Universität Stuttgart

Designing Smart Home Appliances Displaying Non-Urgent Everyday Information

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Zusammenfassung

Im Zeitalter des Smart Homes verändern sich die Wohnumgebungen erheblich. Smart Home-Technologien bieten den Benutzern neue Möglichkeiten um intelligente Haushaltsgeräte zu steuern oder zu überwachen. In naher Zukunft wird es notwendig sein, dass intelligente Haushaltsgeräte ihre Benutzer über Alltagsinformationen zu Hause informieren, z. B. über den aktuellen Status des Haushaltgerätes. In früheren Arbeiten wurde bereits die Benutzer-Akzeptanz von Benachrichtigungen zu Alltagsinformationen im Smart Home untersucht. Bisher wurde jedoch nur wenig untersucht, in welcher Form die Alltagsinformationen an die Benutzer weitergeleitet werden sollen.

In dieser Arbeit wird untersucht, wie intelligente Haushaltsgeräte, welche Alltagsinformationen an den Benutzer übermitteln konnen können, gestaltet werden sollten. Diese Dissertation enthält die Ergebnisse zu neun durchgeführten Benutzerstudien, die entweder den Nutzungskontext sowie die Benutzeranforderungen für solche Haushaltsgeräte analysieren oder welche die entwickelten Beispielanwendungen evaluieren. Hierbei konzentriert sich die Untersuchung darauf, welche Modalitäten, Standorte und Informationsstrategien verwendet werden sollten, um Alltagsinformationen in einem Smart-Home an die Benutzer zu übermitteln. Darüber hinaus wird betrachtet, wie solche Haushaltsgeräte gestaltet werden sollten, sodass sie zu den komplexen Routinen im Alltag der Benutzer passen. Darüber hinaus wird untersucht, welche Evaluierungsmethoden für die

Bewertung von intelligenten Haushaltsgeräten geeignet sind, welche Alltagsinformationen darstellen können. Der Beitrag dieser Arbeit enthält Einblicke in Vor- und Nachteile für verschiedene Bewertungsmethoden sowie Gestaltungsrichtlinien für die Entwicklung von intelligente Haushaltsgeräten, welche alltägliche Informationen an den Benutzer übermitteln können.

Abstract

In the smart home era living environments are significantly changing. Smart home technologies offer new opportunities for the users to control or monitor their smart home appliances. In the near future, smart home appliances may need to inform their users about everyday home details, such as their current states. Previous work already investigated the users' acceptance of smart home notifications presenting everyday information. However, little research has been done on how users can access the everyday home information.

This thesis examines how smart home appliances presenting everyday home information should be designed. It reports about nine user studies investigating either the context of use or the user requirements for smart home appliances presenting everyday home information or evaluating the design solutions for the investigated research probes. As a result of this, we focus on which modalities, locations and information strategies should be used to convey everyday information in a smart home context. In addition, we study how smart home appliances cab be designed to suit to the users' complex daily routines. We further investigate which evaluation methods are suitable for evaluating of smart home appliances presenting everyday home information. This thesis contributes insights into advantages and disadvantages for various evaluation methods and design guidelines for the development of smart home appliances that present everyday home information.

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Table of Contents

Please consider before reading:

To keep this thesis consistent, the scientific plural is used in this thesis.

1

Introduction

Through the smart home, living environments are significantly changing. Smart home appliances will not only be connected, but they will also connect with their users. Today, many users are using a large number of smart home appliances, including smart speakers, security systems, smart heating, robotic vacuum cleaners, or smart weather stations. In the near future, we assume that users will regularly use a constantly increasing number of smart home appliances to monitor or control them.

Smart home appliances have to provide consumers with a variety of information about their homes regularly. A robotic vacuum cleaner, for example, must inform users when its dust bag needs to be replaced, or a washing machine must inform users when the laundry process is complete. Previous work investigated the acceptance of home reminder systems that could use notifications to present everyday information [114, 186, 187], but it was unclear how these everyday home information should be communicated to users.

Mobile notifications are an established communication channel to present a large amount of information to the users, including incoming messages, upcoming appointments, or available updates [147, 161]. However, a body of work shows that the number of mobile notifications that users receive daily overwhelms them. Further, notifications are causing negative effects, such as distractions, interruptions from current tasks, and even stress [11, 42, 88, 109]. These adverse effects will be amplified if smart home appliances used mobile notifications on users' smartphones to display everyday home information to them.

It is necessary to consider the already overwhelming amount of notifications users receive when designing smart home appliances that can alert them about everyday home information. Current technologies enable many options to present information in the home environment, e.g., by using ambient information systems. However, smart home appliances must be designed for domestic use [52] and fit within the home environment.

> "I don't think that simple home appliances – stoves, washing machines, audio and television sets – should look like Hollywood's idea of a spaceship control room. They already do, much to our consternation."
> *(Don Norman [134])*

Designers for smart home appliances must be aware of the complex routines within the home [52] and consider the existing infrastructure [179]. Therefore, it is essential to explore the design space, investigate and evaluate research probes for different smart home appliances to be able to derive design guidelines for the design of smart home appliances displaying everyday home information. Therefore, the research probes should investigate different kinds of information and different strategies for delivering everyday home information to the users, such as whether a smart home appliance should notify its users proactively or only upon when the users request for it.

1.1 Research Questions

This thesis explores how smart home appliances should be designed to present everyday home information by investigating research probes for novel smart home appliances. The exploration is based on six high-level research questions (RQs). Table 1.1 lists the research questions (RQs) that are investigated in this thesis.

A thorough understanding of the methods for evaluating smart home appliances appliances is an important basis for our exploration. Advances in technology enable us to use augmented reality (AR) and virtual reality (VR) for rapid prototyping and collecting feedback for early prototypes. However, since it is currently unclear whether the evaluation method influences the investigation results, it is important to study which methods are suitable for evaluating early prototypes of smart home appliances (RQ1). To be able to choose the right evaluation method for an investigation, it is important to understand their advantages and disadvantages (RQ2).

It is important to examine how smart home appliances can display home information and how they can make users proactively aware of everyday home information. First, it is critical to investigate which modalities are suitable for making users proactively aware of home information when designing smart home appliances displaying home information (RQ3). Also, it is important to investigate which locations in the home are suitable to display everyday information (RQ4). Further, it needs to be examined whether home information should be persistently displayed, though the users can perceive continuous changes in the information or whether the users should be only made aware of the information based on specific events such as actions that need to be accomplished (RQ5).

It is also essential to investigate smart home appliances where the user initiates the interaction with the smart home appliance. In this case, appliances present the information unobtrusively or display the information only to the users based on a user's request (i.e., user-poll mechanism). Hereby, it is important to study how such smart home appliances can be designed to fit into the users' routines (RQ6).

Research Question	No.	Chapter
Understanding evaluation methods regarding smart home appliances		
What are the suitable evaluation methods to study smart home appliances informing the users about everyday information?	(RQ1)	Chapter 3
What are the advantages and disadvantages of different methods for the evaluation of smart home appliances?	(RQ2)	Chapter 3
Making users proactively aware of everyday home information		
Which modalities are suitable to inform users about everyday information in the era of the smart home?	(RQ3)	Chapter 4, Chapter 6
Which locations are suitable to display everyday information in a smart home?	(RQ4)	Chapter 4, Chapter 5
Should smart home information be persistently displayed to the users or be made aware of specific events?	(RQ5)	Chapter 5
User-initiated interaction with smart home appliances presenting everyday information		
How should smart home appliances be designed to fit into the users' routines?	(RQ6)	Chapter 6, Chapter 7

Table 1.1: Overview about the RQs that are investigated in this thesis.

1.2 Methodology and Evaluation

> "Design presents a fascinating interplay of technology and psychology, that the designers must understand both."
> *(Don Norman [134], Chapter 1, p. 7)*

Designing, developing, and evaluating novel applications is an essential part of human-computer interaction research. In 1985, Gould and Lewis defined three key principles for the development of usable and easy to use computer systems [72]: (1) focusing early on the users by studying the characteristic of the users and understanding the context of use, i.e., the user types, their tasks, the resources and

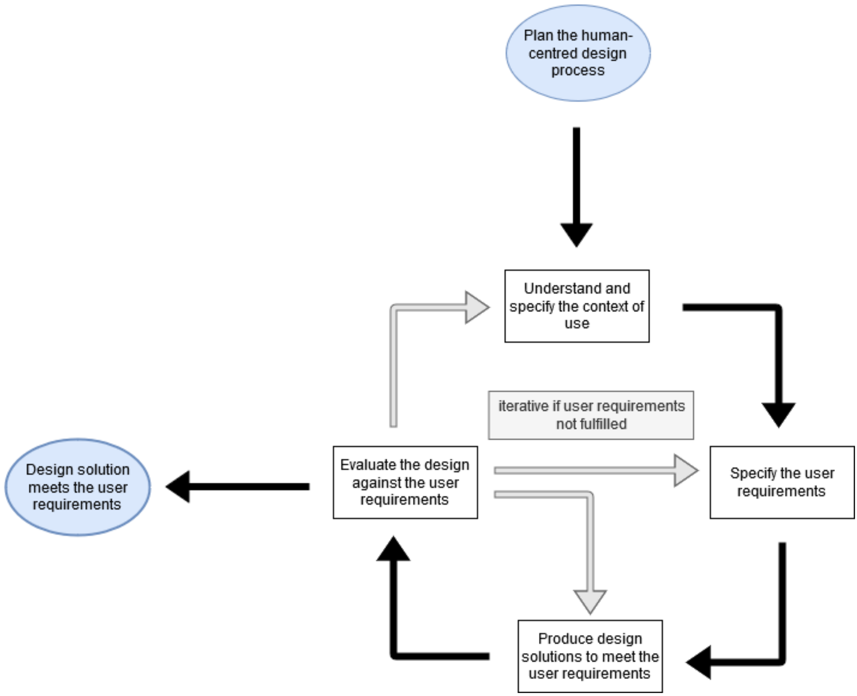


Figure 1.1: The human-centered design process consists of the following phases: specifying the context of use, specifying the user requirements producing design solutions as well as evaluating the design solution against the user requirements until all user requirements are met by the developed design solution

the environment (2) using empirical measurements observe the performance and reactions of intended users and (3) applying an iterative design by repeating the steps of design, test, and measure as often as necessary.

The research conducted in this thesis is inspired by the human-centered-design process (IS0 9241-210) [63]. To investigate the research questions different research probes will be developed and evaluated. The human-centered design process (see Figure 1.1) consists of the following iterative four phases [63, 182]:

Understand and specify the context of use: During this step, the context of use is studied by taking into account the environment, the tasks, and the intended users. The context of use can be investigated using different techniques, e.g., by conducting observations, interviews, focus groups, or online surveys. The context of use is specified based on the observations.

Specifying the user requirements: Afterwards, the intended system's user requirements are specified.

Produce design solutions to meet the user requirements: The design solutions will be developed to meet the user requirements. These design solutions can be prototypes with different fidelity, e.g., with a low fidelity such as paper prototypes.

Evaluate the design against the user requirements: The developed design solution will be evaluated, e.g., by conducting studies or applying heuristic inspections [132]. If the evaluation reveals that the prototype fulfills the user requirements specified for the developed system, the iterative process ends. If the prototype did not meet the user requirements, the steps are repeated until the user requirements are fulfilled. With this, it is important to note that not all phases from the human-centered design process need to be repeated, e.g., by revising the produced design solutions.

1.3 Challenges and Research Contributions

By investigating the research questions (RQs) listed in Table 1.1, we make the following contributions: In Chapter 3, we compare five evaluation methods for studying smart home appliances. Here, we contribute that empirical methods can significantly affect the outcome of user studies indicating that results from studies using different empirical methods might not be comparable. In Chapter 4, we conduct an exploration of the design space of smart home notifications. Here, we contribute an understanding of the relation between the information's urgency and the used modality and location for the representation in the home. In Chapter 5, we study a smart plant system as a research probe informing the users proactively about the plant's current state. We contribute a systematical analysis of different strategies to present non-urgent smart home notifications.

In Chapter 6, we investigate calendar applications as research probes. We contribute an understanding of how smart home appliances giving information that users can manually check should be designed to fit the users' routines. In Chapter 7, we observe how novel users integrate smart speakers by conducting a four-week in-situ study. We contribute implications to improve the design of future smart speakers. An overview of all research probes that were developed and investigated in the context of this thesis is displayed in Table 1.2.

1.4 Research Context

The research that led to this thesis was conducted from 2015 to 2019 in the Institute of Visualization and Interactive Systems at the University of Stuttgart in the Department of Socio-cognitive systems under the supervision of Prof. Dr. Niels Henze. Furthermore, this research was conducted within the context of the Graduate School Simulation Technology of the Stuttgart Center. This thesis was subjected to a mid-term evaluation by Prof. Dr. Niels Henze and Prof. Dr. Dominik Gödekke regarding the rules of the Cluster of Excellence in Simulation Technology (SimTech) Graduate School.

Funding The main part of this thesis was conducted with the scope of the project "Designing adaptive and ambient notifications (DAAN)" at the University of Stuttgart. The project DAAN was funded by the Federal Ministry for Education and Research in Germany (BMBF). After the BMBF project ended, I was founded by base funding until the end of 2018. Afterward, I was founded by remaining funds from the former Department for Human-Computer Interaction of Prof. Dr. Albrecht Schmidt.

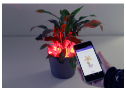
Picture	Research probe	Description	Chapter
	Smart artifacts	The cup saucer displays the coffee's temperature. The stand indicates the filling level for the respective mill. The speaker displays the volume of the played music. The plant pot displays if the plants needs water.	Chapter 3
	Plant system	The smart plant system displays the plant's water level either directly on the plant pot or on the user's smartphone.	Chapter 5
	Wall calendar	The wall calendar displays the user's schedule and event suggestions fitting the user's interests.	Chapter 6
	Calendar data representations	Calendar representations using established displays and novel displays, such as smart lights or e-paper displays.	Chapter 6

Table 1.2: Overview about the research probes that were developed in this thesis.

Previous work The research presented in this thesis is based on the following publications that were published at international scientific conferences and workshops: [192–194, 196–199, 201, 203]
Please consider that the scientific plural is used in this thesis.

The following collaborative efforts contributed to the described research probes and user studies in this thesis:

Chapter 3 - Evaluation Methods for Smart Home Artifacts: The author suggested the idea of the described study; the final study design was developed in discussions between the author, Sven Mayer, Valentin Schwind, and Niels Henze. The implementation of the apparatus was distributed between the author (i.e., AR prototypes), Sven Mayer (i.e., VR and physical prototypes), and Valentin Schwind (i.e., modeling the physical objects for VR and developing the used online survey). The author executed the study. The statistical analysis was conducted by Valentin Schwind, while the author executed the analysis of the qualitative data with the support of Valentin Schwind. The resulting publication was written by the author with the input from Sven Mayer, Valentin Schwind, and Niels Henze [201].

Chapter 4 - Exploration of Displaying Smart Home Notifications: This chapter reports two user studies. The first study investigating modalities and locations for displaying information in a smart home is based on the student project of Nicole Krawietzek, Daniz Aliyev, and Bernd Jung. The project was supervised by the author, Dominik Weber, and Stefan Schneegass. The students conducted the reported focus groups. Stefan Schneegass wrote the resulting publication with the author's and Dominik Weber's support [192].
The author stemmed the idea, concept, study design, and the execution of the second user study. Valentin Schwind provided the investigated pictures presenting the notification types. Tonja Machulla analyzed the collected data. The resulting paper was mainly written by the author and Stefan Schneegass with the support of Tonja Machulla, Dominik Weber, Valentin Schwind, and Niels Henze [198].

Chapter 5 - Long-term Deployment for the Investigation of Notification Strategies and Locations: The described system was developed in Marie Olivia Salm's Bachelor thesis. The author primarily supervised the Bachelor thesis. The student did the focus groups, implementation, and a part of the evaluation. The author also conducted a part of the evaluation. The author analyzed the qualitative data with the support of Dominik Weber and Paweł W. Woźniak, while the author conducted the statistical analysis. The author primarily wrote the resulting publication with the input of Dominik Weber, Yomna Abdelrahman, Paweł W. Woźniak, Stefan Schneegass, Katrin Wolf, and Niels Henze [197].

Chapter 6 - Effects of Personal Content in Domestic Environments: This chapter describes a total of four user studies. Elizabeth Stowell designed the first described user study reporting the calendar usage of retirees with the support of the author. The author analyzed the survey with the support of Elizabeth Stowell and Dominik Weber. The idea and concept of the second reported user study was stemmed from the author. The apparatus was developed by Dominik Weber and Steffen Süpple from Intuity Media Lab named the prototype. The author and Dominik Weber conducted the lab study. The author executed the analysis of the collected data. The paper reporting the two user studies was written by the author with the input of Dominik Weber, Elizabeth Stowell, and Niels Henze [193].
The third user study that investigated the implementation and evaluation of the Caloo system was developed in Manuel Müller's Master thesis project. The student did the implementation of the system and the described user study. The author primarily initiated and supervised the project with Rufat Rzayev's support. The author wrote the published paper with the input and support of Rufat Rzayev, Dominik Weber, and Niels Henze [199] .
The last described user study in this chapter was part of the student software project from Amil Imeri, Anton Tsoulos, Daniel Koch, Kai Chen, Marcus Rottschäfer, Robin Schweiker, Valentino Sabbatino, Annika Eidner, Steven Söhnel. The student project was envisioned in discussions between the author and Dominik Weber. Further, the student project was supervised by the author and Dominik Weber. The students implemented the apparatus

and conducted the user study. The author conducted the data analysis. The author wrote the resulting publication with the input from Dominik Weber and Niels Henze [196].

Chapter 7 - Understanding digital assistants in context: The idea and concept of the reported user study was stemmed by the author with the support of Paweł W. Woźniak. The study was conducted as a part of the student project of Henrike Weingärtner, Maike Ernst, and Andres Michaela Klapper. The data analysis was executed by the author, Jasmin Niess, Paweł W. Woźniak and the support of Caroline Eckerth. The resulting publication was written by the author, Paweł W. Woźniak, and Jasmin Niess [203].

The papers presented in this thesis are motivated by a cooperation with Dominik Weber and his research about managing notifications on established personal devices: [7, 191, 208–210, 212, 213, 215–217]

Within the context of the research presented in this thesis, multiple workshops focusing on attention management were organized: [57, 140, 185, 202, 214, 218]

Cooperation within the Institute of Visualization and Interactive Systems In addition to the publications related to this thesis topic co-operations within other researchers in the institute has resulted in the following publications: [8, 10, 96, 193, 200, 211, 219]. A cooperation regarding smart fabrics with Stefan Schneegass resulted in the following publications: [167, 189, 190]
Especially successful was a cooperation with Katrin Angerbauer, Sven Mayer and Michael Sedlmaier which lead to a publication at IEEE VIS [219]. Another cooperation with Patrick Bader, Huy Viet Le, Niels Henze and Albrecht Schmidt led to an article published in ACM Transactions on Computer-Human Interaction (TOCHI) [10].

External Collaborations Other collaborations with external researchers or other companies lead to the following contributions:

Miriam Beljaars and Stefan Kohn from Deutsche Telekom AG [194], Frederik Wiehr, Sven Gehring and Antonio Krüger from the German Research Center for Artificial Intelligence (DFKI) [220], Christoph Witte and Daniel Kärcher from Intuity Media Lab GmbH [195, 220], Karola Marky, Stöver Alina and Max

Mühlhäuser from the Technical University of Darmstadt and Kai Kunze from Keio University and Svenja Schröder from University of Vienna [110], Jasmin Niess from University of Bremen and Caroline Eckerth from University of Munich [203]
In cooperation the following workshops at international conferences were organized: [47, 168]

1.5 Thesis Outline

This thesis consists of eight chapters, followed by the bibliography and enumerating lists for figures and tables. The thesis is structured as follows:

Chapter 1 - Introduction: This chapter contains the description and motivation of this thesis. Further, it presents an overview of the research questions (RQs) and contributions. Lastly, it contains this outline.

Chapter 2 - Background: This chapter describes the former work that is relevant to this thesis. It contains the former work about designing for the home, about the smart home, and conversational agents. Finally, it describes previous work about ambient information systems and mobile notifications.

Chapter 3 - Evaluation Methods for Smart Home Artifacts: This chapter studies the evaluation method online survey, studies using VR and AR, as well as established lab and in-situ studies for the evaluation of early prototypes of smart home appliances. We show that the method used for evaluation can significantly affect the outcome of the investigation, e.g., studies using VR or AR can get affected by novelty effects. This investigation addresses RQ1 and RQ2.

Chapter 4 - Exploration of Displaying Smart Home Notifications: This chapter explores how and where everyday information could be displayed in the home environment by conducting focus groups and an online survey. This investigation addresses RQ3, RQ4, and RQ5.

Chapter 5 - Long-term Deployment for the Investigation of Notification Strategies and Locations: In this chapter a smart plant system informing the users about the plant's water level is developed as a research probe. A long-term in-situ study is conducted that investigates different strategies to display notifications as well as different locations to display such notifications. This study addresses RQ4 and RQ5.

Chapter 6 - Effects of Personal Content in Domestic Environments: This chapter investigates the representation of calendar data in the home. Using different studies, we observe how our research probes displaying calendar information fit the users' routines. This investigation addresses RQ3 and RQ6.

Chapter 7 - Understanding digital assistants in context: This chapter observes how smart speakers are integrated into the users' routines when they are newly introduced in a home environment. Furthermore, we investigate how users experience smart speakers in their daily lives. This study addresses RQ6.

Chapter 8 - Conclusion: This chapter summarizes and discusses the results presented in the former chapters. In addition, we present directions for future research to build upon this thesis.

2

Background

This thesis investigates how smart home appliances should convey everyday home information to their users. Consequently, the research reported in this thesis builds upon previous work from the following research strands: *designing for the home*, *smart home*, *conversational agents & smart speakers*, *ambient information systems* and *mobile notifications*.

This chapter is partly based on the following publications:

A. Voit, D. Weber, Y. Abdelrahman, M. Salm, P. W. Wozniak, K. Wolf, S. Schneegass, and N. Henze. "Exploring Non-Urgent Smart Home Notifications Using a Smart Plant System." In: *19th International Conference on Mobile and Ubiquitous Multimedia*. MUM 2020. Essen, Germany: Association for Computing Machinery, 2020, 47–58. ISBN: 9781450388702. DOI: 10.1145/3428361.3428466

A. Voit, J. Niess, C. Eckerth, M. Ernst, H. Weingärtner, and P. W. Wozniak. "'It's Not a Romantic Relationship': Stories of Adoption and Abandonment of Smart Speakers at Home." In: *19th International Conference on Mobile and Ubiquitous Multimedia*. MUM 2020. Essen, Germany: Association for Computing Machinery, 2020, 71–82. ISBN: 9781450388702. DOI: 10.1145/3428361.3428469

2.1 Designing for the home

Designing and exploring interactive systems for the home has a long tradition in HCI research. Almost two decades ago, Edwards and Grinter [52] identified seven challenges in the context of ubiquitous computing for the home. For instance, one challenge the authors discussed was 'Designing for Domestic Use'. They emphasized the need for designers to build an in-depth understanding of the home's complex routines and how these might lead to the adoption or the abandonment of new technologies. We aim to shed more light on these processes and their consequences. Nylander et al. investigated which kind of computing devices users generally prefer using [136]. They found that users prefer using mobile phones at home since they considered performing tasks on phones due to their availability as quicker and easier. Grinter and Edwards further investigated how households make their home network function and found that they need to coordinate the usage of different home appliances and the effort to configure and manage the appliances [74]. Further, Tolmie et al. found that designers for networking technologies in domestic environments need to consider the existing infrastructure in the home and how future technologies can be integrated into existing routines [179].

Former work also investigated how technology can be introduced into domestic environments. For example, Crabtree et al. identified places in the home (i.e., ecological habitats, action, and coordinate displays), such as tables or notice boards that habitually draw the users' attention [38]. They identified those places as prime sites for ubiquitous computing applications that support everyday activities and focus on sharing communication media between the residents in a home context. In another vein, Crabtree and Tolmie [37] showcased in their observational study that the assemblage and the arrangement of things are connected to everyday routines. Earlier, Odom et al. [137] investigated how the arrangement and presence of future technologies in teenage bedrooms might affect self-exploration and identity construction processes.

We learned in this section that it is important to consider the specific constraints within the users' homes when designing smart home appliances for domestic use. Therefore, it is important for this thesis that we understand the context of use and the users' regular routines before designing research probes presenting everyday home information. Further, we need to investigate how the design of smart home appliances presenting everyday home information can fit the users' routines (RQ6). Here, we should investigate the usage of mobile phones as their usage is experienced as convenient [136].

2.2 Smart home

Although smart home technology is around for multiple years, many users are still not using them in their homes. Previous work observed the integration of smart home technology [12, 69, 77, 222]. Balta Ozkan et al. investigated possible social barriers hindering users adopting smart home technologies [12]. They found that reasons for the lacking consumer acceptance include concerns regarding a loss of control and apathy, privacy and data security, the reliablity of the devices and the fact that the new smart home technology might be incompatible with other - especially older - appliances. Hargreaves et al. investigated the domestication of smart home technologies in a long-term study [77]. They found that these technologies can be disruptive, that the need for adoption and familiarization can limit their use of the technology and that learning the functionalities of the technology is a time-consuming task. Geeng and Roesner observed how smart home technologies affect the existing relationships within a home and found smart home technologies change the dynamics and lead to power structures [69]. Williams et al. found that the upcycling of existing objects by light-weight modifications within a home minimizes the risk of destabilizing domestic relationships and values [222].

Visualizing the smart home appliances' states in a calendar form enables the users to understand complex routines and increases their trust in the smart home technology [118, 119]. Castelli et al. investigated a configurable dashboard display that shows real-time information of the smart home on a room level basis, integrates weather forecasts, and accesses the smart home's configuration settings [26]. They found that offering pre-defined visualizations is essential. However, smart home appliances should offer opportunities to map data of the smart home appliance easily to different kinds of smart home visualizations, such as charts. However, the user needs to be able to adapt the visualization according to their needs [26].

Technology advancements have enabled the ue of smart homes as well as the support of new scenarios. Knierim et al. explored the design space of using AR in domestic environments [94]. Although their participants saw a potential for integrating AR into the homes, the authors concluded that new privacy and transparency rules are needed.

2.2.1 Smart home reminder and notification systems

McGee-Lennon et al. showed that people from all age groups likely forget tasks in and around their homes [114]. Specifically, they found that middle-aged and younger people tend to forget more diverse tasks than older adults. Thus, there is a need for home reminder systems supporting users of all age groups. It was found in the former work that many people use paper-based reminders (e.g., notes), people-based reminders (i.e., they ask someone to remind them) or physical reminders (e.g., by placing objects close to the entrance door so as not to forget to take them when leaving their homes) [91, 114]. Further, McGee-Lennon et al. reported that people also integrate tasks into their routines or use technological and specialized reminders in their homes to be aware of upcoming tasks or their schedules [114].

An important factor for home reminder systems is their acceptance. If a reminder system is not accepted, users might turn it off or ignore displayed reminders [114, 187]. Previous work investigated factors that support the acceptance of technological reminder systems in domestic environments [114, 186, 187]. McGee-Lennon showed that reminder systems are more accepted when they use metaphors or reminding strategies users are already used to [114]. Further, the acceptance of displayed notifications in domestic environments depends on the urgency of the notification [186, 187]. High-urgent notifications are more accepted than non-urgent ones [186, 187]; medium-urgent notifications were accepted when they were unobtrusively presented to the users [186]. In contrast, low-urgent notifications were not accepted by their participants [186]. Their results showed that low-urgent notifications should be delayed until the urgency of the notification increases. If the urgency of a low-urgent notification does not increase, it should not be displayed to the user. Furthermore, in contrast to a notification's urgency, the user's current primary task does not influence the acceptance of notifications in the users' home environments [186].

Previous work investigated how different modalities to display notifications in home environments affect a primary task [206, 207]. Warnock et al. found that the modality affects the time required to perceive a notification, but has no effect on disrupting a primary task [207]. However, Warnock et al. showed that the modality does not influence primary task's performance (i.e., error rate) [206].

A body of work investigated the design of future notifications systems [43, 192, 198]. Czerwinksi et al. found that devices in smart environments compete for users' attention [43]. Hence, there is a need to design notification systems informing users by displaying information subtly. Bourgeois et al. found that delayed and real-time feedback are not appropriate tools to support demand shifting behavior; instead, proactive suggestions and contextual control support users in organizing their daily lives by micro-planning and micro-scheduling household activities [21]. Further, notification systems in the home should support natural and transparent interactions [91].

Other work investigated home reminder systems that support their users in certain routines (e.g., when leaving home) [91, 170]. Kim et al. developed a home reminder system with a display close to the entrance door that reminds the users of things they have to take with them when leaving their homes [91]. They reported that users do not want to interact explicitly with a home reminder system. In contrast, users prefer natural and transparent interactions. Seiderer et al. developed a system that uses ambient lighting to display if all critical doors and windows are closed (e.g., to prevent burglaries when leaving home or going to sleep) [170]. They found that their system improved the certainty of the state of critical doors and windows.

2.2.2 Privacy in the smart home

Since smart home technologies can access or collect sensitive data of their users, the users' privacy must be considered during the development of smart home appliances [224]. However, former work observed that their participants could not name privacy consequences beyond general privacy issues such as data collection [71, 89]. In addition, previous work showed that there is a trade-off between the functionality a device offers or the users' convenience and privacy and security [225, 226]. An example of this trade-off is the opportunity to interact remotely with a smart home appliance vs. storing the data in the cloud [226].

Other work investigated whether users trust companies or manufacturers of devices with protecting their privacy [156, 177, 225]. Rodden et al. observed that users in the UK are not trusting the energy providers in monitoring energy data since they were concerned that the companies would use the data for their own advantages [156]. In contrast, other study has revealed that users trust device manufacturers without verifying if their trust is justified [225] or even when they are aware of the devices' privacy and security issues, such as of smart speakers [177]. Reasons for trusting companies, e.g., manufacturers of a device are that companies that cannot afford misusing the collected data because of possible results of data misuse such as losing the reputation.

In addition, other research investigated the data collection of smart home technologies regarding privacy [54, 100]. For example, Emami-Naeini found that users prefer sharing data collected in public spaces than in private environments such as homes [54]. Further, users are willing to share also sensitive data with third parties such as manufacturers of smart home appliances as long as the collected data is sufficiently abstracted and anonymized [100] or beneficial [54]. In addition, former work reported no privacy issues when environmental data is collected [54]. However, biometric data should not be collected in any case [54].

Further, former work found that most users do not consider privacy before purchasing or installing smart home appliances [53, 110]. However, these users get concerned about privacy issues afterward [53], e.g., they were concerned about sharing their data with potential bystanders in their home [110].

Current work also investigated how smart home technologies can affect the inhabitants' privacy regarding present bystanders in the home environment, such as other inhabitants or visitors [110, 181]. Ur et al. found that teenagers were concerned that their parents could monitor them closely if smart locks or entryway cameras would be installed in their various homes [181]. This means that in addition to the trade-off between functionality and privacy regarding third parties [226], the social dynamics within the home need to be considered before purchasing or installing smart home appliances. In addition, Marky et al. investigated what kinds of information can be displayed within the home without causing privacy issues by the presence of other bystanders such as other inhabitants or visitors who could also access the information [110]. They found that the majority of their participants had no concerns about sharing their household information with others; in addition, some participants stated that it would be even beneficial if household data would be shared with other persons close to them. The willingness to show privacy-sensitive information in the home is affected by the location in the home where the information would be displayed [10, 110]. However, privacy options such as a visitor mode can make it possible to display sensitive information such as calendar data in the home environment in places that others can access [110].

In this section, we learned that visualizing smart home data is important to increase users' trust in the used smart home technologies [118, 119]. Another important factor is that smart home technologies should offer opportunities for their users to adapt the visualizations according to their needs [26]. However, when designing smart home appliances, we need to consider that the integration of smart home technologies can affect the social dynamics within the home [69, 181]. Williams et al. suggested enhancing already existing objects in the domestic environments to reduce the risk of affecting the social dynamics within the home [222]. Furthermore, we found that novel technologies such as AR can be used to prototype and evaluate smart home appliances. However, we do not know whether using novel technologies could affect the outcome of the conducted evaluation. Therefore, we need to investigate which evaluation methods are suitable for evaluating prototypes of smart home appliances that display everyday information (RQ1). We must understand the advantages and disadvantages of different evaluation methods to choose the right evaluation method for the specific purposes of a study (RQ2).

Furthermore, we found that smart home appliances presenting everyday home information can support users from all age groups to remind them about upcoming home tasks. Former work already reported what kind of information the users would like to receive based on investigating the acceptance of smart home appliances for different kinds of information with different urgency levels. However, it remains unclear how these kinds of home information should be conveyed to the users. Therefore, it is important to study which modalities (RQ3), and locations (RQ4) are suitable to inform the users about these kinds of information as well as when the home information should be displayed (RQ5).

Finally, we learned that privacy issues could impact the acceptance and usage of smart home appliances. Therefore, it is important to consider privacy options when designing smart home appliances - especially when personal data is displayed. In this case, a visitor mode could be integrated, or the users could configure the smart home appliance's output accordingly to its location in the home. We also learned that the participants were not concerned when household data was shared with other persons. As a result, research probes presenting household information should not cause privacy issues.

2.3 Conversational Agents & Smart Speakers

Smart speakers feature a conversational agent, a new conversation partner designed for regular 'communication' with the user. Since smart speakers are becoming popular everyday devices in the users' homes[1], the functionality of smart speakers could be extended to inform their users' proactively everyday home information to the users.

Research that addresses smart speakers is inherently related to understanding conversational agents' integrated conversational agents on mobile phones or laptops. In contrast to other conversational agents, smart speakers are located at a static position in the users' homes [169]. Smart speakers have an integrated conversational agent that can be activated through an activation word. For instance, Amazon Echo, the smart speaker from Amazon, connects to the voice-controlled conversational agent Alexa.

Former work that studied conversational agents revealed that most users could not accurately judge the system capacities of conversational agents. Users without

[1] https://techcrunch.com/2020/02/17/smart-speaker-sales-reached-new-record-of-146-9m-in-2019-up-70-from-2018/

knowledge of computer science were mostly missing an exact mental model of how conversational agents work [105]. Unfortunately, that resulted in a tendency to anthropomorphize the conversational agent and setting unrealistic expectations.

A body of work investigated how users interact with conversational agents [29, 35, 36, 51, 120, 149]. Clark et al. investigated differences between human-to-human and human-to-agent conversations. They found that participants used similar interlocutor characteristics in communication with strangers or casual acquaintances and communication with conversational agents [29]. However, their participants questioned the need for bonding and developing a relationship with conversational agents. Porcheron et al. in their work showed that users predominantly react to conversational agents' failures by repeating the original query or reformulating it [149].

Other work identified barriers that act as barriers for users of conversational agents [35]. Users were often frustrated by the need to combine touch and speech interaction to interact with conversational agents, e.g., selecting a contact to call or unlocking the phone before a query can be entered [35]. Further, users prefer to enter non-private data to conversational agents [51, 120] and use conversational agents in safe or domestic environments [120]. Reported reasons for avoiding speech interaction in public were mainly privacy concerns [120], embarrassment in front of strangers [36, 120], and cultural factors [36].

Several recent works studied different aspects of how users interact with smart speakers [14, 16, 150]. Bentley et al. [16] investigated habits in smart speaker use through analyzing an extensive database of voice history logs from Google Home. They found that playing music was by far the most used action on the smart speaker. As the users owned the device longer, music usage was still high but declined. On the other hand, users increasingly used more automation, suggesting that the smart speaker was further integrated into the home environment. Porcheron et al. [150] analyzed audio data from a month-long Amazon Echo usage period to study the intricacies of the dialogues between users and smart speakers. They found that the 'atomic' way one communicated with a smart speaker bore little resemblance to real conversations. Beneteau et al. analyzed the situation in which the communication between family members and the smart speaker was breaking down and found that in these cases, family members often collaborate to repair the communication with the smart speaker by discoursing scaffolding and varying the speech, e.g., the pronunciation, the language, such as the used wording [14]. Sciuto et al. studied usage logs and conducted interviews with users of Amazon Alexa [169]. They found that users of smart speakers explored the functionality of smart speakers within the first few days. Afterward, their participants used the smart speaker constantly week-over-week for the first year. However, the number of daily requests varied between households.

Other work studied how users experience smart speakers [101, 154] or investigated privacy perceptions [106, 120]. Lau et al. conducted diary studies and interviews with smart speaker users and interviews with non-users of smart speakers about their experience while focusing on privacy perceptions [101]. They found that non-users do not see the utility in smart speakers, while users of smart speakers are aware that they trade in their privacy for convenience. Users, as well as non-users of smart speakers, are distrusting the speaker companies. Manikonda et al. showed that smart speakers' users prefer to use them in their daily lives, although they are concerned about privacy, e.g., about being hacked or about the data collection and data storage [106]. Furthermore, they showed that even some tech-savvy users were not aware that smart speakers are always listening. Once their users were made aware of this fact, the privacy concerns increased significantly. Moorthy and Vu analyzed privacy and security issues that are caused by conversational agents [120]. They showed by investigating different possible attacks that the users' interaction with the conversational agents is the weakest link. Here, one of the reasons is the used (predefined) wake word of the conversational agents that are easy to guess by others and can also be triggered by external sources such as advertisements shown on the TV. Pradhan et al. analyzed Amazon reviews and interviews to study how smart speakers supported accessibility [154]. They found that smart speakers at home were perceived as particularly beneficial by participants with a vision impairment who actively used the devices to facilitate many daily actions.

2.3.1 Anthropomorphism of conversational agents & smart speakers

There is an increasing interest in the HCI community to explore the intricacies of designing future digital assistants using conversational agents [31]. However, it still remains a challenge to design technologies that can become meaningful digital assistants [133], i.e., technologies that carry personal and social meaning. Lopatovska and Williams [104] reported that a significant share of Amazon Echo's users expected the device to exhibit social behavior. Preliminary results by Purington et al. suggest that users tend to ascribe human qualities to smart speakers despite the 'non-human' conversation style [155] . They analyzed user reviews of the Amazon Echo and found that user satisfaction seems to be connected to the technology's more personification.

The class of behaviors mentioned above can be called anthropomorphism and defined as the attribution of human-like characteristics, motivations, emotions, or intentions to non-human agents, such as animals or objects [55]. Epley et al. state that anthropomorphizing serves three purposes, namely: (1) making sense of situations, (2) reducing uncertainty in specific situations, and (3) establishing social connections [55]. Early research in HCI found that humans react towards technologies in social ways [125, 126]. However, Nass and colleagues take another, contrasting stance compared to Epley et al. and state that these social reactions are triggered by social cues [125]. Kuzminykh observed that smart speakers' anthropomorphization is related to their implemented behavior regarding the categories approachability, sentiment, professionalism, intelligence, and individuality, e.g., Alexa is perceived as genuine and caring while Siri is perceived as cunning and disingenuous [99]. Further, Gao et al. found that anthropomorphizing smart speakers also show more positive emotions than users who treated the smart speaker like an electronic device [65].

2.3.2 Abandonment and non-use of smart speakers

Some studies of smart speakers reported that participants reduced their interactions over time [169], whereas other results indicate that there is no decline regarding the usage [16]. However, to date, to the best of our knowledge, only two studies [28, 67] have focused explicitly on the abandonment of a class of devices that included smart speakers. Cho et al. investigated smart speakers' abandonment in a long-term diary study with first-time users of smart speakers [28]. They found that the reasons for the abandonment of smart speakers after a few weeks of usage are based on a disappointing exploration leading to minimal usage or abandonment. Garg and Kim [67] conducted an exploratory study to build an understanding of the usage of the Internet of Things (e.g., voice assistants, smartwatches, smart locks). Their preliminary results showed that participants mainly stopped using devices due to demotivating interactions (e.g., distracting notifications, notifications of failure to achieve a goal). Further, they found that participants stopped using the device when it was too complicated to use or provided unnecessary, confusing information. Only a few participants mentioned privacy concerns as a determining factor regarding continued usage. One of the relevant factors for continuing usage was autonomy in daily activities.

Other work investigated the reasons for the non-usage of devices [163, 164]. Satchell et al. found that the technology's adoption could be lagging according to active resistance by the users, disenchantment, disenfranchisement, displacement, and disinterest [164]. Sambasivan et al. identified the reasons for avoidance by the user (e.g., by turning the devices off), pretending usage by the user, and resistance to devices that were forced on them [163].

In this section, we learned that smart speakers are popular devices in the users' homes and are mainly used to execute specific tasks or for automation purposes [16]. Previous work observed that users prefer to enter non-private data to smart speakers [51, 120]. Previous work also observed that the usage of smart speakers decreases over time [169]. Reasons are barriers to a missing mental model of how smart speakers work, resulting in dissatisfaction. However, other users humanize smart speakers. Therefore, some researchers envision that smart speakers could act as digital assistants in the future [133]. It remains unclear whether smart speakers can be used to inform their users about everyday home information. Furthermnore, investigation needs to be done on how smart speakers can be designed to fit the users' routine (RQ6).

2.4 Ambient information systems

Ambient information systems display non-urgent information in the periphery of the user's attention using abstract and aesthetic displays [107]. Such systems can either be integrated into existing objects, e.g., by using augmentation or use additional devices to display information in the surroundings [180]. Since these devices are visible in the users' environments, aesthetic aspects are important for their acceptance [153]. Ambient information systems can use visual [80, 227], auditory [4], tactile [152] or olfactory [19, 22] cues to deliver information.

Previous work investigated how ambient information systems should display information [111, 113]. Matthews et al. found that displayed information in ambient information systems should be perceivable at a glance [111]. The information displayed by an ambient information system is usually non-urgent but is still important for the users' awareness or the sense of the users' well-being [153]. Therefore, the information should be displayed unobtrusively and in an abstract way; for example, an ambient information system could use ambient light displays to present color encoded information. Matviienko et al. analyzed the color-coding from diverse applications using ambient light displays and suggested using common metaphors to display information, e.g., the traffic light's color pattern [113].

2.4.1 Taxonomies for ambient information systems

Matthews et al. created the first taxonomy of ambient information systems consisting of abstraction, notification, and transition level. They showed that optimal information representation depends on the information's importance and how much attention the user needs to spend [111]. The information that should be displayed using an ambient information system can be gained by either extracting specific features or reducing the information's fidelity. An ambient information system's notification level describes the level of importance of the displayed information [111]. The notification level contains the items: ignore, change-blind, make aware, interrupt, and demand attention. Depending on the importance of the information, the users can ignore it, or the system should make them aware of the information. For important or urgent information, the system should interrupt the users from their current primary tasks. The transition describes any permutation from one notification level to another, e.g., when the displayed information's notification level switches from ignoring to interrupt. How such a transition should be displayed to a user is not described in the taxonomy.

Based on the first taxonomy of Matthews et al. [111], Pousman and Stasko developed a second taxonomy by analyzing published ambient information system from former work [153]. Their taxonomy contains the levels: information capacity, notification level, representational fidelity, and aesthetic emphasis. The information capacity describes whether ambient information systems present information from a single source of data - such a system would be classified as having a low information capacity or if the ambient information system can present data from multiple sources - such an ambient information system would be classified as having a high information capacity. For the notification level, Pousman and Stasko revised the notification levels from Matthews et al. [111] by replacing the item ignore with user-poll resulting in the following items: user-poll, change-blind, make-aware, interrupt and demand attention. The representational fidelity is similar to the abstraction level in the taxonomy of Matthews et al. [111] and describes how the presented information is encoded. For their taxonomy, Pousman and Stasko [153] divided the categories indexical, iconic, and symbolic into the following items for the representational fidelity: indexical, iconic with drawings, doodles or caricatures, iconic using metaphors, symbolic using language symbols, and symbolic using abstract symbols. The aesthetic emphasis level of ambient information systems highlights the importance of the aesthetics of such a display since these displays are usually placed visibly in the environment. However, an ambient information system's aesthetics is usually a compromise affected by the information capacity and the representational fidelity of an ambient information system. Therefore, the aesthetics of an ambient information system can be accessed by the range from a low to a high aesthetic emphasis.

Similar to Pousman and Stasko [153], Tomitsch et al. also revised the original taxonomy by Matthews et al. [111] and developed a taxonomy for ambient information systems [180]. The taxonomy of Tomitsch et al. is more detailed and contains the following nine levels: abstraction level, transition, notification level, temporal gradient, representation, modality, source, privacy as well as dynamic of input. The abstraction level describes to which degree the information is abstracted for the representation. The metric for the degree of abstraction applied is low, medium-high. The transition describes whether an ambient information system displays changes in the presented information by applying slow, medium, or fast transitions. Using slow transitions, users will only be aware of large changes in the presented data, while applying medium changes will be perceived more abruptly. Fast changes appear immediately on display. The taxonomy of Tomitsch et al. uses the same items for the notification level as Matthews et al. [111], resulting in: ignore, change-blind, make aware, interrupt and demand attention. The level temporal gradient describes whether an ambient information system displays only current data or also historical data. The representation of an ambient display specifies if the display is either an own devices build solely to present the information (i.e., physical representation) or if the presented information is integrated into an already existing object (i.e., integrated representation). If established screens such as Liquid Crystal Displays (LCDs) are used to represent the information, this belongs to the item 2D. The modality describes which modality is used to display the information. Possible modalities are: visual, tactile, olfactory, auditory, or by enabling movement. The source's level describes whether information collected in the same environment (i.e., local) is displayed or if the information was collected at a distant location or if the information was collected in the virtual world (i.e., virtual). The privacy level describes if the display is placed in a private, semi-public, or public environment. The level dynamic of input describes how often the displayed information is updated. The metric for this level is slow, medium, fast.

2.4.2 Evaluation of ambient information systems

Former work investigated how ambient information systems can be evaluated [81, 82, 107]. One option for the evaluation of prototypes is to conduct an inspection that is called heuristic evaluation. A heuristic evaluation is used to investigate whether the system is compatible with the intended needs and preferences of the users [132]. During a heuristic evaluation of a system, the system is accessed by a small set of evaluators who judge the system's compliance with recognized usability principles (i.e., the heuristics used in the inspection) [132]. Evaluators of such a system can be usability professionals as well as non-usability specialists [131]. However, Nielsen found that usability professionals are better at conducting heuristic evaluations and detecting usability issues than non-usability specialists [131]. Mankoff et al. improved Nielson's general heuristic [132] by revising them to evaluate ambient displays [107]. Hereby, they proposed to also consider the information design, the information mapping, the visualization of the states, the usefulness of the information, the easy transition to more detailed information, and the 'peripherality' of the ambient display (i.e., the characteristic of being unobtrusive on one hand but still offering the option to be easily monitored by the user if necessary). However, an heuristic evaluation can only identify usability issues connected to the applied heuristic during the inspection; all other possible usability issues, including issues related to the context of use, will remain undetected [183].

Hazlewood et al. showed that it is necessary to evaluate ambient displays outside the lab, e.g., by conducting long-term in-situ studies [81, 82]. Furthermore, Hazlewood et al. identified four design directions to improve the evaluation of ambient displays [81]. Research can trigger artificial events during an in-situ study to address the lack of rarely occurring events in a study. Furthermore, they can log and analyze when the users are looking at an ambient display, e.g., through gaze-detection using an integrated eye-tracker. Another opportunity to improve ambient displays' evaluation is to develop multiple ambient displays and investigate which of them have a potential for sustained use. Finally, to improve the design of an ambient display, an interaction criticism phase could be added into an interaction design process.

In this section, we learned that ambient information systems are used to display information in the users' periphery. Based on different factors of an ambient information system, it can influence how the data is perceived, for example, by implementing a fast change in the displayed data [180]. An important factor for ambient information systems is their aesthetics. For example, ambient lighting can be used to display color-coded information to the users [113]. Different notification levels can be used for ambient information systems to display the information, e.g., an ambient information system could only display data based on the user's request, or the ambient information system can make the user aware of the information or even interrupt the users in their current activities or demand their attention [153]. However, it remains unclear whether ambient information systems should be used to represent everyday home information and which notification/transition levels would fit the users' routines.

2.5 Mobile Notifications

Mobile notifications are an established communication method to inform users proactively about different kinds of information. Mobile notifications could also be used to convey everyday home information. Nowadays, apps inform users proactively through mobile notifications using visual, auditory, or tactile cues [88]. Former work analyzed which kind of notifications users receive on their smartphones [147, 161]. Pielot et al. found in an in-situ study in 2014 that their participants received about 63.5 notifications per day [147]. Notifications on smartphones inform their users mainly to support communication [147]. Users value notifications from messaging apps and notifications containing information about people or their current context [161]. Weber et al. found that users prefer receiving notifications on their smartphones - although they are used to receive notifications on all of their smart devices, including smartwatches and tablets [213]. However, the proximity to devices, if they are currently used, and the user's current location can affect if users are willing to receive notifications on their devices.

In the following subsections, we will investigate how notifications are perceived, what kind of adverse effects can be caused by notifications, which effects are caused by mobile unavailability, and which approaches researchers evaluated to reduce the adverse effects caused by notifications.

2.5.1 Awareness and perception of notifications

Chang et al. investigated the perception of mobile notifications. They found that only 62% of the notifications received were seen by the users [27]. Weber et al. revealed that the users perceive the majority of the incoming notifications as not important and non-urgent [210]. Other works investigate the attentiveness of notifications [9, 46, 60, 147]. Pielot et al. extracted features to generate a model that predicts whether a user will see a message within the next minutes or not [147]. However, Dingler et al. found that inattentiveness occurs rarely and subsides quickly [46]. Bahir et al. showed that users were more attentive regarding notifications that contained either images/icons or action buttons that enable them to respond to the notification within the notification drawer [9]. Bahir et al. observed that their participants responded faster to notifications, which were received in the afternoon or evening [9]. In contrast, Fisher et al. found that a notification's content affects how fast users attend to notifications [60].

Prior work also investigated how users deal with the number of incoming notifications [191, 208]. Weber et al. found that there are three different kinds of users [208]: (1) The frequent cleaners who frequently attend to incoming notifications, (2) the notification regulators who respond to notifications before the number gets too high, (3) the notification hoarders who usually do not dismiss notifications regularly. Voit et al. found that only a few users configure the notification system on their smartphones to disable notifications [191]. Instead, they observed that users apply other strategies to deal with notifications, including ignoring them or uninstalling the application, muting the smartphones, or even putting their smartphones away.

Further, Exler et al. showed that notifications displayed using tactile or auditory feedback were most perceptible [56]. However, auditory notifications were perceived as too annoying, disturbing, and obtrusive for everyday use [56]. This confirms the observation of Gallud et al. which stated users are switching from receiving notifications with sound to visual notifications [64]. Tactile notifications were perceived as more private and subtle; however, this can lead to awkward situations when others cannot foresee an action arising from such a notification [76].

2.5.2 Negative effects of notifications

A body of related work investigated which negative effects such as distractions, interruptions, lower productivity and higher error-prone performance are caused by notifications [11, 88]. Weber et al. showed that users underestimate the number of notifications that they receive in their daily lives [215]. Iqbal and Horvitz found that email notifications displayed on desktop computers cause distractions from primary tasks at work [88]. Mehrotra et al. showed how disruptive the users perceive a notification depends on how the notification is displayed, the sender-recipient-relationship, and the primary task in which the user is currently engaged [117]. In addition, Bailey and Iqbal observed that interruptions in moments with increasing mental workload also cause negative effects including a slower task performance and frustrations [11]. Turning off notifications [145] and blocking non-work related distractions from social media [108] lead to increased productivity and reduced distractions. However, users feel less responsive and less connected to their social contacts [145]. In addition, some users feel when receiving notifications more temporal demand and stress [108]. Pielot et al. showed that users experience social pressure to respond fast to incoming messages [147]. Users are feeling a social obligation to answer fast to incoming messages as otherwise other persons such as family members or friends express frustrations regarding their delayed and unpredictable answer patterns [6].

Previous work also investigated how notifications are related to negative behavior patterns [6, 103]. Aranda and Biag found that users are triggered by incoming notifications or phantom cues to use their devices [6]. Afterward, users are keeping in the loop of interacting with the device or application, e.g., by implemented automatic triggers within websites or applications such as infinite scrolling or recommended content [6].. This is especially problematic since Lee et al. showed that notifications could initiate problematic usage patterns especially for users that are more susceptible for smartphone overuse [103].

2.5.3 Effects of mobile unavailabilty

Former work also investigated how users experience mobile unavailability [6, 160]. Aranda and Biag found that the level of control (i.e., voluntarily or forced disconnect) and the duration of non-use (i.e., short-term or long-term) are affecting how the disconnection is experienced by their users [6]. When their participants self-consistently disconnected to draw boundaries for their devices usage, they experienced the "joy-of-missing-out" (i.e, they were happy and less stressed). However, participants that were disconnected because of even short-term outages experienced the "fear-of-missing-out" (i.e., they felt anxious and inconvenient). Russo et al. analyzed comments on a web article and found users spend time and effort deciding when to disconnect from their devices [160]. Further, they identified four main reasons why users self-consistently disconnect from their devices; (1) to improve their current role performance, this includes focusing on their current primary activities as well as resting and recovering, (2) to implement a personal digital philosophy, e.g., to be an example for others such as children (3) to minimize undesirable behaviors, e.g., to not interact with their phones while being out with friends, and (4) to shield their own priorities within their lives.

2.5.4 Reducing negative effects caused by notifications

Another strand of prior work aimed to reduce distractions by developing models for receiving notifications or delaying incoming notifications to opportune moments. A body of work investigated delaying incoming notifications to opportune moments such as breaks between different primary tasks [59, 146] and identifying opportune moments for interruptions. Mehrotra et al. showed that taking the sender-recipient relationship, the context, as well as the current context into account, leads to a better prediction of the users' interruptibility [116]. Adamczyk et al. showed that identifying opportune moments in a user's task sequence can decrease the negative effects caused by interruptions on the social attribution and the user's emotional state [2]. In contrast to other work, Weber et al. found that users mainly delayed notifications related to people and events that were not fitting to their daily routines [217]. Further, they found that notifications should no longer be delayed than the following morning. In order to detect opportune moments, Okoshi et al. developed a system that detects breakpoints in the current activity on the users' smartphones [139] as well as breakpoints between physical activities of the user [138].

Other work investigated using rules to reduce the number of notifications received [7, 115]. [7] Mehrotra et al. developed a machine-learning model that learns users' preferences for receiving notifications [115]. Hereby, the system generates rules based on the user's former response to such notifications, the type and arrival time of notification, as well as the context of the user (i.e., the users' activity and location). These rules are displayed to the users who can either accept or reject them.

In this section, we found that current applications inform their users proactively using mobile notifications, e.g., to notify the users on their smartphones. While users value being proactively informed about incoming information [161], notifications also cause negative effects for the users such as distractions, interruptions, lower productivity, and a higher error-prone performance [11, 88]. A body of work investigated how the negative effects of incoming notifications could be reduced, e.g., by delaying the information to opportune moments [59, 145] or by using rules [7] or machine-learning approaches [115]. Therefore, designers of smart home appliances that display additional information to the users should also consider the number of notifications that the users receive in their daily lives to not overwhelm the users with more information.

2.6 Summary

The introduction of novel technologies in the users' homes enables new opportunities for smart home appliances to support the users in their daily lives, e.g., by informing them about everyday home information. Previous research investigated the acceptance, effects of different modalities for displaying everyday information in the home context [186, 187, 205, 206]. The investigations of Vastenburg et al. revealed that presenting more urgent everyday information is more accepted by the users. Also, low-urgent information should be delayed until the urgency increased [186]. Further, the modality that is used to deliver the information to the users affects the time to perceive the information, but not the disruption or the performance according to the user's current primary task [206]. Neither does the current primary task affect the acceptance of receiving notifications about everyday information [186].

Different technologies can be used to implement smart home reminder systems that convey everyday home information to users. These technologies include using ambient information systems, mobile notifications, and smart speakers. Regardless of which technology is used to convey home information to the users, former work identified factors that affect the acceptance of those systems, including visualizing smart home data [118, 119], offering opportunities to adapt the visualizations [26], and considering the social dynamics in the home [181].

Marky et al. found that the display's location in the home can affect the willingness to display sensitive data in the home environment. Further, they found that everyday information, such as household data, can be shared with others. Some of their participants even stated that it would be beneficial for them if other persons, including visitors, could see their household data.

Czerwinski et al. envisioned that many appliances would compete for the users' attention in the future [43]. Therefore, home information should be displayed subtly. However, it remains unclear how smart home appliances should convey home information to their users. For example, an investigation of suitable modalities (RQ3) and locations (RQ4) to present everyday home information is missing. Besides, we need to investigate how the information should be displayed (RQ5). For example, a study should investigate whether smart home appliances should persistently visualize their current state or whether the user should only be informed based on specific events. Further, we need to study how the smart home appliances displaying everyday information need to be designed to fit into the users' routines (RQ6).

In addition to integrating AR applications in domestic environments as Knierim et al. [95] suggested, novel technologies such as AR can also be used for rapid prototyping and evaluating early prototypes [97, 151, 188], e.g., for smart home appliances. However, it remains unclear whether using AR or VR affects on the results of the conducted study, i.e., if the gained results will be reproducible, valid, and reliable [85]. To be able to study smart home appliances informing the users about everyday information, it is crucial to investigate which evaluation methods are suitable for the evaluation of early prototypes in the context of smart home appliances presenting everyday information (RQ1) and to understand the advantages and disadvantages of each evaluation method (RQ2).

3

Evaluation Methods for Smart Home Artifacts

Empirical studies collecting quantitative and qualitative feedback are essential to investigate how users experience smart home artifacts' design. Technical progress constantly enables new study methods that can be used for evaluations of prototypes. Online surveys, for example, make it possible to collect feedback from remote users. Progress in augmented reality (AR) and virtual reality (VR) enables us to collect feedback with early designs. In-situ studies enable researchers to gather feedback in natural environments. While these methods have unique advantages and disadvantages, it is unclear if and how using a specific method might affect the results and, therefore, have effects while applying the user-centered design process [135]. Therefore, in this chapter, we will investigate which evaluation methods best suits the evaluation of smart home appliances that inform the user about non-urgent everyday information (RQ1). Further, we will need to understand the advantages and disadvantages of the different evaluation methods to choose the right method for evaluating research probes (RQ2).

In detail, we report about a study with 60 participants to compare the different evaluation methods online survey, a study using VR, a study using AR, a study using a traditional lab setup, and evaluating the prototypes in the users' homes (i.e., in-situ study) for the evaluation of early prototypes (see also Figure 3.1).

This chapter is based on the following publication :

A. Voit, S. Mayer, V. Schwind, and N. Henze. "Online, VR, AR, Lab, and In-Situ: Comparison of Research Methods to Evaluate Smart Artifacts." In: *Proceedings of the of the 2019 CHI Conference on Human Factors in Computing Systems*. CHI 19. New York, NY, USA: ACM, 2019, p. 12

3.1 Related work

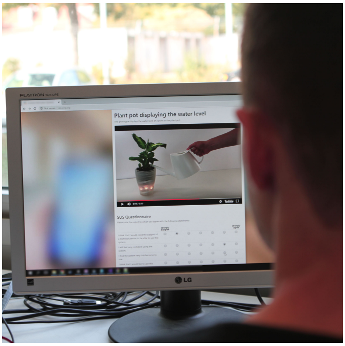
Our work is inspired by previous work that applied and investigated different study methods. It is based on a body of work that compared multiple methods to reveal how the study methods can affect the results of a study.

3.1.1 Empirical Methods in HCI

A range of methods is widely used to evaluate prototypes. Among the most established methods are online surveys [142, 198], lab studies [3, 22, 193], and in-situ studies [83, 119, 188]. Advances in technology further enable new methods; recent examples include using VR [95] and AR [151] to evaluate prototypes.

Online surveys are the most efficient opportunity to conduct surveys with a broad range of participants as they are cheap and time efficient [44, 174]. Further, online surveys are comfortable for participants because they can attend the survey when they are available and at home [44].

Lab studies are used to evaluate prototypes in a controlled setting without interruptions [48]. In lab studies, a research assistant acts as a human moderator to gain results with a high internal validity. Lab studies can occur either in an abstract setting [50] or in environments that resemble parts of the real world to simulate a natural usage context [93, 176].



(a) Online

(b) VR

(c) AR

(d) Lab

(e) In-Situ

Figure 3.1: Examples of the five study methods online, virtual reality (VR) and augmented reality (AR), lab study and in-situ studies.

In contrast to online surveys and lab studies, in-situ studies are used to evaluate prototypes in their natural environment [48, 157], e.g., at home, to determine results with high external validity [83]. In addition, in-situ studies can be used to understand the user experience [24, 157] and capturing the context of use [158], e.g., by combining different data collection strategies such as interviews and logging data in the background. However, by conducting in-situ studies, researchers are not fully in control over the environment. Therefore, distractions and interruptions, e.g., caused by other persons, can occur [48].

Advances in technology, enable to conduct studies using VR and AR to evaluate prototypes. Especially, VR can be useful to conduct studies that are too expensive or too dangerous to be conducted in the real world or the lab [48, 49]. VR studies can be conducted outside of the lab and even with a large number of participants over longer periods of time [121]. Former research compared different presentation formats for VR studies and found that using head-mounted displays provides the most immersive experience [32]. Researchers also started using AR for rapid prototyping and the evaluation of radically new interfaces [97, 151].

When conducting an evaluation, it is essential that the evaluation investigates not only the prototypes' usability aspects, but considers also hedonic and emotional aspects of the interaction [184]. When investigating the user experience of prototypes, Väänänen-Vainio-Mattila et al. found that a majority of former work investigates the first-time experience with the prototypes [184].

3.1.2 Comparison of Empirical Methods

Previous work compared the effects of conducting online surveys or lab studies on the participants and the study results [30, 44]. Online surveys have higher dropout rates as participants in the lab feel more committed to participate in the experiment [44]. Further, lab study participants can be more engaged and can also be more accurate when solving demanding tasks than in online surveys [44]. One reason is that participants in online surveys are more distracted than those in lab studies [30]. In online surveys, researchers are not present and therefore have no control over the environment where the survey is answered [30, 44].

A large body of work compared lab and in-situ studies. There is an ongoing discussion whether it is worth the hassle to conduct in-situ studies to evaluate prototypes [92, 93, 130, 158]. Most of these comparisons showed that both evaluation methods enable users to identify similar usability problems [86, 90, 93]. However, other studies found that themes related to usability problems (i.e., cognitive load and interaction style) identified in the in-situ study, were not found in the lab study [130]. Further, in-situ studies enable finding usability problems associated with external factors of the natural environment that are difficult to simulate in regular lab studies, e.g., the movement in a train [50]. In addition, Sun and May found differences in participants' engagement [176]. They collected more feedback related to data validity and precision in the in-situ study, while in the lab participants focused more on details of the interface.

Related work also investigated differences in the perceived user experience [157, 176]. It has been found that the surroundings of a study can affect the user experience. For example, Sun and May found that the user experience ratings in the in-situ study were higher as participants were affected by the positive atmosphere in a sports stadium [176].

Former studies differed in their setups' level of realism. Some studies were conducted in highly realistic lab setups that resembled parts of the natural environments [93, 176] for comparison. Other comparisons, were conducted in more abstract lab setups, e.g. an actual train ride was compared with sitting at a table [50]. Some in-situ studies were conducted in the actual context such as a sports stadium [176], while others were conducted in similar environments which the researchers could better control [130].

Finally, Kjeldskov reported that the suitability of a method (i.e., lab or in-situ study) depends on the specific research questions and goals [92]. However, previous work agrees that in-situ studies are better suited to investigate how a prototype integrates into users' lives, to capture the real user behavior and to determine the context of use with high external validity [86, 158].

3.1.3 Summary

HCI research uses different study methods with different advantages and disadvantages for the evaluation of prototypes. A body of work investigated how different methods (i.e., online survey vs. lab [30, 44] and lab vs. in-situ [92, 93, 130, 158]) affect the results of usability and user experience investigation. Which study method is the best method and should be applied depends on the research questions. For example, in-situ studies should be conducted to investigate the integration of a prototype into the participants' daily lives or observing the user behavior [86, 158]. HCI research recently started using VR [95] and AR [151, 188] for the evaluation of prototypes, but we do not know how methods using novel technologies such as VR or AR affect the results compared to established methods such as online surveys, lab, and in-situ studies.

3.2 Study

To investigate the effect of different methods on the results of a study, we conducted a study in which we compared five different methods for the evaluation of smart home artifacts. Furthermore, the usage of smart artifacts enables us to investigate different empirical methods by keeping the measurements the same and the possible influence of the participants' backgrounds low. To increase the generalizability of the results, we assessed multiple prototypes of smart artifacts with each method. We evaluated four smart artifacts with the following study methods: online survey (*Online*), a lab study in virtual reality (*VR*), a lab study using augmented reality (*AR*), a lab study with physical prototypes (*Lab*), and an in-situ study in participants' homes (*In-Situ*).

3.2.1 Design

We used a mixed-design with the two independent variables: METHOD and ARTIFACT. While METHOD was a between-subjects variable with the following five levels: *Online* survey, *VR* study, *AR* study, *Lab* study, and *In-Situ* study; ARTIFACT was a within-subjects variable with four levels: *Cup*, *Mill*, *Plant*, and *Speaker*. Thus, each participant was subject to one METHOD and all ARTIFACTS. We used a Latin-square design for the order of the presented artifacts to prevent learning or fatigue effects. In prior to the study, we balanced participants' age and gender over the five METHOD levels to further limit a possible effect caused by the participants' background.

We used a Wizard-of-Oz approach to present the four artifacts to the participants. A researcher, the wizard, controlled the ambient lighting using an application on a tablet and gave the participants the illusion that the displayed artifacts are fully functional. For the recruitment of the participants, we made the participants think that we want to investigate smart artifacts with integrated ambient lighting itself in the smart home and not to compare different study methodologies.

3.2.2 Smart Artifacts

For the study, we decided to investigate different smart artifacts (ARTIFACTS) that differ in their functionalities and provide different utility to the users. Thus, all artifacts differ in their purposes and how often state changes are occurring. In the following, we describe the functionality and tasks for each of the smart artifacts. For the representation of the displayed information through ambient light, we used the traffic light metaphor with a fading from green through yellow to red as Matvienko et al. [113] suggest for displaying progress and state for ambient light systems (see for example Figure 3.4).

Cup saucer displaying the drink's temperature:

The *Cup* saucer (see Figure 3.2) shows the temperature from not drinkable red to drinkable green. Participants were asked to place the cup at the coffee machine and brew a cup of coffee. Once a cup of coffee is brewed, the participants place the cup on the saucer and saucer's light display illuminates in red as the coffee is hot. We asked the participants to experience the temperature change displayed at the saucer and simulated a time lapse for the coffee cooling down. For *AR* and *Lab*, the coffee was brewed using a pad machine. Participants in the *In-Situ* method used their machines to brew the coffee. For *Online* survey condition, we used a video displaying a hand executing the interaction as in the *Lab*. To highlight the time lapse, we added an animation showing a time change at a clock. In the *VR* condition, a controller was used to grab the cup and to start elicit brewing animations by using the controllers' trigger button.

Figure 3.2: The investigated Cup as a physical prototype indicating that the temperature of the coffee is pleasant.

Stand for pepper and salt mills displaying filling levels:

The *Mill* stand (see Figure 3.3) indicates the filling level for both pepper and salt mill, from green for full via yellow to red indicating one mill to be empty. Both mills have their individual light around their stand. At the beginning of the interaction the pepper mill was full (i.e., display lights in green) and the salt mill half-full (i.e., display lights in yellow). Participants use the pepper mill, and we simulated multiple cookings; as soon as the light turned from green through yellow to red, the participants had to open, and refill the mill with pepper until the display turned back from red through yellow to green to indicate a full mill. Afterward, the participants closed and used the mill again and put it back in the stand. In the *AR*, *Lab*, and *In-Situ* methods the participants refilled the mill with provided pepper. Further, we supported the participants with in-situ instructions about how to refill the mill if necessary. For the *Online* condition, we used a video displaying a hand executing the interaction as in the *Lab*. To highlight the simulation of multiple cookings, we added an animation showing a time change at a clock. In *VR* a controller was used to grab mills or to start animations for using and refilling the mills.

Figure 3.3: The investigated Mill as a physical prototype indicating that the pepper needs to be refilled.

Plant pot displaying the water level:

The *Plant* pot (see Figure 3.4) expresses if the plants needs water. We use red light for needs water urgent and green for everything is fine. The plant with a sufficient water level was shown to participants. A time lapse was simulated, and we asked the participants to experience the light display while the water level dropped (i.e., the light display turned from green through yellow to red). When the water level indicator changed to shades of red participants were asked to water the plant until the indicator switched from red through yellow to a bright green indicating the plant's sufficient water level. We used a regular watering can for *AR* and *Lab*. Participants in the *In-Situ* method used their watering can. For *Online* we used a video displaying a hand executing the interaction as in the *Lab*. To highlight the time lapse, we added an animation showing a time change at a clock. In *VR*, the HTC Vive controller was used to grab the can using the trigger button.

Speaker displaying the volume:

The *Speaker* (see Figure 3.5) displays the volume of the music. Green light indicates the volume is pleasant to listen to, and red light indicates the music

Figure 3.4: The investigated plant pot as a physical prototype representing a plant that has sufficient water

is way too loud. Participants were asked to turn on the speaker, start playing music; at the beginning music is played at a high volume. Thus, they reduced the volume of the music to a lower volume, and observed the ambient lighting fading into yellow, than green when the music is pleasurable. Participants control the music and the volume using a smartphone for *AR*, *Lab*, and *In-Situ* conditions. For the *Online* condition, we recorded a video displaying a hand executing the interaction using a smartphone to control the music. To highlight the volume change, we added a visualization of the current music's volume to the video. In *VR*, we displayed a remote control on the left controller with play and volume buttons that are controlled using the trigger of the second VR controller.

3.2.3 Apparatus

As our apparatus changes depending on the METHOD, we had to implement a set of systems to serve all METHOD. For the *AR*, *Lab*, and *In-Situ* conditions, we used physical prototypes. We added capabilities to the artifacts to show the current state in the *Lab*, and *In-Situ* condition (see Figure 3.6a and Figure 3.6b) using an ESP8266 chip to control the LEDs via WiFi.

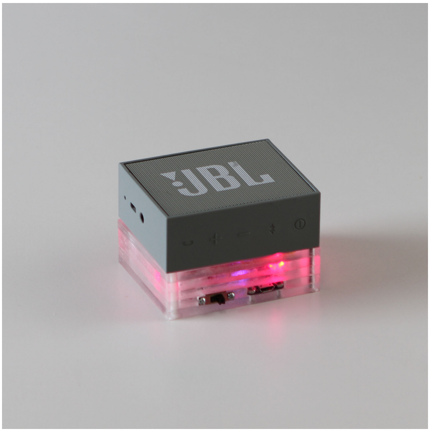


Figure 3.5: The investigated Speaker in the physical form representing music played with a high volume.

For the *AR* condition, we added an illumination layer to the physical artifacts used in the *Lab* condition (see Figure 3.7a). In the *AR* condition we used a Microsoft HoloLens in combination with Unity and Vuforia[1] for object recognition.

In the *VR* condition, we modeled the study room as well as the artifacts in 3D to resemble the lab environment. Moreover, we added functionally to all artifacts, e.g., opening the pepper mill and getting coffee out of the machine (see Figure 3.7b). The *VR* condition was implemented in Unity, the environment was modeled in 3ds Max, and the participant used an HTC Vive with two controllers to interact with the virtual world.

Lastly, the *Online* condition presented video clips of each physical prototype recorded in the same lab environment. Each clip was 30 seconds long in which the function was presented and the ambient light explained.

Finally, we developed an Android application to enable the experimenter to change the ambient light of all artifacts using a Wizard-of-Oz approach. The application shows one slider per artifact and sends the light commands to the ARTIFACTS regardless if it is a physical, AR or VR artifact.

[1] `https://www.vuforia.com/`

(a) Lab condition

(b) In-Situ condition

Figure 3.6: The physical prototypes of the Mill used in the lab and in-situ conditions.

3.2.4 Measures

Since the previous work found in comparisons of the lab and in-situ studies that empirical research can affect the usability [50, 130] and the perceived user experience [157, 176], we decided to determine the artifacts' usability and user experience by collecting quantitative and qualitative feedback.

In all conditions, we asked the participants to rate all artifacts individually using the standardized questionnaires, AttrakDiff [78, 79], augmented reality immersion (ARI) [70], and system usability scale (SUS) [23]. The SUS [23] is a frequently used standardized questionnaire to assess the usability of a prototype. Furthermore, user experience research focuses on different characteristics of inter-

(a) AR condition

(b) VR condition

Figure 3.7: The prototypes of the Mill used in the VR and AR conditions.

active products such as the hedonic quality [13]. The AttrakDiff is an often used questionnaire in HCI that investigates the attractiveness of a product by accessing its pragmatic and hedonic qualities and attractiveness for the users [78, 79]. To assess the quality and visual fidelity of the methods with virtual content, we used the ARI [70] questionnaire, which focuses on location-awareness, engagement, and immersion. As the questionnaire is designed to compare content in the real world with virtual content, we also used the ARI questionnaire using the other methods. Furthermore, we used qualitative questions to investigate the suitability of ARTIFACT.

Figure 3.8: The Mill in use in the Online condition (i.e., a video screenshot)

Beyond the questionnaires, we measured the task completion time (TCT) of the primary task and the TCT for answering the questionnaires. At the end of the study, a final questionnaire to reflect on ambient light integrated into home artifacts was given to participants.

3.2.5 Procedure

In all conditions, we asked the participants to fill in the consent form and a demographics questionnaire. Then, depending on the METHOD, we guided participants through the study one ARTIFACT after the other. We also asked them to interact with the prototypes by accomplishing the given tasks since research found that using haptic cues increases presence in VR [84]. In the end, we asked participants to fill a final questionnaire and finally rewarded them with 5 €.

For the *Online* method, we sent participants a link to fill in the online survey. The guidance through the study was provided here through the survey itself. At the end of the survey participants were asked to leave their personal information to also reward them with 5 €.

3.2.6 Participants

We recruited 60 volunteers (40 male, 20 female) between the ages of 17 and 70 ($M = 26.9$, $SD = 8.1$) from our mailing lists and social networks. The five conditions were counterbalanced such that each condition had 8 male and 4 female participants.

3.3 Results

In the following, we present the results of the study. We analyze differences between the different empirical methods by investigating the ratings of the standardized questionnaires and their item reliability, the average times for answering the questionnaires, and the quality of the qualitative feedback.

3.3.1 Questionnaire Scores

We conducted a mixed-model multivariate analysis of variance (MANOVA) with the between-subject variable METHOD and the within-subject variable ARTIFACT to determine if the five subjective measures are independent. Participants were entered as a random factor. We found a significant main effect of METHOD, $F(24,212) = 2.821$, $p < .001$, Pillai's trace = .968, $\eta_p^2 = .075$, and ARTIFACT, $F(18,486) = 2.479$, $p < .001$, Pillai's trace = .252, $\eta_p^2 = .028$, but no interaction effect of METHOD × ARTIFACT, $F(72,990) = 1.094$, $p = .281$, Pillai's trace = .442, $\eta_p^2 = .033$. Six univariate ANOVAs for the questionnaire measures were conducted. All post-hoc tests were performed using Bonferroni-corrected p-value adjustments. Aggregated means of the methods and their 95% confidence intervals are shown in Figure 3.9.

Univariate ANOVAs using the scores of the SUS questionnaire (see Figure 3.9) revealed no significant main effect of METHOD, $F(4,55) = 1.125$, $p = .354$, but of ARTIFACT, $F(3,165) = 3.124$, $p = .027$. There was no significant interaction effect of METHOD × ARTIFACT, $F(12,165) = .978$, $p = .472$. Pairwise comparisons could not show between which ARTIFACTS the significant differences occur (all with $p > .05$).

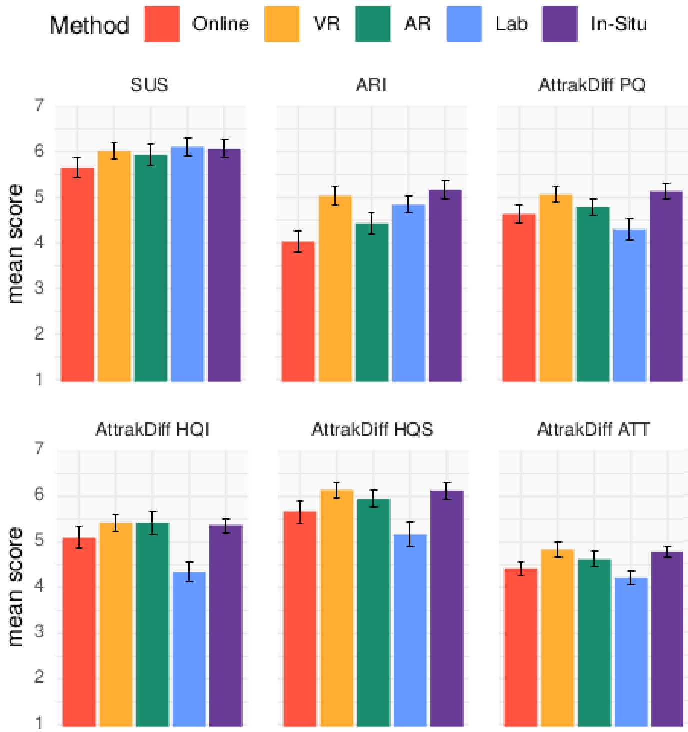


Figure 3.9: Mean scores of the five questionnaires SUS, ARI, AttrakDiff (PQ,HQ,ATT) determined using four different methods (Online, VR, AR, In-Situ). Excepting the means of the SUS, all questionnaire scores depend on the used method. Error bars show CI95. Further, the scales were adjusted post-study to increase the comparability of the different standardized questionnaires.

For the ARI scores (see Figure 3.9), we found significant main effects of METHOD, $F(4,55) = 5.004$, $p = .002$, and of ARTIFACT, $F(3,165) = 4.473$, $p = .004$, but no interaction effect of METHOD $\times$ ARTIFACT, $F(12,165) = 1.058$, $p = .399$. Post-hoc tests revealed significant differences between *AR* and *In-Situ*, *AR* and *VR*, *In-Situ* and *Online*, *Lab* and *Online*, *Online* and *VR* (all with $p < .05$).

For the AttrakDiff Pragmatic Quality (PQ) (see also Figures 3.9 and 3.10), we found significant main effects of METHOD, $F(4,55) = 4.765$, $p = .002$, and of

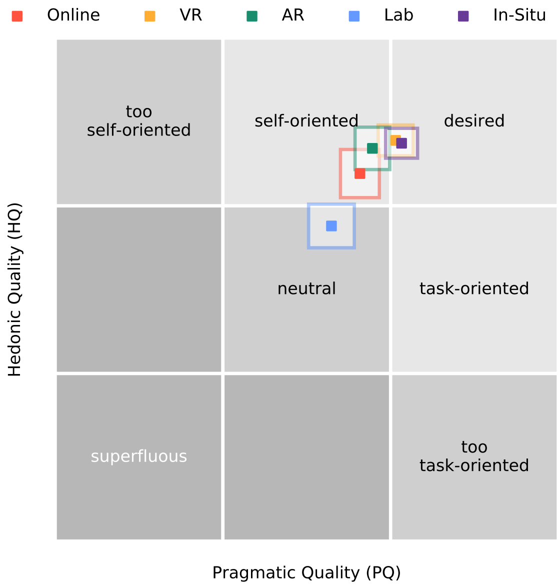


Figure 3.10: Portfolio presentation graph comparison of the AttrakDiff, with Hedonic Quality (HQ) = Hedonic Quality-Identity (HQ-I) + Hedonic Quality-Simulation (HQ-S).

ARTIFACT, $F(3,165) = 9.172$, $p < .001$, as well as a significant interaction effect of METHOD × ARTIFACT, $F(12,165) = 2.104$, $p = .019$. Post-hoc tests could reveal significant differences between *AR* and *Lab*, *In-Situ* and *Lab*, *In-Situ* and *Online*, and *Lab* and *VR* (all with $p < .05$). Considering the ARTIFACTS, there were significant differences between *Plant* and *Mill* as well as between *Plant* and *Cup*. Differences between the combinations of the interacting factors could not reveal significant differences (all with $p > .05$).

Considering AttrakDiff Hedonic Quality Identity (HQ-I) (see Figures 3.9 and 3.10), we found significant main effects of METHOD, $F(4,55) = 6.893$, $p < .001$, and of ARTIFACT, $F(3,165) = 6.935$, $p < .001$, as well as a significant interaction effect of METHOD × ARTIFACT, $F(12,165) = 2.554$, $p = .004$. Pairwise tests for significant differences were found between *AR* and *Lab*, *Lab* and *In-Situ*, *Online* and *Lab*, and *VR* and *Lab* (all with $p < .05$). For the ARTIFACTS there were significant differences between *Mill* and *Plant* as well as between *Plant* and *Speaker*. Test of pairwise combinations between the interacting factors could not reveal any further differences (all with $p > .05$).

For the AttrakDiff Hedonic Quality Simulation (HQ-S) (see Figures 3.9 and 3.10) we found significant main effects of METHOD, $F(4,55) = 5.449$, $p < .001$, and of ARTIFACT, $F(3,165) = 6.179$, $p < .001$, as well as a significant interaction effect of METHOD $\times$ ARTIFACT, $F(12,165) = 1.968$, $p = .030$. Pairwise tests for significant differences were found between *AR* and *Lab*, *Lab* and *In-Situ*, *Online* and *Lab*,*Online* and *VR*, as well as between *VR* and *Lab* (all with $p < .05$). For the ARTIFACTS there were significant differences between *Mill* and *Plant* as well as between *Plant* and *Speaker*. Test of pairwise combinations between the interacting factors could not reveal any further differences (all with $p > .05$).

Finally, we analyzed the AttrakDiff Attractivity (ATT) measure (see also Figure 3.9) for product attractivenesss and found a significant main effect of METHOD, $F(4,55) = 3.996$, $p = .006$, and of ARTIFACT, $F(3,165) = 7.471$, $p < .001$, but there were no interaction effect of METHOD $\times$ ARTIFACT, $F(12,165) = 1.450$, $p = .148$. Post-hoc tests revealed significant differences between *AR* and *Lab*, *In-Situ* and *Lab*, *In-Situ* and *Online*, *Lab* and *VR*, and *Online* and *VR* (all with $p < .05$). Considering the ARTIFACTS, we found a significant difference between *Plant* and *Speaker* ($p < .05$).

Thus, the results show that five of six questionnaire scores were significantly affected by the used METHODS. The SUS questionnaire was not affected by the METHODS. All questionnaire measures were significantly affected by ARTIFACTS. Three measures of the AttrakDiff questionnaire (PQ, HQ-I, and HQ-S) even showed an interaction effect of METHOD $\times$ ARTIFACT, which means that those measures depend on both factors and has an impact on the comparability of studies using different methods.

3.3.2 Item Reliability

To assess the overall consistency of the questionnaire measures concerning the methods, we used Cronbach's alpha test for internal reliability. Overall internal reliability of the questionnaires was questionable for SUS ($\alpha = .698$), acceptable

Table 3.1: Reliability measures (Cronbach's α) for item reliability of the questionnaire measures using the five research methods.

	SUS	ARI	AttrakDiff			
			PQ	HQ		ATT
				HQI	HQS	
Online	.734	.846	.870	.668	**.892**	.833
VR	.703	.747	.813	.616	**.895**	.758
AR	.718	.860	.829	.512	**.909**	.854
Lab	.648	.617	.726	.483	**.861**	.811
In-Situ	.513	.700	.790	.540	**.911**	.786
All	.698	.794	.814	.559	**.911**	.806

for ARI ($\alpha = .794$), good for the PQ measure of AttrakDiff ($\alpha = .814$), poor for HQ-I ($\alpha = .559$), excellent for HQ-S ($\alpha = .911$), and good for ATT ($\alpha = .806$). Table 3.1 shows the reliability scores using each method. The subscale HQ-S of the AttrakDiff questionnaire shows the highest internal reliability measures using all methods.

3.3.3 Questionnaire Completion Time

The total duration to fill in all questionnaires was measured (see Figure 3.11). The completion time was entered into an ANOVA with METHOD as the only independent variable. The analysis revealed a significant effect of the used METHODS, $F(4,296) = 2.996$, $p = .019$. Pairwise comparisons using Bonferroni-corrected t-tests revealed significant differences between *AR* and *Lab*, *AR* and *Online*, *In-Situ* and *Lab*, and *Lab* and *VR* (all with $p. < 05$).

3.3.4 Word Count Analyzes

Words of all feedback items were counted. ANOVA of aligned and ranked tests (Aligned Rank Transform (ART)) [223] for non-parametric data revealed significant difference between METHOD, $F(4,55.890) = 3.944$, $p = .006$, but not between the feedback items of ARTIFACT, $F(4,221.417) = .814$, $p = .517$. There was no significant interaction effect of METHOD $\times$ ARTIFACT, $F(16,221.419) =$

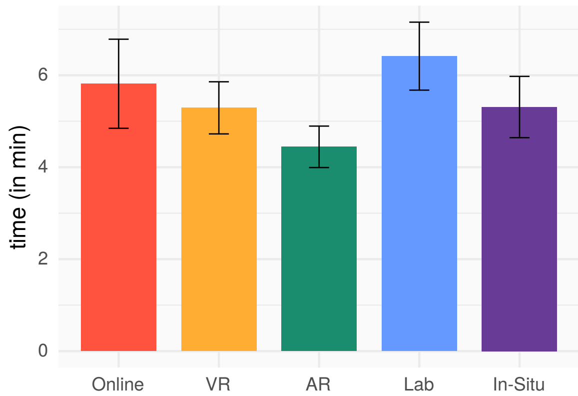


Figure 3.11: Average completion time of the users to fill in all questionnaires. Error bars show CI95.

1.291, $p = .203$. Pairwise Bonferroni-corrected Wilcoxon signed rank tests revealed significant differences between *AR* and *Lab*, *AR* and *Online*, *AR* and *VR*, *In-Situ* and *Online*, *Lab* and *Online*, and *Online* and *VR* (all with $p < .05$). The average word counts are shown in Figure 3.12. The highest average word counts were found for *Lab* and *VR*, respectively. The lowest average word counts were found for *Online* and *AR*. We also determined the number of answered qualitative questions per method. The most qualitative questions were answered for *Lab* (94.4%), followed by *VR* (87.5%), *In-Situ* (83.3%), and *AR* (77.8%). For *Online*, the fewest qualitative questions were answered by the participants (50.0%).

3.3.5 Qualitative Analysis

The qualitative analysis focuses on the effect of the methods on the quality of the feedback. In the first iteration, we used a thematic analysis of the user experience [18] with open coding for the qualitative answers for each artifact. Two researchers went through the comments and coded them individually. The disagreements between the two sets of annotations were resolved through discussion. However, in the second iteration, the author alongside another researcher continued the analysis of the protocols using axial coding based on the derived

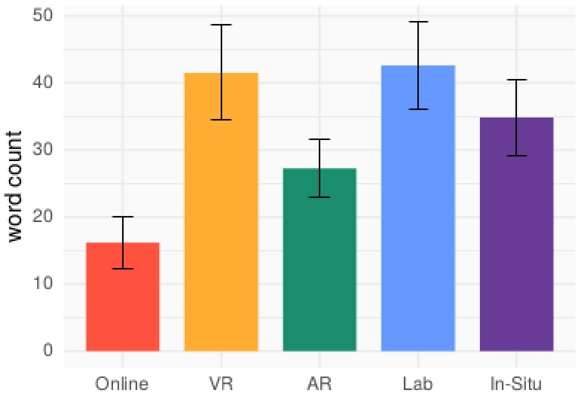


Figure 3.12: Average word count for each method. Error bars show CI95.

themes to understand why a specific method could affect the user experience. The decomposition of the axial coding themes into the methodological effects is based on discussion. Through the analysis we identified twenty-eight themes (not reported) of comments and two reasons for the observed effects between the different methods.

Method assumed to be part of the system

Although the participants were explicitly told that the aim is to evaluate the concept of the artifacts, the opinion about a system also influenced the opinion about the artifacts. This is particularly evident in statements where the system was specifically mentioned. For example, participants stated after the AR condition that they "[...] see the advantage to get useful information" and the disadvantage that they "[...] always have to wear the HoloLens" (P44, Plant/AR) or that"[the HoloLens] is barely usable as a device" (P27, Final Question/AR).

Motivation without experimenter

Implications of device usage were mainly found when an experimenter was present during the study. Thus, we found useful implications in all methods except the online survey. Highlighted implications were possible effects on the *future*, "it could be possible that people start depending too much on the artifacts and stop using their brain for some activities" (P24, Final Question/VR) on their own *feelings*, "I like to listen to loud music and would probably feel guilty through the red light and would not use the light at all" (P11, Speaker/AR), and on *social relations* when multiple persons are involved, "show all residents that [the plants] have to be watered again or that they should not be watered anymore" (P3, Plant/Lab). Lacking motivation for increasing the quality of their comments in the online condition was also evident by the participants' comments regarding which other artifacts supporting ambient lighting the participants can imagine having in their homes, "Google Home" (P58, Final Question/Online). Thus, we assume that the presence of an experimenter motivate participants to increase the quality of their responses.

3.4 Discussion

Empirical studies are an integral part of HCI research. The used empirical methods must be reproducible and produce valid and reliable results [85]. While each method has its own advantages and disadvantages, the method can also affect a study's results.

In this chapter, we compared five empirical methods. We showed that methods could significantly affect the results of the standardized questionnaires ARI and AttrakDiff. Further, we found that the method also affected the average time to answer the questionnaires and the quality of qualitative feedback (i.e., word counts and addressed themes).

Therefore, it is important to understand the effects of the study method as well as its unique advantages and disadvantages that we will discuss (RQ2):

Online surveys Online surveys offer researchers the opportunity to conduct studies in a cheap and time-efficient manner with a broad range of participants [44, 174]. An advantage for the participants is that they can participate in the survey whenever they are available [44]. A drawback of the online method (RQ2) is that we observed that the participants were less engaged compared to the other methods where a researcher was present (i.e., VR, AR, lab, and in-situ studies).

This confirms and extends the results by Dandurand et al. [44], who found that participants in lab studies felt more committed to their participation in lab studies than in online experiments. In our study, we received significantly less qualitative feedback from participants in the online method. Furthermore, we also found that the quality of the comments from participants in the online method was lower than in the other methods, i.e., participants answered more with short and unsubstantiated descriptions.

In contrast to all other methods, the online method participants did not mention themes that address important insights, such as implications for future development [162], and how such artifacts might affect their feelings or social relationships. Finally, we observed that while participants in the online method gave less qualitative feedback (e.g., fewer responses, significantly lower word counts), the questionnaires' answering times were similar to the other methods. We assume that our participants were distracted or did something in parallel during answering in our online survey, which affirms with the results of Clifford et al. [30].

Surprisingly, we observed similar high ratings for their usability, attractiveness, pragmatic and hedonic qualities, and augmented reality immersion using the in-situ and VR methods. Furthermore, the qualitative feedback quality (i.e., word count and addressed themes) and the average time to answer questionnaires were similar for both methods. We have not expected that since we displayed the artifacts in the VR application using a 3D model of our lab instead of using a living environment such as a living room to increase the comparability with the other evaluated lab-based methods (i.e., AR and Lab). While our results suggest that VR and in-situ provide similar insights, future work should further compare especially different environments in VR, e.g., a natural environment being compared to a lab setup and different effects between studies using VR and in-situ studies.

Evaluating early prototypes by using AR or VR technologies Using AR and VR enable researchers to develop rapid prototypes [151]. Further, using VR for the evaluation enables researchers to conduct studies outside of the lab environment [121]. However, we also observed drawbacks when AR or VR is used for the evaluation of early prototypes. Although we told the participants at the beginning of the study that the method is only used to investigate smart artifacts, we observed that the used method affected the results. One explanation is that the participants cannot ignore the method and are potentially biased through novelty, distractions, or concerns that the method could be part of the investigated technology, which is one of the most significant drawbacks of the applied methods (RQ2). This is supported by qualitative analysis. We assume that the ratings in the AR method were negatively affected since the participants experienced wearing a Microsoft HoloLens as more inconvenient than wearing VR glasses, for example, because of the HoloLens' weight and the limited field of view to display content. When designing empirical studies, researchers must consider that participants might not differentiate between the evaluated prototypes and the used system to evaluate the prototypes, especially when novel technologies such as AR or VR are used. It is conceivable that these effects might disappear if technologies such as VR and AR will become more common for users in their daily lives.

Lab studies Lab studies enable researchers to conduct investigations in a controlled environment without external distractions [48]. Therefore, the results of lab studies have high internal validity.

By conducting lab studies, researchers can identify similar usability issues then by conducting in-situ studies [86, 90, 93]. However, a drawback of lab studies is that former work found that some usability issues regarding the cognitive load or the interaction style were not identified in lab studies [131]. Similarly, usability issues based on environmental factors in the natural environment are hard to observe in a lab study [50].

Further, we observed differences regarding the investigated artifacts' perceived user experience for the methods lab study and in-situ study. While evaluating a prototype using the AttrakDiff questionnaire, for example, with the in-situ method, one could conclude that the prototype is perceived as desired by the participants. However, investigating the same physical prototype in a lab study could conclude that the prototype is only perceived as neutral.

In-situ studies In-situ studies are mainly used to study prototypes in their natural environment [48, 157]. They are useful in capturing the context of use [158] or understanding the user-experience [24, 157]. Results gained by conducting in-situ studies usually have a high external validity [83]. Drawbacks of in-situ studies is that researchers are not in control over the environment where the study takes place, which enables distractions or interruptions, and their higher costs [48].

Suitable Methods for the Evaluation of Smart Home Appliances Our investigation revealed that the evaluation method can significantly affect prototypes' assessment, which highly affects the suitability of the different research methods to evaluate early prototypes of smart home appliances (RQ1). Therefore, there is no best method for evaluating early prototypes of smart home appliances informing the users about everyday information. However, since novelty effects nowadays can occur when VR or AR are used to evaluate prototypes that investigate how smart home appliances could inform the users about everyday information, these methods are currently not suitable evaluating early prototypes. Although, our study found that participants are less-engaged in the online survey [44]. Further, we found that the online survey condition participants did not mention implications for future development. That does not mean that online surveys cannot be a suitable method to investigate specific research questions - similar to the lab and in-situ methods, the method must fit the specific research questions and goals for the inspection [92]. However, researchers should keep in mind that the results of investigations of early prototypes might be misleading. Therefore, researchers should frequently check their results in follow-up investigations during the whole user-centered design and development process. Therefore, the best method to evaluate smart home appliances informing the users about non-urgent everyday information is to conduct long-term in-situ studies to investigate how a smart home appliance integrates into users' lives, to capture the user behavior, and to determine the context of use with high external validity [86, 158].

Insights regarding the standardized questionnaires Finally, we found a significant interaction effect between the used methods and the investigated artifacts for the pragmatic and hedonic qualities of the AttrakDiff questionnaire. Thus, the result of an investigation of a specific prototype depends on the empirical method and the evaluated prototype being used. Since the AttrakDiff questionnaire is mainly used to determine the attractiveness of products for users, this impacts the investigation of products and the comparison of different products. While one method for the assessment of hedonic and pragmatic qualities of an investigated product might show that a product is experienced as desired, by applying another, the method could indicate that the product is experienced as neutral (see also Figure 3.10).

The highest internal item reliability among the items was found for the HQ-S scale. The questionnaire's subscale is designed to determine the novelty and originality of a product and showed the strongest factor loading among the AttrakDiff measures [78, 79]. As it is sensitive to the novelty of a product, we assume that it is also sensitive towards the method, which was confirmed by the main interaction effects between artifact and method. Consequentially, products that were evaluated using different study methods might not be comparable. Furthermore, the empirical studies in a human-centered design process [135] that use the AttrakDiff questionnaire could lead to misleading results from an evaluation that influence the further development of a product. This error could not be noticed until an evaluation of an improved version conducted at a later point in time might figure out different results. Therefore, the results gained by applying the AttrakDiff could not be reliable when early prototypes of smart home appliances are evaluated.

In contrast to ARI and AttrakDiff questionnaires, the analysis of the SUS [23] results revealed only significant differences between the tested artifacts. Thus, the SUS questionnaire is more robust against different methods. However, the significant measured differences regarding the evaluated artifacts were too sensitive for conducted posthoc tests to identify the significant differences. Considering that we evaluated the artifacts with a total of 60 participants, using the SUS questionnaire to measure the usability might also be not the best option.

Limitations

One limitation of our work is that we compared the five evaluation methods using four specific smart artifacts. However, designing smart artifacts displaying additional information without overloading the users' attention is a relevant research topic investigated in this thesis. Its evaluation, therefore, is important by itself. Further, investigating smart artifacts also enabled us to keep the influence of participants' background low. We assume that the results are transferable, but future research should also investigate other types of systems and other domains.

4

Exploration of Displaying Smart Home Notifications

During the review of the related work, we learned that future smart home appliances will compete for the user's attention [43] and that users need to deal with the adverse effects caused by the number of mobile notifications that they already receive in their daily lives [11, 88]. Furthermore, if smart home appliances would also inform their users about everyday home information by sending mobile notifications to the users' smartphones, these adverse effects could be further amplified. Therefore, it is essential to investigate how future smart home appliances should be designed.

In this chapter, we conduct the first exploration of smart home notifications. Here, we conduct two focus groups and an online survey to investigate how home information could be displayed in the future. With the conducted studies, we will investigate the following research question by studying our research probe.

- Which modalities are suitable to inform users about everyday information? (RQ3)
- Which locations are suitable to display everyday information in a smart home? (RQ4)

This chapter is based on the following publications:

A. Voit, T. Machulla, D. Weber, V. Schwind, S. Schneegass, and N. Henze. "Exploring Notifications in Smart Home Environments." In: *Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services Adjunct*. MobileHCI '16. Florence, Italy: ACM, 2016, pp. 942–947. ISBN: 978-1-4503-4413-5. DOI: 10.1145/2957265.2962661

A. Voit, D. Weber, and S. Schneegass. "Towards Notifications in the Era of the Internet of Things." In: *Proceedings of the 6th International Conference on the Internet of Things*. IoT'16. Stuttgart, Germany: ACM, 2016, pp. 173–174. ISBN: 978-1-4503-4814-0. DOI: 10.1145/2991561.2998472

4.1 Exploration of Modalities and Locations to Represent Home Information

Home information cannot be displayed only on personal devices such as the users' smartphones and the home environment. Previous research has looked at using the environment to communicate information to users, such as using ambient light information systems in an office environment [123], using an ambient orb to display text messages [3], or the TV as a central notification display [211]. However, all previous work focuses on displaying notifications similar to the ones generated on smartphones, e.g., messaging apps, and bringing them into the environment. In our exploration, we focus on notifications generated by the environment itself (e.g., through sensors attached to plants, heatings, or integrated into furniture). As a result, we explore how the notification's sending device and the location where it is displayed should be linked. Further, we study how the notifications can be visualized to implicitly conveying the content. In this subsection, we report on two focus groups.

4.1.1 Method

We conducted two focus groups with 6 participants each. The main task of each focus group was collecting ideas of how notifications generated by smart devices can be visualized in the home environment. The participants were aged

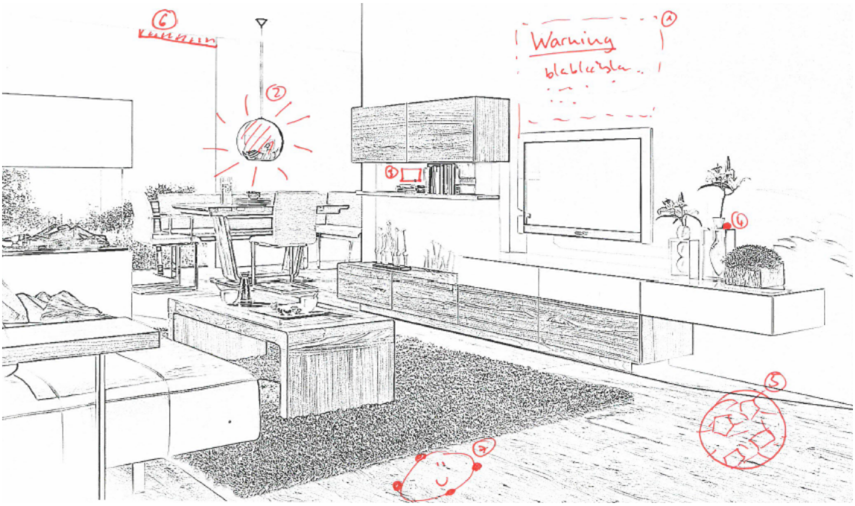


Figure 4.1: One of the worksheets used in the focus groups showing a living-room setting and the drawings made by a participant.

18 to 28 years ($M = 24.4$, $SD = 2.93$) and recruited through University‘s mailing lists. Each focus group involved two main tasks. First, we collected different devices that could produce notifications in the future. Second, the participants draw on provided design sketches of different rooms (see also, Figure 4.1) how notifications could be visualized and where they could be located.

4.1.2 Results

In the following, we report the results of the study by investigating the notification modalities as well as the used visualization type and location to represent information in the home.

4.1.2.1 Notification Modalities

The participants described different output methodologies suitable for grabbing the attention of the user.

Visual Output: The participants mainly mentioned visual cues due to their ambient characteristics. Visual cues include, for example, projection on arbitrary surfaces (e.g., projecting appointments), light installations using ambient lighting (e.g., umbrella gets illuminated if the user should take it), and using other smart home appliances such as TVs or controllable lamps (e.g., displaying a reminder).

Haptic Output: Participants also mentioned haptic output. In contrast to on-body haptic feedback for notifying users [166], they mainly focused on feedback integrated with smart home objects. For example, the participant suggested that the sofa starts vibrating as a reminder to go to an appointment.

Auditory Output: Most participants did not mention auditory output except for urgent scenarios (e.g., Pizza needs to get out of the oven). They argued that auditory output would be disturbing with an increasing number of notifications.

4.1.2.2 Visualization Type

The participants suggested different visualization methods for presenting home information visually. We then analyzed their suggestions and grouped them into textual, color-coded, and symbolic visualizations.

Textual: Textual notifications presented content similar to current notifications on the smartphone. Participant, for example, mentioned "water missing" projected next to a plant to notify the user on watering the plant. Another example was showing a receipt next to the oven in the kitchen.

Color-coded: Abstract notification include highlighting a plant red to indicate that the user needs to water the plant or coloring the door in a light red or green based on whether it is locked or not. These visualizations could be realized with LED integrated into the environment.

Symbolic: Participants also mentioned symbolic visualizations in which the notification shows the action that the user requires. Symbolical visualizations required projection and sophisticated design but yield the advantage of being potentially easy to understandable. Examples include projecting on a plant so that the leaves look like they are almost toasted to remind the user to water the plant. Another typical example would be visualizing rain over the plant to indicate the absence of water.

Allow Multimedia Content: Using animations (e.g., rain or rising warm air) was suggested in both focus groups. Additionally, using a specific color was one of the most mentioned ways to notify the user (e.g., at the door or in the whole room).

4.1.2.3 Location to Display Notifications about Home Information

We analyzed the output locations mentioned by the participants sorted them into three groups, namely, central notification area, on-object, and ambient.

On-Display Notifications: Participants mentioned using a single notification screen, e.g., a central display in the home, for general purpose notifications. This could be either a dedicated display or integrated into already existing devices in the home, such as a smart TV. The participants mentioned mainly examples that focus on reminding the user. For instance, they mentioned using a digital picture frame that lights up and/or shows a picture of a person you planned to visit as a reminder.

On-Object Notifications: Presenting notifications directly on the object generating the notification has been mentioned since the spatial relation supports the understanding of the notification. A lot of smart devices do not have dedicated output possibilities such as displays (e.g., hydrometer in a flower pot). Thus, a projection could be used to present information on the object [75]. Examples include displaying items on the fridge the user is running out (e.g., milk is almost empty) or animation of water trickling on the plant to indicate the necessity of watering it.

Ambient Notification: Participants listed many scenarios in which ambient notifications could be used, similar to the work by Müller et al. [123]. Particularly, for displaying continuous notifications such as information about energy or water consumption (e.g., changing the color of the lighting slightly to red indicating high consumption). Another typical example mentioned was that reducing the illumination could indicate that users should go to sleep or change all lighting to a red color to notify of emergency.

4.2 Investigation of Locations for the Representation of Information in the Home

After exploring suitable modalities and locations for displaying home information in future homes, we decided to investigate the suggested locations on-display and on-object by conducting an online survey to compare them with other locations such as established location to present notifications, e.g., on-smartphone. We chose to investigate these locations in an online-survey by investigating these locations in specific contexts using textual descriptions for the representation of the home information to avoid any effect regarding the aesthetics of the representation.

4.2.1 Method

We conducted an online survey to evaluate where users prefer to receive smart home notifications and how they assess the different locations.

4.2.1.1 Apparatus

Locations to present smart home notifications For the online survey, we take four locations with different distances to the users into account to present home information in form of notifications. For some of the investigated locations the information is displayed next to the user, while in other cases, the information is displayed at a fixed position in the home. Therefore, we will compare the suggested locations in the environment that display home information visually in the environment, i.e., the locations on-display and on-object, with the established visualization on a personal device (i.e., on-smartphone) as well as an additional location to display such information on the body of the users, (i.e. on-body location).

The following locations were compared in the online survey:

On-Body A possibility for presenting notifications is using on-body displays such as display-augmented body parts [141] or garment based displays [98]. Although current textile-based displays offer only low-resolution solutions [5]. In the future, these displays will become indistinguishable from current smartphone displays. By placing such a display on the user's forearm, an ubiquitously available display can be used to present notifications. Another example of this category are wearable gadgets that provide visual feedback such as smart jewelry [61].

Here the location for the incoming notification should be most of the time in the glimpse of the user. Therefore we choose to represent the notification as a wearable textile display on the left forearm of the user.

On-Smartphone Smartphones present most of the notifications for a user (see also [144]) and are often near the user (see also, [221]). Also the smartphone is mostly placed close to the user (see also, [221]). We choose the smartphone as the personal device for displaying the notification because it is an established location to receive notifications. Most smartphones visualize an incoming notification using a pop-up message on the screen.

On-Display Central displays placed in the environment of the user can be utilized to present smart home notifications. Müller et al., for example, visualized different kinds of information with ambient light displays [122], e.g., displaying with color encodings how much time is left until the next appointment. Consolovo et al. used a display to present health information, intake of medicine or food, and activities [34]. The display presents a picture of the caring elderly and information about the health status, intake of medicine or food, and activities [34].

For the investigation of the on-display location, we use a tablet as a peripheral display in our environment similar to the CareNet display [34]. This tablet acts as a picture frame and all incoming notifications are represented as a pop-up message on the tablet's screen.

On-Object In this case, the notifications are presented on the smart home appliance generating the notification itself, for example by using low-cost displays (e.g., E-Ink). Sukthankar proposed the idea for an ambient projection [175].

They combine different projectors to enable the projection on every surface in an environment. Garcia Macias et al. created an augmented reality application that shows the watering state of the plant on the plant pots [66].

For the representation of the on-object location, we displayed the information textually next to the object that generated the home information similar to the ambient projection approach by Sukthankar [175].

4.2.1.2 Scenarios

Our main focus in this online survey is knowing where people prefer to receive their smart home notifications. Therefore, we chose four different scenarios with different urgency levels. In these scenarios, smart home appliances will notify the user about from moderate importance to urgent events.

In the following we describe the scenarios in detail:

Opening the Entrance door: The smart home system recognizes visitors at the entrance door and sends a notification to the user. An immediate reaction is required, otherwise visitors might assume that nobody is at home.

Closing a window: It starts snowing while a windows is opened for ventilation. To prevent snow from getting into the room, the system notifies the user by presenting a notification. In such case, the urgency level is rather high and the user should react in the next few minutes.

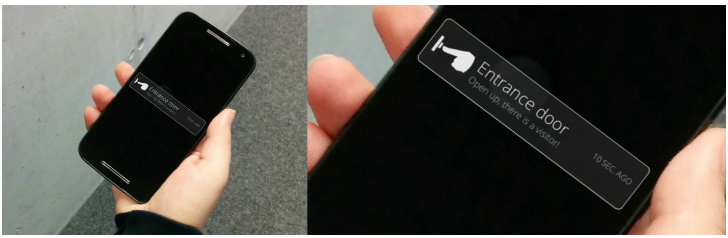
Taking medicine: The user needs to apply eyelid ointment every evening. The smart home system detects that the ointment should be applied and informs the user. In this case the user should react soon.

Watering a flower: The smart plant pot detects that the winter rose needs to be watered and sends a notification. The urgency level of this notification is rather low and the user should react to it within the next hours.

(a) On-Body

(b) On-Display

(c) On-Object



(d) On-Smartphone

Figure 4.2: Four examples of scenarios and locations as shown in the online survey.

4.2.1.3 Procedure

Participants were presented with 16 consecutive images (in a randomized order), one for each possible combination of scenario and location (see Figure 4.2 for examples). Participants answered a questionnaire consisting of six items for each image, each on a 7-point rating scale. The first item required participants to rate how suitable the location was for the particular scenario. Next, participants responded to five semantic differentials, i.e., rating scales between two bipolar adjectives. The adjective pairs were: bad – good, disturbing – not disturbing, not easy to perceive – easy to perceive, not useful – useful, and complicated – simple. These pairs were selected based on informal interviews conducted prior to the survey [41]. They were chosen to capture the diversity of aspects expected to influence participants' evaluation of the locations. Further, we asked participants for each scenario to rate whether they would want to be notified in this scenario. Finally, the participants ranked the four locations according to their preference and could comment on the locations and the scenarios.

4.2.1.4 Participants

In total, 183 people between 18 and 76 years ($M = 23.83$, $SD = 5.44$) participated in our online survey (110 female, 73 male). Most participants were students (172), followed by 10 employees and 1 retired participant.

4.2.2 Results

In the following, we report the results regarding the relevance of the investigated scenarios, the semantic differentials, the suitability of the different locations as well as the rating of the participants regarding the different locations.

4.2.2.1 Relevance of Scenarios

For the question if the participants wanted to be notified in the given scenarios, we conducted a one way repeated measures analysis of variance (ANOVA) (sphercity assumed, Huynh-Feldt corrected). We found that participants differed in how relevant they considered the scenarios, $F(2.63, 480.40) = 94.36, p < .001$. Overall, most participants agreed that they would like to receive notifications for *taking* *medicine* ($M = 5.84$, $SD = 1.42$), followed by *watering a flower* ($M = 4.81$, $SD = 1.72$), *closing a window* ($M = 4.24$, $SD = 1.88$), and *opening the entrance door* ($M = 3.25$, $SD = 2.05$).

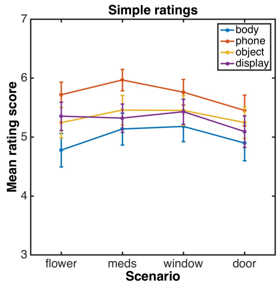
4.2.2.2 Semantic Differentials

Each participant rated each combination of scenarios and presentation location using five semantic differentials. We conducted six 4 x 4 repeated-measures analyses of variance (ANOVA) with the factors location and scenario, one for each semantic differential, and one for the suitable location ratings (LSR). The results are reported in Figure 4.1. The main effect of location was significant in all six cases, indicating that ratings differed with the location. This effect was further modulated by the scenario, as indicated by the significant interaction term (except in the case of rating non-disturbances). We conducted a series of post-hoc comparisons (paired-samples t-tests as reported in the following) to further investigate the effects of particular interest. Only if significant, the p-values were adjusted for multiple comparisons using Bonferroni corrections. Mean ratings are shown in Figure 5.7.

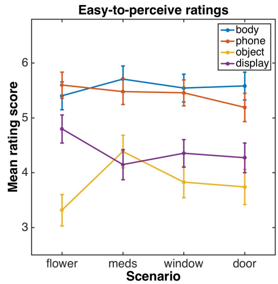
Simple: Disregarding the influence of scenario, participants' ratings were highest for smartphone and lowest for on-body (phone vs. object ($t(183) = 4.04$, $p < .001$), object vs. display ($t(183) = 14.65$, $p < .001$), display vs. body ($t(183) = -10.98$, $p < .001$)).

Easy-to-perceive: Disregarding the influence of scenario, notifications presented closer to the user were rated as easier to perceive (body vs. object ($t(183) = 3.82$, $p < .001$), body vs. display ($t(183) = 8.81$, $p < .001$), phone vs. object ($t(183) = 12.91$, $p < .001$), phone vs. display ($t(183) = 9.18$, $p < .001$)).

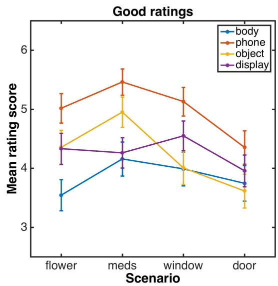
Non-disturbing: Disregarding the influence of scenario, participants' ratings for on-body were much lower than for the other locations (body vs. phone ($t(183) = -12.55$, $p < .001$), phone vs. display ($t(183) = -0.09$, $p = .930$),



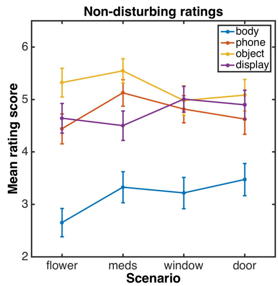
(a) simple



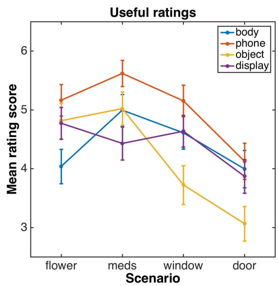
(b) easy to perceive



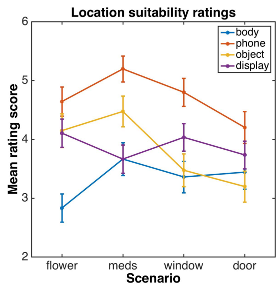
(c) good



(d) non-disturbing



(e) useful



(f) location suitability

Figure 4.3: Ratings per scenario and location for simple, easy to perceive, good, non-disturbing, useful and location suitability. Error bars represent 95% confidence intervals.

Scenario	df_M	df_R	F	p
simple	2.80	513.27	6.59	$< .001$
easy to perceive	2.86	522.99	2.83	$= .041$
not disturbing	2.98	545.55	1.58	$= .194$
good	2.83	517.64	28.96	$< .001$
usefulness	2.83	517.35	34.86	$< .001$
Location Suitability Ratings (LSR)	2.63	487.95	24.30	$< .001$

sphercity assumed, Huynh-Feldt corrected

(a) Scenario

Location	df_M	df_R	F	p
simple	2.44	445.86	19.49	$< .001$
easy to perceive	2.84	520.00	95.02	$< .001$
not disturbing	2.94	537.19	128.87	$< .001$
good	2.86	522.45	33.26	$< .001$
usefulness	2.99	547.03	19.63	$< .001$
LSR	2.76	512.92	42.52	$< .001$

sphercity assumed, Huynh-Feldt corrected

(b) Location

Interaction	df_M	df_R	F	p
simple	8.78	1,606.05	1.71	$= .084$
easy to perceive	8.53	1,561.19	8.37	$< .001$
not disturbing	8.71	1,593.42	20.64	$< .001$
good	8.34	1,525.90	8.20	$< .001$
usefulness	8.27	1,513.38	21.75	$< .001$
LSR	7.92	1448.36	16.29	$< .001$

sphercity assumed, Huynh-Feldt corrected

(c) Interaction

Table 4.1: The results of the inferential statistics.

display vs. object ($t(183) = -4.27$, $p = .001$)). On-body ratings for the least urgent condition, flower, were lower than ratings for the most urgent condition (flower/on-body vs. door/on-body, $t(183) = -5.37$, $p < .001$).

Good: Disregarding the influence of scenario, participants' ratings were highest for smartphone and lowest for on-body (phone vs. object ($t(183) = 6.49$, $p < .001$), object vs. display ($t(183) = -0.40$, $p = 0.690$), display vs. body ($t(183) = 3.40$, $p = .002$))). Disregarding the influence of location, ratings were lowest for door (door vs. flower ($t(183) = -4.38$, $p < .001$), flower vs. window ($t(183) = -1.30$, $p = .195$), window vs. medicine ($t(183) = -3.67$, $p < .001$).

Useful: Disregarding the influence of scenario, participants' ratings were highest for smartphone and lowest for on-object (phone vs. body ($t(183) = 4.97$, $p < .001$), body vs. display ($t(183) = -0.15$, $p = .884$), display vs. object ($t(183) = 2.29$, $p > .04$). Notifications on the object were judged least useful in the two urgent scenarios (window/object vs. flower/object ($t(183) = -1.64, p < .103$), window/object vs. medicine/object ($t(183) = -6.70, p < .001$), door/object vs. medicine/object ($t(183) = -10.46, p < .001$), door/object vs. flower/object ($t(183) = -5.01, p < .001$)).

4.2.2.3 Location Suitability Ratings (LSR)

Disregarding the influence of scenario, participants' LSR were highest for smartphone and lowest for on-body (phone vs. object ($t(183) = 6.93$, $p < .001$), object vs. display ($t(183) = -0.53$, $p = .599$), display vs. body ($t(183) = 4.25$, $p < .001$). Disregarding the influence of location, LSR were lowest for door (medicine vs. window ($t(183) = 5.40$, $p < .001$), window vs. flower ($t(183) = -0.25$, $p = .803$), flower vs. door ($t(183) = 3.65$, $p < .001$)).

To test whether urgency affected the LSR, we performed four linear mixed effects analyses, one for each location. As the fixed effect, we entered the scenarios in increasing order of urgency and as the random effect the participants. The p-values were obtained by using a likelihood ratio test of the full model with a null model without the fixed effect. We hypothesized that the LSR would increase for more urgent scenarios when notifications were displayed close to the user (i.e., smartphone and on-body) and decrease when displayed in a location of undefined distance to the user (i.e., display and on-object). This hypothesis was partially verified. While LSR increased moderately for on-body notifications it decreased for the other three locations (on-body: $\chi^2(1) = 13$, $p < .001$, increases

LSR by 0.15 ± 0.04 (SE) per level of urgency; phone: $\chi^2(1) = 16$, $p < .001$, increases LSR by -0.17 ± 0.04; on-object: $\chi^2(1) = 55$, $p < .001$, increases LSR by -0.39 ± 0.05; display: $\chi^2(1) = 16$, $p < .001$, increases LSR by -0.07 ± 0.04). Thus, urgency is not the only factor determining participants' LSR.

We performed a linear mixed effects analysis of the relationship between the LSR and the ratings of the five semantic differentials. The latter were entered as fixed effects into the model (without interaction terms). As random effects, we entered participant, location, and scenario. p-values for each semantic differential were computed using a likelihood ratio test of the full model against an alternative model without the semantic differential of interest. Results show a positive relationship between location fit and the ratings of each of the semantic differentials (non-disturbing: $\chi^2(1) = 195$, $p < .001$, increasing the rating of non-disturbing by 1 increases suitable location ratings by 0.18 ± 0.01 (SE); useful: $\chi^2(1) = 189$, $p < .001$, increases location fit ratings by 0.19 ± 0.01; easy: $\chi^2(1) = 128$, $p < .001$, increases location fit ratings by $0.14 \pm .01$; simple: $\chi^2(1) = 8$, $p = .004$, increases location fit ratings by 0.04 ± 0.01; good: $\chi^2(1) = 618$, $p < .001$, increases location fit ratings by 0.43 ± 0.02).

4.2.2.4 Ranking of Locations

Figure 4.4 shows the order of the location according to the participants' preferences. The *smartphone* was placed most often on the first position. Also, *on-display* and *on-object* were most often placed on the second and third position. The *on-body* location was mostly positioned last.

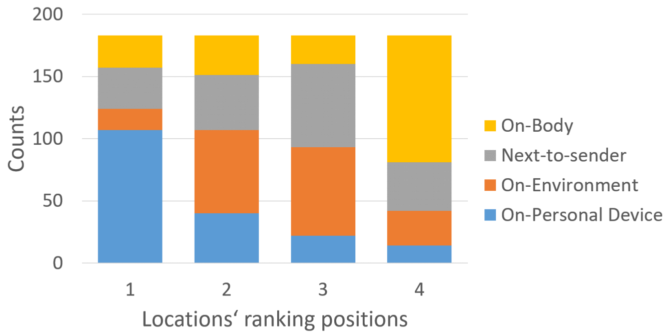


Figure 4.4: The overall ranking of the presentation location.

4.3 Discussion

This chapter explored the design space of displaying everyday home information in the smart home context by conduction two focus groups and an online survey.

We were interested in identifying suitable modalities to inform users about everyday information (RQ3). We observed in the focus groups that none of the participants explicitly was in favor of auditory cues. While current notifications on the users' personal devices are rather obtrusive, notifications for smart devices may overload the user due to the sheer number of potential notifications. Thus, many of the notification visualizations created during the focus group involved visual cues, including textual, symbolic, and color-coded representations that weave themselves into the environment. This confirms the finding that auditory cues are too annoying and obtrusive for everyday use [56] and strengthens the observation of an ongoing trend from switching from auditory to visual notifications [64].

Further, we investigated which locations are suitable for displaying everyday information in the smart home (RQ4). In the focus groups, we observed that participants added particularly non-urgent information on the creator in the home environment (e.g., the plant pot of a sensor sensed a lack of water for the respective plant). Further, the comparison of the online survey's different locations revealed that participants perceive the smartphone to be the most suitable location for notifications and rate the smartphone as simple, easy-to-perceive, and useful.

Possible reasons for this are that participants are familiar with this technology [comment by participant P105]. Further, performing tasks on a phone is generally perceived as faster and easier [136] by the users due the the fact that their smartphone is usually with the users (e.g., [P117]). Therefore, the participants might have established a habit to frequently check their phones as former work showed [143]. Displaying smart home information on the users' smartphones could increase adverse effects, such as the risk for smartphone addition and social frisk 10.1007/s00779-011-0412-2. The on-body location that is also close to the user was generally not well received. Though on-body notifications were rated to be easily perceptible, they were also distracting, and they received low ratings concerning their suitability as a location to display home information. The perception of on-body notifications as a distraction was more pronounced for the less urgent scenarios. A reason for that could be that people do not want to wear notifications on their bodies where they are perceptible to others, mainly when notifications do not require immediate attention and might have to remain on the body for some time. The display and on-object locations received low ratings for ease of perception. A reason could be that the user is not always close to these locations, e.g., the entrance door [P9]. These two locations received intermediate ratings in most other regards, except for on-object notifications being rated as not very useful in urgent situations. We find some support for our hypothesis that the scenario's urgency determines the perceived suitability of a location for notifications. Locations that are at a distance from the user were judged to be less suitable as urgency increased. In contrast, on-body notifications within the user's immediate reach were judged as more suitable as urgency increased. However, in the case of smartphone notifications, we also found an effect opposite to the one predicted, indicating that factors besides urgency determine the perceived suitability of a location. For instance, we found that the chosen scenarios differ in terms of their urgency and how relevant participants consider them. For example, the entrance door is rated very low – people do not consider it a scenario in which they would like to receive notifications. Lastly, we showed that suitability is a function of how simple, good, easy-to-perceive, non-distracting, and useful a location was rated.

Limitations

We conducted focus groups and an online survey with a limited number of participants to investigate the research questions in our first exploration. These results are important because we understood how everyday home information could be displayed in the home environment besides using the established communication channel using mobile notifications, e.g., by on-object notifications. However, we have to keep in mind that these results could have been affected by the limitation of evaluation methods (see further Chapter 3). Their familiarity with mobile notifications could have influenced the users' preference to receive the information on their smartphones as they had not the chance to experience the other locations in their daily lives. Therefore, the research questions need to be further investigated by a follow-up investigation that compares mobile notifications with on-object notifications in an in-situ study. Such a follow-up study would enable us to investigate smart home appliances' integration into the users' lives or gain high external validity results.

5

Long-term Deployment for the Investigation of Notification Strategies and Locations

We explored in the previous Chapter 4 with which modalities and at which locations everyday home information could be displayed to the users in the future. We found that the participants in the conducted studies preferred using visual cues to present non-urgent everyday information. Regarding suitable location to display such information, the participants in the online survey preferred displaying home information on their smartphones, while locations for displaying home information in the home, e.g., by using on-object displays, received only intermediate ratings. However, the investigation of different evaluation methods (see Chapter 3) revealed that an applied evaluation method could have an effect on the results of a survey; meaning that the participants in the online survey might have overlooked future implications such as the amplification of negative effects that are caused by mobile notifications [11, 88].

In this chapter, we re-investigate suitable locations (RQ4) for displaying non-urgent everyday information by conducting a long-term in-situ deployment using a research probe to gain results with high ecological validity. In addition to this, we investigate how such information should be displayed (RQ5). We also investigated whether non-urgent everyday information should be displayed continuously (i.e., by displaying a persistent notification) or if the users should only be informed based on specific events (e.g., by an event-based notification when an action is necessary).

This chapter is based on the following publications:

A. Voit, D. Weber, Y. Abdelrahman, M. Salm, P. W. Wozniak, K. Wolf, S. Schneegass, and N. Henze. "Exploring Non-Urgent Smart Home Notifications Using a Smart Plant System." In: *19th International Conference on Mobile and Ubiquitous Multimedia*. MUM 2020. Essen, Germany: Association for Computing Machinery, 2020, 47–58. ISBN: 9781450388702. DOI: 10.1145/3428361.3428466

A. Voit, M. O. Salm, M. Beljaars, S. Kohn, and S. Schneegass. "Demo of a Smart Plant System As an Exemplary Smart Home Application Supporting Non-urgent Notifications." In: *Proceedings of the 10th Nordic Conference on Human-Computer Interaction*. NordiCHI '18. Oslo, Norway: ACM, 2018, pp. 936–939. ISBN: 978-1-4503-6437-9. DOI: 10.1145/3240167.3240231

5.1 Definition of Non-urgent Notifications

We anticipate that smart home appliances will inform users about an increasing amount of information in the future. More and more devices will become connected and transfer their status to the digital domain. As simply making the device status available cannot scale when the number of devices increases, current smart home appliances already use notifications to inform users about status changes. Notifications have been defined as visual cues, auditory signals, or haptic alerts generated by an application or service that relays information to a user outside of the current focus of attention [88, 161]. In a smart home context, notifications about many status changes, including the following, do not necessarily require immediate attention.

- Washing machines and dryers can inform about the laundry process.
- Dish washers can inform about the finished cleaning process.
- Fridges can inform about their stocks and grocery expiry dates.

- Freezers can inform about the need to defrost groceries, e.g., defrosting bread for breakfast before going to sleep.
- Robotic vacuum cleaners can inform about the need to change the dust bag.
- Coffee machines and air humidifiers can inform about the need to refill the water tank.
- Coffee machines and kettles can inform about the need for descaling.
- Plant systems can inform about the need for watering, adding fertilizer, etc.
- Doors and windows can remind users to lock them before going to bed.
- Calendars can inform about upcoming appointments such as garbage collection dates or upcoming events.
- Smart TVs can inform about the availability of new episodes of the user's favorite series (e.g., Netflix, etc.).

We extended the definition of notifications [88, 161] for non-urgent notifications (see Definition 5.1):

Definition 5.1 (Non-Urgent Notifications)
Visual cues, auditory signals, or haptic alerts generated by an application or service that relays information to a user outside of the current focus of attention where a response can be delayed by up to several hours or even days.

While an extensive body of work investigated how to effectively deliver prompts that make the user act immediately [159], much less attention was devoted to communicating information that may be acted upon later. In order to explore this gap, this chapter focuses on *non-urgent smart home notifications displaying everyday information*.

5.2 Smart plant system

We decided to design and implement a smart plant system that notifies users about the state of a plant as an exemplary use-case for our inquiry. A smart plant system represents a single representative source of notifications, which enables systematic assessment. We chose to investigate a smart plant as it is universally acceptable in a home environment and pleasant for diverse users so that its aesthetic qualities do not bias the study. Further, it limits the burden on the user and is easy to deploy. Previous research also explored the illumination of real and artificial plants [17, 33, 194, 198, 204]. Nowadays, smart plant systems that inform users about the plant's state are commercially available. Therefore, it represents a valid use-case. However, the fact that a limited number of users owns smart plant systems that support them in taking care of their plants enabled us to study notifications from smart plant systems without bias caused by past use of smart plants.

As no design guidelines for such systems exist, we conducted two focus groups to guide the design.

5.3 Focus Group Study

We conducted two focus groups to explore how notifications could be displayed in smart home environments. We decided to investigate the design opportunities of a future smart home notification system using a simple daily home task that most participants in the focus groups are familiar with. Throughout the focus groups, we used the use case of a smart plant system as the exemplary source of notifications. Both focus groups lasted approximately 50 minutes and were conducted in German. One of the groups was conducted in a living room; while the second group was conducted in a meeting room. Both rooms had a large table and a projector. We provided sheets of DIN A4 paper with a sketch of a plant pot printed on one side and handed out pens in multiple colors. Further, we provided snacks and beverages. The participation was voluntary, and the participants did not receive a monetary reward. A single researcher moderated both focus groups, and discussions were audio recorded. In the following, we will first describe the procedure of the focus groups, followed by information about the participants, and finally, the results.

Procedure

Both focus groups followed the same structure consisting of an introduction, an idea creation round, an open discussion, and, finally, a closing discussion.

Introduction: We welcomed the participants and asked them to fill out a consent form. The participants were informed about the audio recording and the option to withdraw their participation at any time. We then asked them for their demographic data. Afterward, we started the audio recording. We gave a presentation to introduce the topic of notifications in smart home environments, ending with a brief outline of the focus group. Finally, we distributed paper sheets.

Idea creation: We first asked the participants what information regarding their plants they want to know. We collected ideas from all participants for approximately 10 minutes. In a follow-up question, we asked how this information should be displayed, and invited the participants to draw their suggestions on the paper on their own. Again, this part took approximately 10 minutes.

Open discussion: During the open discussion, participants presented their sketches. Then, the groups discussed the advantages and disadvantages of the proposed systems. If not addressed by the participants, the researcher explicitly asked about the use of light-, text- and symbol-based visual notifications to display the state of the plant in the home environment. This part took approximately 15 minutes.

Closing discussion: Finally, we briefly asked the participants how their ideas could be realized. This was again discussed in the whole group. This part took approximately 10 minutes before thanking the participants for their participation and collected all materials.

Participants

Ten participants (4 female, 6 male) took part in our focus groups. We conducted two focus groups with five participants each. For one of the focus groups, we deliberately chose participants who did not care for plants regularly to also take inexperienced users into account. The first group consisted of three students, one computer scientist, and one housewife. Participants were between 22 and 62 years old ($M = 30, SD = 16.10$). Four of five participants mentioned that they take care of plants regularly. The second group consisted of five students, aged between

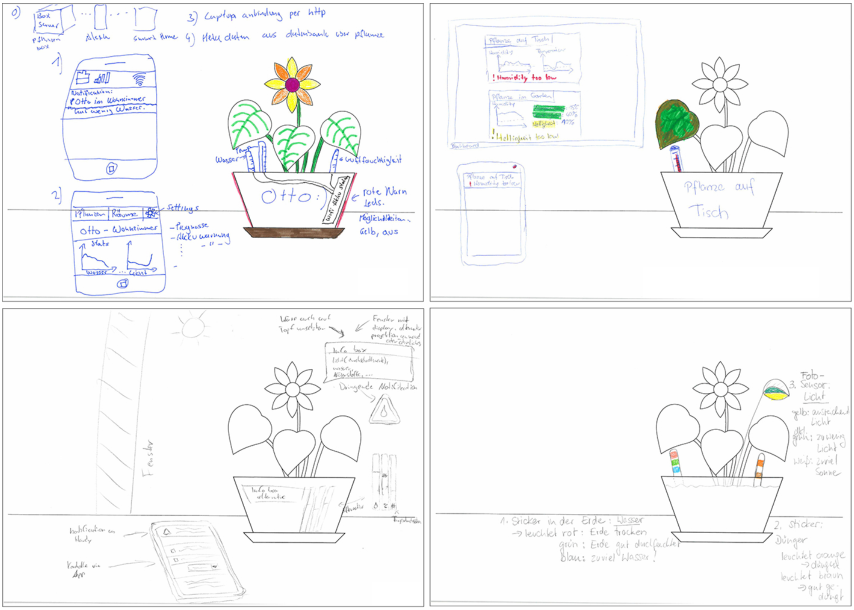


Figure 5.1: Sketches of smart plant pots created by the participants of the focus groups.

22 and 23 ($M = 22.4, SD = 0.55$). None of the participants in the second group is taken care of plants regularly. All ten participants owned a smartphone, two a tablet, and one a smartwatch.

5.3.1 Results

The results are based on the group discussions and the sketches that were created during the focus groups. The researcher who led the focus groups transcribed the discussions, identified themes, and categorized the ideas in the sketches.

Information needs

All ten participants were interested in being able to know the water level of their plants. Other types of information participants were interested in include light requirements (4 participants), fertilizer and pests (4), temperature (3), and humidity (3).

Information presentation

Figure 5.1 shows the sketches created by the participants during the focus groups. Nine participants mentioned that information about the plant could be shown on a smartphone, seven mentioned a central display in the home environment, and seven mentioned displaying the information directly on the plant or the plant pot. On the smartphone, statistics could be shown in an app and push notifications could alert users about the state of the plant. Seven participants liked the idea of receiving push notifications on their smartphones to prompt watering the plant.

Six participants agreed that the information could be color-coded, and stated that complex color-coding should be avoided. Examples for color-codes include red for dry soil, green for enough water, and blue for too much water. Light conditions could be coded as yellow for not enough light, green for enough light, and white for too much light. Orange could be used to indicate the need for fertilizer, while brown could show that there is enough fertilizer. For the overall state of the plant, the colors red, yellow and green were suggested. A similar idea only uses a red color to highlight that some action is needed.

Further suggestions include progress bars, symbols, and text displayed on a nearby wall or the plant pot. A textual percentage for the water level could be used, with values over 100% indicating overwatering. Seven participants were against displaying text on plant pots due to readability concerns. Similarly, five participants were concerned about using projection on a nearby wall to indicate the state, as readability would depend on the light conditions.

Realization

Participants provided several suggestions for the implementation of a smart plant system. Nine participants suggested a smartphone app to display sensor values.

Two participants mentioned a central display in the home environment that could be combined with a weather station. Further, one participant suggested displaying the information on a PC. Wi-Fi was suggested to connect the devices. Being able to use the system with existing plant pots was important for four participants. Six participants liked the idea of using small sensor sticks, similar to thermometers, which could be put in the soil. The sticks could read the water level and display it at the same time. Alternatively, LEDs could be used on or inside the plant pot.

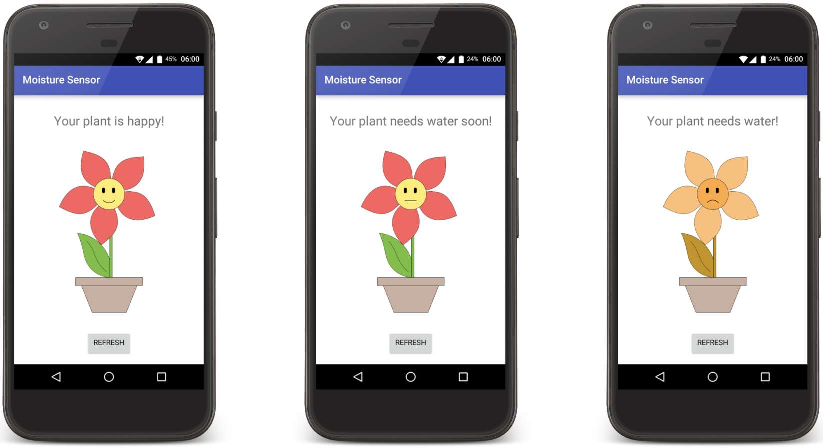
To power the system, five participants liked the idea of using solar energy. In the case of a battery powered system, four participants wanted to be able to see the battery level. Three participants were against using batteries, and two participants suggested wireless charging.

Summary

The water level was the most often mentioned information in the focus groups, as watering plants are the most common. Seeing the information on a smartphone was often requested, including the option to receive push notifications when watering is required. Other suggestions include a central display at home and displaying information on the plant or the plant pot itself. Many suggestions for color-codes were given, including using the traffic light metaphor (red, yellow, green) to indicate the plant's state that was also suggested in the related work [113]. The idea of using text on plant pots or projected to a nearby wall was rejected due to readability concerns. Based on the results of the focus groups, we implemented a smart plant system that can display the current water level of a plant on smartphones and directly on the plant pot. The water level can be displayed persistently using the traffic light metaphor or based on thresholds at the plant pot. In the following section, we describe the implementation of the system in-depth.

5.4 System

To investigate how non-urgent information should be provided in home environments, we developed a functional research probe of a smart plant system. Based on the results of the focus groups, we decided to implement an Android



(a) Water level is sufficient **(b) Water level is falling too low soon** **(c) Water level is too low**

Figure 5.2: View of the developed Android app to monitor the plant's current water level. From left to right: The plant's water level is sufficient, the water level is falling too low soon, and the plant's water level is too low.

application that can monitor the plant's current state and to integrate ambient lighting into a smart plant pot to display state also in the home environment as well as directly on the plant pot. As all participants of the focus groups were interested in being informed about the water level of their plants, we developed a smart plant system that informs the users when the plant placed in a smart plant pot needs to be watered. Therefore, the smart plant system measures the water level through a moisture sensor. The implemented system supports informing users through LEDs on the plant pot as well as through a smartphone application. The system displays three different kinds of information about the plant's water level. (1) The system informs the user if the water level is sufficient for the plant, (2) it notifies the user if the water level falls too low soon, and (3) the system informs the user if the water level is too low.

(a) persistent display: on the plant pot

(b) event-based display: on the plant pot

Figure 5.3: Images for the supported notification types displayed on the plant pot. The persistent notification strategies display always the current state of the plant's water level, while notifications in the the event-based strategy occur only when the plants need to be watered. Persistent notifications shown on the plant pot (a). Event-based notifications shown on the plant pot (b).

5.4.1 Notification Types

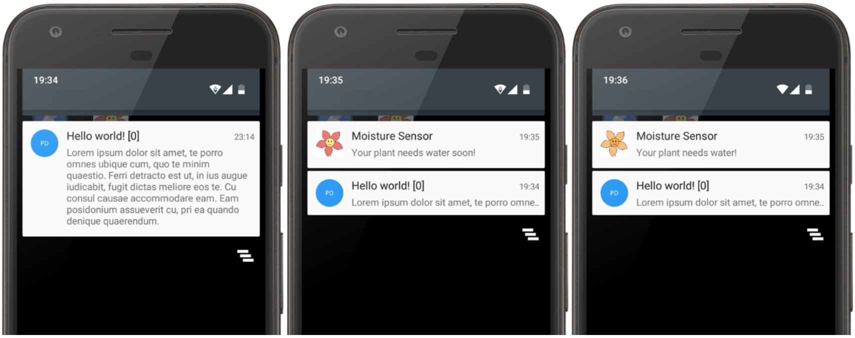
To compare different notification types for displaying non-urgent notifications, we implemented a system that supports multiple notification strategies and notification locations. The system supports the two strategies *event-based* and *persistent* to notify the users. In the case of the *event-based* strategy, the system only notifies the user if it is necessary to water the plant. The *persistent* strategy permanently displays the current water level of the plant. Both strategies were implemented to be displayed on either the plant pot itself or the user's smartphone. Thus, the smart plant system supports the following four notification types. The plant pot can either persistently show the current water level (see Figure 5.3a) or use the event-based strategy to notify the user only when the plant needs water (see also Figure 5.3b). Similarly, we designed two output mechanisms for the user's smartphone. The current water level can be shown through a persistent notification (see also Figure 5.4a), or an event-based push notification can notify the user in case the plant needs water (see also Figure 5.4b).

Displaying the plant's state directly on the plant pot using ambient lighting is realized by color-coding the state with the traffic light metaphor (green, yellow, red). This metaphor was suggested by the participants of the focus groups and by guidelines for ambient lighting systems of prior work [113]. The color-coding matches the supported states of the plant (water level is sufficient, the water level is falling too low soon, the water level is too low). In the persistent representation at the plant pot, the plant is augmented in green light when the plant's water level is sufficient. The LEDs light in yellow when the water level falls too low soon and in red when the plant needs to be watered because the water level is too low (see Figure 5.3a).

For the event-based representation of the plant's current state, we also use the traffic light metaphor. In contrast to the persistent representation, we turn the LEDs off when the plant has sufficient water. Again, the plant is augmented with a yellow light when the water level will fall too low soon and in red when the plant needs to be watered because the water level is too low (see Figure 5.3b). For both notification strategies on the plant pot, the LEDs are automatically are turned off at night. The times when the LEDs are turned off are configurable by the user.

We developed an Android app to display the plant's current state on the user's smartphone. For the mobile notifications, the icon's different facial expressions match the states of a plant. Here, a smiling plant is displayed in the notification center if the plant's water level is sufficient. A neutral face is displayed when the water level falls too low soon, and a sad and decayed plant is displayed if the water

(a) persistent notifications: on the smartphone



(b) event-based notifications: on the smartphone

Figure 5.4: Images for the supported notification types on the phone. The persistent notification strategies always displays the current state of the plant's water level, while notifications in event-based strategy only occur when the plants need to be watered. Persistent notifications are shown on the smartphone (a). Event-based notifications shown on the smartphone (b).

level is too low (see Figure 5.4). For the persistent strategy, a persistent notification is shown in the device's notification center that displays the current state (see Figure 5.4a). For the persistent strategy, a persistent notification is shown in the device's notification center that displays the current state (see Figure 5.4a). The user cannot dismiss the notification. It is shown at the bottom of the notification center. No visual, tactile or auditory cues are used to inform the user about state changes. For the event-based strategy, the app can also send push notifications if

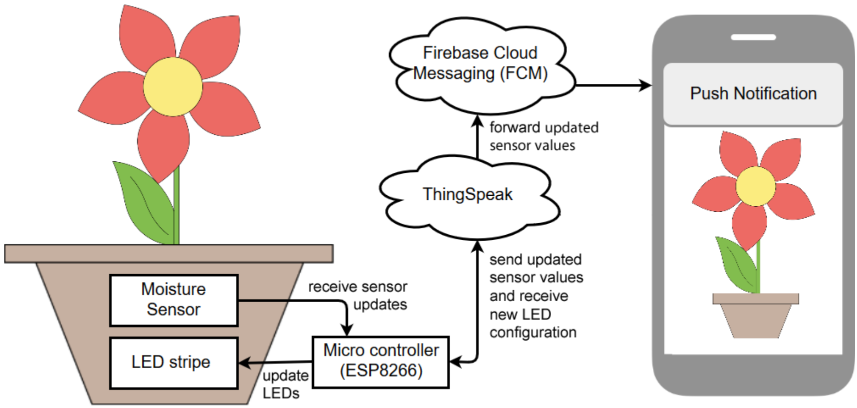


Figure 5.5: Architecture of the smart plant system consisting of the smart plant pot (*ESP8266* microcontroller, moisture sensor, LED stripe), the *ThingSpeak* platform, the *Firebase Cloud Messaging (FCM)* service, and the Android app.

action is required (see Figure 5.4b). Same as the event-based strategy on the plant pot, notifications are sent if the water level will be too low soon or is already too low. This notification can be dismissed by the user and will not be re-triggered once dismissed. They are shown at the top of the notification center and are additionally shown on the lock screen and status bar. When triggered, these notifications use the device's default notification sound and vibration pattern. They follow the device's ringtone setting and therefore may be silenced by the user.

5.4.2 Architecture

The smart plant system consists of a microcontroller, a moisture sensor, LEDs, and an Android app. The architecture of the system is shown in Figure 5.5. The microcontroller is embedded in the plant pot in a waterproofed case and is powered by a wall socket. Further, the microcontroller powers and connects to the moisture sensor in the soil and the LEDs inside the plant pot. Changes detected by the moisture sensor are coupled with a unique ID and sent via WiFi to a central server. The server controls the LEDs and can forward the current water level to a connected smartphone.

5.4.3 Hardware

We used an *ESP8266* microcontroller, due to its small size, low power consumption, and integrated Wi-Fi module. To detect the moisture of the soil, we used a *Grove Moisture Sensor*. The LED stripe in the plant pot had a length of one meter and contained 30 RGB LEDs, which can be controlled individually. The stripe was placed in the inner diameter of the plant pot and, therefore, augmented the plant from below. All components in the plant pot were waterproofed to avoid bringing the electronics in contact with water. We used a 3D printer to print enclosures and closed gaps between the enclosures and cables using hot glue.

5.4.4 Software

The microcontroller code is written in C++. Water level updates from the moisture sensor are sent to the backend via HTTP. We used the cloud platform *ThingSpeak*[1] to collect the water levels of all connected plants. When an updated water level is sent to *ThingSpeak*, the service stores the value and responds with LED colors that should be shown. Therefore we were able to remotely configure the LEDs, including turning them off at night. Depending on thresholds, the platform can perform predefined actions such as sending push notifications to connected smartphones using the *Firebase Cloud Messaging (FCM)*[2] service. To display the plant's current state on smartphones, we developed an Android app. The app listens to updated water level values and triggers persistent or event-based notifications depending on the current notification strategy. The main view of the app also displays the plant's current state.

5.4.5 Measurements

To gain insights into the values measured by the moisture sensor, we measured dry, normally watered, and very wet soil. Using these empirical measurements, we defined two thresholds for the plant's state. We consider a water level between 38% and 100% as good. In the traffic light metaphor, values in this range represented by a green color. When the water level falls below 38%, the plant

[1] `https://thingspeak.com/`
[2] `https://firebase.google.com/products/cloud-messaging/`

		Location	
		on-object	on-smartphone
Strategy	Persistent	condition 1 [C1]	condition 3 [C3]
	Event-based	condition 2 [C2]	condition 4 [C4]

Table 5.1: A 2x2 Matrix for notification location and strategy, constructing the conditions for our study.

needs to be watered soon. This is represented by yellow. If the water level falls below 26%, the plant needs to be watered. In that case, the color is set to red. To reduce the noisiness of the measured moisture values, we calculated the moving average of the last 20 measurements.

5.5 Method

To gain an understanding of how non-urgent smart home notifications should be displayed in the future, we conducted a long-term in-situ study using the developed smart plant system.

5.5.1 Design

We conducted an in-situ study with a within-subjects design to investigate the benefits and drawbacks of the different notification strategies and locations. We deliberately decided to deploy one plant per participant to reflect how notifications from smart home appliances should be designed. While a single smart home device will not overwhelm participants with notifications, users already receive a large number of notifications from their smartphones, tablets, and PCs as shown by previous work [147, 161]. We, therefore, assumed that the deployment enables participants to imagine the behavior of future systems, internalize the nature of smart home notifications and reflect on the provided designs.

The study uses a repeated measures design, where all participants were exposed to all conditions. We studied the two independent variables: (1) the notification location: whether on the object or on the smartphone, (2) the notification strategy: persistent or event-based. We used the four supported notification types (see Figure 5.3 and Figure 5.4) as conditions (see also Table 5.1).

The smart plant system can notify the user directly on the plant pot using a persistent representation of the plants' current state (Condition 1 [C1], see also Figure 5.3a) or use an event-based notification strategy by only notifying the users when the plant needs water (Condition 2 [C2], see also Figure 5.3b). Also, the smart plant system can notify the users on their smartphones through a persistent notification (Condition 3 [C3], see also Figure 5.4a) or an event-based mobile notification in case the plant needs water (Condition 4 [C4], see also Figure 5.4b).

Each of the notification types was evaluated for two weeks. We distributed the conditions Latin-square. We sent an online questionnaire about their experience with the current condition to our participants after every condition. After the participants experienced all supported notification types, we conducted semi-structured interviews to understand how a smart home system should display non-urgent smart home notifications in the future. The participation in the study was rewarded with 30 EUR per participant.

For the study, we deployed our smart plant system for eight weeks in the participants' homes. We let the participants decide to place the plant in a sufficient location in their homes (see Figure 5.6).

5.5.2 Apparatus

For the study, we provided our smart plant system with a Spathiphyllum (6cm diameter) in a plant pot (14cm diameter). We chose the Spathiphyllum for the study because it is a popular indoor plant that has to be watered approximately more than once per week and we wanted to avoid that users integrate watering the plant into their daily routines.

5.5.3 Procedure

The study was conducted in the summer. At the begin of the study, we visited participants in their homes to deploy our smart plant system. After they signed the consent form, we asked them to answer a demographic questionnaire with additional information about how they usually care for the plants in their homes.

(a) Kitchen **(b) Living room**

(c) Dining table **(d) Private office**

Figure 5.6: Examples for placements the participants chose to place our smart plant system in their homes during the study.

Afterward, we set up the plant in their home and connected the *ESP8266* to the participants' Wi-Fi network. Also, we set up the smart plant system according to the first condition and installed, if necessary, the Android app on the participants' smartphones. Finally, we explained how our smart plant system will notify the participants in the first condition. The study started on the next day after we set up the smart plant system in the participants' homes.

After two weeks of study, we asked participants to answer a questionnaire about the notification type used for the last two weeks and set up the system for the next condition. This process was repeated for the remaining two conditions.

For each condition, the participants were asked about how they experienced the current notification type and if the notification type was supporting them to care for the plant.

To investigate how the participants experienced the notification strategies and locations, we asked them for each notification type to rate the following five statements from "‘Strongly disagree"’ (1) to "‘Strongly agree"’ (5) on a 5-point Likert item.

- **(Q1)** I very much like this notification type.
- **(Q2)** This notification type supports me.
- **(Q3)** This notification type is very useful.
- **(Q4)** This notification type is easy to perceive.
- **(Q5)** This notification type is not disturbing.

After the participants experienced all notification types, we asked them to rank all notification types. Finally, we conducted semi-structured interviews which involve asking the participants how they experienced the different notification types and investigated how they want to receive non-urgent smart home notifications in the future.

5.5.4 Participants

We invited 20 participants (11 female, 9 male) through university mailing lists and social media. The active use of an Android smartphone was a requirement for the participants . Three participants were excluded due to technical reasons. For one participant the included *ESP8266* in the provided smart plant system broke resulting in excluding the participant, and for another participant, the smartphone was not working. For another participant, the internet connection was broken for a week within a condition. We excluded these participants from further evaluation.

The remaining 17 participants (8 female, 9 male) were aged between 21 and 60 years (M=31.94, SD=12.45). Seven participants were students; one was a Ph.D. student, and seven were employees. One of them was a florist and therefore a professional in taking care of plants. Another participant was self-employed,

ID	Age	Gender	Profession	Housemate(s)	Condition order
1	22	male	Student	Parents	C4, C2, C3, C1
2	57	female	Self-employed	Partner and son	C4, C3, C2, C1
3	46	female	Employee	Partner and two children	C3, C4, C1, C2
4	60	female	Housewife	Partner, daughter and boyfriend	C4, C1, C2, C3
5	23	male	Student	Parents and sister	C2, C1, C3, C4
6	22	female	Student	Four flatmates	C1, C3, C2, C4
7	24	male	Student	Parents and two siblings	C2, C4, C1, C3
8	24	male	Student	Parents	C2, C3, C4, C1
9	23	male	Student	Parents	C3, C1, C4, C2
10^{Δ}	27	female	Student	Two flatmates	C1, C2, C4, C3
11^{*}	26	female	Employee	Partner	C1, C3, C4, C2
12	27	male	Student	Flatmate	C3, C2, C1, C4
13	27	female	Ph.D. Student	Partner	C2, C1, C4, C3
14	34	male	Employee	Partner	C3, C4, C1, C2
15	30	male	Employee	None	C4, C3, C1, C2
16	45	female	Employee	Daughter	C1, C4, C3, C2
17	21	female	Employee	Parents	C2, C4, C3, C1
18	32	male	Employee	Partner	C3, C1, C2, C4
19^{Δ}	23	female	Employee	Partner and friend	C4, C2, C1, C3
20^{Δ}	25	female	Student	Partner and baby	C1, C2, C3, C4

Table 5.2: Overview of the participants in our study. The participant marked with * is a professional in taking care of plants. Participants marked with $^{\Delta}$ were excluded from the analysis due to technical reasons.

and one was a housewife. Ten participants were living together with their families, four with their partner, two lived in shared apartments with friends or colleagues, and one participant lived alone. Further details are shown in Table 5.2.

Four participants had no plant in their homes before the study, six had up to five plants, four participants had up to ten plants, and another four participants had more than 20 plants. Eight participants placed their plants in multiple rooms; three placed their plants in a single room and two only owned outdoor plants.

Two participants had plants on their balconies as well as in their gardens. Two participants strongly disagreed with having a green thumb; three disagreed, five were neutral, four agreed, and three strongly agreed.

Nine participants stated that they water their plants at different points in time and five participants water all plants together. One participant stated that she waters the plant when necessary, another participant waters the plants daily, five participants water the plants multiple times per week, three water them once per week, and another participant waters his plant every once or the second month.

5.6 Results

In the following, we present the results from the questionnaires as well as the results of the interviews.

5.6.1 Quantitative Analysis

We applied the Aligned Rank Transform (ART) [223] procedure to participants' ratings, using the ARTool toolkit[1] to align and rank our data. In addition, we used a two-way repeated measures analysis of variances (ANOVAs) to determine significant effects of the location and strategy on participants' ratings. The results of the ratings are displayed in Figure 5.7.

Event-based notifications on the plant pot ($M = 4.19$, $SD = 0.69$) were most liked by the participants, followed by event-based notifications on the smartphone ($M = 4.06, SD = 0.97$), persistent notification on the smartphone ($M = 3.53, SD = 1.07$) and persistent notifications on the plant pot ($M = 3.29$, $SD = 1.31$). The ANOVA revealed no significant effects for location [$F(1,48) = 0.00, p = .965$] but a significant effect for strategy [$F(1,48) = 10.47, p = .002$]. Event-based notifications were significantly more liked than persistent notifications. We found no significant location$\times$strategy interaction effect [$F(1,48) = 0.49, p = .488$].

Event-based notifications on the smartphone were the most supporting notification type ($M = 4.47$, $SD = 0.51$), followed by event-based notifications on the plant pot ($M = 4.29$, $SD = 0.60$), persistent notifications on the smartphone

[1] `http://depts.washington.edu/madlab/proj/\ac{ART}/index.html` last accessed: 2018-01-03

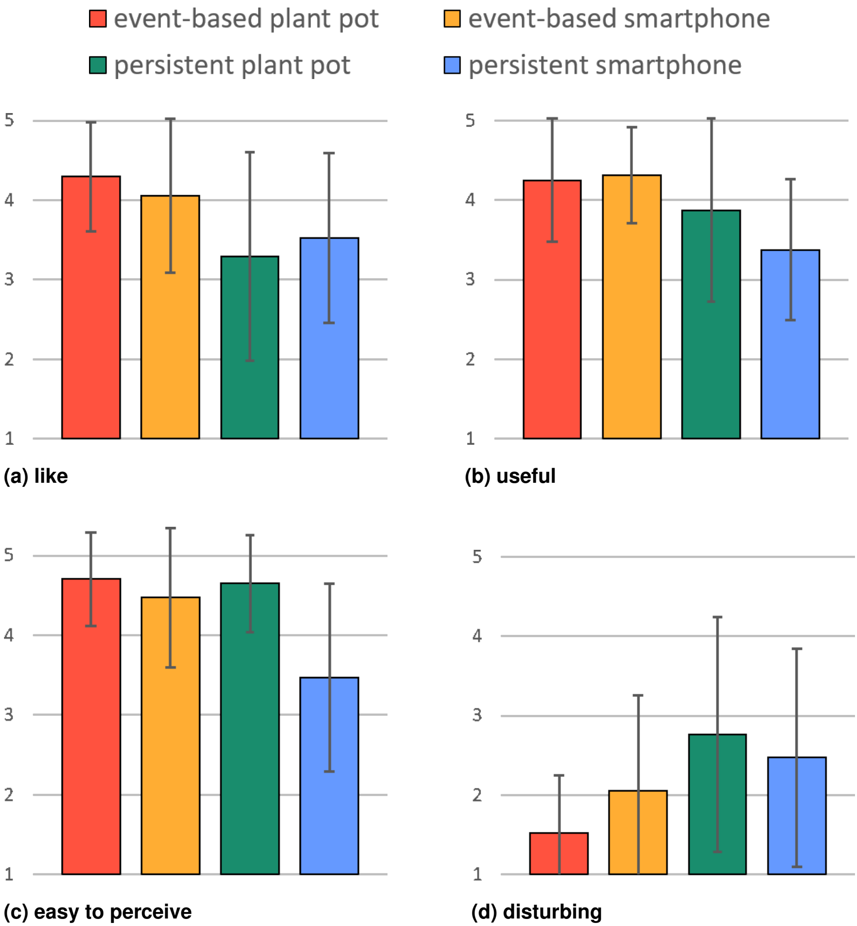


Figure 5.7: Ratings different notification types. Error bars show the standard deviation. (1 = strong disagree, 5 = strong agree)

($M = 4.12$, $SD = 0.78$) and persistent notifications on the plant pot ($M = 3.94$, SD =1.03). We found no significant effects for location [$F(1,48) = 0.50, p =$ .483], strategy [$F(1,48) = 3.17, p = .082$] or the interaction of location×strategy [$F(1,48) = 0.01, p = .940$].

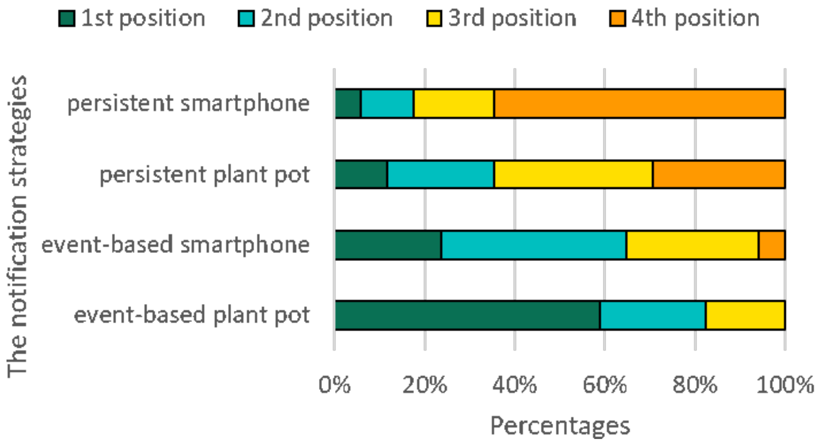


Figure 5.8: Ranking of the four notification types. ($N = 17$)

Participants found event-based notifications on the smartphone most useful ($M = 4.35$, $SD = 0.61$), followed by event-based notifications on the plant pot ($M = 4.29$, $SD = 0.77$), persistent notifications on the plant pot ($M = 3.76$, $SD = 1.20$) and persistent notifications on the smartphone ($M = 3.47$, $SD = 0.94$). We found no significant effects for location [$F(1,48) = 1.58, p = .214$] but a significant effect for strategy [$F(1,48) = 11.88, p = .001$]. Event-based notifications were rated significantly more useful than persistent notifications. We found no significant location×strategy interaction effect [$F(1,48) = 1.69, p = .200$].

Event-based notifications on the plant pot were rated easiest to perceive ($M = 4.71$, $SD = 0.59$), followed by persistent notifications on the plant pot ($M = 4.65$, $SD = 0.61$), event-based notifications on the smartphone ($M = 4.47$, $SD = 0.87$), and persistent notifications on the smartphone ($M = 3.47$, $SD = 1.18$). We found a significant effect for location [$F(1,48) = 15.19, p < .001$]. Notifications on the plant pot were rated significantly easier to perceive than notifications on the smartphone. We also found a significant effect for strategy [$F(1,48) = 10.57, p = .002$]. Event-based notifications were rated significantly easier to perceive than persistent notifications. In addition, we found a significant location×strategy interaction effect [$F(1,48) = 8.18, p = .006$]. Accordingly, all conditions were significantly different.

Event-based notifications on the plant pot were rated least disturbing ($M = 1.53$, $SD = 0.71$), followed by the event-based notifications on the smartphone ($M = 2.06$, $SD = 1.20$), persistent notifications on the smartphone ($M = 2.47$, $SD = 1.37$) and persistent notification on the plant pot ($M = 2.76$, $SD = 1.48$). We found no signification effect for location [$F(1,48) = 0.07, p = .789$] but a significant effect for strategy [$F(1,48) = 11.42, p = .001$]. Persistent notifications were rated as significantly more disturbing than event-based notifications. We found no significant location×strategy interaction effect [$F(1,48) = 2.57, p = .116$].

We asked participants to rank the four notification types (see Figure 5.8). Event-based notifications on the plant pot were most often ranked on the first position ($Md = 1$), followed by event-based notifications on the smartphone ($Md = 2$), persistent notifications on the plant pot ($Md = 3$), and persistent notifications on the smartphone ($Md = 4$). Again, we used the Aligned Rank Transform and a two-way repeated measures ANOVA to determine significant effects of the independent variables location and strategy on participants' ranking. Notifications on the plant pot were significantly better ranked than notifications on the smartphone [$F(1,48) = 7.33, p = .009$]. Event-based notifications were significantly better ranked than persistent notifications [$F(1,48) = 31.53, p < .001$]. We found no significant location×strategy interaction effect [$F(1,48) = 0.00, p = 1.000$].

5.6.2 Interviews

All interviews were audio recorded, and, later, transcribed verbatim. We used thematic analysis [18] with open coding to analyze the interviews. Two researchers coded four representative interviews in parallel to establish an initial coding tree. After a review meeting, the researchers agreed on a coding protocol. A single researcher then coded the remaining interviews. Representative quotes were translated to English. Through the analysis, we identified three themes: SITUATEDNESS, CONTEXT, and FUTURE USE.

5.6.2.1 Situatedness

Participants reflected on the suitability of a smart plant system and captured factors influencing the acceptance of a smart plant system at home. The system was perceived as supportive by different types of users – users without “green thumbs” as well as expert users with busy lifestyles:

> *"I always wanted a small Bonsai tree, but I always forgot to water it. [Such a system] adds a character to the plants, and I get a feeling that the plant is there and needs something. " (P8, general)*

Participants commented extensively on the aesthetics of the smart pot and how it influenced their perception of an ambient notification system. Some felt that the persistent lighting provided too much feedback:

> *"The [persistent lighting] really got on my nerves. The plant was entirely in the background, and the colored lighting was what you perceived. " (P16, persistent plant pot)*

Participants wondered if they would eventually stop noticing the notifications after some time:

> *"My experience is if I receive a [persistent] notification, the notification and also state changes [...] will end up in my internal spam filter and I don’t perceive [it] anymore." (P15, persistent smartphone)*

In contrast, event-based illumination, appeared to offer a more subtle and unobtrusive experience.

> *"I found the [event-based lighting], where the green does not appear at all, the most visually appealing. [The plant is illuminated] in yellow and red only for short times until you react [to the notification]. I found that not as annoying as the [persistent ambient lighting]." (P4, event-based plant pot)*

Event-based notifications were also seen as more actionable and unobtrusive:

> *"I mean, obviously, it is more noticeable if [the plant] is only illuminated if it needs attention [because it needs to be watered]." (P11, event-based plant pot)*

Participants thought about supporting multiple plants. To reduce the number of non-urgent notifications on smartphones, participants suggested adapting established notification strategies by being notified once per day at opportune moments and opportune locations.

> *"[I could imagine] to receive a summary once per day. Notify me always at 8 pm then I am at home in any case and tell me these are the plants you should water now." (P1, general)*

In contrast, participants were generally content with on-object notifications and remarked that it has high scalability.

> *"[The event-based ambient lighting shows me] which plants I have to water. I would keep it how it is. In the respect, that all plants are illuminated." (P8, general)*

Overall, participants saw a high potential for integrating ambient notifications for a smart plant system in a domestic environment. Furthermore, they were eager to benefit from the functionalities provided. Yet, whether or not a smart plant system could become a situated object in a home depended largely on how it would react to the usage context at hand.

5.6.2.2 Context

This theme describes how participants used and experienced the smart plant in context. The applicability highly depends on the location of the plant in the home:

> *"If you don't enter the room periodically, I think the phone would be better [to receive the] notification." (P12, event-based smartphone)*

Even if a smart home device was placed in a frequently visited location, participants were still concerned about forgetting to water the plant when they are too busy.

> *"If [...] the LEDs of the plant pot turn off from 11 pm to the next morning. It could be that I come home several days in a row around midnight and leave the house at 6 am in the morning nevertheless. Thus, it could happen that I am not at home when the plant [...] notifies me." (P15, persistent plant pot)*

We also observed that participants were concerned that they could not differentiate if the smart plant system was turned off (in the event-based strategy) or malfunctioning which could result in a dying plant.

> *"You never know if the system is still working correctly since there is no indicator [when the light is off]." (P9, event-based plant pot)*

Participants remarked that they sometimes receive notifications at inopportune moments where they cannot immediately react to a notification, e.g., when they are on the go and therefore not at home. One participant remarked that being unable to take immediate action leads to frustration:

> *"I was on the bus, or train, or some other place where I was bored. So I checked if there is something new and saw that I forgot the plant and it needs water. What should I do? I'm not there. It is not as useful as the light because when you see [the light] you are actually there" (P8, persistent smartphone)*

In contrast, some participants enjoyed being aware of the state of their plant and required care during their day:

> *"[Through notifications I received on the way,] I was prepared that I should water the plant today" (P13, event-based smartphone)*

We observed two kinds of user behaviors when notifications were received on the go. One group dismissed notifications that were received in inopportune moments and usually forgot to water the plant when they arrived at home.

> *"If you are on the go and receive a push notification, you cannot act on it. Moreover, if you dismiss it, you'll not remember it when you're back home" (P1, event-based smartphone)*

Some participants kept the notification in the notification center to counter this issue until they watered the plant.

Participants remarked that the system could be useful during longer absence at home:

"[The system] could make it simpler for many [people] to water [the plants of other] persons that are on vacation." (P11, event-based plant pot)

All in all, the interviews revealed that users required a high degree of context-awareness. They expected that a smart plant system would reflect their complex routines and socio-temporal conditions and constraints.

5.6.2.3 Future Use

Participants provided suggestions for smart home notification systems in the future. They were interested in receiving notifications from a diverse set of other smart home appliances that could support users' daily lives. Participants requested notifications about regular household tasks such as unloading the washing machine, or maintaining tasks such as changing the robotic vacuum cleaner bags:

"I would like to receive push notifications when the laundry process is finished. It happened to me that I made the laundry and forgot about [it]. Hours later I remembered when I went to bed that I still have to hang up the [textiles]" (P15, general)

In addition to the supported locations for displaying notifications (i.e., on the smartphone and on-object), users suggested taking other existing devices (e.g., Smart TVs), or a central smart home display into account.

"[Such a smart home display] could be placed in frequently visited areas such as the living room. Also, it could be like a tablet so that you can carry it around. For example, you could sit outside in your garden, and you would be notified when the current processes of your [home devices] finished." (P11, general)

In general, participants were positive about additional sources for notifications at home. We observed that they easily imagined going beyond a smart plant pot system.

5.7 Discussion

We conducted an eight-week long in-situ study to better understand the design of non-urgent smart home notifications. We used a smart plant system as a representative smart home device. The results of the in-situ study show that our participants were interested in receiving notifications about non-urgent information, e.g., about the current state of their smart home appliances. They welcomed the possibility to receive non-urgent smart home notifications about non-urgent everyday home information in the future.

Previous work already investigated related questions. Vastenburg et al. investigated the acceptance of smart home notifications with different urgency levels in a lab study [186]. Their results revealed how the urgency influences the acceptance of smart home notifications. As "low-urgent" notifications (e.g., watering plants) were not accepted by their participants, Vastenburg et al. suggested delaying these notifications until the urgency of the content increased or skipping such a notification entirely when the urgency is not increasing. In contrast, our participants also liked the concept of receiving notifications for non-urgent information as they wanted to be aware of upcoming tasks as we found in the CONTEXT theme.

Insights regarding the Notification strategy to Display Everyday Information Regarding the research question which notification strategy should be used to present smart home notifications (RQ5), we observed that participants generally preferred receiving event-based notifications. Event-based notifications were significantly more liked and perceived as more useful, easier to perceive and less disturbing than persistent notifications. In addition,the SITUATEDNESS theme revealed that event-based notifications gain the user's attention only when necessary and are experienced as explicit reminders.

We observed in the SITUATEDNESS theme that participants expect that smart home appliances reduce the effort required by the users. For example, a smart plant system should minimize the number of watering processes during the week by aggregating the watering of multiple plants. To further reduce the number of triggered notifications, the system should collect similar kinds of information during the day and notify the user only once.

Participants were concerned about being overwhelmed by notifications on their smartphones if such a system would support multiple plants; as we observed in the SITUATEDNESS theme. The system notified the participants only when it was necessary to water the plant, which occurred about twice a week. However, the number of smart home notifications users have to attend increases with the number of supported notification sources. In addition to plants, participants mentioned a broad range of further smart home notification sources that could support their daily routines. In essence, the notifications have to be designed carefully to avoid overwhelming users with smart home notifications.

Insights regarding the Locations to Display Everyday Information Further, regarding the investigation which at which locations the non-urgent every home information should be displayed (RQ4), we observed that participants liked notifications displayed on the plant pot more than notifications received on smartphones. Notifications displayed on the plant pot were rated significantly easier to perceive and ranked higher than notifications received on the smartphone. We observed in the SITUATEDNESS theme that notifications displayed on the plant pot are subtle and can be easier integrated into participants' lives. As an alternative to using LEDs, designers of smart plants systems could investigate using more natural and unobtrusive visualizations, such as generating a artificial shadow of the plant [33]
.

In the CONTEXT theme, we found that participants could immediately react when they perceived a notification that is displayed on-object. However, participants noted that the usefulness of on-object notifications depends on the location of the notifying device. For example, on-object notifications are useful for devices that are located in frequently visited environments, such as the kitchen. On the other hand, on-object notifications might be less useful than on-smartphone notifications for devices located in less frequently visited areas (e.g., in the basement).

In the CONTEXT theme, we observed that participants were concerned that they could miss notifications. Participants were concerned that they could miss notifications on their smartphones because of the number of other notifications they have to attend. Also, they stated that they could miss on-object notifications when they are busy or do not frequently visit the room where the device is located. Furthermore, participants were concerned that they might not recognize when a system is malfunctioning. They explained that missing notifications could lead to forgetting to accomplish daily tasks. To counter this, participants suggested to deliver notifications at opportune moments and in opportune locations, e.g., when they are at home in the evening and are able to accomplish the upcoming tasks immediately.

In our previous inquiry (see Chapter 4), we found that smartphones were generally preferred to display smart home notifications and ambient on-object notifications received lower ratings. However, the long-term deployment of the smart plant system revealed that participants preferred ambient notifications compared to notifications received on smartphones. This supports the results of our comparison of different evaluation methods showing that used method to evaluate smart artifacts can effect the results (see Chapter 3). We found that the artifacts in the online survey condition received lower ratings than the same investigated artifacts in the in-situ condition during the comparison of the different methods. Further, reasons for these differences could be that the participants of the online survey were only used to receive notifications on their smartphones, but our participants experienced smart home notifications using ambient lighting in their daily lives. Therefore, we assume that the differences between both inquiries can be explained by the higher external validity of our study.

Limitations

One limitation of our study is that we deployed a single smart plant. Thus, participants received a small number of notifications generated by the system. However, the study enabled participants to reflect on the scalability of a smart plant system supporting multiple plants. Further, they made suggestions to reduce the number of non-urgent smart home notifications by collecting information and notifying the users at opportune locations and moments. Another limitation is that we let the participants decide where they would like to place a plant in their homes. However, as there are architectural constraints for users where they can place specific smart home appliances in their homes. For plants the location is determined by personal preference and requirements for the specific plants (e.g., light or temperature conditions). Therefore, we decide to give participants an agency as placing the plant in a predetermined location would create an artificial home environment. In addition that also contributes to ecological validity. Another limitation is that participants experienced only smart home notifications generated by a single smart home device. However, support to care for plants is a relevant use-case since smart plant assistants are already widely available. In addition, watering plants represent a range of other use-cases where users are informed about upcoming non-urgent tasks. We observed in the FUTURE USE theme that they welcomed the possibility of receiving smart home notifications for other kinds of upcoming non-urgent home tasks similar to watering plants.

6

Effects of Personal Content in Domestic Environments

We investigated in Chapter 5 how impersonal household data can be delivered to the users by proactively informing them. We found that the users prefer to use smart home appliances with integrated displays that inform the users based on specific events, e.g., tasks that need to be accomplished in their home.

Since smart home appliances should be able to inform their users about personal data, therefore, more sensitive information than regular household information it needs to be investigated how sensible information should be displayed. In addition, the previous investigated research probe of the smart plant system informed the users only about a single source of information, i.e., whether or not a specific plant needs to be watered. However, everyday home information that needs to be conveyed to the user could have a higher information density, i.e., when the smart home appliances needs to inform the user when and with whom a specific task needs to be executed. Therefore, this chapter investigates how smart home appliances should display personal and therefore sensitive information with a higher information density within a smart home environment. We are especially interested in investigating how those smart home appliances can be designed to fit the users' routines (RQ6) and which modalities should be used to present the information (RQ3). In contrast to our previous investigation in Chapter 5, we study in this chapter also the design of smart home appliances that present the data in the users' home using different kinds of displays. With this, we also study unobtrusive displays that the users can check when it is appropriate, i.e., in this case, the user initiates the interaction with the display in the home. Also, we investigate how smart home appliances can make the users proactively aware of the information with a higher information density. We decided to use a calendar application as a research probe since calendar systems have been used for scheduling and reminders for a long time. Also, calendar information has a high information density since a calendar informs the user about multiple kinds of information, including the time of an event, the purpose of the events, its timing, location, and other attending persons. Further, Marky et al. found that displaying calendar data in the home is accepted by the users as long as they can influence the positioning of the display, and the display supports a visitor mode [110].

This chapter is based on the following publications:

A. Voit, D. Weber, E. Stowell, and N. Henze. "Caloo: An Ambient Pervasive Smart Calendar to Support Aging in Place." In: *Proceedings of the 16th International Conference on Mobile and Ubiquitous Multimedia*. MUM '17. Stuttgart, Germany: ACM, 2017, pp. 25–30. ISBN: 978-1-4503-5378-6. DOI: 10.1145/3152832.3152847

A. Voit, R. Rzayev, D. Weber, M. Müller, and N. Henze. "Investigation of an Ambient and Pervasive Smart Wall Calendar with Event Suggestions." In: *Proceedings of the 7th ACM International Symposium on Pervasive Displays*. PerDis '18. Munich, Germany: ACM, 2018, 10:1–10:5. ISBN: 978-1-4503-5765-4. DOI: 10.1145/3205873.3205892

A. Voit, D. Weber, A. Imeri, A. Eidner, A. Tsoulos, D. Koch, K. Chen, M. Rottschäfer, R. Schweiker, S. Söhnel, V. Sabbatino, and N. Henze. "Exploration of a Multi-Device Smart Calendar Platform for Smart Homes." In: *Proceedings of the 17th International Conference on Mobile and Ubiquitous Multimedia*. MUM 2018. Cairo, Egypt: ACM, 2018, pp. 403–410. ISBN: 978-1-4503-6594-9. DOI: 10.1145/3282894.3289732

6.1 Related Work

Prior work investigated how people use calendars to organize private daily schedules. Abdul Razak et al. investigated how seniors (aged 55-60 years) use physical and digital calendars [1]. They found that calendars for seniors must be simple to use, and that their participants preferred to see the date prominently displayed. Further studies investigated how other groups, such as families or friends, manage their personal [25, 73, 87, 127, 129] or shared calendars [87, 148, 178]. Working parents use calendars to organize their days and get an awareness about their own schedules and what their family members were up to [73, 128, 129]. Thayer et al. found that calendars are mainly shared to coordinate appointments [178].

Calendars can reveal information about the calendar's owner – especially if they are shared with others. Users often have more than one shared calendar to control who can access which information [178]. Users are often concerned about putting their personal events in their work calendar, because they do not want to lose privacy or open themselves up to judgment from their peers [73]. To address users' privacy concerns, Schaub et al. developed a prototype that changes the appearance of a public work calendar based on the people who are present, and personal privacy settings [165].

Displaying their calendar data in physical spaces can increase the awareness and attention regarding upcoming appointments. Related work investigated how calendar data can be displayed with tangible objects as cubes to increase the user's awareness regarding appointments and additional information such as weather information [112]. Other work investigated how calendars and technology can be combined in home environments [40, 127, 148]. Crabtree et al. investigated how groupware calendar systems should be designed for usage in home environments and found that it is important to display the digital information in the users' homes where they can be seen frequently [40]. Plaisant et al. developed a shared calendar information system for multi-generational families using digital paper and pens [148]. Additionally, Neustaedter et al. used an inkable family calendar to coordinate family affairs [127]. Furthermore, Boll et al. developed a multimodal reminder system using sound and ambient light as well as tactile feedback that reminds their users about calendar events such as upcoming tasks or appointments [20].

Especially for novel reminder systems, McGee-Lennon et al. found that using existing metaphors and strategies supports the acceptability and usability [114]. Social networks suggest events to their users, allowing them to plan to attend a suggested event or attend events that their friends will attend. However, there is no link between current calendar systems and event suggestions.

Voit et al. envisioned a smart calendar system, which communicates with smart home devices to support older adults in their daily activities [195]. Their proposed smart calendar system aims to support healthy older adults by learning the user's interests and preferences, and reinforcing healthy behaviors. It should also support older adults when they develop health concerns by motivating them to adopt or readopt healthy behaviors to address the concerns.

In this section, we learned that calendars are mainly used by users who want to be aware of their daily schedules. For this context, users use physical calendars in their homes and digital calendars [1]. Further, families use calendars to organize their daily lives [73]. Therefore, calendars are mainly placed at locations where they are frequently seen, e.g., in the kitchen [40]. Social networks are used to get informed about upcoming events, but a link to automatically add the events to the users' calendars is currently missing.

6.2 Understanding the Calendar usage of Retirees

Retired older adults are spending more time on their private life than in their professional life. Therefore, their usage of calendars and requirements for a calendar system might differ from the use of families or employees. In the related work section, we already learned how families and employees use calendars to organize their daily lives. However, the use of calendars by retired older adults might differ because they have to schedule their private appointments with professional ones. To study how a calendar system can be designed to fit into the users' routines (RQ6), the system must consider all possible user groups.

6.2.1 Method

We conducted an online survey to understand how retirees use calendars. We focused on physical and digital calendars, types of entered events, and privacy aspects. Participants were recruited via mailing lists of senior computer clubs.

6.2.1.1 Procedure and Participants

In total, 22 people participated in our online survey. We excluded one participant who was not retired. The remaining 21 retired people (14 male, 7 female) were aged between 63 and 82 years ($M = 71.90$, $SD = 6.76$). Two participants lived in assisted living homes, eleven with their partner, two with their partner and family members and four alone. All participants owned a desktop computer or laptop, 16 smartphones, eight mobile phones without internet access, and seven tablets. The survey consisted of three parts. First, we asked for demographic data. Then, we asked how they use calendars. Here, we investigated which kinds of calendars are used by the participants and how often and for what purposes the different kinds of calendars are used. For example, we asked the participants what kind of appointments they enter to the different calendars. In addition, we studied whether they would be willing to share their calendar data with others and with whom. Further, we investigated what kind of tools our participants usually use to remember upcoming appointments or tasks. Finally, we asked for feedback about calendars. At this point, we investigated what our participants like or dislike regarding calendars, why they consider calendars as suitable tools, and how calendars could be improved. All questions were mandatory and consisted of 5-point Likert items to study the participants level of agreement or the frequency of calendar usage, multiple choice questions and open questions.

6.2.2 Results

For the open response questions, we conducted a thematic analysis. After inductively developing a codebook, three researchers deductively applied the codes to all responses independently. Any disagreement between the coders was discussed until an agreement was reached.

The most used calendars were digital calendars (15) and the most used physical calendars were wall calendars (12), followed by pocket (10) and table calendars (7). Physical calendars were used more often than digital calendars for social events, appointments as well as special events (see also Table 6.1). In general, participants appreciated the ability of digital and physical calendars to provide them with an overview (11). Other valued aspects were the reminder function (6), being able to see public holidays (3), the mobility of calendars (3), and the ability to use the calendar as a diary (3). For physical calendars, participants disliked limited space to enter their events (3), that recurring events must be entered each time manually (2), and the immobility of the calendar (2). Important features for calendars were the use of color codes (3), and preloading important dates and public holidays (2) were suggested. We also asked who is using the participants' physical and digital calendars as well as who can see their calendar entries (see Table 6.2). The participants used their calendars either alone or together with other family members within the same household. Most often family members within the same household have access to the participants' physical and digital calendars. Regarding the privacy of certain event types, six participants stated that they would share all calendar entries. Four participants stated that personal and private appointments should not be shared, while three participants stated that no calendar entries should be shared. Another two participants stated that their willingness to share calendar entries depends upon the person with whom they would share them. Additionally, they noted that they would share everything with family members. Finally, we asked about reminder tools other than calendars. Eleven participants used digital devices, seven used sticky notes, and four used notebooks or notepads. Six participants stated that they only use calendars. The most common uses for reminder tools were birthdays (10), private social events (9), shopping lists (6), doctor's appointments (5), public events (5), contact information (4), trips (3), and talks (2).

6.2.2.1 Summary

The participants used both physical and digital calendars. The most used physical calendars were wall calendars. Physical calendars were mainly used for special events, appointments, and social events. Compared to younger users [178], retired

	Physical Calendars			Digital Calendars		
	Md	*M*	*SD*	*Md*	*M*	*SD*
Appointments	5.00	4.10	1.58	3.00	2.90	1.70
Social events	5.00	3.81	1.75	3.00	2.86	1.74
Coordination with others	3.00	3.05	1.56	2.00	2.86	1.85
Awareness of family	3.00	2.76	1.61	2.00	2.62	1.72
Intake of medicine	1.00	1.24	0.89	1.00	2.05	1.60
Special events	5.00	4.00	1.61	3.00	3.10	1.73
Repeated events	3.00	2.67	1.77	2.00	2.61	1.69

Table 6.1: Agreements to the statements “I use physical/digital calendars for the following purposes”. 1 = do not agree at all, 5 = fully agree

	Access to physical cal.	Access to digital cal.	Uses my calendars
Family (same household)	11	7	10
Family (different household)	2	1	0
Friends	0	0	0
Visitors	1	-	-
No one besides myself	6	9	11

Table 6.2: Number of people that have access to the participants’ digital and physical calendars and who is using the calendars (N=21).

older adults use calendars less to coordinate appointments with others, use them alone, or share their calendar data mainly with family members living in the same household. Most participants were therefore not concerned about the privacy aspects of calendars. They appreciated calendars for providing an overview of events, the current date and public holidays. At the moment, our participants have to synchronize their different physical calendars such as wall calendars with the digital calendars by themselves. Another drawback of current physical calendars is that users have to add recurring events in the calendar manually each time they occur. If physical calendars offer the same functionality as digital calendars, users would not have to put effort into synchronizing their calendars.

6.3 Caloo: Investigation of an Ambient and Pervasive Smart Wall Calendar Supporting Event-Suggestions

Based on the results of the survey about how older adults use physical and digital calendars and the results of former work for families, we designed and implemented *Calendar of Opportunities (Caloo)*. *Caloo* is prototypical ambient and pervasive smart calendar system that displays the user's digital calendar data in the home environment. Further, *Caloo* displays event suggestions fitting to the user's interests.

6.3.1 Method

We conducted qualitative interviews with retirees about the presented prototype. In the following, we describe the apparatus, the method and the procedure of the conducted interviews. Afterward, we provide information about the participants and present their answers and feedback.

6.3.1.1 Apparatus

Wall calendars were the most used physical calendars in our online survey as well as in the work of Brush and Turner [25]. Further, wall calendars are often placed in hubs of the users' homes [40, 114] and generate awareness regarding upcoming appointments. Therefore, we implemented *Caloo* as a digital wall calendar (see Figure 6.1). For the prototype, we used two 13.3″ tablets in a wooden box. The calendar layout is implemented as a web application and is based on physical wall calendars, consisting of a large image, the current month and the year. The picture is shown on the upper part, and the color that displays the user's appointments can be customized. In contrast to physical wall calendars, this allows for a greater degree of personalization. The lower part of the calendar shows the user's appointments for the current week. Appointments can be added or modified using the touch screen. *Caloo* should synchronize with users' digital calendars. Apart from displaying appointments set by users, *Caloo* can automatically add suggestions for upcoming events of interest as new calendar entries (shown with a gray background, see Figure 6.1). These event suggestions can be accepted or declined by the user and they should allow older adults to stay active in their daily lives. For the interviews, we displayed mock-up events to ensure that all participants were confronted with the same scenario. We displayed general appointments (e.g. doctor, talks), social appointments (birthday party), as well as daily tasks (shopping) on the prototype.

6.3.1.2 Procedure and Participants

We recruited participants via a local computer club for seniors and a regional amateur radio club. Participants were compensated with 10 EUR. We interviewed 4 retired older adults (2 female, 2 male), aged between 61 and 80 years ($M = 71.25$, $SD = 7.80$). All participants lived in their homes (2 with their partner, 2 with other family members). They owned a smartphone, a tablet and a laptop or desktop computer.

In all interviews, one researcher guided the discussion while another researcher took notes. Additionally, all interviews were audio recorded to complement the notes. The interviews consisted of four parts. First, we asked how and why participants use physical and digital calendars. Afterward, we asked them what kinds of events they use calendars and how they are informed about events. Moreover, we demonstrated the smart calendar and discussed it to gather qualitative feedback. We explained the layout of the calendar and how the picture and color can be personalized. Further, we demonstrated how events are displayed, how they can be added and modified, and how event suggestions can be accepted or declined. Finally, we asked participants about possible privacy concerns.

6.3.1.3 Results

For analysis of the collected data, we conducted a thematic analysis. Two researchers deductively applied the inductively developed codes to all responses. Any disagreement between the coders was discussed until an agreement was reached. Regarding the current calendar usage, P1 stated that she uses a calendar app on her smartphone (see Figure 6.2) for all appointments, which are not routine (e.g. the weekly church service). Furthermore, she adds information about

Figure 6.1: The *Caloo* smart calendar prototype as shown in the pilot study. Event suggestions are entered as entries with gray background.

interesting TV shows into this calendar. Additionally, she uses a wall calendar together with her husband for garbage collection reminders. P2 mentioned that she uses a calendar app on her tablet for all appointments. She appreciates the overview that digital calendars offer and the possibility to search and filter appointments. P3 uses a calendar app on his smartphone and tablet. He enters all appointments, which he should not forget into his digital calendar. However, he adds appointments for his daughter's exams. P4 records all his activities in pocket or Leporello calendars (see Fig. 6.2). Every year, he starts a new pocket calendar and stores calendars from previous decades. He stated that he uses the calendars as a diary and added all appointments, tasks and activities. Also, he uses different color codes for different activities, e.g. sport and talks. P4 owns a wall calendar but uses it solely for the images. All participants receive invitations by mail, post or both about upcoming events. Additionally, newsletters and mailing lists were noted as an important source of information for all participants. Two participants mentioned the daily newspaper. Depending on the event, participants attend events alone, with family, friends or acquaintances with shared interests.

Regarding the prototype, all participants liked the ambient overview of appointments without checking other devices. Three participants liked the idea of changing images at the top of the calendar (P1, P3, P4). P1 stated that she likes the idea of showing suitable images related to visitors or special days such as their own wedding day. Another participant mentioned that this concept generates an emotional connection to the calendar (P4). Two participants asked for minor changes to the application. In detail, one participant suggested to also add her husband's appointments to the calendar (P1), while another participant was interested in different views for different time scales (daily, weekly, monthly, yearly). Three participants liked the idea of automatic suggestions for events according to their interests (P1, P2, P3). These suggestions include scientific talks, appointments for club activities, local street festivals, and local music events. One participant also requested an automatic filtering of announcements in the newspaper or from theaters (P1). However, another participant mentioned that he thinks automatic suggestions are not convenient (P4). All participants mentioned that such a smart calendar application would be useful for older adults to remember for their appointments and tasks.

Finally, we asked participants if they have privacy concerns and what they think about sharing their calendars with other family members. All participants mentioned that all their appointments should be displayed in the smart calendar application. Three participants stated that they do not need specific privacy settings because they would place the smart calendar system at locations where visitors do not have access. Another participant mentioned she would hide all appointments if there were visitors in her apartment. One participant mentioned privacy issues if family members have access to her appointments in the smart calendar system. Only one participant liked the possibility of having access to the calendars of other family members for being able to coordinate appointments.

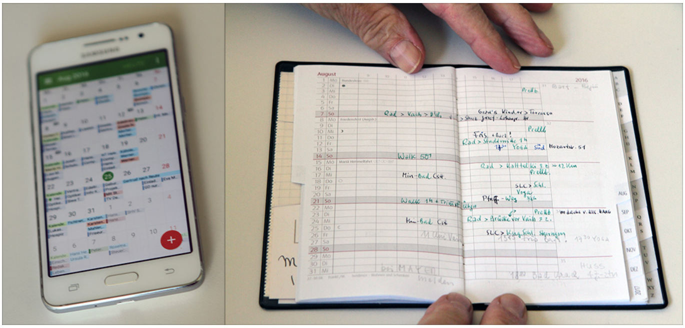


Figure 6.2: Two of the calendars of the participants. Left: Calendar app on a smartphone. Right: Pocket calendar.

6.3.2 Development of a Smart Wall Calendar Application

Based on the results of the pilot study, we developed *Caloo*. This system supports users in their daily lives by increasing awareness regarding appointments and supporting them to be active through local event suggestions. In the following, we describe *Caloo*'s hard- and software implementation.

6.3.2.1 Digital Wall Calendar

The hardware of the wall calendar consists of two 13.3" Android tablets. Both tablets have a resolution of 1920x1080 pixels and display a full-screen web browser, hiding all other user interface elements. Using a laser cutter, we created a wooden box to stack both tablets vertically. The tablets are powered by USB but can also be temporarily driven by the tablet's internal batteries. No data is stored on the tablets themselves. Both tablets display the web-based top and bottom halves of *Caloo* (see also Figure 6.3).

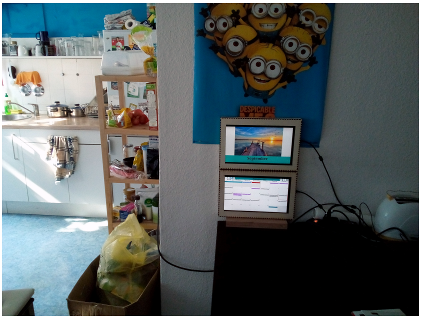
6.3.2.2 Architecture

Caloo integrates with a user's existing Google Calendar. When first signing in, the system uses OAuth to authenticate the user's Google account and request read and write authorization for the user's Google Calendar and Google Drive cloud storage. The user is also asked to select interest tags, ranging from music, movies, sports, to literature and art.

Figure 6.3: Implemented views of Caloo that was used in the in-situ study.

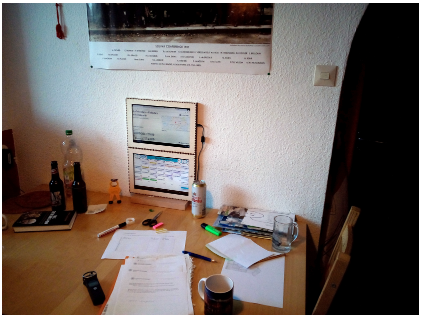
The top half of *Caloo* displays an image and the current month. The images are taken from a particular folder in the user's Google Drive cloud storage. Users can place images in the folder, and *Caloo* automatically generates a slide show that periodically changes the displayed image.

On the bottom half, the user's calendar appointments are shown. We implemented day, week and month views. The calendar appointments are periodically synchronized with the user's Google Calendar, enabling seamless integration with other devices. Users can tap on an appointment to open a detailed view in the top display. In the detail view, users can edit and delete appointments.

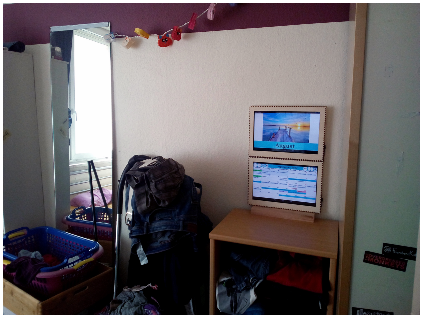


(a) Placed on the eating table close to the kitchen

(b) Placed in the living room



(c) Placed on the eating table



(d) Placed on a highboy in the private room

Figure 6.4: Placements the participants chose to place Caloo in their homes during the study.

6.3.2.3 Event Suggestions

Caloo retrieves event suggestions from local event websites, and Rich Site Summary (RSS) feeds. We implemented an event crawler to periodically access these resources that often publish events in chronological order. Because the formatting differs from resource to resource, we implemented simple parsers on a per-resource basis. Our event crawler extracts the title, description, date, location, and interest tags of events. The data is transferred in a uniform event presentation and then forwarded to an event scheduler. Based on the user's interests, the event scheduler attempts to fit the crawled events in the user's calendar. Existing appointments in the user's Google Calendar are taken into account to avoid overlaps and make sure the user has enough time to go to the event. Scheduled events are then automatically inserted into the user's Google Calendar using a "suggestion" layer.

Event suggestions in the "suggestion" layer are synchronized exactly like other appointments in the user's calendar. They are accessible on the user's other devices, and the layer's visibility can be toggled. In *Caloo*, events in the "suggestion" layer are displayed grayed out. Tapping on an event suggestion opens the detail view similar to regular appointments. Here, users can accept or decline suggestions. Declining a suggestion will delete it from the "suggestion" layer, while accepting the suggestion will copy it from the "suggestion" layer into the main calendar and then delete it from the "suggestion" layer. This causes the event to be displayed normally instead of grayed out and appear on the user's other devices. Users can manually request new event suggestions by tapping on a button.

A logging component takes note of accepted and declined events. By making use of these logs, the event schedule can be improved over time by learning the user's habits and adjusting the interest matching.

6.3.3 Method

We conducted a four-week long in-situ study to observe user behavior to gain insights and to further improve the design of *Caloo*. During the study, four participants used *Caloo* in their homes.

6.3.3.1 Design

We deployed *Caloo* for four weeks in the participants' homes. For the deployment, we visited the participants in their homes to set up the system. We let the participants decide to place *Caloo* in a sufficient location in their homes (see Figure 6.4). The study started the day after we deployed *Caloo* in the domestic environments of the participants. The active use of Google Calendar was a requirement for the participants. All participants used *Caloo* with their existing Google Calendars that they also used on their smartphones. During the study, we logged all interactions with *Caloo* and all event-suggestions the participants received. Finally, we conducted semi-structured interviews with all participants after the end of the study. All interviews were audio-recorded.

6.3.3.2 Participants

We recruited the participants via university mailing lists. Because of the specific technical requirements needed to be fulfilled by the participants (e.g., actively using the Google Calendar), we decided to recruit students for our study. Further, we assume that any usability issues that students identify are also valid for other user groups such as retirees. The participants were compensated for their participation with 20 EUR. In total, four participants (1 female, 3 male) took part in the study. The participants were aged between 25 and 27 years ($M = 26.00$, $SD = 0.82$). All participants were students, had a technological background and lived in shared apartments. All participants used the Google Calendar before they participated in our study. Three participants also used a physical wall calendar in their homes.

6.3.3.3 Procedure

After the participants gave informed consent, we asked them to fill in a demographic questionnaire. Further, we asked them to place *Caloo* in a suitable location in their domestic environment. Then, we supported our participants in setting up *Caloo*. After *Caloo* was connected to the participants' Google Calendar and Google Drive, we added the standard background images in the participants' Google Drive folder. Then, we asked our participants to set interests and requested initial event-suggestions to explain the functionalities of *Caloo*. After four weeks of using *Caloo*, we revisited our participants in their homes and conducted the semi-structured interviews.

6.3.4 Results

On average, participants interacted with *Caloo* 17.62 times per day ($SD = 10.82$) and switched 3.02 times ($SD = 2.47$) between the different views per day. They opened the detail view for regular appointments on average 4.75 times per day

($SD = 8.85$), added new regular appointments using *Caloo* 1.75 times per day ($SD = 3.50$), and edited 0.5 new appointments per day ($SD = 1.00$) using *Caloo*. Our participants chose from 10 to 20 interests ($M = 15.25$, $SD = 4.99$) of the offered categories. In total *Caloo* suggested 206 events ($M = 51.50$, $SD = 28.80$) to the participants according to their selected interests. From the received event suggestions our participants accepted 20 events ($M = 5.00$, $SD = 3.74$) and declined 44 events ($M = 11.00$, $SD = 12.19$). On average participants opened the detail view for event suggestions 2.75 times per day ($SD = 1.85$).

6.3.4.1 Interviews

We audio-recorded all interviews and transcribed their content verbatim. We used thematic analysis with open coding to gain an understanding of the interviews. One researcher coded all interviews. Also, we translated all quotes from German to English. We identified in the qualitative data the following four themes *Experience with a digital calendar*, *Interests*, *Experience with local event suggestions*, and *Suggestions to improve event suggestions*.

Experience with a digital calendar: This theme describes how our participants experienced the calendar feature of an ambient smart wall calendar. All participants stated that they would use an ambient smart wall calendar such as *Caloo* in the future. Our participants explained that a digital wall calendar erases the limitations of traditional physical wall calendars.

> *"The space in the physical wall calendar will eventually run out. Therefore, variable views are good." (P3)*

Further, they appreciated the awareness *Caloo* creates regarding their schedules as well as the opportunity to adapt the view according to their current needs.

> *"If you are planning something, the weekly view is good to go through [all appointments]." (P1)*

> *"I liked the monthly view to get overview [about all appointments and events]." (P3)*

To further improve the awareness of the daily schedules, one participant suggested that a smart wall calendar could also support multiple users by displaying information such as shared responsibilities or tasks in addition to appointments and events.

> *"I can imagine that [a smart wall calendar] is good for families - [one] large digital calendar for all appointments [or a] cleaning schedule." (P1)*

Interests: This theme captures aspects to further improve the event suggestions based on the defined interests. We observed that users prefer more fine-grained options for interests. Our participants mentioned that the suggested events based on defined interests fitted quite well for them. However, some of the suggested events were inappropriate because the offered categories were too generic and not specific enough.

> *"I added education [as interest], that also contained suggestions such as homework help. [That] belongs to education, but [it is] not interesting for [me as] a student." (P1)*

Furthermore, an event recommendation system such as *Caloo* should also consider preferred music bands or sports teams of the users.

> *"A fan of [the soccer team FC] Schalke [04] is not interested in matches of [another team such as BVB] Dortmund." (P4)*

Experience with local event suggestions: This theme describes the experience of our participants with receiving local event suggestions based on their interests. Our participants mentioned that *Caloo's* event suggestions generated an awareness regarding local events and opportunities.

> *"There are few opportunities to get informed about all local events - if you are not online on Facebook all the time and have not joined all groups." (P3)*

> *"It [is] interesting to see what happens pretty close. [...] Many events took place in a small coffee [shop], there are so much options [for attending events]." (P2)*

Furthermore, *Caloo's* event-suggestions made our participants curious about many local events. However, only 2 participants explained that they attended suggested events by *Caloo*. One participant explained:

> *"I become more open to events. Unfortunately, I could not attend an event because I had exams." (P3)*

Suggestions to improve event suggestions: This theme captures aspects to improve the event suggestions of a smart wall calendar system. An event recommendation system should improve the event suggestions using machine-learning approaches based on the user's former attended events.

> *"Two weeks after I accepted an event suggestion about a soccer match of the [local team] VfB Stuttgart] there was again a home match. [This time,* Caloo*] did not suggest the match to me. Instead, it suggested another soccer match for the [local team] Stuttgarter Kickers which [...] collided [with the other match]. That was a pity." (P4)*

In addition to former visited events, such a system should also consider the importance of an event to the user.

> *"If you like a [...] certain musician, [concerts from the musician] should be suggested immediately." (P4)*

Also, our participants mentioned that they are also interested in being informed about events that occur regularly, as well as some permanent exhibitions which do not have specific appointments.

> *"[Regarding the planetarium], these events occur every Thursday and Friday. [*Caloo *should] display all appointments or highlight them in gray. Thus, I can deliberate when to attend." (P1)*

To be able to plan attending local events together with other people, our participants suggested delivering event suggestions from one to four weeks in advance and connecting the system with social networks such as Facebook.

"I want to be informed early [about events] to be able to plan with friends." (P2)

"For important events such as city festivals [...] I want to be informed earlier." (P3)

In general, our participants preferred receiving multiple events per day (from two up to five events per day) and being able to decide which event is the most interesting for them.

*"[I prefer] if [*Caloo*] displays multiple event suggestions, also overlapping suggestions. Thus, I can have a look at them and choose one." (P4)*

In addition to recommending events in available time slots, such a system should also offer the opportunity to suggest events only in time slots where users are open to attend such events.

"Maybe you can define a time slot [to receive event suggestions]." (P1)

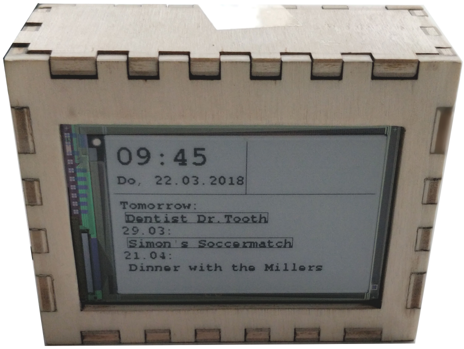
6.4 Comparing novel Smart Home Appliances displaying calendar data with established personal devices

Since the smart home offers more options to inform their users about their schedules, we also investigated other smart home appliances that could inform the users in the future about their calendar data. With this, we decided to compare the suitability of novel smart home appliances such as smart speakers informing the users about their schedules with established personal devices such as smartphones or smartwatches.

6.4.1 Method

In a lab study, we explored the suitability of seven smart home appliances for conveying calendar information to users. In detail, we investigated three novel

(a) Smart Mirror



(b) E-Paper Display

(c) Smart Light

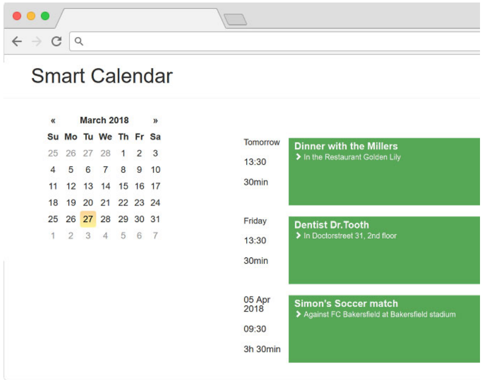
Figure 6.5: Novel devices presenting calendar information.

smart home devices (i.e., smart mirror, e-paper display, and smart light) as well as four common commercially available smart devices (i.e., smartphone, smartwatch, smart speaker, and website) for presenting calendar information.

6.4.1.1 Design

For the conducted lab study, we used a within-subject design with the device as the independent variable. Thus, all supported devices were presented to each participant. The order of the presented devices was randomized among all participants.

(a) Smartphone



(b) Website

(c) Smartwatch

(d) Smart Speaker

Figure 6.6: Common commercially available devices presenting calendar information.

6.4.1.2 Apparatus

We developed a Smart Calendar Platform (SCP) that can be used to control a wide range of smart devices. The SCP consists of a central database that controls user accounts and appointments. Smart devices connect to the SCP using WiFi and WebSockets. The SCP also supports user detection using Bluetooth Low Energy beacons with a room level precision. This can be used to only display appointments if the user is nearby. We integrated seven smart devices with the platform, including commercially available and novel device types (see Figures 6.5 and 6.6).

Smart Mirror We created a smart mirror using a 27” monitor in portrait orientation with a custom wooden frame and a two-way glass mirror (see Figure 6.9). The device is connected to a Raspberry Pi 3 hidden in the wooden frame running the Android Things operating system and a full-screen Android app for listing the appointments. Important appointments can be highlighted using colors.

E-Paper Display The e-paper display consists of a 2.7” black and white e-paper display from Pervasive Displays connected to a Raspberry Pi Zero W inside a wooden box. Since there is no color, important events are underlined.

Smart Light We combined a LIFX Color 1000 light bulb with an IKEA FADO table lamp and connected it to a Raspberry Pi 3 via WiFi. The smart light fades from white to green to indicate an upcoming event. Important appointments fade to red instead.

Smartphone & Smartwatch We created a custom app for Android-based phones and watches that connect to the SCP and display a list of appointments. Similar to the previous artifacts, the apps can highlight important appointments using color-codes.

Smart Speaker We developed a custom skill for the Amazon Echo Dot smart speaker. The skill uses a wake word and text-to-speech to announce upcoming appointments aloud.

Website We created a website intended to be used on laptops and PCs that lists upcoming appointments.

6.4.1.3 Procedure

We individually invited the participants to our lab and asked them to sign a consent form and fill in a demographic survey form. The participants then sketched their living environment on a desktop computer using the Microsoft Visio diagramming

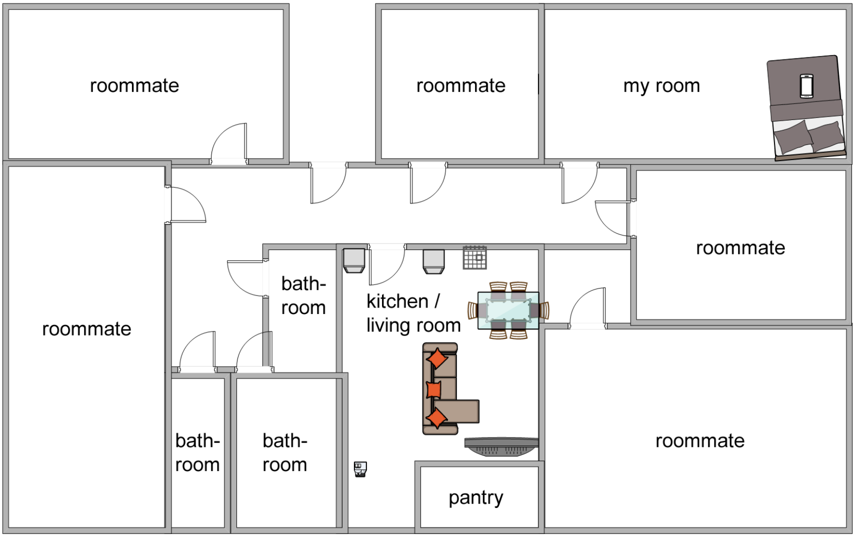


Figure 6.7: Exemplary sketch created by P1.

software (see Figure 6.7). This was done to enable the participants to reflect on their own homes during the study. While the participants were creating the sketches, we asked them about their daily routines. We then presented the seven artifacts (see Figure 6.9), with three exemplary appointments each. Afterward, we asked the participants to add the artifacts they could see themselves using to the sketches of their living environments. We asked the participants to speak aloud their reasoning where and why they placed the artifacts. We then conducted semi-structured interviews in which we asked about suggestions and concerns. Finally, we thanked the participants for their participation and rewarded them with sweets. Each session took approximately 45 minutes.

6.4.1.4 Participants

We recruited participants using university mailing lists, social media (university groups), and flyers on the campus. Eighteen participants participated in the study (4 female, 14 male). They were 20-26 years old ($M = 22.56$, $SD = 1.77$). All participants were students. Six participants lived in shared apartments, four alone, three with their partners, and five together with their families. All participants owned a smartphone. Additionally, ten participants owned a tablet, six a smart TV, three a smartwatch, one a smart speaker and one a smart light.

6.4.2 Results

In this section, we report about how our participants usually use calendars and analyze how they experienced our prototypes and whether they would be willing to use them to get informed about upcoming appointments or what kind of additional devices they can imagine to use.

6.4.2.1 Calendar usage

First, we analyzed how our participants use calendars in their daily lives. All participants except one used digital calendars to organize their appointments. Three participants shared their digital calendars with other people. Thirteen participants stated to use wall calendars. Seven of those share them with other people. Further, three participants use table calendars and two pocket calendars. Apart from these traditional calendars, participants also stated to use to-do lists, sheets of paper, alarm clocks, timetables, and reminder functions of devices to manage their appointments.

We asked the participants which types of appointments they use in their calendars. Most of the participants (13) used them to manage their university courses and exams. Other types of appointments were doctoral appointments (5), birthdays (4), work-related appointments (3), sports (2), vacations (2), meetings with friends (2), and music practice (1).

6.4.2.2 Artifacts

Figure 6.8 shows the agreement ratings to the statement that participants would use a specific device to manage their personal appointments.

The *smartphone* received high agreement ratings, as participants already use the device and want to continue to use it. Participants liked that they can manage their appointments on-the-go, as the smartphone is always with them, and they liked the fact that they receive notifications about upcoming appointments.

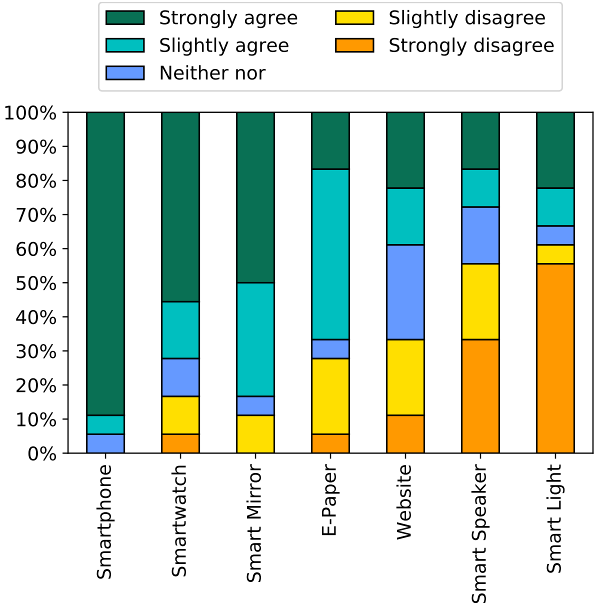


Figure 6.8: Agreements to the statement *"I would use the device to display my personal appointments."* on a 5-point Likert scale.

Participants stated that in some cases the *smartwatch* could be more convenient.The smartwatch allows checking appointments at a glance without having to take out the smartphone. Participants stated that they frequently check the time anyway. Further, they like the idea of being notified unobtrusively through vibrotactile notifications. However, some participants disliked wearing a watch.

The *smart mirror* was overall well received for all kinds of appointments. Participants suggested replacing existing mirrors, e.g., in the bathroom and entrance corridor. This way, participants could get an overview of their appointments when they already use the mirror. Participants liked the idea of using the smart mirror in the morning or evening. They suggested that the additional screen space could be used to provide additional information, e.g., displaying maps and estimated travel times.

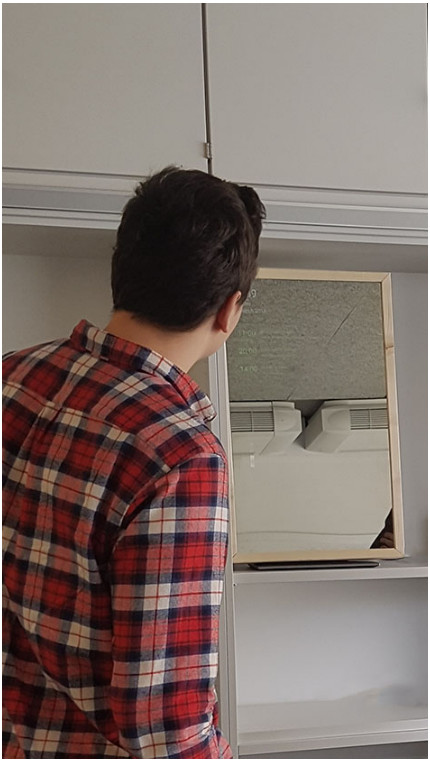


Figure 6.9: Placement of the smart mirror in the lab study.

Participants suggested placing the *e-paper display* on their nightstand or desk. They liked the idea of the e-paper display being a flexible device that could be placed almost anywhere. Further suggestions include walls and doors, where it could replace traditional wall calendars.

The participants found the traditional *website* limiting. They disliked the idea of having to boot their PC or laptop to be able to check their appointments. However, they found it a viable alternative if, for instance, their smartphone battery was empty. Similar to the smart mirror, participants suggested making better use of the additional screen space.

The *smart speaker* received low ratings. Most participants disliked the idea of the smart speaker listing their appointments using text-to-speech. Participants stated that the speaker reported the appointments in a monotone fashion, which requires a high cognitive effort to keep up. As multiple appointments could easily overwhelm the participants, the smart speaker should only be limited to important appointments to keep the list short. However, participants stated that the smart speaker could be used while cooking for a hands-free interaction or if the smartphone is not in reach. We used an Amazon Echo Dot in the study that many participants were already familiar with. Some participants raised security and privacy concerns regarding using an always-listening smart speaker that processes voice commands and appointments using cloud services.

Participants found that the *smart light* does not convey enough information. They stated that the smart light could be used as a second channel for notifications, e.g., telling the user when to leave for an appointment in a subtly and unobtrusively. However, this should be limited to special appointments to not to overwhelm the users. Participants suggested that the smart light could be used in every room by replacing existing light bulbs as the user sees fit. Further, they suggested that the colors and patterns used should be customizable.

6.4.2.3 Additional Devices

We asked participants for suggestions for additional devices. Participants would like to integrate the smart calendar platform in the entertainment system for their cars, in wall clocks, and smart TVs [212]. Further suggestions included using projection to display the calendar on the ceilings or shower curtains [62]. One participant suggested integrating e-paper displays in couch pillows. Another participant suggested blinds that automatically open depending on appointments.

6.4.2.4 Concerns

Participants raised privacy concerns about calendar appointments being visible in the smart home environment. They stated that the artifacts should only display appointments when the user is nearby. In some cases, sharing appointments with multiple users might be useful. However, this depends on the user's relationship with the other party.

6.4.2.5 Additional Comments

Participants suggested conveying additional information apart from calendar appointments. Participants mentioned weather updates, news, to-do lists, traffic information, emails, shopping lists, and alarms.

6.5 Discussion

This chapter investigated two research probes displaying calendar information to investigate how such smart home appliances can be integrated into the users' routines (RQ6).

In the investigation of different novel displays that could present calendar data in the home, we observed that participants wanted to continue using smart devices that they already use, for instance, the smartphone that is almost always with them. However, participants could also imagine using novel smart home appliances such as smart mirrors or portable e-paper displays that present their daily schedules. In both investigations, we observed that our participants valued the passive awareness by having displays in their environment that displayed an overview about their schedules that the users could access at a glance (i.e., using *Caloo* or using a smart mirror or an e-paper display presenting calendar information). Therefore, smart home appliances must offer an overview about the relevant information to the users that are glance-able, e.g., by displaying the information on the start screen, to generate awareness about the information.

We observed that the users of *Caloo* wanted to control the settings regarding the generation of multiple event suggestions for the same day and consider appropriate time slots in addition to available time slots. Therefore, designers should also consider that users have different interests and preferences. Therefore, the smart home appliances should offer a fine-grained control about the presented information in the home.

Further, we reported that some of the suggested events that fitted the general interest of the users were more interesting for them, while other events from that category were perceived as irrelevant. Therefore, smart home appliances should either access the importance of the presented information, e.g, by prioritizing the information using a machine-learning approach based on the users' reactions and responses, or by enabling a fine-grained control for the users to enable or disable as well as prioritize specific kinds of information.

Similar to our findings in Chapter 4 regarding suitable modalities for the presentation of everyday home information (RQ3), we also observed in this investigation that users prefer, in general, the usage of visual cues for the representation of calendar information. However, smart home appliances must convey sufficient information to users. While smart lights might be suitable to convey additional information in the background as an ambient notification without interrupting the users (e.g., when it is time to leave home to be on time for an appointment); they are inappropriate for displaying other relevant parts of information (e.g., which appointment type it is or where the appointment is taking place). Auditory output for informing the users about calendar data, as current smart speakers nowadays could provide, was experienced as too monotone and associated with high a cognitive effort.

Limitations

A limitation of our deployment study regarding the *Caloo* application is that only four participants participated in our study. For future evaluation of such a system, we need a more diverse set of participants. However, we assume that four participants are enough to gain first insights about how users experience and integrate such an ambient smart wall calendar with integrated event suggestions in their lives. Further, we identified several design implications to design smart home appliances displaying home information with a high information capacity.

A limitation of our study investigating novel displays for calendar information in the home, is that we explored the suitability for displaying additional information on seven smart devices in a lab study. However, the presentation of the artifacts enabled the participants to imagine how the artifacts would behave in their daily lives. However, our results are consistent with our previous findings from the exploration study (see Chapter 4) and the insights gained in the deployment study of *Caloo*.

7

Understanding digital assistants in context

In the previous chapters, we investigated mainly smart home appliances that use visual cues to inform users about everyday information since the participants preferred these modalities to explore how everyday information could be displayed in the home environment (cf. Chapter 4). In Chapter 6, we observed that users experienced the smart speakers' output of calendar information too monotone and that auditory output was associated with a high cognitive effort. However, related work found that smart speakers or conversational agents could become digital assistants in the future [133].

In this chapter, we investigate smart speakers to understand how smart speakers should be designed to fit into the users' routines (RQ6). Therefore, we assess how smart speakers are integrated into the users' lives by investigating the usage in the first weeks of owning a smart speaker and investigate the social implications of their users. As a result of this, we investigate how users living in different social settings integrate the smart speakers into their daily lives.

This chapter is based on the following publications:

A. Voit, J. Niess, C. Eckerth, M. Ernst, H. Weingärtner, and P. W. Wozniak. "'It's Not a Romantic Relationship': Stories of Adoption and Abandonment of Smart Speakers at Home." In: *19th International Conference on Mobile and Ubiquitous Multimedia*. MUM 2020. Essen, Germany: Association for Computing Machinery, 2020, 71–82. ISBN: 9781450388702. DOI: 10.1145/3428361.3428469

7.1 Method

This study investigates how users integrate smart speakers into their routines when they are introduced to their home environments and how they experience smart speakers in their daily lives. Therefore, we conducted a four-week in-situ study where we deployed the Amazon Echo Dot in a variety of households.

7.1.1 Procedure

At the beginning of the study, we visited all participants in their homes. First, we asked all household members (except underage children) to sign the consent form and answer the demographic questionnaire. Afterward, we conducted an initial semi-structured interview with each household member individually (except underage children). At the end of our first visit, we asked the participants where they would like to place the Amazon Echo Dot (Version 2) in their homes (see Figure 6.6d). However, we required that the Amazon Echo Dot were placed in a shared location in their homes (i.e., kitchen, living room) to ensure access to the device for all household members. In addition to the device, we provided the official Amazon Echo Dot's guidance sheet instead of showing the participants the functions of the smart speaker to ensure comparability with regular users of smart speakers. After we deployed the Amazon Echo Dot, we asked the participants to use the device for the next four weeks. We did not further encourage the participants to interact with the smart speakers to avoid influencing their behavior. The study started on the day after deploying the Echo Dot. Two weeks after the initial deployment, we revisited the participants in their homes and conducted the mid-term semi-structured interviews with every household member

Figure 7.1: The investigated smart speaker Amazon Echo placed in the home of a participant during the study.

individually. At the end of the study (i.e., after four weeks), we visited the participants, conducted the final semi-structured interview with each participant individually, and collected the deployed Amazon Echo Dots. Finally, we rewarded every household with a EUR 40 Amazon voucher for their participation in the study.

7.1.2 Participants

In the participant selection process, we explicitly looked for households with diverse living situations to investigate the integration of smart speakers in different social settings. Therefore, we recruited households with different settings including people living alone, couples and families living together, and living in shared apartments. Another requirement for participation in our study was that the participants have not used a smart speaker before, but were willing to test and use one for the study duration (i.e., four weeks). In total, nine households with 20 household members (including three children aged between 1 and 6; $M = 3.66$, $SD = 2.52$) living in Germany participated in the study. Since all children were underage and could not give consent, we excluded all children from the interviews. The remaining 17 adult participants (5 female, 12 male) were aged between 21 and 35 years ($M = 26.29$, $SD = 4.18$; cf. Table 7.1). Five households placed the smart speaker in the kitchen; three in the living room, one participant, placed the speaker in his single-room apartment. Two households were single-person households, and three households were shared apartments. Also, two couples and two families with their underage children participated in our study. All participants owned a smartphone, and all but one participant also owned a laptop/desktop computer. Further, one household owned smart lights. In total, eight participants stated that they had previously used conversational agents integrated to their smartphones, i.e., Siri or the Google Assistant. However, seven participants mentioned that they were using it infrequently. All participants stated that they were not using conversational agents integrated into their laptops or desktop computers. One hint regarding the reported participant numbers in this thesis: The first digit of the participant id (PID) encodes the household the participant resides in. Further, we use the notation PX to refer to the entire household, e.g., P1X refers to P11 and P12 collectively.

7.1.3 Interviews

In total, we conducted three interviews individually with each household member. We opted to interview participants individually to capture their unique perceptions of how the smart speaker affected the household. We informed them that their opinions would stay confidential and anonymized which enabled sharing information that could be viewed negatively by other members of the household.

Initial interview: In the initial interviews, we asked the participants about their experiences with voice assistant systems, their knowledge about smart speakers, and the functionalities provided by Amazon Echo Dot. Further, we investigated how they usually accomplished daily tasks and activities that could be supported by the Amazon Echo Dot, such as playing music or checking weather conditions [16].

Mid-term interview: In the mid-term interviews, we investigated how the participants used the Amazon Echo Dot in their daily lives so far (i.e., how often and why they interacted with Amazon Echo Dot, which functions or additional skills they explored). Further, we investigated if technical support was needed.

	PID	Age	Gender	Highest Education level	Occupation
Shared apartments	P11	23	m	High School	Student
	P12	27	m	High School	Student
	P31	21	m	High School	Student
	P32	22	m	High School	Student
	P33	23	m	High School	Student
	P71	35	m	Bachelor	Employee
	P72	28	m	Bachelor	Employee
Families with children	P81	34	f	Vocational training	Employee
	P82	38	m	Vocational training	Employee
	P83	6	m	-	-
	P84	4	m	-	-
	P91	28	f	Vocational training	Employee
	P92	25	m	Bachelor	Employee
	P93	1	m	-	-
Couples	P21	23	m	High School	Student
	P22	22	f	High School	Student
	P41	26	m	Bachelor	Employee
	P42	25	f	Vocational training	Employee
Single person	P51	32	f	Bachelor	Employee
	P61	25	m	High School	Student

Table 7.1: Overview of the participants. The first digit of the participant id (PID) encodes the household the participant resided in. We use the notation P#X to refer to the entire household, e.g. P1X refers to P11 and P12 collectively.

Final interview: In the final interviews, we asked the participants to reflect on their usage behavior and if they would use a smart speaker system in their homes in the future. We aimed to elicit stories of using the Amazon Echo Dot in their daily lives. We were especially interested in how the participants integrated the Amazon Echo Dot into their household and if they changed their usual routines. We also addressed changes in usage over time. We used interpretive questioning [45] to gain more information about concepts of particular importance to our study once they were mentioned in the stories. The interview script paid specific attention to instances where participants discussed their relationship to the Amazon Echo Dot, possible anthropomorphism of the devices and differences in the interaction with the device when other household members or visitors were present.

7.1.4 Data Analysis

All audio recordings were transcribed verbatim and imported into the Atlas.ti analysis software. Two researchers coded a representative sample of 15% of the material using thematic analysis with open coding [18]. Next, a coding tree was established through iterative discussion. The remaining transcripts were coded individually by one researcher. A final discussion session was conducted to finalize the coding tree after all material was coded. Three researchers then identified themes in the coded data.

7.2 Results

In general, the user stories reported in our study can be classified into two meta-categories. In four households (P2X, P3X, P8X, P9X), smart speaker usage gradually declined, and the participants hardly ever used the Echo at the end of the study period. In contrast, five households (P1X, P41, P51, P61, P7X) reported using the device steadily throughout the study and developed a relationship to the device. This suggests that the data gathered in the study showcases a spectrum of attitudes towards a smart speaker. The themes, which we identified in the data, often present contrasting attitudes of the participants. In the following, we describe the participants' experiences with the smart speaker in detail through the themes derived from the data, illustrating them with interview quotes. All excerpts were translated from German to English. We begin with the more elementary themes and outline the more complex themes at the end of the results section. An overview about all themes can be found in Table 7.2.

7.2.1 Concerns and Nuisances

This theme describes the negative presuppositions and functionality problems the participants expressed during the study and their feelings about the smart speaker as not being helpful or even annoying for subjects. The relatively high error rate

Theme	Short Description	Example
CONCERNS AND NUISANCES	This theme describes a variety of reasons to not use the smart speaker in the long run.	Being afraid to lose decision-making power in purchasing decisions.
ESTABLISHING HABITS	This theme describes the formation of habits in connection with the smart speaker.	Greeting the smart speaker every morning.
BUILDING RAPPORT	This theme describes contrasting insights into the antropomorphization of the smart speaker.	Feeling less lonely while interacting with the smart speaker.
RELATIONSHIP FORMATION OVER TIME	This theme describes how the relationship with the smart speaker evolved over time and discusses the complexities of the relationship formation in connection with the different social settings of the participants.	Integrating the smart speaker as an additional roommate into a shared flat.

Table 7.2: Overview of the identified themes with explanations and examples.

during daily use was one of the primary reasons for participants deciding against using smart speaker more extensively. Furthermore, our participants feared a violation of their privacy, also about personal data that could be shared with secondary sources, personalized advertisement, and a growing dependence on the smart speaker company that owned their data:

> *"I know, that it is actually stupid when you are doing a lot on the web or when you are active on Facebook [...]. I know, that everything is being tracked anyways, but it may be a kind of psychological component, because you feel screened, because you say to oneself: 'Ok, there is something that is listening permanently'. Because, of*

course, it has to listen to you in order to be responsive [...]. Even though it does not make sense at all, but it is just a feeling." (P41, initial interview)

Participants reported a lack of transparency regarding the use of data by the smart speaker company. Instead, they wished to take control of their personal data. It remained unclear to them what exactly happened with their data. Another aspect of concern was the fear to buy items through voice interaction unintentionally, or other persons taking advantage of their smart speaker account and buy items with just one voice command.

"I would not connect the [Amazon Echo Dot] to my Amazon account. [...] If someone else enters and says "Alexa, buy this and that." [...] However, that's my account. I just do not have any [control] anymore." (P32, mid-term interview)

Some participants were dissatisfied with being the only people in their social group with a smart speaker. They were unable to rely on the opinion and advice of friends and family in using the device. One participant attributed different patterns in smart speaker use to generational issues:

"I just believe that the most people who would buy smart speakers [nowadays] are [non-digital-natives, i.e.,] they haven't grown up with a smartphone, and consider it as strange to talk to [smart speakers]. I believe that in the next ten years [people] who would buy smart speakers have grown up with their mobile phones [and that] will change [a lot]." (P12, final interview)

A different household faced the problem of connecting between the functions within the smart speaker. For instance, when the subjects turned off the power of their smart speaker, they were not able to turn on the room lights. Therefore, they became dependent on their smart speaker to benefit from their other smart home devices.

"Yes, she [Echo] was often turned off. And then, she was turned off again and I wanted to turn on the light, [but that] wasn't working. I

had to connect her [before] I was able to turn the light on. [That] wasn't occurring daily but happened [every] now and then." (P81, final interview)

Also, in order to make full use of a smart speaker, other smart devices or accounts were required which not all of the users had in advance, which limited their spectrum of use.

"In order to be able to use [a smart speaker] appropriately, [I] just need to own a lot of [smart devices such as] smart lights and shutters, that inter-operate with it." (P22, final interview)

7.2.2 Establishing Habits

The second theme describes the ways users establish habits around the smart speaker. In general, users in single households commented more extensively about forming habits around the smart speaker compared to participants in shared households. One participant described how previously formed habits affected her interaction with technology. She reflected that she did not use it for tasks where she was used to using her phone. Instead, she built new routines around the anthropomorphized smart speaker:

"Out of habit, I played music or used the timer of my phone. However, at some point, I established that I'm wishing her a 'Good Morning' every day." (P51, final interview)

In contrast, some participants have been more critical about social interactions with the smart speaker. One participant described a feeling of unease when there was a possibility of being overheard by someone while talking to the smart speaker. He further reflected on the potential impact these human-technology interactions could have on humanity:

P: "Ehm, I feel stupid [when I interact with my Echo]. It goes so far that, when I have the window open, I hope that nobody hears me when I speak with my Echo, because I feel absolutely stupid."

I: "Can you explain why that is?"
P: "No, not really. It just feels like talking to a device is the next level of distancing oneself from humanity." (P61, final interview)

Similarly, another participant also preferred to talk to the smart speaker when nobody could hear the conversation. However, in contrast to the statement above, this was not explained by a critical stance regarding the digitized world. Instead, some participants emphasized that talking to an inanimate artifact made them feel lonely:

"I think that's better than talking to her when no one is around. [...] Because somehow it feels strange. [...] On my own, I feel a little stupid talking with such a device. It makes me feel so alone." (P12, final interview)

Many participants mentioned the conscious decision to adjust interactions with the smart speaker by assessing if it was appropriate at the present moment. One participant described a situation, where the smart speaker was not used in the company of other people not to interrupt their conversation:

"I've often used Alexa to turn the music up or down via voice control. But when I had company, I was more likely to operate her with the buttons, because I talked to the person who was there at the moment. So I'd rather talk to the human than to Alexa and operated her with the buttons." (P71, final interview)

7.2.3 Building Rapport

This theme describes the development of 'an understanding' around smart speakers and subtle differences in the anthropomorphization of such technologies. We identified two subthemes, one where the participants humanized the technology, independently of their functionality and one where the relationship towards the technology seems to be connected to its functionality.

The participants developed ways to manage situations where the smart speaker did not work as expected, humanizing the device. This is reflected in the following statement, where a participant explained that the smart speaker was reprimanded if she did not work as expected:

"[...] so for me, it's like she's not there sometimes, then I just reprimand her [i.e., Alexa] for being active while she's not supposed to." (P82, mid-term interview)

The following statement illustrates the tendency of some participants to anthropomorphize their device, irrespective of if the smart speaker operated as desired, e.g., activating the speaker when not desired. However, two participants decided to solve the problem proactively. They agreed on calling the technology 'Alexa' when talking about *her* and 'Echo' when talking to *her*, in order to make sure that *she* (i.e., the smart speaker) did not misinterpret the communication:

"Oh well, when you talk about Alexa, sometimes she interprets that as if you're talking to her. [...] We compromised by calling her Echo instead." (P11, mid-term interview)

However, some participants had a more practical attitude towards their smart speaker. One participant stated that the name did not make the smart speaker more human and it did not lead to him appreciating the device more:

"My personal relationship with Alexa is pragmatic, not emotional. [...] If the device had a different name, I would call it that. [...] Just because Alexa is called Alexa, it is not human. [...] I know it is a device and nothing more. I haven't developed a personal connection to the device and I would even say that I value my phone ten times more than Alexa." (P41, final interview)

Some participants were unhappy and frustrated about the functionality problems of the smart speaker. One participant reflected that, due to technical issues and because he did not use the smart speaker regularly, no personal relationship to the technology could form. Interestingly, even though the participant was dissatisfied with the smart speaker the propensity to humanize the technology was also showcased here:

"So I think it's like a person you cannot talk to and who upsets you at some point. And you just think 'just be quiet, I do not want to keep talking to you'. [...] We didn't have the slightest personal

relationship [...] because I hardly used it and because it did not always work properly. Then you were annoyed again." (P31, final interview)

Interacting with the smart speaker because using the technology per se was perceived as pleasant was a recurrent topic. Some participants, especially those from single households, felt that the presence and the interactions with a smart speaker made them feel good and less lonely. One participant emphasized how pleasant the voice of the smart speaker was and reflected on how the interactions with her made him feel:

"It's nice not to be so lonely. [...] That's a very pleasant voice. And if someone speaks to you or reads the news to you, it is really... So you are completely alone in an 80-square meter flat, and someone reads the news to you, that has feel-good character. Well, I think that's psychological. It's kind of nice. Apart from that, I don't know. I'm not really a radio listener, but it was great to come to the kitchen and say, 'Alexa play some music', and she just turned on some radio station." (P72, final interview)

7.2.4 Relationship Formation Over Time

This theme describes the intricacies of the social dynamics and the connected relationship formation with the smart speaker over time. The interactions with smart speaker can be situated on a spectrum that ranging from "the speaker" mediating social interactions between different household members to the artifact taking on an active role within the social interactions. The social influence of smart speakers on individual users can be described as more additive, with some participants building new habits around the anthropomorphized speaker, whereas others maintained a pragmatic relationship to it. In addition, our results reveal an interesting difference in smart speaker relationship formation between users with initial privacy concerns and users without initial privacy concerns. Surprisingly, we found that initially cautious participants anthropomorphized the smart speaker, despite their initial attitude. However, our findings also show that, potentially due to the reservations towards the technology, the relationship between users with privacy concerns and the smart speaker remained distant. Hence, we hypothesize that this could be explained by users keeping the smart speaker at a distance since they doubt the technologies' trustworthiness. The statement from P11 showcases this contrast. The participant described the relationship with the smart speaker as impersonal. Simultaneously he compared it to a polite, distant human relationship:

> *"My relationship with Alexa is very loose. We talk, that's it, that's my relationship, nothing personal. Comparable to the relationship to the Asian neighbor, who used to live in the basement. Once I saw him, I exchanged a few words with him, but he had no place in my heart. So, I didn't develop a personal relationship with Alexa." (P11, final interview)*

Further, our results showcase that some participants without initial privacy concerns formed a relationship with the smart speaker and humanized it. For instance, one participant described the smart speaker as "a fourth person in their apartment". Concurrently, they later became reluctant to discuss personal issues "in her presence". This indicates that the emerging relationship with the device can potentially lead to increasing privacy concerns as users begin to perceive the speaker as more human-like and thus a potential threat to privacy:

> *"My relationship with Alexa is comparable to a human relationship, because, at our flat, Alexa is actually a person. [...] She's actually like a fourth person in the flat. [...] Yes, but I wouldn't discuss private information in front of her [i.e., Alexa]." (P32, mid-term interview)*

Some users reported that their attitude towards the smart speaker changed in due course, while others emphasized that more time was needed to build a relationship with the device. The latter is illustrated by the following statement, where the user comments on the connection between the frequency of use, the time of use and the relationship with the smart speaker:

> *"I didn't develop a personal relationship with the Echo. [...] We just had her for a limited period of time and I knew that she would be gone after that. Also, we did not use her that much, so [that] no relationship could develop." (P21, final interview)*

In contrast, other participants emphasized that interacting with the technology did not feel like interacting with an actual human being, even though some functionalities of the smart speaker were assessed very positively. One participant praised the smart speaker's voice and contemplated the reasons he did not build a deeper relationship with her. He reflected that if the smart speaker became more human-like, the smart speaker would turn into a companion, comparable to a pet:

> *"It's not a romantic relationship. I will not miss her when she's gone, even though it was nice. Alexa is not completely human-like yet, but it remains unclear why that is so. Therefore, I think it is difficult to really develop something that can be called a relationship. Like I said [earlier], the voice is super pleasant and very human, but there is no character behind it, the consciousness, something human is missing. That's what the whole world is working on I suppose. [...] Then the feeling of 'I'm happy that she's here' is going to develop. People are buying pets to have company, and that's how it is going to be with smart speakers. For sure." (P72, final interview)*

Furthermore, our data analysis indicates that the social setting influences differences in relationship formation. In multi-person households (e.g., families, shared apartments), the interaction with the smart speaker led to the implicit or explicit formation of rules. In households with similar roles (shared apartment), participants described playful power struggles. In contrast, in households with a more prevalent hierarchy (family), the individual interactions remained playful, whereas the power struggles changed into something more stressful. Therefore, a tense atmosphere developed within some households, intensified because different participants from shared households had differing views regarding whether rules around the smart speaker have been set or not. This is showcased in the following statement from a participant who set usage rules during meals for the children. It happened that the smart speaker was sometimes turned off since the device still responded to requests by the children when they were supposed not to use it. However, the participant's husband stated that they had not established any rules regarding the smart speaker:

> *I: "Your husband told me that you haven't established any rules regarding Alexa?"*

P: ”I have established one rule. Alexa must not be addressed while we’re having lunch and in the morning. Because, in the beginning, the first thing the kids did was, that they came in here and demanded their favorite songs in full volume. Since then, I have set the rule that there is no Alexa during breakfast and lunch. Sometimes this worked, sometimes it didn’t.” (P81, final interview)

7.3 Discussion

The thematic analysis helped us gain an understanding of how smart speakers can be integrated into households. Based on our understanding, we can provide guidelines on how the design of smart speakers should be designed to fit better to the users’ routines (RQ6).

Support existing and new routines Our findings indicate that smart speakers should support routines and not necessarily simply offer functionality. For instance, one participant recounted that she was wishing the smart speaker ‘Good Morning’ every day. Since wishing the smart speaker a good morning does not seem to serve a purpose or lead to an apparent benefit, such interactions with the smart speaker are currently not supported in the interaction process. The smart speaker is not going to say ‘Good Morning’ when not greeted and the smart speaker is also not going to address the fact that she forgot to wish her a good morning. Supporting such interactions might lead to more positive interactions and, consequently, deeper engagement.

Further, we observed that the introduction of a smart speaker to a household prompted experimentation and altering the home’s digital landscape. As we observed in the CONCERNS AND NUISANCES and BUILDING RAPPORT themes, users creatively adapted their homes and their smart speaker features to match their daily routines and preferences. Future smart speakers can explore this opportunity and further empower users to make creative use of the digital home infrastructure’s resources. Through this, smart speakers may become the mediator technology that lets users become *bricoleurs* [58] in their homes.

Furthermore, many appliances available in the users' homes support functionalities similar to those provided by smart speakers. In the ESTABLISHING HABITS theme, we observed that users were already accomplishing specific tasks using their existing home appliances and established routines for them, e.g., setting the alarm in the evening before going to bed. While it is easy for users to integrate a smart speaker into new practices, it is time-consuming to modify existing routines in order to integrate a smart speaker in the process. This is also a reason why users abandon smart speakers and continue using other appliances such as their traditional alarm clocks. Therefore, smart speakers could specifically inform the user how using the smart speaker instead of other appliances can make the process to accomplish a particular task more efficient. For instance, setting up a routine to inform the users in the morning about the weather conditions while they are preparing for the new day in the bathroom is much more time-efficient than checking the weather conditions manually on the phone.

Reflect the social landscape Our results indicate that smart home appliances could benefit from explicitly supporting social interaction through audience-aware behaviors. Smart home appliances could detect the social situation, for instance, if there is a communication going on or if there are people present in the home, who are not members of the household and adjust the amount of interaction accordingly. Our results confirm that the social context often determines interaction with a digital assistant [120], even at home. This is in line with findings from Benlian et al. [15]. They showed that unintentional voice activation of smart speakers led to interpersonal conflicts. They conducted an experimental vignette study and an additional cross-sectional study. Their participants already had experience with smart speakers. In contrast, we conducted a longitudinal in the wild study with novel users (i.e., without prior experience with smart speakers), as recommended by Benlian et al. [15].

Moreover, our results show that a context of use where multiple people are around the device might lead to issues that affect the group. For instance, if multiple users want to issue commands simultaneously, this can potentially lead to a power struggle, which can have a negative impact on the group dynamics and affect the user experience with the smart speaker negatively. Hence, designers of smart home appliances need to consider the social implications of integrating technology into existing social dynamics or limit interaction based on social usage rules. This shows that contextual sensing for smart home appliances such as smart speakers should go beyond location (as proposed by Sciuto et al. [169]) and also include sensing the current composition of the group around the device, much like in the case of tabletops [102].

Furthermore, we observed that current smart speakers fail to follow the organizational structures within a home and respect the users' current context as we observed in the ESTABLISHING HABITS and BUILDING RAPPORT themes. This is related to the relationship between technology usage and space ownership that was addressed by Edwards and Grinter [52] (i.e., how different inhabitants of a home can watch their own programs on the TV). Smart speakers need to take established social conventions between the different inhabitants into account in order to avoid an occurring loss of autonomy, e.g., a loss of autonomy between parents and their children. The opportunity to establish explicit rules [39] (i.e., no device usage by the children during meals or allowing specific actions only for defined users) might help to keep the user in control [172], and therefore, dissolve some of the concerns that we identified (e.g., someone else adds items into a user's shopping cart) and support the social conventions within a home at the same time.

Consider the existing smart home infrastructure Through our analysis, we identified various factors that determine why smart speakers are abandoned by new users of smart speakers after initial testing and novelty periods, such as privacy concerns, no added value, and functionality issues. These findings are partly in line with previous work (e.g. [106, 120, 177]).

Usually, smart home appliances such as smart speakers are introduced in a home environment populated with various other appliances. Thus, users need to integrate their smart home appliances into their existing home ecologies or smart home infrastructures. While it is easy to create a smart home around a specific smart home appliance such as a smart speaker that can be used to control appliances by extending the infrastructure, it is much more difficult to integrate a smart home appliances such as a smart speaker in existing ecologies as not all existing appliances in the home might be compatible to the introduced smart home appliance. Also, if users do not own other smart home appliances, e.g., smart lighting, or do not have access to third services, e.g., a streaming subscription, these circumstances restrict which functions of the smart speaker's users can use as we observed in the CONCERNS AND NUISANCES theme.

Hence, the benefit of smart speakers is limited since they are only immediately effective in a rare and precise structural set-up. This confirms the results by Sciuto et al. [169] who analyzed history logs of smart speaker users and found that their users bought additional smart home appliances that are compatible with their smart speaker system to be able to use more of the functionality spectrum of their smart speakers. Further, this echoes the results by Tolmie et al. [179] that designers of future systems such as smart speakers need to take also existing devices in domestic environments into account, e.g., by enabling the support of more home appliances.

Consider ludic interactions Another way forward is to explore to successfully implement ludic elements [68] in the design of smart speakers. As shown in our results (cf. ESTABLISHING HABITS), users interact with the smart speaker in ludic ways. Gaver remarked that ludic design should de-emphasize the pursuit of external goals and maintain openness and ambiguity while promoting curiosity, exploration, and reflection. Consequently, the ludic design emphasizes playful exploration. The question remains if it is possible to implement ludic elements in the design of such technologies successfully. At first glance, the rationale of ludic design to offer multiple meanings [171] contradicts the rationale of the focused and task-oriented processes the smart home appliances such as smart speakers should offer. Offering the user multiple ways to perform a specific task and playful, ludic interactions and consequently exploring how this might affect user engagement emerges as a challenge for future work. Consequently, our work suggests that future designs for smart speakers should offer indirect, ornamental ways to achieve common tasks or even expand the range of non-functional features.

Limitations

Our study is prone to certain limitations. First, this study investigates a sample of novel users who received a smart speaker. Hence, our sample might be biased. Second, some of the participants would probably not buy a smart speaker themselves which could have influenced the lack of social bond that leads to the abandonment of the smart speaker. While we do believe that this is a limitation of this study, it also offers an opportunity, since previous studies mainly focused on power-users, enthusiasts, and users who already owned a smart speaker for a certain period. In contrast, we focused on novel users, comparable to users who received a smart speaker as a present.

Another limitation is the study duration. Since we specifically focus on the integration and potential (non-)use of smart speakers, a longer study period potentially could have led to further insights into this process's intricacies. Even though our findings indicate that the time frame of our study was long enough to account for the declining novelty effect, future work should investigate potential critical factors for long-term engagement with the technology.

Furthermore, even though we are convinced that our conscious decision to conduct a qualitative inquiry with individual interviews, a different methodological approach (e.g., collecting quantitative measures or group sessions) potentially would have led to different results. Hence, one challenge that emerges for future research is the exploration of our findings through, for instance, a longer inquiry that combines quantitative methods with a qualitative inquiry.

Finally, in our study, we asked the participants to place the smart speaker at a shared location in their homes to ensure that all inhabitants had access to the deployed smart speaker. This is decision could have influenced how the speaker was used by the participants, especially with others present in the household [120]. However, current statistics to the placement of smart speakers show that smart speakers are mainly placed in the living room or the kitchen[1]. These locations were also favored by our participants.

[1] techcrunch.com, mycroft.ai/blog

8

Conclusion

With the integration of smart home appliances our living environments are significantly changing. Soon, smart home appliances will be connected to each other or can be monitored by their users but they will also need to inform their users about everyday home information. For example, a robot vacuum cleaner will need to inform the users when the dust bag needs to be changed or a smart fridge could inform the users when they are running out of specific groceries. Previous work already investigated the acceptance of smart home notifications to inform the users about everyday information in a smart home [186, 187]. However, research has not investigated yet how these kinds of everyday information should be conveyed to the users. Furthermore, it is important that research also considers the number of mobile notifications that users already receive today on their personal devices to avoid further amplifying the negative effects of notifications.

This thesis examines how future smart home appliances presenting everyday home information to their users should be designed. This thesis starts with a description of the motivation and the human-centered design approach that guided the presented work and a review of the related work regarding the research strands designing for the home smart home, conversational agents, ambient information systems and mobile notifications. Further, we reported in Chapter 3 the comparison of five methods (i.e., an online survey, a study using VR, a study using AR, a lab study and an in-situ study) to evaluate early prototypes of smart home appliances presenting everyday information. This comparison was conducted to understand the unique advantages and disadvantages of the different evaluation methods to be able to choose the right method for the specific goals and requirements for the studies that were conducted during this thesis. In Chapter 4, we conducted two studies to explore the design space of smart home notifications. This enabled us to identify possible suitable modalities and locations for displaying everyday information in a smart home and to gain an understanding about the relation between the urgency of the information and the suitability of a location to display the respective information. With the studies reported in Chapter 5, we developed and evaluated a smart plant system that informs the users about the current state of a plant. This study enabled us to collect feedback with a high external validity about how non-urgent information with a low information capacity could be displayed by using smart home notifications. In Chapter 6, we investigated how sensitive information with a high information capacity could be displayed in smart homes. Further, we investigated how smart home appliances representing such information should be designed to fit their users' complex routines in their daily lives. Hereby, we used a calendar application as a research probe since calendars are usually used for organizing the users' daily schedules and reminders. Further, former work found that displaying calendar data in the environment is accepted under specific constraints [110]. In Chapter 7, we observed how novel users integrate smart speakers into their daily lives and how the design of smart speakers could be improved to fit better to the users' routines.

In the following, we will describe our research contributions and answer the research questions that were investigated in this thesis.

8.1 Summary of Research Contributions

We contributed to the following three areas: (i) understanding the effects of the evaluation method on the results (ii) how smart home appliances should be designed that make the users proactively aware of non-urgent everyday information and (iii) how smart home appliances that display home information that users can check manually should be designed to fit the users' complex routines.

In Chapter 3, we contributed a comparison of five evaluation methods for studying smart home appliances. Our results show that empirical methods can significantly affect the outcome of user studies. This implies that results from studies using different empirical methods might not be comparable. In Chapter 4, we conducted a first exploration of the design space of smart home notifications by conducting two studies. This contributes to an understanding of the relation between the urgency of the information that should be displayed and the used modality and location for the representation of the information in the home. In Chapter 5, we investigated non-urgent smart home notifications by studying a smart plant system as a research probe. Here, we contribute a systematical analysis of different strategies to present non-urgent smart home notifications. In Chapter 6, we investigated two calendar applications as research probes for smart home appliances that users could check manually to get information about their daily schedules. We understand how it should be designed to fit the users' routines by providing an overview of relevant information and offering fine-grained controls for the users. In Chapter 7, we contributed a four-week in-situ study that observes how novel users integrate smart speakers. Further, we derive implications to improve the design of future smart speakers. In the following, we answer the research questions that were investigated in this thesis:

Understanding evaluation methods regarding smart home appliances

RQ1: *What are suitable evaluation methods to study smart home appliances informing the users about everyday information?* In Chapter 3, we observed that an evaluation method can significantly affect the study's results. We found that especially studies that use VR or AR for the presentation of the prototypes are prone to be influenced by novelty effects since participants might not distinguish between the studied artifact and the used technology for its presentation. Therefore, there is no best method that can be used for the evaluation of early prototypes for smart home appliances presenting everyday home information. Therefore, we suggest to use established evaluation methods (i.e., online surveys, lab and in-situ studies) that fit the specific research questions and goals of an inquiry. However, researchers could keep in mind that the results of their inquiry might be misleading and, therefore, follow-up investigations should be conducted.

RQ2: *What are advantages and disadvantages of different methods for the evaluation of smart home appliances?* Researchers as well as practitioners investigating future smart home appliances should be aware of the advantages and disadvantages of the different evaluation methods that could be applied. Online surveys offer the opportunity to investigate their objectives with a broad range of participants in a cheap and time-efficient manner [44]. However, participants in online surveys are less engaged in studies with a researcher present as we observed in Chapter 3. Using novel technologies such as AR or VR enables researchers to rapidly prototype future smart home appliances [151]. However, we observed in Chapter 3 that the results were influenced by a novelty affect as our participants could not distinguish between the studied artifacts and the used technology for their representation. Using lab studies enables researchers to study their objectives in a controlled setting and therefore, the results have a high internal validity [48]. However, comparisons between lab and in-situ studies revealed that especially usability issues related the natural environment might not be identified in lab studies. Further, we observed in Chapter 3 additional differences regarding the perceived user experience of smart home appliances since the physical prototypes in the lab condition were experienced as neutral, while the same prototypes in the in-situ condition were perceived as desired. Long-term in-situ studies enable researchers to study their prototypes in their natural environment [48, 157] and to capture the context of use [158] as well as to gain an understanding of the artifact's user experience [24, 157]. The drawbacks of in-situ studies are the higher costs for conducting the studies [48]. Further, the researcher cannot control the user-activity nor the environment where the study takes place [48].

Making users proactively aware of everyday home information

RQ3: *Which modalities are suitable to inform users about everyday information in the era of the smart home?* Designers of smart home appliances should prefer using visual cues for the presentation of everyday home information. However, it is important that the used visual cue fits to the information density of the presented information. While using ambient lights enables the designers to display the everyday information unobtrusively in the background, e.g., to inform the users about state changes, using ambient light is inappropriate to display more complex information, e.g., details about upcoming events. In contrast, auditory cues should only be used for conveying urgent information as we observed in Chapter 4 since these cues are too obtrusive for everyday use [56]. Further, auditory output spoken by smart speakers can be experienced as too monotone and were associated with a cognitive effort to grasp the information as we observed in Chapter 6.

RQ4: *Which locations are suitable to display everyday information in a smart home?* Designers of smart home appliances that need to inform their users about everyday home information need to consider notification blindness. We observed in the long-term deployment of our smart plant system in Chapter 5 that our participants overlooked persistent notifications on their smartphones. They got used to notifications being displayed in the notification drawer of their smartphones and did not read the text anymore; This shows that users already started to become notification blind on their personal devices which is related to the display blindness for public displays [124]. Consequently, developers should consider displaying notifications in the smart home environment by displaying the information directly on the smart home appliances, e.g., using ambient lighting. However, a smart home notification system should also take the location of the smart home device into account. Designers of smart home appliances have on the one hand to consider the kind of information that should be displayed since sensitive data should only be displayed in shared environments in the home under specific constraints [110]. On the other hand designers have to take into account that while on-object notifications might be useful for a smart home appliance placed in the kitchen, on-smartphone notifications or a central smart home display might be more appropriate for a smart home appliance located in the basement.

RQ5: *Should smart home information be persistently displayed to the users or should they be made aware based on specific events?* Smart home appliances should keep the number of used smart home notifications low to make the users aware of everyday home information proactively. Therefore, the users should only be informed when their attention is necessary. While the data collected through sensors in a smart home is typically continuous, designers should consider discretizing the information into a small number of events as we observed in Chapter 5. Thus, smart home devices would notify the users only if this is necessary, e.g., when the users have to perform a certain action (i.e., watering the plant or descaling the coffee machine) and attention of the user is only required in certain moments. Additionally, developers should consider collecting similar information during the day but only convey the information at the right moment to the user to further reduce the number of notifications, e.g., a smart fridge could collect information about the stock during the day inform the users when they will leave the house to go for grocery shopping in the afternoon. Since we observed in Chapter 5 that participants were afraid to miss a notification or a malfunctioning system resulting in a dying plant, smart home appliances should display the current state of the system (e.g., using a small LED indicator showing the device's state as traditional home appliances do and to provide opportunities for the user to check the current state on demand similar to the Visual Information-Seeking Mantra [173]. An app on the smartphone could provide additional information regarding the smart home appliance that the users could access on-demand.

User-initiated interaction with smart home appliances presenting everyday information

RQ6: *How should smart home appliances be designed to fit into the users' routines?* Designers of smart home appliances need an understanding about the routines in the home [52]. We observed in Chapters 6 and 7 that designers need to consider the existing infrastructure in the users' home environments. On the one hand, users might want to continue the usage of their existing personal devices (see Chapter 6), However, as we observed in Chapter 7 similar to Tolmie et al. [179], it is difficult to integrate a new smart home appliance in an already existing ecology. Not all existing appliances might be compatible with the new smart home appliance. Therefore, designers should also take into account the support of other smart home appliances [179]. In addition, while it is easy to adopt routines for newly introduced practices by using the new introduced smart home appliance, it is time-consuming to adapt existing routines to use the new smart home appliance. Further, designers of smart home appliances need to consider also the social dynamics within a home. As a result of this, the smart home appliance could support setting to enable specific functionalities only for specific users or user groups, e.g., using rules to enable children's interactions only at specific times or to display everyday home information only to specific users such as the person who is responsible for the specific home task. Finally, designers of smart home appliances need to consider the different preferences of their users as we observed in Chapter 6. Therefore, smart home appliances should provide fine-grained controls for the users to configure how the information should be displayed and provide a default configuration for the respective smart home appliance [191]. A smart home appliance should allow users to prioritize specific kinds of information that they consider important. Further, designers should take into account to develop a learning system that adapts its behavior based on previous interactions (i.e., similar to the work of Mehrotra et al. [115]), e.g., how or when they responded to the displayed information to improve the representation of the information over time.

8.2 Future Work

In this thesis, we focused on the design of individual smart home appliances presenting everyday home information to their users in a smart home context. During our inquiry, we identified new challenges beyond the scope of this thesis. In the following, we list directions for future research.

Understanding Effects on the Results of an Investigating Caused by Different Evaluation Methods In this thesis, we showed that applying different evaluation methods to investigate the same research probes and using the same questionnaires can lead to significantly different results. Therefore, future work could further investigate the differences in the results that might be caused by applying different evaluation methods, e.g., to investigate how researchers could compare results from studies that applied different evaluation methods. In addition, a recent study in the visualization community that replicated our study found that there was no significant effect regarding their investigated visualizations supporting Do It Yourself (DIY) tasks in the home [219]. However, they also observed that users might not be able to differentiate between the used technology and the investigated research probe. Therefore, future work could also investigate the difference between both studies, e.g., by conducting follow-up studies. This effect could be caused by the investigated research probe and its use-case and its possibility to excite users. Research probes such as smart home appliances supporting everyday tasks could cause a more emotional connection resulting in a higher user experience than tools supporting DIY tasks such as a visualization supporting a drilling task rarely conducted in the home. Another possible relevant factor that could be investigated by future work is the influence of the complexity of an investigated task and; therefore; the concentration the user needs to accomplish the task.

Perception of Different Locations Displaying Everyday Information in a Smart Home In this thesis, we investigated how smart home appliances displaying everyday home information could be designed. However, we have not investigated differences in the perception of the information when this information is displayed at different suitable locations in the home. By understanding the differences in the perception of such information displayed at different locations, the smart home appliance could also judge the importance and urgency of the information and choose the output locations accordingly. Similarly to the work of Warnock et al. [206], who investigated differences in the perception of notifications that are delivered with different cues, future work could analyze differences in the perception of different locations in the home that present everyday information.

Investigating Home Information Management Systems Supporting Multiple Kinds of Everyday Home Information In this thesis, we investigated only how individual smart home appliances can display everyday information to their users. Therefore, future work should also investigate how a home information management system could coordinate and prioritize everyday home information from multiple smart home appliances not to overload the attention of the inhabitants since as Czerwinski et al. [43] envisioned that devices in smart environments would compete for the users' attention. Implementing an information management system for everyday home information based on the observations in this thesis and evaluating this system in a long-term in-situ study to collect results with a high external validity.

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Table of Definitions

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List of Acronyms

ANOVA	analysis of variance
AR	augmented reality
ARI	augmented reality immersion
ART	Aligned Rank Transform
BMBF	Federal Ministry for Education and Research in Germany
Caloo	Calendar of Opportunities
DAAN	Designing adaptive and ambient notifications
DIY	Do It Yourself
HCI	human-computer interaction
HQ-I	Hedonic Quality Identity
HQ-S	Hedonic Quality Simulation
IV	independent variable
LCD	Liquid Crystal Display
LSR	Location Suitability Ratings
MANOVA	multivariate analysis of variance
RQ	research question
RSS	Rich Site Summary
SCP	Smart Calendar Platform
SimTech	Cluster of Excellence in Simulation Technology
SUS	system usability scale

TCT	task completion time
TOCHI	ACM Transactions on Computer-Human Interaction
VR	virtual reality