the infrastructure may exclude desirable user experience. In other words, the user experience in smart homes rely heavily on what the technical infrastructure allows.

Heating infrastructure defines heating experience in Hill Care+

What the user experiences when it comes to heating control in Hill Care+ is constrained to the capabilities the heating infrastructure provides. The current temperature of the room might function as a barometer before a resident decides to adjust the temperature. However, the thermostats in Hill Care+ merely display the numbers between -3.0 and 3.0, which indicate the difference from the standard temperature set in the BAS. In reality the thermostats have various display options, which means the product itself can be set to display the current temperature, but this cannot be done by either the residents or the caretakers who use the thermostats the most. Required resources for changing display settings on the thermostats and consequences of doing so are unknown in this study. However, the current program settings applied to the thermostats constrained possibilities, which influenced and limited the user experience in the smart home.

As described in the previous chapter, the radiators in Hill Care+ stop working when the windows in the room are open. Unlike in their previous residences, the residents in Hill Care+ cannot sleep with the windows open in the bedroom. Even though they want to ventilate the room with fresh air, keeping the room temperature at a constant level, there is currently no available option in the apartments of Hill Care+. The present solution is designed for efficient energy consumption in the building, but this constrains a certain desirable user goal. There is no option for the residents but to accept the current situation as it is. They need to accept the allowed possibilities and adapt their behavior to achieve certain goals in the smart home. The heating system in the apartments of Hill Care+ demonstrates how the design choice made by the infrastructure shape the user experience.

Broken anticipation of the role of BAS in the troubleshooting process

The BAS of Hill Care+ could not meet the anticipations of the operation team in the UWF. Although the BAS was not primarily designed for troubleshooting it was expected to play a supportive role in troubleshooting of the heating infrastructure. The GUI of the BAS used in Hill Care+ displays a standard set of information commonly found in other BAS. What could have helped the operation team in the process of error detection and troubleshooting was an overview of multi-layers, which could provide a path to trace the underlying technical infrastructure so that the operation team could investigate the hierarchical structure of the control system in Hill Care+. As such, what the operation team could do in the troubleshooting using the BAS was limited because of the constrained possibilities it provided.

7.1.2 Interjected abstractions

Interjected abstractions are concerned with the situations where low-level infrastructural concepts become parts of the conceptual model in applications built upon the infrastructure. In the development of the applications these abstractions are used to describe the structure of the infrastructure. Users are exposed to the infrastructural abstractions when they use these applications built on the top of the infrastructure.

Heavy memory and comprehension load

Most of the residents of Hill Care+ are used to regulate the heating by directly adjusting the valve attached to the radiator. The thermostats mounted on the wall in Hill Care+ are physically detached from the radiator, but it is not intuitive and visible how those thermostats are connected to the radiators in the apartment. One way to recognize the connection between them is to understand the numbers and symbols which appear on the screen of the thermostats, as they are the visually interjected abstractions of the heating system in the apartment. One of the major reasons the residents did not attain control over the heating regulation in Hill Care+ could be found in the high exposure of interjected abstractions and the heavy memory and comprehension load imposed both on the residents and the caretakers. There are numerous abstractions to understand to properly regulate the heating in the apartment.

First of all, the residents have to understand they can regulate and change the temperature of the apartment through the thermostat mounted on the wall. They might notice that the radiators in the apartment of Hill Care+ do not offer them any access to regulate the temperature, unlike the ones they used to have in their previous home, on which they could directly adjust the heating. However, the thermostats implemented in the apartment are not easily recognizable since they do not show any obvious connection to temperature control.

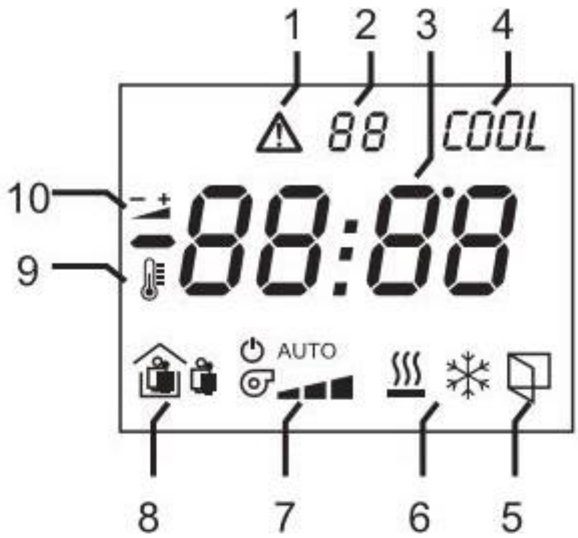

Figure 14. Numerous symbols on the thermostat[35]

Secondly, the residents need to be informed about what the number and various symbols on the screen of the thermostat indicate to understand the functional status of the heating system

[35] The figure is retrieved from the user manual made by the vendor. Each number indicates: 1) Error 2) Messages 3) Measured values 4) Setpoint name 5) Window open 6) Heating/cooling active 7) Ventilation status 8) Presence status 9) Actual temperature 10) Manual setpoint adjustment

in the apartment. The symbols which can be displayed on the thermostat are numerous (Figure 14) and it is challenging for the residents to recognize all of them. However, not all the symbols appear on the screen at the same time and the symbols consistently presented on the screen are mostly the same ones. After some period of repetitions or having a list written on paper which specifies the symbols on the thermostat might help the residents to better understand the heating control on the thermostat, but this does not enhance residents' power of control over the heating. It is rather a temporary solution to assist them to recognize the representations on the thermostat.

Thirdly, the residents need to understand the connection between the open windows and the consequent indoor temperature. As mentioned in the previous section on constrained possibilities, the heating system is not designed to keep the set temperature when windows are open. When windows are open, it is supposed to be indicated on the thermostat with a symbol of a window in the bottom right corner (Number 5. in the Figure 14). The residents are required to understand this merely through a tiny symbol that appears on the screen when the windows are open.

As Norman [33] maintains, the machines are designed by professionals who know the rules that the machines must follow. The abstraction of the infrastructure is the representation of such rules of the machines, which do not work along with human beings since we have different rules of logic. This should be well mediated by, for instance, an easily understandable presentation to assist the users to comprehend the interjected abstractions. The challenges of understanding interjected abstractions have become more evident as the heating system was not fully functional. Even with a properly working heating system, the current thermostats expose unnecessarily many abstractions to the residents and the caretakers and impose on them a heavy memory and comprehension load.

7.1.3 Unmediated interaction

Unmediated interaction happens when users must interact with the infrastructure directly without any mediating applications. When everything is fully functional the infrastructure is well hidden, but it reveals its complexity when the error occurs.

Unmediated interaction with the infrastructure during troubleshooting

The case of Hill Care+ demonstrated how malfunctions in the infrastructure were exposed to users and urged them to interact directly with it. The major responsibilities of caretakers are to help the elderly residents to make the most of the technology implemented in Hill Care+ and assist them to manage the situation when an alarm goes off. The BAS they work with provides an overview of current temperatures and status of alarms in each apartment of Hill Care+. However, it did not indicate what caused the malfunction of the heating installation and why only some apartments were affected. In order to discover the source of the error, they needed to engage with the low-level of the heating infrastructure by checking whether the thermostat functioned normally, whether radiators became warmer after temperature adjustment, and whether the measured temperatures matched with the values presented in the BAS.

The same situation applies to the operation team of the UWF. Their major responsibilities are operation and maintenance of the building. The BAS was supposed to mediate interaction with the infrastructure in Hill Care+, but in the troubleshooting process it could not assist the operation team in the way they expected. The extent to which the BAS could mediate the interaction between the operation team and the infrastructure was not deep enough to detect the source of the error, which forced the operation team to examine one level higher up in the structure of infrastructure, where they did originally not have access. The KNX is an example of unmediated interaction the operation team was exposed to, as it was not designed for the building managers, and its user-interface was highly technical compared to that of the BAS.

7.2 Summary

The infrastructure which enables the smart home technology to function provides users with enormous capabilities, but when designing the infrastructure, its usability and what user experience it provides should not be neglected. Functionalities of high quality become meaningless if the users cannot properly make use of them because they are too complicated to use. The efforts and technological expertise required to design infrastructure on such a large scale are immense. However, it is critical that infrastructure design takes human aspects into consideration so as to ensure that the infrastructure is properly used.

This chapter analyzed why the users of smart home technology in Hill Care+ could not maintain control over the technology in the malfunction of the heating infrastructure. The design choices made solely by the technical infrastructure constrained possibilities in achieving user goals, such as checking the current temperature, and using the BAS actively in the troubleshooting process. The users were also urged to understand the numerous interjected abstractions on the thermostats and the BAS, and this imposed on them a heavy memory and comprehension load. The users were exposed to unmediated interactions with the heating infrastructure because they could not properly comprehend the interjected abstractions and the mediation layer was missing , especially in the digital infrastructure which constitutes the heating control.

8 Discussion

The three infrastructure challenges which diminished users' power to control the smart home technology were detected and analyzed from the heating malfunction case of Hill Care+ in the previous chapter. This chapter will address those three causes in layers of the heating infrastructure, as Edwards et al. [14] present in their framework. The framework consists of a set of approaches - *surface, interface, intermediate and deep* - and each of them engages with a different level of the infrastructure. Those approaches will also be referred to as layers in this chapter. Using the approaches by Edwards et al., I will attempt to find possible ways to deal with the current situation in Hill Care+ so that the users could better handle an error situation afterward, with enhanced power of control over the smart home technology.

8.1 Surface

The surface layer indicates the superficial part of the infrastructure. It concerns mostly the appearance of the infrastructure presented to the users. In the surface approach the infrastructure is regarded as given, and the efforts are made on how to present the surface in a more aesthetical and understandable way to the users. In this study the surface layer entails the display screen and the design of the thermostats in the apartments and the Graphical User Interface (GUI) of the Building Automation System (BAS), with which the caretakers and the operation team interface and interact.

The main focus of HCI work has been put on the surface layer, as this is the place where the users interact with the system the most. It was studied how to improve the presented pictures of the software application that the users face. The usability criteria proposed by Nielsen [31] could be applied best to this surface layer to improve the usability of graphical presentations for the users. Well-presented information via a software application or on the control device, such as thermostats, can help users understand the *interjected abstractions,* and a well-established understanding of such abstraction could assist them when *unmediated interactions* with the infrastructure are required. However, it cannot overcome *constrained possibilities,* as the surface is built on unchangeable infrastructure. The design solutions and the information available are limited to the functionalities afforded by the underlying infrastructure. Although the surface is well designed its affordance is still highly constrained by the capabilities the underlying infrastructure provides because it merely masks them by hiding their complexity. Even if *mapping* between the abstraction of the infrastructure, such as the structure or rough understanding of how the underlying system works behind the screen or the wall, and the user-facing presentation was successful, if the abstractions break because of errors or defects of the infrastructure, as in Hill Care+, this surface layer cannot protect the users from unexpected exposure to the infrastructure.

In the case of Hill Care+, the surface-layer was not ideally designed to assist the residents and the caretakers to properly control temperature and to shield them from unexpected exposure to the infrastructure of the smart home caused by the defects of heating installations in the building.

8.1.1 The thermostats should fulfill usability goals

The thermostat is supposed to mask the underlying heating infrastructure, hiding its complexity from the residents and the caretakers. The current surface of the thermostats rather contributed to diminishing users' power of control over the heating system in Hill Care+. One of the most challenging aspects of using the current thermostat in Hill Care+ is that there are several buttons which are not in use and several symbols appearing in the display. Without reading the user manual, it is difficult to memorize all the available symbols. The lack of comprehension of those functions and the feedback presented via various symbols results in frequent errors and frustration. The poorly designed surface also affected the troubleshooting process. Without understanding the current situation, the residents could not report to the caretakers the exact status of their apartment and the caretakers had to bring additional thermometers to measure the actual temperature in the apartments even though the advanced digital thermostat was mounted on the wall. In order to provide better control over temperature adjustment the thermostat should be re-designed to improve its usability.

8.1.2 More learnable and efficient GUI

The Graphical User Interface (GUI) of the BAS in Hill Care+ is highly complicated for the caretakers. The targeted users are mainly the operation team who has a higher level of competence in technical management and maintenance of the building. However, it is inevitable for the caretakers to interact with the BAS to manage the building, so that they can assist the residents when they use the smart home technologies on a daily basis, for instance temperature adjustment or alarm management when they go off. The GUI should be more learnable and efficient so that the caretakers can manage it more independently, without relying on assistance from the operation team unless it is necessary.

A better presentation of the available information could lead to a better user experience when users engage with the BAS, but it does not provide the additional information necessary for even better technological management of Hill Care+. The challenge in using the current GUI is not only the poor presentation of information, but also the insufficient information for troubleshooting.

The BAS of Hill Care+ could not assist the operation team much with the troubleshooting. This is because it mainly presents the current operation status, such as temperatures in each apartment, whether the alarm is on or off and so on, but not the current effect of each infrastructure or whether the actuator is functional. The operation team, thus, needed to come to Hill Care+ and check the components connected to the heating infrastructure in the reported apartment to detect the source of the error. The type of information to be presented in the BAS can be ordered by the client, which in the case of Hill Care+ is the UWF. However, it is unclear to what extend the users can anticipate, before they even use the system, what information will be required or useful to have. It indicates again that the surface-layer approach is restricted to the possibilities that the infrastructure provides and is not an approach which provides a holistic understanding of the cause of the error situation and a solution for handling the fundamental problems which might be caused by the underlying infrastructure.

8.1.3 Consistent GUIs

In the digital infrastructure of Hill Care+ there are three levels of software applications. The top layer is the BAS, the primary tool that the operation team interacts with most. The second layer is the KNX system which receives all the signals from the components, interprets them, and forwards them to the BAS. The last layer is other underlying systems connected to each component or sub-installation.

These multiple layers of software applications in Hill Care+ made the troubleshooting highly complicated. Numerous applications were delivered by various vendors and their maintenance was also conducted by the different engineers responsible for each system. The operation team had to detect the specific location of the error by engaging with those numerous layers of software applications on their own before reporting the error situation.

The process could have been more efficient if there was one single standardized GUI for multiple software applications. If each GUI of the applications had been consistent it could be easier for the operation team to build a good comprehension of the structure of the control system in Hill Care+ within a shorter period of time. This could save a lot of resources required from the operation team.

However, a standardized surface of multiple layers does not mean that all the underlying systems should be controlled centrally by one single unit. The type of building control that the operation team wants in the upcoming projects is a decentralized one where each underlying application is independent, so that the whole control system could be more reliable than the current centralized control in Hill Care+. A consistent GUI is also important in the de-centralized form of control. The feature missed and desired in the troubleshooting process was a well-integrated and standardized surface layer which could provide a well-organized overview of the technological structure of Hill Care+ that might enable the operation team to trace the source of the error more efficiently during troubleshooting.

8.2 Interface

The interface layer refers to the applications which mediate users and systems in the infrastructure. In contrast to the surface-layer approach which attempts to mask the underlying infrastructure by providing a well-designed presentation of information, the interface approach seeks to expose the infrastructure to the users in a way that they can perceive the underlying abstractions of the infrastructure. Exposure can be done by providing an appropriate conceptual model which allows users to reason and even improvise the use of the infrastructure. Even though the interface approach attempts to modify the infrastructure on a low-level it does not mean that it attempts to change it fundamentally, which can eventually overcome the *constrained possibilities*.

In the numerous applications which mediate between the residents, the caretakers, the operation team and the infrastructure of Hill Care+, a well-structured conceptual model is missing. Norman [33] stresses the importance of a good conceptual model as a key factor to overcome the complexity of systems. This is because a sound understanding of how the system operates acquired by a well-designed conceptual model could assist the users to make the most of the system. He maintains that a good conceptual model could be built by mapping each architecture of infrastructure with the human cognitive structure to make it easy to explain the tasks. His approach echoes with *reflective architectures* that Edwards et al. [14] present as a method to build a good conceptual model. They also refer to the term *accounts* by Dourish [12] as a method to design reflective systems. This allows the applications to provide an account of how the infrastructure functions with a great extent of transparency in the structure of the infrastructure. Even though the interface approach still cannot overcome the problems with constrained possibilities caused by the underlying infrastructure, a good account which explains the structure more transparently could assist, especially super users such as the operation team, to easily trace the cause of error when the system breaks down.

8.2.1 Reflective structure is required

The most desired aspect of the software applications during the troubleshooting process in Hill Care+ was a reflective architecture which could show paths which indicate what value is retrieved from which component, to where they are sent, and how they are presented in the BAS. The number presented in the BAS must be correct in order to initiate the troubleshooting process from the right place. When the operation team checked the temperature in one of the apartments reported as cold it showed 24 °C in the apartment. They had assumed that the number shown in the BAS was correct, but it accidentally turned out to be incorrect because the value was retrieved from the wrong apartment. The one false value had great impact on the rest of the data presented in the BAS. Thus, it was necessary for the operation team to ensure that all the temperatures presented in the BAS were accurate, and received from the correct room and apartment. A way to check the reliability of the temperature data in the BAS was to trace the origin of data. Therefore, it was essential for them that the systems could be able to trace and show the origin of data, such as the address of where the raw data of was retrieved.

There are numerous layers of applications which constitute the control system in Hill Care+. In order to trace the very origin of the data presented in the BAS the operation team had to engage with various applications where the raw data is retrieved, interpreted and presented. The way to save resources required in the troubleshooting is to provide them with a reflective architecture where they can make sense of the structure, hierarchy and connection of those underlying infrastructure of Hill Care+, so that they can reach the problematic area more quickly, potentially adapt its behavior and eventually solve the problems. Such a reflective structure could assist the super users like the operation team to overcome the challenges of understanding *interjected abstractions* when *unmediated interaction* is required.

8.2.2 The significance of the caretakers' role in mediation of troubleshooting

The role of caretakers is significant for the management and operation of Hill Care+. They are neither next of kin of the residents nor technicians who operate and maintain the building. However, they function as a bridge, firstly between the residents and the building, and secondly between the residents and the operation team of the UWF. They offer the initial assistance when the residents have inquiries about the apartment or the alarm goes off in the apartment. As the building and the apartment is equipped with smart home technology and administrated by the BAS, it is inevitable for them to interact with the BAS to manage the various alarms and adjust the temperatures in the apartment upon the inquiries from the residents. This indicates that they should also have an understanding of how the building works beneath the surface layer. While the residents interact only with the thermostat, the caretakers should have competence in using both the thermostat and the BAS. Simple troubleshooting can be handled by the caretakers when they come up and check the apartment themselves or reset the alarm warning appearing in the BAS (Figure 7). Accordingly, it is crucial that the caretakers have a conceptual model of how the smart home technologies work and are controlled by the BAS. This enables them to speak both the language of the residents and of the operation team in the troubleshooting process and to better inform the residents and the operation team about the current operation status of the smart home technologies.

8.2.3 Visualized step-by-step information needed

As discussed in the proceeding section, the lack of reflective architecture made the troubleshooting process more challenging. It is not necessary for the caretakers to comprehend all the technical abstractions to the full extent. However, if the GUI of the BAS could have provided the caretakers with a set of step-by-step guidelines which reflect the configuration and state of the system it might have assisted the caretakers to conduct a more effective management of the building and troubleshooting.

After three years of experience, the caretakers in Hill Care+ have already established a set of work practices to handle a troubleshooting process. When a resident report that there is not sufficient heating in his or her apartment they might take three steps they have already used in the initial troubleshooting process in cooperation with the operation team of the UWF. Firstly, they would come up to the apartment and confirm that the windows are not open and then measure the physical temperature in the living room and the bedroom. Secondly, they would check the number shown on the two thermostats. Thirdly, they would compare the physical measurements from the apartment to the values in the BAS.

Such actions established by the caretakers were built upon their own conceptual model acquired from their experience in the heating malfunction case. If the actions had been integrated in the BAS, it could have saved them a lot of time and other resources they had to invest in the troubleshooting process. Troubleshooting steps integrated in the conceptual model of BAS could guide the caretakers to better handle *unmediated interaction* with the infrastructure of Hill Care+ when the system is not entirely functional. When everything is operational and the residents are satisfied with the current setting, the current BAS should be sufficient to manage Hill Care+. However, when there is a malfunction such as in the heating case, the current system cannot be of help in providing details to track the cause of the error. It does not, however, mean that the system should be able to offer all the details of the installation. It rather means that a conceptual model can take a form of a step-by-step guide which is more explanatory about the functionalities and the structure of the system which controls the smart home technologies in the apartments so that it can support the users in an error situation.

Even though it could not be implemented in the initial design of the application, the work practices they have established afterward in the troubleshooting process should be able to be embodied in the applications in order to transfer their experience and further develop their know-how and their conceptual model of the BAS.

The missing troubleshooting assistance is also observed in the management of the flood guard[36] in the bathroom. When too much moisture is detected on the floor of the bathroom

[36] "Vannføler" or "Vannalarm" in Norwegian

the alarm goes off locally and sends the warning both to the system and to the caretakers. The critical action which should be taken before resetting the alarm in the BAS is to dry the floor completely. This is also a part of the work practice related to the management of smart home technologies which is not indicated anywhere in the BAS. As such, if the actions to be taken in the troubleshooting of smart home technology were integrated in the conceptual model and more visible to the caretakers, it might have provided them with a more systematic and efficient approach to handle the smart home technology, especially when the system malfunctions.

8.2.4 Increasing the independence of the residents

In addition to the unnecessarily complicated design of the thermostats, the absence of the residents' comprehension of the heating control system made the case more complex. The reason for this significant mismatch between users' mental models and the systems' operation is twofold.

Firstly, the current system behavior, that is the configuration, is not decided by the resident nor the caretakers and its affordance is not well understood by them. The caretakers know the range of temperature adjustment, which is positive or negative three degrees, but the interviewed caretaker mentioned that she was not sure what other functions the thermostat performs, since there was no reaction observed after the buttons were pressed. It was not answered in the field work who decided the standard temperature in the apartments, the current display settings of the thermostat, and what available functions of the thermostat would be in use and what the reasons for those choices were. One obvious thing, however, was that neither the residents nor the caretakers, who will be affected the most by the configurations, were included in the decision process. They had to accept the current setting as it is and had to adapt themselves to it.

Secondly, no solid conceptual model built on how the heating system works was observed. This conceptual model could be built by providing the residents with a simple explanation of each component and how they work together. The core of the orientation should be started from explaining that it is the thermostat which controls the heating in the apartment, and the residents can adjust the temperature by interacting with those thermostats. Based on the understanding of the thermostat in the central control they need to be informed that the radiators receive the order from the thermostat and the heating automatically stops working when the window is open to save the energy. If the residents had established such a rough comprehension of the heating system in the apartment it could have enhanced their feeling of independence over the smart home technologies.

The understanding necessary to understand the behavior of the heating system in the apartments does not require a high degree of technical competence. As Edwards et al. [14] suggest, what the residents need is a *support for intelligibility* to understand how a new home works. When we buy a new home appliance, it takes time and requires some efforts to get used to it. Some might argue that since the residents of Hill Care+ are elderly people this will cause extra challenges for such support. However, their competence in using technology should not be underestimated. As already proved in their use of tablet-PC[37] it is challenging to generalize their average technology competence. It would vary for each resident how fast they learn and competently use the technological components implemented in the apartment. The motivation and the needs for learning or the fear of making mistakes might also play an important role in how much they are willing to learn.

The residents in Hill Care+ constantly request help from the caretakers. Not everyone needs assistance, but the caretakers of Hill Care+ receive many inquiries, especially concerning the smart home technologies in the apartment. As the interviewed caretaker mentioned, it could be regarded as a part of the security the caretakers provide the residents. However, one of the most important purposes of the smart home technology in Hill Care+ is to increase the independence of residents. Currently, some residents might feel that they have lost control over the apartment because of the invisible and automated smart home technologies which seem too advanced for them. The malfunction of the heating installation made them feel even more confused. However, the heating installation is getting fixed, and when it is fully functional, it is time for the residents to take back control over their apartment.

The caretakers and the operation team commonly pointed out that it is hard to reach the elderly residents when they provide them with explanations about the implemented smart home technologies in the apartment. This should be an essential issue to be addressed to build the conceptual model for the residents. The interviewed caretaker mentioned some possible causes for this situation.

The first orientation is usually given when they move in. The new residents might be easily distracted and stressed when they have to get used to a new environment. It is not exactly the

[37] All the residents in Hill Care+ are given a tablet-PC. It varies from resident to resident how active they use the tablet PC.

best timing for learning new things. People learn differently. Some people learn by doing it themselves, but others learn by reading, for instance a user manual. The most frequent form of orientation is a verbal explanation from the caretakers but this is easily forgettable. All the residents get provided a binder with general information about Hill Care+ and the smart home technologies implemented in the apartment. However, this is a general description of the available components in the apartment and Hill Care+, not a user manual which informs them how each component behaves and how to use them. The residents usually go down to the reception and ask about what they want to know, or call the caretakers if it is urgent or if they cannot move easily. Such approaches could build a good personal relationship between the caretakers and the residents but do not contribute to enhancing the residents' understanding of the smart home in the long term.

Providing support is important, but it is still a supplementary action. A fundamental solution should obviously be a better design with a good conceptual model integrated, minimizing the need for support, and an infrastructure which allows such design. For instance, a good design which could be applied to the thermostat should entail clear feedback on the connection between the radiator, the thermostat, and the window contacts, and the presentation of functional status in a more understandable way. The current usability of the thermostats in Hill Care+ could possibly be improved by the supplementing conceptual model which explains the design, even though it becomes a long-term process before bridging the gap between the residents' mental models and the system operations.

In the interviews with the operation team and the service team of Solid construction respectively, it was mentioned that the current smart home technologies in Hill Care+ are too advanced for the elderly residents. They commonly maintained that as long as all the systems are functional, the main issue with regard to temperature adjustment is not concerned with the technology itself but with the users. However, if the technology cannot project a good conceptual model, it is not only the users' fault that there are frequent errors. Support for a long-term orientation, explaining system functionalities and configuration in an understandable way, is regarded as one of the possible actions to in the short term overcome the problems of *interjected abstractions* and thus *unmediated interaction* in Hill Care+. It might assist the residents with building a conceptual model which could function as a basis on which to interact with the exposed infrastructure.

8.3 Intermediate

The intermediate layer refers also to the applications built on the top of the infrastructure, but compared to the interface layer, the intermediate approach seeks to construct novel applications by engaging more closely with the infrastructure. In contrast to surface- and interface approaches, where they accept the infrastructure as it is and thus are still dependent on the allowed capabilities provided by the infrastructure, the intermediate layer attempts to take more proactive actions. Edwards et al. [14] refer to context-aware computing, tangible computing, flexible document management and distributed user interfaces as the works of HCI to construct new types of applications which can overcome the limitations of existing infrastructure. They present a couple of methods including *top-down* manner and *proxies* as new infrastructure technologies and processes which can be applied to the intermediate approach. A *top-down* manner indicates to push down pre-identified user needs into the infrastructure. However, if the infrastructure needs to be built beforehand, multiple lightweight prototypes could be made as *proxies* of applications which could perform upon the infrastructure. Although the intermediate approach engages more with the infrastructure the development of novel application is still dependent on the underlying infrastructure.

8.3.1 Why top-down manner did not work in Hill Care+

The infrastructure of Hill Care+ was constructed adopting a top-down manner. User-facing needs were identified first, and they were interpreted into functional requirements which the UWF and Solid construction should fulfill in the construction of Hill Care+. The applications delivered to Hill Care+ were standard products and the desired functionalities were abstracted out and adapted to the infrastructure of Hill Care+ afterward. Since Hill care+ was constructed with the smart home technologies integrated it did not have any legacy or old infrastructure which might not support certain applications. However, such top-down approach did not ensure good usability of smart home technologies in Hill Care+. As Edward et al. [14] assume, the top-down approach can succeed only if the applications were built and evaluated ensuring a good fit with human needs and capabilities. The thermostats and the BAS program were developed as a standard product and adapted to Hill Care+, fulfilling the functional requirements. In this study, however, it was not investigated what design process and user-testing the vendors of the thermostat and the BAS have conducted. Upon the observed use of smart home technologies in Hill Care+ the fulfilled capabilities of those delivered products cannot be said to fit the user needs. It is, thus, in question how to bridge the gap between the user needs and the functionalities, and in the current situation between user understanding and the available functionalities.

8.3.2 How to interpret usability needs into functional requirements

The operation team has emphasized the importance of a better competence in the procurement process for upcoming Care+ projects. They have to comprehend what features are necessary and proper both for the residents, the caretakers and for themselves. It is not sufficient to merely fulfill the standard requirements from the municipality, as they are the minimum requirements. That is, the standard requirements secure the minimum functionalities, but they do not ensure the best design and a good user experience in Care+ buildings.

As discussed in the previous section, the functional requirements reflect identified user needs. However, they merely ensure the required functionalities to be implemented, but does not guarantee that the capabilities provide the residents with a positive user experience which gives them a feeling of control over the technologies. However, it is not simple to translate non-functional aspects which could influence usability and user experiences into general functional requirements. There are numerous aspects which form good usability and positive user experiences and they vary depending on the user groups and the context where they are placed.

It is regarded worthwhile for the operation team to attempt to take non-functional aspects, such as usability or user experience goals, more into consideration in the process of specifying the standard requirement by organizing a multi-disciplinary team which includes not only engineers of technical infrastructure, but also HCI experts who have specialized in, for instance, usability engineering, user experience or interaction design. Such a team could assist the UWF to transform the standard functional requirements into ones which meet not only utility goals but also usability goals. However, this process requires a lot of resources from the UWF. They have limited resources which must be distributed on the entire process, including the construction process that would demand the largest expenses, which makes it challenging to make a large investment early in the planning process.

8.3.3 Trial operation as user testing and final adjustment

Even though it is challenging to make changes to the physical applications procured, it is still possible to enhance the user experience in the smart home by minimizing the negative interaction effects [26] caused by implemented heterogeneous components. The malfunction of the heating installation in Hill Care+ could have been prevented if the problems were discovered during the trial operation.

The current requirement specification demands that all the installations should function from the very first day of opening. The manager of the service department in Solid construction emphasized that the original purpose of the trial operation is to adjust the technical installations according to the user needs. All the construction work should be completed before the trial operation starts and the only work to be conducted during the trial operation is to tune in the installations for optimal use. However, it is often used for a troubleshooting process for fixing small malfunctions right before the building is delivered to the client. Unlike the digital products, most of the smart home technologies are hardware products and they are not easily changeable after they are mounted and installed. The only way to make changes is to adjust how they behave. It is not the most proactive way to improve the usability of smart home technologies in the building, but the trial operation should enable the users of the smart home to adjust and tune the behavior of the smart home technology to better suit their needs and preferences. Various coordination settings of the heterogeneous components in smart homes could be tested to figure out how they work together and what feedback they provide.

To carry out a successful trial operation, the manager of the service department in Solid construction proposed to keep a close dialog with the client, the contractors and the users of the building. The contractors should provide explanations on the technical installations, demonstrate them, and correct the errors if there is any malfunction. The operation team and the users of the building have to understand what technologies are implemented in the building, how they operate, and express their preference on the settings of operation. Then the service technicians can regulate and adjust the installations and the operation team could ensure the quality of the delivered technology and retain the preferably adjusted settings and keep the quality.

8.4 Deep

Deep approaches engage directly with the underlying infrastructure. They concern the deepest layer where the stakeholders outside the HCI community should be involved. Thus, it is the layer where not much HCI work has been conducted yet. This indicates that the deep approach seeks cooperation between technical infrastructure engineers and HCI experts to influence the fundamental infrastructure which the surface, interface and intermediate layer rely upon. Edwards et al. [14] propose *educating* developers of technical infrastructure on HCI practices and *communication* across multiple disciplines as possible actions in the deep approaches.

8.4.1 Flexibility is required

The smart home technologies implemented in Hill Care+ are centrally operated and a margin for individual regulation is not large. The interviewed advisory consultant of the municipality maintained that three degrees are a too small margin for temperature regulation. Considering the susceptible health condition of the user group and the cold climate in Norway, it is not likely that the residents of Hill care+ would often decrease the temperature. She indicated that when the need for increased temperature is bigger than the need for decreased temperature, three degrees might be too small a margin for temperature adjustment. It is not a simple task to satisfy all the residents in a centrally controlled smart building by finding a comfortable temperature for every resident. A central system which allows individual regulation to a great degree might require a large budget. However, the budget is not always sufficient to meet the increasing social demand for care of the elderly population. It is also not feasible for the municipality to apply for a large investment for the most advanced technology for all the coming Care+ buildings.

The most advanced technology, however, does not automatically ensure the best user experience either. Rather, the desired aspect of the smart home technology to be implemented is not necessarily numerous advanced functions, but a higher degree of flexibility. Flexibility does not necessarily indicate advanced technical capabilities. It rather means to expose the available options to the users so that the system should adapt to users' preferences on various contexts instead of users adapting themselves to the system.

8.4.2 A set of assessment criteria as a boundary object

It is discussed in the HCI community that qualitative aspects such as flexibility might address their importance in the technical design process if they have quantitative metrics through which they can be quantified and measured. If so, it might be easily accepted and applied by the infrastructure designers as it takes a similar form as other commonly used methods in the technical design process. Edwards et al. [14], however, point out the challenges of obtaining data which enable a proper comparison and establishing benchmarks for such qualities. Additionally, when qualitative aspects employ such quantitative properties, their subtle qualities would be lost, since it is closely concerned with human factors which are difficult to measure in isolation because of diverse contexts and aspects. Instead of quantitative metrics they suggest a set of assessment criteria which can be served as *boundary object* among multiple disciplines such as HCI, software engineering and infrastructure design involved in the design process.

In upcoming Care+ projects, the most proper phases to make use of such assessment criteria are when the functional requirements are specified and when the smart home technologies are tested during the trial operation. If the requirement specifications oblige all the vendors to make the products meet the assessment criteria in the production process, and the composition of heterogeneous components in smart homes is tested using the assessment criteria during the trial operation, this could contribute to a design for shaping a more positive user experience in smart homes.

8.4.3 Reliable infrastructure is a basis of good usability

As learned from the heating case of Hill Care+, both utility and usability of smart home technologies are equally important for forming a basis for reliable infrastructure. Without properly functional heating infrastructure, well-designed thermostats or BAS would not be useful. The surface and the interface layers cannot work without the reliable infrastructure. Thus, the usability of the surface and interface layer is dependent on the utility of underlying infrastructure.

To establish and implement the assessment criteria is one of the fundamental approaches for making a smart home where the users understand the implemented technologies and have control over them. This presumes that applications are built on and supported by reliable infrastructure. To avoid any malfunction in the heating infrastructure, both the UWF and Solid construction emphasized the importance of coordination of various installations of the smart home. In this context, technology integrators play a significant role in smart homes and buildings. Their responsibility is to guarantee all the processes conducted to integrate the technical installations in the building. They have an overview of the various technologies equipped in the building and ensure multi-device communication by coordinating them to restrain and minimize negative interaction effect [26].

8.5 Summary

This chapter discussed how to address three infrastructure challenges on the four levels Edwards et al. [14] presented. On the surface level, the importance of a better appearance, that is a graphical or physical design of the thermostat and the BAS, was emphasized. The current design solutions in Hill Care+ do not support the users' understanding of the *interjected abstractions* of the infrastructure. The users therefore needed to handle *unmediated interactions* when there were malfunctions. On the interface level, the conceptual model was presented as a possible solution to assist the users to understand the interjected abstractions in order to better handle unmediated interactions when the infrastructure malfunctions. However, the possible actions both in the surface and interface approach are still limited because of the *constrained possibilities*. The intermediate approach engages with the infrastructure more deeply. The Hill Care+ project adopted the top-down manner to intermediately address infrastructure challenges, but the misfit between the user needs and the system capabilities could hinder its success. The deep approach is the most fundamental one, which can overcome constrained possibilities no other approach could address by making a direct change in the infrastructure, which could sequentially improve challenges with understanding interjected abstractions and handling unmediated interaction.

9 Design implications and suggestions

The framework of Edwards et al. [14], used in the previous chapter, enabled a systematical analysis to address the infrastructure challenges imposed on shaping the user experience in Hill Care+. This chapter will discuss in more detail and illustrate what concrete actions Hill Care+ can take to improve the current situation so that the users get back control over the smart home technologies. Being in control indicates that the users understand the capabilities of the technology and independently take necessary actions to change the current system behavior to suit their preference. The measures to be discussed in this chapter could hopefully be useful for upcoming Care+ projects in the municipality to help the users maintain control over the smart home technology.

The users in this chapter refer to the residents, the caretakers and the operation team in Hill Care+, as in the previous chapters.

9.1 Surface

The previous chapter discussed that the surface layer in Hill Care+ needs to be re-designed so that the users can make sense of the design and take advantage of the functionalities. To understand the design intention and system capabilities is essential for having control. The surfaces the users of Hill Care+ interact with the most are the thermostats and the Graphical User Interface (GUI) of the software applications such as the Building Automation System(BAS). Thus, this section will first discuss what elements of the thermostat and the GUI of the BAS to re-design and then how to re-design by presenting mockups of alternative designs for the thermostat and the GUI of the BAS.

9.1.1 Design principles for the redesign of the thermostat

The current design of the thermostat in Hill Care+ needs to be re-designed to enhance the user control over the temperature adjustment in the apartment. Suggestions will be made based on the design principles presented in Chapter 3.

It is not easy to understand how to adjust the temperature in the apartment of Hill Care+ because of the low visibility of the thermostat. It is not intuitive for the residents to recognize the purpose of the digital thermostat, as it merely displays a number between 0.0 and ± 3.0. If the screen of the thermostat displays the current physical temperature in the room, it might improve the visibility of the thermostat. The display of current temperature might help the residents guess what the thermostat does, but the functionality of the thermostat is still not visible enough to inform the residents how to control the heating system in the apartment.

While the physical buttons on the thermostat invite the users to push them, the numerous symbols which appear on the display of the thermostat do not have real affordance as the buttons have. The symbols attain perceived affordance when the residents and the caretakers learn the meanings of those symbols. With the current design, all the feedback on every action and operation is given through the symbols appearing on the display of the thermostat. However, they must be learned to be recognized.

The most missed design principle in the thermostat is feedback. Feedback visualizes the interaction. In the case of Hill Care+, this feedback relies either on the symbols on the display of the thermostats or the physical senses of the residents or the caretakers, feeling an increased or decreased temperature in the room. They do not clearly indicate input action or output result. The residents thus remained confused, not knowing what has been done and what to do next to when controlling the heating in the apartment. If the screen could have displayed the current temperature in the room, it could have functioned as feedback on the current status or any actions taken. In addition to showing the current temperature on the screen, the feedback could be provided in various ways. Small colored lights, for instance, could be placed on the thermostat to indicate the operation status, by turning on the red light in the case of an error situation and the green light when it is functional.

The thermostat in Hill Care+ is a standard product which allows numerous functions, such as ventilation, heating and cooling. However, not all the available functions are in use in Hill Care+. Accordingly, deactivated buttons, for instance for adjustment of the fan speed or altering the display option between Celsius and Fahrenheit, do not provide any feedback when users press them. If it is challenging to remove unused buttons, constraints in the design should be implemented to direct the users to interact with the thermostat in a certain way, by marking only the buttons in use, for instance with different colors.

9.1.2 A new design for the thermostat

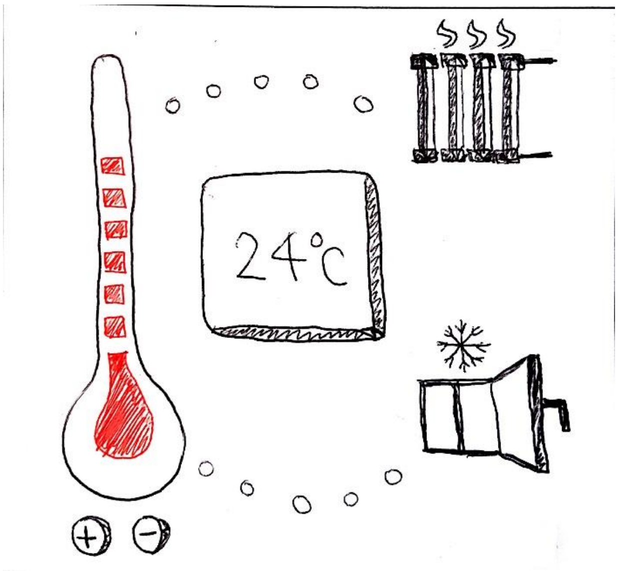

Figure 15. A new design suggestion for the thermostat

By pressing the buttons below the thermometer (bottom left) the users can increase or decrease the temperature. The radiator symbol (top right) indicates that the heating is on, and the backlight of the window symbol (bottom right) will be turned on when the window in the room is open.

Based on necessary improvements discussed in the preceding section I made an alternative design for the thermostat. As shown in Figure 15, the new design has three large figures on the thermostat. The biggest one on the left side is a traditional thermometer. Inside the thermometer, each degree is represented as one block displayed in red color. There are two buttons below the thermometer where users can increase or decrease the temperature by pressing them. When the users adjust the temperature, the block in the thermometer will be displayed indicating how many degrees users have increased or decreased. The total number of blocks indicate the adjustable temperature range in the apartment. In the middle, the current temperature will be displayed on the screen. Right after users have adjusted the temperature, the small LED lights between the thermometer and the radiator symbol will be gradually turned on one by one, indicating that the heating is working. The backlight of the radiator symbol will also be turned on to give the users feedback on the current status. When a window is open in the room, the window symbol will be turned on, and the small LED lights between the symbol and the thermometer will be turned on to warn the users that the temperature will fall.

The new design fulfills numerous design principles. Firstly, the function of the thermostat is highly visible. A figure of a thermometer represents the primary function, and this makes it easy to recognize the purpose of the thermostat. Secondly, the figure and the symbols placed on the thermometer have a high degree of affordance. The symbol of the radiator and the window respectively mock their real appearance as much as possible so that users do not have to learn what these symbols indicate. The buttons under the thermometer will be embossed so that users can recognize that they can push them to adjust the temperatures. Thirdly, feedback will be more apparent on the actions taken, ongoing action and the consequences. Every time there is an action either from users or the environment, such as an open window, the feedback from the action will be indicated on the thermostat by turning on the small LEDs and the relevant symbol, either the radiator or the window. Fourthly, on the thermostat, only the available interaction is placed. By removing unavailable functions, the users can focus on the possible actions only. Lastly but most importantly, it visualizes the conceptual model required for understanding the heating control system in the apartment and aids the users to comprehend it by using the thermostat. More about the conceptual model will be elaborated in the next section discussing interface.

The alternative design of the thermostat is expected to achieve usability goals with this new design of the thermostat. Since there is only one singular interaction available on this thermostat, it is not complicated to learn how to use it. The simplified interaction would cause fewer errors and help the users to complete the task efficiently. Even after not using the thermostat for a long time, it is intuitive to recognize how to use, so the users do not have to learn again. The experience of using the new thermostat might provide the users with a feeling of accomplishment.

9.1.3 Usability attributes for the redesign of the GUI of the BAS

It is necessary to redesign the GUI of the BAS so that any users can utilize them without a high level of technical competence. The set of usability attributes suggested by Nielsen [30] provides criteria for evaluating why the current GUI does not assist the users to achieve their goals.

First of all, the current interface is not easy to learn. There is too much text in the GUI of the BAS, and the presentation of text-based information does not match with the logic of the users to understand the functionality of the system. This low learnability results in low efficiency in completing tasks and achieving goals. If the users do not use the system often, they easily forget how to use it and need to repeat the learning process whenever they use the system again. The user experience gained using the BAS is not satisfactory because of the low learnability and frequent errors resulting from improper use and mistakes caused by the less than ideal design.

Based on the evaluation above, it is important to enhance the learnability of the design of the interfaces, as a highly learnable interface would lead to better efficiency in completing tasks and save time on learning even after users have not used the system for a long time. An improved usability of the system would provide the users with a feeling of accomplishment.

9.1.4 A new design of the GUI of the BAS

This section will present my alternative design for the BAS, made based on the design principles and the evaluation using the usability attributes in the preceding section.

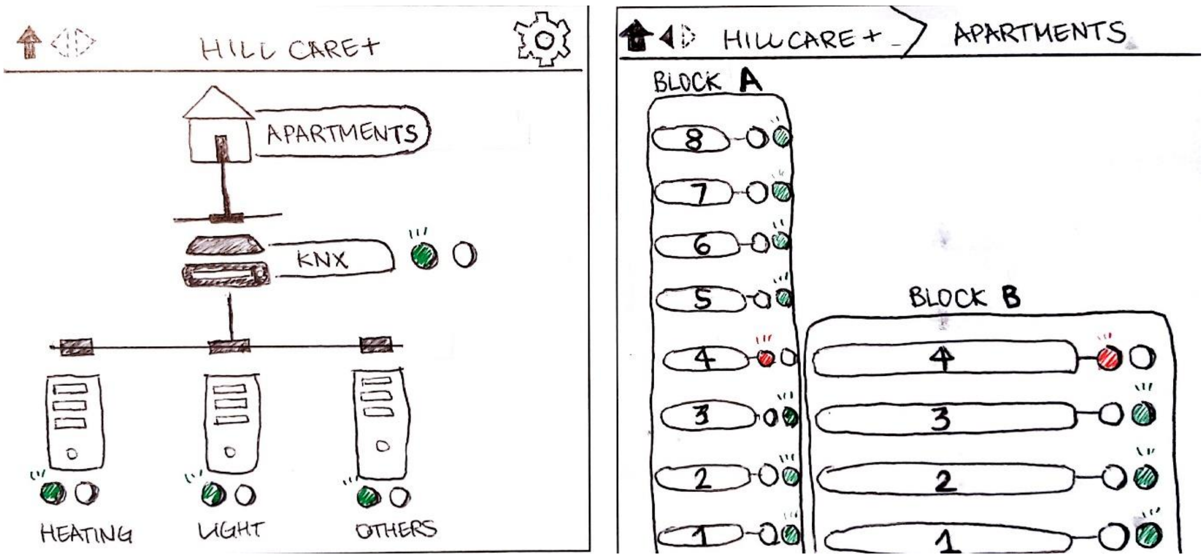

Figure 16. A new design suggestion for the BAS 1

The front page(left) presents a conceptual structure of the control system in Hill Care+. On the apartment level(right) the operation status of each level will be indicated with either a red or the green light.

As demonstrated in Figure 16, the front page represents the conceptual structure of the control system in the BAS. The lights next to each level indicate the current operation status. The caretakers would mostly use the system on the apartment level while the operation team would use it on the deep system level. When the caretakers choose the apartment level (left in Figure 16), two building blocks are displayed indicating whether any irregular situation has occurred on each floor level. On the page of the selected apartment (the top in Figure 17) where an error situation has occurred, the three rooms of the apartment will be presented, and the red light will indicate in which room there is an error. On the room level (the lower left in Figure 17), available categories of smart home technology are presented, listed with the lights next to them indicating the status. When the caretakers select one of the categories (the lower right in Figure 17), the banner expands and shows the conceptual control model with the current status of each component.

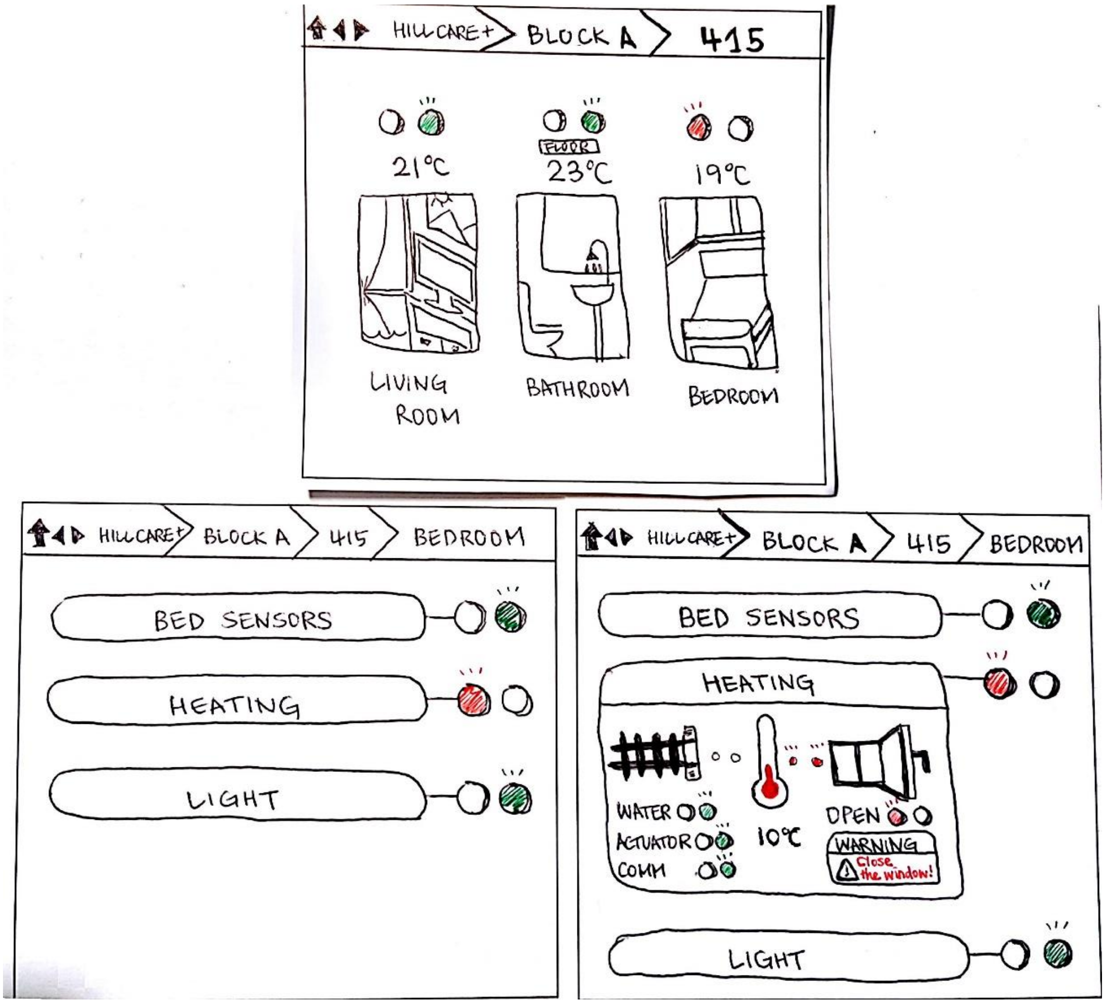

Figure 17. A new design suggestion for the BAS 2

The front page of each apartment (top) will present the rooms where the smart home technology is implemented indicating general status of each room. In each room (left) the type of smart home technologies will be listed up and the colored light will indicate its status. When the users select one of the technologies (right) the banner will be extended to demonstrate the detailed status of each component.

The design principles were used as guidelines for the new designs (Figure 16 and 17). Firstly, the available functions have been made visible by using less text and more images. The information is organized and presented to reflect the actual structure of the system so that the users can easily map between their logic and the control structure in the system. Secondly, similar graphical design, such as the lights placed next to each level and the banners, is used consistently so that so that users can easily learn and make an immediate diagnosis. Thirdly, each banner and icon are shadowed so that users can understand that they are clickable. The icons used imitate the objects in reality, and this does not require the users to learn to perceive what they represent. Fourthly, only available functions are presented on each page so that users can avoid making errors by selecting incorrect options. The purpose of the limited number of interaction is to constrain the system to only certain options in order to guide the users to interact with the system properly without making mistakes. However, this constraint might entail unnecessarily numerous clicks to reach the option that the users want. Fifthly, every time the users go up or down a level in the BAS, the header is updated showing the path, indicating which level users are exploring in the BAS. The updated headers function similarly to breadcrumbs on a website which allows the users to keep track of the location of the page on the website. Lastly, the suggested design integrates both the conceptual model and the troubleshooting process. This will be discussed in detail in the next section discussing interface.

Concerning the usability goals, the new design will assist the users to learn the BAS relatively easily compared to the current design in use. The breadcrumbs on the head section will help them to navigate the menus, and the interface, where only available interactions are presented, will assist them to not make errors. Even though the users are required to go into several levels to reach the component level in the apartment, this would be expected to be more efficient than looking for necessary information in the flood of text in the current design. As there are no special skills required for using the new design, it would not take long to learn the system, even after not using it for a while.

9.2 Interface

As Norman maintains [32], a good conceptual model becomes more important when things do not work. It is because the users who have a good conceptual model can find the available options and decide what actions to take to improve or change the current situation based on their understanding of the system. Conceptual models are essential in this sense to understand and predict the behavior of the systems which is a core competence for retaining control over the technology. Without conceptual models, users cannot comprehend the cause, the effect of the action and especially what to do next when things go wrong. It is the conceptual model which would guide the users to see what has happened and assist them in correcting the situation or recovering from the errors. Good conceptual models are missing in numerous devices in Hill Care+. The absence of a conceptual model for heating control aggravated the complexity of the case along with the malfunction of the heating installation. This section will discuss what conceptual models the smart home technology in Hill Care+ requires and how to implement them in the continued presentation of the new design suggestions.

9.2.1 Building and implementing the conceptual model for the heating control

The understanding needed for the heating control in the apartments of Hill Care+ is twofold. Firstly, the residents should know that it is the thermostats which control the temperature in the apartment. Contrary to a traditional heating system, the thermostats are at the center of the temperature adjustment, not the radiators. Secondly, they need to recognize the connection between the thermostats, the radiators, and the window contacts. The residents who are used to ventilating the room while the radiator is on should understand that they cannot do the same in Hill Care+. When the window is open, the thermostat in the room should indicate this, and the temperature will fall.

The biggest challenge that the elderly inhabitants could face in interacting with the thermostat might be a fear of making mistakes. Without knowing why and what to expect the users could feel apprehensive about pressing buttons on the thermostat. Both verbal and written instructions are required to build a good conceptual model of temperature control. Abstract contents are usually more easily understood when they are visually illustrated. Compared to a short verbal instruction, a visualized instruction could be referred to anytime the residents need and this could improve the learnability. As such, the conceptual model required for the thermostat in Hill Care+ is a highly visualized and intuitive one, integrated into the design. An exemplary conceptual model and its implementation were illustrated in the previous section (Figure 15).

The large and visible figure of the thermometer and the digital display of the current temperature in the middle of the thermostat help the users to relate it to the temperature control, and the symbols of the radiator and the window indicate a relationship between the temperature, heating, and ventilation. This visible connection between them with LED lights will contribute to establishing a conceptual model for heating control in the apartment. When the temperature is adjusted using the buttons placed under the thermometer, the number of red blocks displayed inside the thermometer will give the users an immediate feedback on the adjustment action and the total number of red blocks will indicate the available temperature adjustment range. The LED lights between the radiator and window symbols and the thermometer turn on whenever there is an action between them, and this will reinforce the conceptual model confirming what the users have understood on the relationship between those three elements.

9.2.2 Building and implementing the conceptual model for the BAS

Conceptual models can be constructed through experiences, training, and instruction [32]. Through the interactions with the BAS and the experiences from managing the smart home technologies implemented, the caretakers have built a conceptual model and developed work practices based on it. They now understand what triggers various alarms and how to manage them both in the apartments and in the BAS, which indicates that they have control over the smart home technology in the apartment.

The conceptual model that the caretakers have constructed should be stored and transferred for the accumulation of their experience and expertise. Their conceptual model is highly valuable as it is not merely the understanding of how the smart technology works in Hill Care+, but rather a combination of both the conceptual model and the work practices. These work practices entail actions to be taken in the case of an error situation, which the BAS does not tell them. Such well-established conceptual models of the caretakers should be documented so that they could be applied to any other error situations or transferred to new caretakers. Thus, it is highly recommended to keep a record of the already established conceptual model, for instance by making a workflow chart which presents each process to avoid false alarms, handle the alarms and reset the alarm warning in the BAS. Ideally, a troubleshooting guide for the building management should have been integrated into the BAS, guiding the users to understand and correct the error situation so that they maintain control over the technology even in an error situation.

The new design of the GUI of the BAS (Figure 16 and 17) reflects the structure of the system to assist the users in building a good conceptual model. The new design aims to provide a reflective structure which explains to the users how the system works and is constructed. By following the menus from the building level to the component level in the apartment, users will gain ideas of how the structure is constructed and what actions to take on which level. However, as in the current design in use, the new design does not offer many options to alter the status of each component. It rather provides a better presentation of available information with a conceptual model integrated and a reflective structure equipped.

As the layout and the structure of menus are organized in the same way as the control system is built, the users can learn the structure of the system by navigating the menus. Since the menus are divided into levels which constitute each control hierarchy in Hill Care+, the users can find out what actions to take on each level if any error occurs. This type of interaction, navigating the layered structure of the system could function as an integrated step-by-step guide to facilitate error detection in the troubleshooting process.

9.3 Intermediate

Edwards et al. [14] emphasize that it be essential to ensure a good fit between the user needs and the system capabilities before adopting a top-down manner in designing infrastructures. Compared to the surface and interface approaches which accept the infrastructure as it is and attempt to mask the underlying layers or expose the infrastructure to the users by building a conceptual model, the intermediate approach, such as the top-down manner, seeks to affect the infrastructure based on the identified user needs.

Hill Care+ is constructed in the top-down manner identifying the user needs first, transforming them into functional requirements and pushing them into the infrastructure. However, this approach could not provide a good fit between the user needs and the system capabilities. The users could not build a conceptual model which enables them to match the underlying abstractions of the infrastructure with the behavior of the system, which in turn diminished the users' power to control the smart home technology. This section will discuss how to conduct the top-down manner successfully in upcoming Care+ projects by examining the causes of unsuccessful top-down approach in Hill Care+.

9.3.1 Causes of unsuccessful top-down manner in Hill Care+

Coming Care+ projects would also adopt the top-down manner by identifying the user needs first and push them down to the infrastructure. However, as the case of Hill Care+ demonstrated, it is important to make a good fit between the identified user needs and the capabilities of the system.

There are two causes of the misfit between the user needs and the system capabilities in the case of Hill Care+. The first cause is the absence of a conceptual model that the users establish by interacting with the system. As the users cannot fully understand what the system does it is hard for them to complete their tasks. After establishing an understanding of how the system works, the users should be able to decide the configuration so that they can use the system in a way of their preference.

The second cause of unsuccessful employment of the top-down manner is the absence of alignment. The alignment indicates to coordinate the system behavior so that it performs as the users prefer. By doing so, the users can align their conceptual model with the abstractions of the infrastructure and bridge the gap between the abstractions and the behavior of the systems. In Hill Care+ this process was not fully conducted, urging the users to accept and follow the configurations that other actors or stakeholders set. When the system behaves as the users expect, it is much easier for them to perform tasks to achieve the goal. The conceptual model can be addressed on the surface and interface level, but the alignment should be conducted on a deeper level where changes could be made in the infrastructure.

9.3.2 Power distribution

The cause of misalignment in Hill Care+ could be found from the fact that the people who made the decisions on the use settings are not the users themselves. In the field study, it was not discovered who decided the standard temperature of the apartments in Hill Care+. It is also unknown who decided the temperature adjustment range, positive or negative three degrees. As the heating is centrally controlled in Hill Care+, it could be challenging to reflect every preference of all residents and decide a unanimously agreed upon standard temperature. A solution for this might be an advanced smart home technology which allows individual adjustment to an extended degree, but as discussed in the previous chapter the budget for Care+ projects is often not large enough to procure such an advanced system. Rather, a high degree of flexibility in the system control was suggested as an alternative solution to assist the temperature control.

User participation in the decision of system behavior could be understood as a way to improve the flexibility of the system behavior. Even though the users cannot fully control the heating system, as long as they have an opportunity to influence the settings of the system, this could be understood as an indirect form of control, which could enhance the flexibility of the system. Although the residents were not included in the early process of configuration, they should be able to have a voice to influence the settings of the system behavior later, while they are living in the smart home. This is essential to make them feel like they have a power of control over their home. If the users cannot change the configuration of the system directly, they should at least have the authority or power to negotiate the rules of the system behavior so that the system works according to their preference.

A seasonal workshop on the indoor temperature, where the residents and the caretakers are present, could be held to provide a collective feedback on the standard temperature and the adjustment range. Such collective feedback could be delivered to the operation team in the UWF. From the perspectives of the building operation, such open communication could result in a more complicated situation. However, it is not the building operators or technicians who stay in the building and use the implemented technology the most. It is the residents and the caretakers who spend the most time in the building and interact with the technology the most.

Through such a power distribution process, the users could get more control back by aligning their conceptual model, the abstractions of the infrastructure, and its behavior.

9.3.3 User testing during the trial operation

A way to align the conceptual model of the users and the behavior of the system, even early the process, is numerous rounds of user testing during the trial operation. The user testing is necessary in another technical aspect. After individual components and systems are produced, they should all be implemented in the smart home. The composite of numerous single interactions from multiple devices could cause a negative interaction effect, and such composite effect is a special feature of smart homes compared to other singular digital products. The negative consequences of the interaction effect should be minimized during the trial operation by testing various configuration options and finding the best one for the end users of the smart home technology. When the production process is completed, major physical changes cannot be made during this period. The digital products, however, can be modified if they do not fulfill the specified requirement.

Testing with the end users, super users and the technicians present, could coordinate and configure the heterogeneous devices of the smart home technology to make them suit the preference of the users. This is an important process to give the users control over the technology implemented in the smart home. Although they cannot directly change the configuration of the system, they should have a voice and be able to influence the behavior of the systems. Such user participation and user testings would be key factors to make the top-down manner successful in upcoming Care+ projects and keep the focus on users having the power of control over the smart home technology.

9.4 Deep

The most fundamental way to increase the autonomy of the smart home users is to ensure that the infrastructure is designed for users early in the process. The user, interaction, and the user experience has not been taken much into consideration in the design of technical infrastructure. However, as studied in the case, it is a bit late to address the challenges found on the surface and interface layer after the production and the installation is completed, as the available actions do not reach deep enough to make direct changes in the infrastructure. Thus, it is important to keep the design and human aspects in mind early in the design process. This section will present a new design process for smart homes where users, interactions, and the user experiences will be taken into account in the early design.

9.4.1 The initial step of the new design process: specification of the standard requirements

A new design process as described in Figure 18, starts from the deep level where designers of technical infrastructure and Human-Computer Interaction (HCI) can cooperate to establish a set of assessment criteria to ensure that the smart home technology would provide the users with positive user experiences. This is done when the standard requirement for a Care+ building is specified with details.

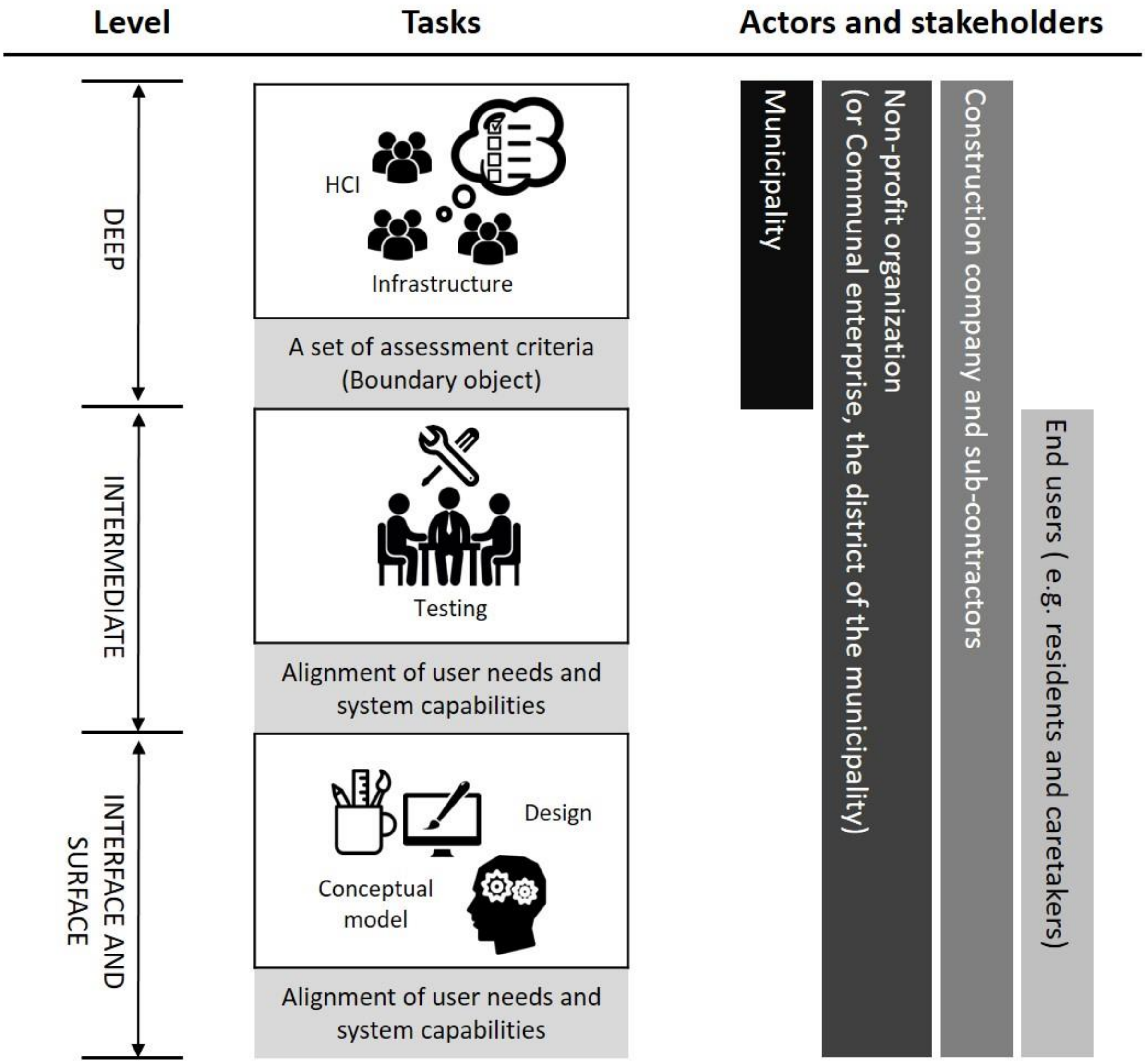

Figure 18. Suggested design process[38]

The standard requirement entails the minimum functional requirements, stating what the product or the system should do. Making the functional requirements has been the domain of the infrastructure designers. However, HCI experts can cooperate with the infrastructure designers by adding non-functional requirements, such as usability or support requirements to take human factors into consideration. This is important especially in designing the surface and the interface level, which the end users would interact with the most. The role of the HCI

[38] Icon made by Freepik and SimpleIcon from www.flaticon.com

experts in this process would be to interpret well-known HCI methods and tools, such as the design principles and the usability goals, into non-functional requirements.

The Deep approach is the most fundamental approach as it ensures that the infrastructure is designed for the users from the very beginning of the design process. By addressing the design concerns at the deepest level where the infrastructure is designed, the basis of users' power to control the smart home technology could be established.

The established functional and non-functional requirements would perform as a set of assessment criteria in both the production of smart home technology and testing during the trial operation. They can become boundary objects for the actors and stakeholders in the Care+ project through which the professionals from the various disciplines can communicate and understand each other. The sub-vendors of the smart home technology have used the functional requirements to confirm that all the functionalities are developed and implemented in the deliverables. The non-functional requirements would also help the sub-vendors and the construction company to consider the aspects which influence the shaping of the user experience early in the production process. It is also important that the construction company ensures that all the deliverables are tested and fulfill all the requirements before they are implemented in the Care+ building.

9.5 Summary

This chapter discussed concrete actions to give the users back control over the smart home technology. As demonstrated in the suggestions for the new design process, it is important that design aspects which influence the user experience should be taken into consideration early in the infrastructure design. In the fundamental approach which engages deeply with the infrastructure, it was suggested to make a set of assessment criteria which could function as boundary objects among various professionals. This is to ensure a good design which could provide the user with a feeling of control and mastery over the smart home technology.

However, if it is challenging to engage with the infrastructure at the deep level, the intermediate approach should be taken to enhance the user control over the smart home technology. In the intermediate approach, it is necessary to conduct a successful top-down manner, which is expected to be adopted in the coming Care+ projects. For a successful employment of top-down manner, user participation in the decision of the system behavior and user testing during the trial operation are the key actions to align the user needs and the system behavior. Such alignment could ensure a good fit between them and support the users to maintain control.

A good design of the surface and the interface layer is critical for the users to build a good conceptual model. A sound understanding of the systems is an essential resource for the users to gain control over the technology, because it is conceptual models which enable them to comprehend what is going on, see the possible options, and take the necessary actions to improve the use situation or recover from errors.

10 Conclusion

This study was started in order to analyze the causes of users' diminished control when using smart home technology and to suggest solutions for giving control back to the users. A case study was conducted in a Norwegian care home for the elderly, Hill Care+, and the malfunctions in the heating system was chosen as the case to be studied. The diminished power of user control over the smart home technology became more apparent when the heating system did not function properly. After the residents had reported about cold apartments, the error detection and troubleshooting process was initiated to find the causes of insufficient heating in Hill Care+. This process took almost two years and revealed the complexity of using the smart home technology built upon the infrastructure of Hill Care+.

During the reconstruction of the history of the case, a complex web of actors and stakeholders and control system in Hill Care+ was revealed. A problem which seemed simple on the apartment level turned out to be a large-scale malfunction which required a comprehensive investigation, examining the underlying heating infrastructure of Hill Care+. The diminished power of control was not caused merely by the imperfectly designed thermostat or the Graphical User Interface (GUI) of the Building Automation System (BAS), but by consecutive problems stretched across underlying layers in the heating infrastructure. Such complexity in the case required a framework to address both Human-Computer Interaction (HCI) and infrastructure matters. Thus, the concepts and the framework of Edwards et al. [14] which addresses infrastructure problems in HCI, were adopted to detect what challenges the heating infrastructure caused for users in maintaining control over the smart home technologies, and to figure out how to address them in the four layers of infrastructure in Hill Care+.

10.1 Answers to the research question

Three challenges - constrained possibilities, interjected abstractions, and unmediated interaction - were detected as the causes of why the users lacked control over the smart home technology when the heating infrastructure malfunctioned in Hill Care+. Those three challenges answered the first research question of this study, why the smart home users lose control over the technologies, forming the basis for further layer analysis to answer the second research question, how to enhance users' power of control over the smart home technologies.

The layer analysis consists of four different approaches; *surface, interface, intermediate and deep*, divided with regards to the depth of engagement in the infrastructure. In the surface and interface approaches, the design and the usability of the thermostat and the BAS was analyzed. After that, a set of design suggestions was presented in order to demonstrate alternative designs which could assist the users to maintain control with the help of a good conceptual model integrated into the design. In the intermediate approach, the top-down manner adopted in Hill Care+ was evaluated to make it more successful in upcoming Care+ projects. The importance of user participation and user testing both in the production process and trial operation was emphasized to ensure a good fit between the user needs and the system capabilities. In the deep approach, more fundamental actions were suggested at the beginning of the design process to transform the user needs both in functional and non-functional requirements, so that professionals from various domains use them as boundary objects to communicate and work through, in order to design for a good user experience, including user control.

Therefore, based on the heating malfunction case in Hill Care+, the power smart home users have to control smart home technologies is diminished because of constrained technological possibilities, interjected abstractions reflected on the applications built on top of the infrastructure, and unmediated interactions when the infrastructure of smart homes malfunctions. The infrastructure of smart homes, studied in Hill Care+, entails a highly complex web of various actors, stakeholders and technology. Considering the complexity of smart home infrastructure of Hill Care+, the framework by Edwards et al. provided a systematic way to address three identified challenges on four layers of different engagement levels. The most recommended solution is to take the user experience and usability into consideration early in the design process, by reflecting them in the requirement specification and make use of them more proactively in the production and evaluation process. User participation is also essential to align the user needs and the system functionalities, because such alignment would contribute to give the users control over the smart home technologies. Good surface design and a good conceptual model would also assist them to maintain control.

10.2 Contribution

There have not been many studies which address challenges in designing for the user experience both in the domain of infrastructure and HCI. There are numerous studies about smart home technology, but not many of them focused on users' diminished control in the context of an error situation and troubleshooting. This study has attempted to provide a way to analyze a complex error situation by dividing the infrastructure into several layers to detect the problem area, and find solutions for improvement of the situation by applying the framework of Edwards et al. [14]. My study extended the work of the *Homework* project [29] by applying the four approaches of Edwards et al. and reflecting the perspectives of both the end users and super users in identifying the infrastructure challenges in HCI. Instead of making direct changes in the infrastructure, as the Homework project did, I made design mockups for thermostats and the BAS and suggested a new design process reflecting the layer analysis to provide practical design implications for upcoming Care+ projects.

When I initiated the study, I assumed that the users' diminished control might be caused by the improper design of the interface. However, during the case study of the heating malfunction in Hill Care+ it was revealed that the user experience challenges, such as the diminished control, are not merely caused by the surface design, but also by problems from underlying layers in the infrastructure. Therefore, I extended the scope by examining the four layers of infrastructure in Hill Care+, where each layer entailed different actors, stakeholders and technology that controls and supports the infrastructure of the smart home. This broader scale of investigation could provide a deep insight into causes of users' diminished control and how to assist the users to maintain control over the smart home technologies.

However, the study could have acquired more diverse perspectives and comparable data if I could have followed other Care+ projects along with Hill Care+. Even though they do not have the exact same problem area in the heating control, they might indicate how the initial design evolves and changes in relation to maintenance, and how the layers of their smart home infrastructure influence the user control over the smart home technologies in the apartments.

10.3 Future research

I observed that each actor and stakeholder is often bound to one certain layer in the infrastructure of Hill Care+. Their responsibilities usually reside in that layer, but they were sometimes extended across other layers to assist other actors or stakeholders during the process of troubleshooting. It took some time for them to be familiar with the new layers, but they could manage after a while and assist the troubleshooting on a layer where they originally did not belong. Future research could focus on the dynamics of the responsibilities attached to the layers in the infrastructure, and study design which enables one single end user to extend control over the multiple layers of the infrastructure in their private homes, in order to attain an even greater autonomy and control over the technologies, even in an error situation.

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Glossary

English	Norwegian
(Requirement) specification	Kravspesifikasjon
Bid	Anbud
Building Automation System (BAS)	Sentraldriftsanlegg (SD-anlegg)
Care home	Omsorgsbolig
Care+	Omsorg+
Caretaker	Husvert
Cooktop	Platetopp
False alarm	Falsk alarm
Flood guard	Vannalarm
Home caregiver	Hjemmepleie
Home care service	Hjemmetjeneste
Maintenance	Vedlikehold
Municipal enterprise	Kommunale foretak
Municipality	Kommune
Non-profit organization	Ideell stiftelse
Nursing home	Sykehjem
Operation team	Driftsavdeling
Procurement	Innkjøp/anskaffelse
Radiator	Radiator
Request for tender	Konkurransegrunnlag
Residence guidebook	Beboerperm
Service department	Ettermarkedsavdeling
Stove guard	Komfyrvakt
The building owner / the client	Byggherre
The design and build contractor	Totalentreprise
The Norwegian state housing bank	Husbanken
The sub-contractor	Underentreprenør / underentreprise
Trial operation	Prøvedrift

Appendix 1. Informed consent form

Forespørsel om deltakelse i forskningsprosjektet

Gjør smarthus enklere å bruke

Bakgrunn og formål
Prosjektet er en mastergradsstudie ved Universitetet i Oslo. Hjemmet vårt har blitt utstyrt med mer og mer avansert teknologi, men dette betyr ikke at teknologien har blitt enklere å bruke. Prosjektet går ut på å utforske hva som gjør teknologien enkel eller vanskelig å bruke, og har som formål å komme med forbedringsforslag til fremtidig design.

Hva innebærer deltakelse i studien?
Under prosjektet vil de som bor eller jobber for Omsorg+ blir observert eller intervjuet for å kartlegge bruk av nåværende smarthusteknologi i huset. I designprosessen vil aktører i Omsorg+ eller eksperter i relevante områder bli spurt om å delta i noen runder med intervjuer, observasjon og brukertester. Spørsmålene vil omhandle for eksempel, brukeropplevelse, nåværende driftssituasjon og meninger om forbedringsforslag i designet. Under datainnsamling kan data registreres i form av notater, lydopptak eller bilder. Bildene som tas under deltakelsen skal ikke inneholde detaljer som kan brukes til å identifisere deltakeren.

Hva skjer med informasjonen om deg?
All data vil bli behandlet konfidensielt. Kun forfatteren og veileder vil ha tilgang til innsamlet data. Prosjektet skal etter planen avsluttes 1.mai 2016. All lydopptakene som blir samlet under prosjektet skal slettes etter prosjektet er ferdig. Bildene som blir tatt uten personlige detaljer kan bli publisert.

Frivillig deltakelse
Det er frivillig å delta i studien, og du kan når som helst trekke ditt samtykke uten å oppgi noen grunn. Dersom du trekker deg, vil alle opplysninger om deg bli anonymisert. Dersom du ønsker å delta eller har spørsmål til studien, ta kontakt med *Jeongyun Choi Doksrød, (telefonnummer)* eller veileder *Tone Bratteteig, (telefonnummer)*.

Samtykke til deltakelse i studien

Jeg har mottatt informasjon om studien, og er villig til å delta i dette forskningsprosjekt.

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Dato/Sted   Signatur

Appendix 2. Interview guide

Spørsmål

Solid construction / ettermarkedsavdeling

1. **ROLLE OG ANSVAR SOM HOVEDENTREPRENØR**
   Hvilke er roller og ansvar har Solid construction som hovedentreprenør for Hill Care+?
   a. Før bygging
   b. Under bygging
   c. Etter bygget er utlevert – ETTERMARKEDSAVDELING

2. **DESIGNPROSESS (KONSEPTDESIGN FOR BYGGET)** – BARE HVIS DET ER RELEVANT!
   Hvordan gjennomfører en hovedentreprenør en designprosess for formålsbygg?
   a. Etter Solid construction har fått oppdrag fra the UWF hva er etterprosess?
   b. Hvordan samarbeider dere med underentreprenør?
      i. Designprosess (konseptbygging)
      ii. Kommunikasjon
      iii. Møte kravene i kravspesifikasjon
   c. Hvordan beboernes behov eller krav er reflektert I prosessen?
   d. Hvis det finnes ekspertgruppe eller beboergruppe (fokusgruppe) for brukeropplevelse, hvordan og når deltar de i designprosessen?

3. **ERFARING OG KOMPETANSE I UTBYGGING AV SMARTHUS/FORMÅLSBYGG**
   Hvilken erfaring og kompetanse har Solid construction fått under utbygging av smarthus som Hill Care+?
   a. Hva gikk bra?
   b. Hva var utfordringer under bygging?
   c. Hva kan forbedres i utbygging av fremtidige Care+-prosjekter?
   d. Prøvedrift
      i. Hva er formålet til prøvedriftsperiode før bygget er utlevert?
      ii. Hvordan gikk det med prøvedrift i Hill Care+?
      iii. Hvilke muligheter har beboeren til å delta i prøvedriftsperiode for å teste teknologien i huset?
         a) Hva er fordel med deltakelsen?

4. **REKLAMASJONSPROSESS**
   Hva er nåværende aktuelle saker hvor dere jobber tett med Hill Care+/the UWF?
   a. Bekreftelse av strukturen som jeg har beskrevet
   b. Generell reklamasjonsprosess
      i. Etter at Solid construction har mottatt reklamasjonssak hvordan undersøker og bekrefter dere at dette er en reklamasjonssak? (Hvordan finner og bekrefter man en feil som er tilmeldt?)
      ii. Hvordan samarbeider dere med underentreprenør i reklamasjonsprosess?
   c. Hvordan har dere håndtert reklamasjonssak i varmeanlegg? (historie)