The Catch(es) with Smart Home – Experiences of a Living Lab Field Study

Timo Jakobi[1,2], Corinna Ogonowski[2], Nico Castelli[1,2], Gunnar Stevens[1,2], Volker Wulf[2,3]
[1]Bonn-Rhein-Sieg University of Applied Science, Sankt Augustin, Germany
[2] University of Siegen, Siegen Germany
[3]Fraunhofer Institute for Applied Information Technology, Sankt Augustin, Germany

ABSTRACT
Smart home systems are becoming an integral feature of the emerging home IT market. Under this general term, products mainly address issues of security, energy savings and comfort. Comprehensive systems that cover several use cases are typically operated and managed via a unified dashboard. Unfortunately, research targeting user experience (UX) design for smart home interaction that spans several use cases or covering the entire system is scarce. Furthermore, existing comprehensive and user-centered long-term studies on challenges and needs throughout phases of information collection, installation and operation of smart home systems are technologically outdated. Our 18-month Living Lab study covering 14 households equipped with smart home technology provides insights on how to design for improving smart home appropriation. This includes a stronger sensibility for household practices during setup and configuration, flexible visualizations for evolving demands and an extension of smart home beyond the location.

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User Experience, Smart Home, Living Lab, Design, Qualitative Study

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H.5.2 [Information interfaces and presentation (e.g., HCI)]: User Interfaces --- User Centered Design; H.5.m Miscellaneous

INTRODUCTION AND BACKGROUND
The smart home seems to be the exemplar *par excellence* of possibilities inherent in the Internet of Things. Currently, both established companies such as Apple, Samsung and Google, and newcomers are positioning their own smart home products in the market. The idea of the smart home is not new and several researchers have already investigated challenges of making homes smart from a feasibility [34,45] and user interaction [22] point of view and highlight the substantial 'work to make a network work' [27] for users. However, in recent years, advancing technology (i.e. the introduction of mobile and ubiquitous computing devices paired with low-power wireless communication protocols) has massively changed the way smart homes can be, and are, equipped and interacted with. For example, Harper's study [28], which dates back more than ten years, took place at a time when wireless affordances were not available, and where interconnected devices were rare.

This evolution has sparked more recent 'in the wild' smart home research that focusses on identifying challenges which smart home users face [10,41]. Mennicken et al. [44] provide an overview of the literature and conduct an interview study with 22 participants, concerning themselves in the main with the relationship between user concerns and those of system builders. What we need, according to Mennicken et al. [42] is to '…stimulate both actionable insights and design artifacts that better capture the evolutionary nature of users and their home contexts'. Some challenges for users, then, are identified, though perhaps not in any great contextual detail. There remains, that is, something of a research gap. We aim, then, to report on the appropriation processes associated with smart home technology, covering the whole customer journey of system setup, installation and configuration, use, reconfiguration and extension, as a first step.

We therefore ask: how do smart home systems perform under real-life conditions? What are current challenges for successfully embedding the smart home into households' everyday practices, both from the system's and the users' perspective? While these questions have been raised in a user-centered manner, so far, there has been no recent long-term study on the smart home, one which actually accompanies households in their struggle to make their homes smart for a longer period of time.

The remainder of the paper is structured as follows. We first further motivate our research question by outlining related work and the current smart home product landscape. Subsequently, the methods and the smart home research artefact are introduced. The results from a case study with 14 households based on qualitative data from interviews, workshops, regulars' table meetings and mobile feedback application input collected in the past 18 months are then presented. Finally, we discuss design guidelines to help

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non-expert users to be able to manage their smart home adequately. Based on our findings, we suggest three main strategies: (a) To further hide technological detail in systems and instead make systems visible in a way that reflects how users construct their demands to make installation and configuration more user-friendly. (b) To acknowledge the individuality of users' information demands and provide flexible visualization solutions for evolving needs. (c) To support flexibility for extending smart homes beyond the home as a place.

RELATED WORK

Researching the smart home has a long, if slightly technology-driven, history. Several commercial and research-driven projects have explored various use cases and the potential of technologies for smart homes [28,31,34,37,45] from a feasibility point of view. In the following, we introduce design-oriented research for the home. Thus, we outline the concept of appropriation for informing smart home design and point towards a lack of long-term appropriation studies of technology in this context.

Informing Smart Home Interface Design

Studies relating to technology design for the home deal with a large number of different issues. For instance, in recent years, smart energy systems have received attention in research [2,62], with a lively community studying smart metering, and with considerable efforts also focussing on privacy [13,49]. In Sustainable Interaction Design [7], much research has focused on how to design energy monitoring systems from a user perspective [3,26,50]. It typically aims at making the consumption of the abstract resource "energy" – mostly electricity – visible and understandable as feedback to the consumer. Those working on Ambient Assisted Living technologies (AAL) [15] are very active in supporting comfortable and independent living for older people [18,30,39]. Amiribesheli et al. [4], for example, present a literature review for AAL and conclude with general design guidelines, supposedly also applicable when designing smart home technology. The role of security for the home has also been researched, e.g. within the field of access control [54] Ur et al. [59], for example, have shown that many smart home systems feature their own login system, thus fragmenting user flow and hindering a positive UX. Yet another issue identified is that of designing eco-feedback. For example, Froelich et al. stress, 'it is critical for the HCI community to step back and define an approach and theoretical foundation for the design and evaluation of eco-feedback technology' [26]. Strengers [55] also critiques the models underpinning eco-feedback systems and argues for an approach embedded in daily life. Such positions, as we argue below, have wider ramifications. Other studies focus on single aspects of a smart home, such as automation [14], activity recognition [56], privacy implications [16,36,58] or certain parts of smart home user interfaces, such as the use of calendars [43].

Smart home systems, however, promise to include a multitude of uses, including but not limited to the ones outlined above. For these complex systems, user-centered research deals, at least to some extent, with challenges posed, drawn from interviews with experts or people living with a smart home. For example, Brush et al. [10] have investigated the user acceptance factors of home automation technology. They identify high costs, inflexibility, bad usability and security issues as the most important barriers to the success of smart home platform systems. Similarly, Mennicken have found barriers to succesful smart home integration, identifying a better support for routines as one central aspect [44].

Understanding the User: Designing for Appropriation

A more comprehensive view on the use of technology can be developed by researching its appropriation in everyday life. This process is understood to include not only interaction with technology itself but also collecting information about it, envisioning possible use cases and developing an overall attitude towards it [11]. Generally, designing for appropriation means taking into account that users will make use of technology in unanticipated or even unintended ways in their everyday life. Design of technology thus should support flexibility in terms of adaptability to different environments, evolving (user) needs and environment as well as ownership [19]. In this vein, Carroll et al. [11,12] have investigated what younger people do with technology, especially mobile phones. Stevens et al. [53] suggest ways of designing for individualized use of software engineering tools. Similarly, Dourish [21] outlines guidelines for supporting appropriation of document management systems in terms of important features to be included within a solution.

When aiming at reducing barriers to the appropriation of smart home platform systems, it likewise stands to reason that a broader view on a product's lifecycle, ranging from the system setup phase, over installation and routinization to reconfiguration can be beneficial. Such an comprehensive approach calls for long-term in-situ investigation into how users ascribe meaning to smart home technology and how this technology evolves in association with social practice and vice versa [52].

However, our inquiries reveal no recent long-term studies, investigating different phases of smart home interaction. As a notable exception, and as mentioned, Harper and colleagues [28] specifically researched the home from the users' perspective, looking closely at the appropriation of technology in the social space of the home. One chapter [48] specifically focuses on what it is like to live with and in a smart home, outlining design guidelines and possible futures. In contrast to most other research, the people in that research actually lived in a smart home, thus entailing a longer term approach to technology appropriation. However, as we have pointed out, the setup had limitations. Participants were not actually living in their own homes and technology at that point did not encompass cloud systems, smartphones, or new low-power wireless protocols, which allow battery-powered sensors and actors to become independent of wall sockets and thus to be installed more flexibly in unelectrified areas of the home. Therefore, more than ten years after Harper's study, it seems reasonable to revisit the appropriation of smart home technology.

BACKGROUND ON SMART HOME SYSTEMS

In principle, smart home systems have existed ever since computers found their way into the home during the 1980s. At that time, hobbyists put huge effort into wiring up their homes. Such "wired homes" [28] were highly customized and characterized more as individual solutions rather than ones with the quality and scalability of a commercial product. Recent advances in low-power wireless communication protocols as well as miniaturization and decreasing costs of hardware have turned smart homes into a main stream and lifestyle product, and they are considered as soon becoming the next digitalized part of daily-life. Currently, in addition to established home automation solution providers, many other IT companies, illumination manufacturers, telcos or even power supply companies are positioning their own smart home products, not to mention start-ups' attempts at gaining a market share.

Under the general term smart home, products vary greatly in terms of the technology used and the use cases covered. For our purpose, we distinguish between smart home systems along two dimensions, similar to Brush et al. [10]. First, there are products that only serve a single use case, such as smart thermostats, and second, platform solutions spanning across use cases and allowing greater flexibility. The latter systems either call for expert installation or are do-it-yourself solutions based on the principles of plug and play.

Single Product vs. Platform Systems

While there are no limits to the heterogeneity of hardware offered for the smart home, components can generally be categorized by use cases supported. Here, four trends can be identified. (1) Systems for supporting comfort, such as by sensing temperature, daytime or brightness and automating shutters, light, and air conditioning, entertainment and related appliances. (2) Increasing security in the home by installing internet-linked or networked cameras, motion detection, sirens, remote control of lights for simulating presence and control as well as alarm notifications via text messages or push notifications on mobile devices. (3) Monitoring and saving energy by avoiding standby consumption, automated switching off of devices and appliance-based measurement of energy consumption as well as visualization of consumption. Here, generally, smart plugs are used, placed between the device's plug and the power outlet. (4) , enabling more sustainable self-determined living through AAL technologies.

While smart home products may consist of only one sensor, platform providers, offering a set of hardware and software, are becoming more popular. These systems typically feature a hardware gateway and address more than one of the aforementioned main use cases with their set of sensors and actors. The multitude of protocols and vendors, however, make the current market highly fragmented. Interoperability between the devices of different vendors is rarely supported even when they use the same protocol. Some systems, however, have a whitelist of products using the same protocol; others allow for extending their system with dongles to enable other protocols to be used.

Smart home systems have three main ways of interacting with and controlling the system. First of all, many systems enable basic interactions via the hardware interfaces of their sensors and actors. For example, simple on-/off switches are provided. Moreover, there are switches dedicated to triggering predefined actions on other actors. More sophisticated controls are sometimes provided by dedicated displays. In most cases, however, smart home platform vendors provide controlling and monitoring mechanisms via mobile or desktop applications. Here, dashboard-styled control dominates, allowing direct manipulation of sensors and actors. Furthermore, these interfaces typically support (1) gaining an overview of the current and past state of the home (2) managing existing and adding new devices, and (3) managing automation rules and groupings.

Expert Installation vs. Plug and Play

For a long time, smart home systems required wired connections between control panels and sensors or actors. Installing and configuring such systems is often accomplished by professionals, and users without expert knowledge can only perform basic configurational settings. Wired connections for the smart home have several benefits. Typically, flush-mounted, they are well integrated into the home and can be almost invisible. Additionally, wired connections guarantee a good connection to control and monitoring stations. On the other hand, using wired connection makes "smartness" very inflexible in relation to evolving demands. Additionally, including a wired smart home into a building – be it new or retro-fitted – requires complex planning and significant investment.

More recent products in the smart home rely on low power wireless communication protocols. Emphasizing their plug and play character, these systems are surface-mounted and battery-powered and thus can be positioned in remote sites within the home. This way, such systems are more flexible in terms of being adaptable for users. They are less cost intensive than wired systems and easier to integrate into existing home infrastructures. However, the burden at present is on the user to setup and manage rules and configurations.

SETTING UP THE SMART HOME LIVING LAB

Against the backdrop of quickly evolving technology, we believe it is appropriate to investigate the appropriation of smart home technologies in everyday life. Following Stevens et al. [53] and Wulf et al. [61], we seek to inform the design of smart home systems through understanding user behaviours throughout the process, thus informing UX design in future smart home products.

The work described in this paper was conducted as part of a 3-year research project focusing on the development of new concepts and strategies for smart home systems with a specific focus on UX. We applied a Living Lab approach [23,25,46] to address the complexity and situatedness of these systems over different stages, namely (1) system setup (2) installation and configuration, (3) use and embedding into practice and (4) extension and reconfiguration in real life environments. Living Labs allow different stakeholders from research and design to be brought together with users and technology in an open-ended design process in real life environments [25] as far as possible, given that they are predicated on the introduction of new technology into the environment in question, Living Labs are intended to be 'naturalistic'. Such frameworks are specifically suited to supporting long-term cooperation, co-design and collaborative exploration among researchers, users and other stakeholders. Involving users in the design process from the very beginning in sensing, prototyping, validating and refining complex solutions in multiple and evolving real life contexts allows a continuous formative evaluation of the designed artefacts and uncovers appropriation phenomena at early stages in the technology life cycle [6]. The advantages of the Living Lab approach lie in its flexibility, allowing for creative spaces for discussions on new concepts, long-term observational studies and, where necessary, lab-based interventions, designed to assess the long-term appropriation of new IT-artefacts [46].

Recruitment and User Sample

We recruited our user sample through a four-staged selection process. From November 2014 to January 2015 (see Fig. 1), we placed information about the study in the local press and via radio stations. We did not offer any compensation for participation. The only incentive we provided was the free provision of a smart home system used as the central research artefact and active participation in the project. Via an online platform, interested people had to provide basic information concerning their households' technical infrastructure, motivation for participation and expectations of the project. At this stage, more than 100 households applied to participate in the project.

Second, we checked all applications in terms of accuracy of fit for our project's demands. We decided to only include households within the postcode of the city of Siegen, Germany. This restriction allowed us to get in touch with them easily, e.g. for home visits, interviews and roundtables. As technological requirements, we defined two more criteria, which we believe are not critical but are worth mentioning. First, only households with a reliable internet connection with at least 2 kbit/s download according to the carrier contract were included. Second, due to budget constraints, only households in possession of at least one smartphone could participate, so households could be provided with tablets.

In a third stage, telephone interviews with each of the remaining 63 households were conducted to gather an impression of the motivation for participation, willingness to actively participate in the project and technical- and smart home-related foreknowledge. Additionally, these interviews served to get to know participants' self-reflectiveness, articulateness and understanding of the character of soft- and hardware prototypes compared to products.

Finally, we characterized all households and chose a sample, varying in terms of age, sex, household size, rented or owned home, house or flat, rural or urban residential area and tech-savvyness as well as educational level. Finally, 14 households with 23 participants were selected. The sample consists of two single-person households, five multi-person households without children and five multi-person households with children. Four households lived in flats, while ten were owner occupied. Participants were aged between 27 and 61 years. Motivation varied, ranging through dissatisfaction with existing smart home systems, technological interest, to curiosity about being part of a research endeavor. Based on this qualitative user sample, we started the longitudinal Living Lab study.

Study Design and Data Collection

In March 2015, we first conducted a kick-off event to brief households regarding our overall research agenda. This was the first opportunity for households to get to know each other. Following this event, we set up an exploratory on-site study with a semi-structured interview guideline. We mainly aimed at a better understanding of the participants' homes, their daily routines and habits as well as their ideas for using a smart home. We also used the initial interviews to get to know each other and to establish trusting relationships. At this point, we also distributed wish-lists for smart home equipment. Households were allowed to pick any combination of available sensors and actors. To avoid a mental overload and to help participants to start thinking 'small', we suggested equipping only one room at the beginning and decided to set a maximum of ten hardware components. However, some households were allowed to order more than ten components if they were able to explain which use cases and scenarios they wanted to realize and what they wanted to achieve with them.

Based on these wish-lists, we provided an out-of-the-box plug and play smart home platform system released on the German market in May 2015 to the households. The installation and configuration process was either observed and video-recorded by researchers on-site (seven households) or self-reported by participants (seven households). To subsequently collect experiences in-situ and maintain a close relationship to households, a mobile feedback application was provided and integrated into the companion app of the smart home system. An informal regulars' table and an instant messenger group were initiated and maintained to foster exchange of experiences, ideas, problems and their solutions between users and researchers. More formal communication about invitations to design workshops, technical announcements or updates about the project`s progression was carried out via email by a university staff member who was responsible as central contact person for participating households and was a communication node between all project members. After this initial setup phase, households used their smart home over 15 months and participated in four design workshops focusing on information collection and interface design for new smart home concepts.

As a first evaluative intervention, in September 2015, after three months of use, we conducted a second interview study gathering experiences, demands and limitations when using the system. We focused on ways of appropriating the system into everyday life and reflections on the installation and usage routines in terms of usability und UX problems. We also asked for examples of best practice and implemented use cases. In August 2016, after 15 months of use, a third interview study was conducted where we asked again for best practices and desired or implemented use cases but also for changes in system configuration based on changed user needs or seasonal influences or based on the integration of new third-party components. We also noted changes within routines and daily habits in the course of using the system. All interviews, workshops and home visits were audio-recorded and videotaped where it was deemed to be helpful for data collection.

Smart Home Infrastructure

We chose a Z-wave based smart home platform system from a German provider. It is marketed as a plug and play solution with surface-mounted components only. Apart from manual control, the system also allows for automated control: setting up rules (if this, then that), scenes (setting a defined state for a number of components) and timers. Devices also can be grouped, for example, by room or by any other custom aggregation. A customizable dashboard serves as a homescreen where all chosen components are presented in widget-style fashion. Additionally, a weather-widget and a text-based home logbook are included. The latter provided information regarding the system state (starting and stopping the gateway, connection to cloud, updates etc.) and listed every event (sensed motion, input, changed settings, triggered switches, rules, scenes or timers) of the smart system.

The sensors and actors were organized via a gateway, which was connected to the home router and thus the vendor's cloud. All existing settings were executable without internet connection, but changing settings and – naturally – remote control out of the home network depended on an internet connection. Controlling the system was possible via sensors and actors themselves (switches, remote control, thermostats and smart plugs), a companion app and a web portal.

While third-party sensors were not officially supported, there were user-generated whitelists in forums. When the project started, the smart home product included the following sensors and actors which households could pick: room thermostats (14 picks), radiator thermostats (31), motion and brightness detection (14), door-/window contacts sensing openness or closedness (29), smart plugs for measuring electricity consumption and switching appliances (45), remote controls (6), freely positionable switches supporting two or four different positions (11) and a smoke detector (10). While the product is offered in typical starter sets and sets focusing on a certain use case, such as heating, we allowed households to freely choose a constellation of sensors and actors for their smart home.

Data Analysis

To identify challenges and experiences of smart home from a user perspective, our analysis is based on all data (interviews, workshops, field notes from home visits and regulars' table, text histories from instant messenger group) collected during the 18-month period of the Living Lab research. All audio-taped material was transcribed. Each document was processed by two researchers individually using thematic analysis with an inductive coding process [9]. After each empirical phase, the codes were consolidated and developed iteratively. We discussed gained insights internally with researchers who were not involved in the project as well as with our industrial partners in the consortium.

For the analysis, we searched for common patterns and categories related to how participants find and select appropriate smart home solutions, how they used smart home components (sensors and actors) as well as looking at software design, interactions and information provided through the system and how households tried to include smart home components into their lives and how everyday life changed through the smart homes. The analysis enabled us to identify four central categories relevant to the successful appropriation of smart home technology within four stages of use. Based on Silverstone and Haddon [52] we have ideal-typically organized these categories into four phases of smart home appropriation: (1) system setup, (2) installation and configuration, (3) routinized use and (4) demands of reconfiguration and extension. All quotes used in our findings section were translated from German by the authors.

FINDINGS: UX CHALLENGES FOR THE SMART HOME

In this section, we present results of our qualitative Living Lab study. We broadly assigned them into the phases of system setup, installation and configuration, routinized use and demands for reconfiguration and extension.

System Setup: Choosing hardware components

Product innovation literature shows that there can be a considerable mismatch between the functionalities on offer and the expectations of consumers (i.e. [40,63]). Our initial interviews showed that most of the households already had informed themselves about smart homes via the internet or magazines. However, participants planning to include smart home technology in their newly built or modernized home were overwhelmed by the number of existing products and their implications for future interoperability. Most common reasons for abandoning the search were a lack of market transparency and helpful information about use cases and best practices as well as an overly technical presentation of smart homes. Here, especially different communication protocols raised uncertainties. A male participant from a more tech-savvy multi-person household describes the assessment of existing smart home technologies as follows:

"I haven't decided on anything yet because I know there are many solutions. It is well known that [product A] is pretty expensive. [product B] is more for hobbyists [...]. Maybe those plug and play systems are better. [...] Investing hours of time reading through forums, writing scripts – which I cannot do myself – or programming something via copy and paste, I simply don't have the nerves for that right now."

While smart home technology is evolving fairly quickly, as far as the integration into home infrastructure goes, items need to be future proof, especially (but not only) when flush-mounted and thus more permanently installed. Additionally, the variety of more sophisticated product packages, and varying payment models requiring considerable financial investment, further discouraged households from deciding to buy.

When households were picking components for setting up their future smart home, it became obvious that many had very little knowledge of the various features of sensors and actors, as well as of their potential for combination. Except for tech-savvy households, participants had problems in articulating their needs and translating them into use cases or more complex scenarios with several hardware components beyond the ones that had sparked the interest in a smart home. Here, households often oriented towards use cases that researchers or other households provided e.g. via the instant messaging group or the regulars' table meetings. This complexity problem for the smart home user is reflected in several comments from participants, such as the case of a couple with grown-up children who have already moved out of the house:

"It has got to stay easy. Not everyone has daily contact with IT. We have seen people standing in [a consumer market] in front of smart home products, and I literally saw the question marks in their eyes."

The core problem our participants had in making their choices was to be able to identify routines to be supported and then map how the system might support a certain use case. While, in respect of hardware, this was unproblematic for use cases where only a single (kind) of sensors was needed, such as heating, the complexity grew strongly with the number of different sensors included in a scenario. Moreover, sensors often have secondary features, such that a motion detector, for instance, also senses brightness. These hidden features made it very hard for households to actually understand what possibilities existed.

Installation and Configuration

In the phase of installation and configuration, households came in first contact with hard- and software. The system setup which households chose needed the hardware components to be installed and paired with the gateway. Additionally, households had to register with their email addresses to gain access to the vendor's cloud portal. Components were used to define rules and relationships on a software level. The installation routine was either accompanied by a researcher or self-reported by the provided in-situ feedback function of the companion app. Even so, households ran into problems getting the system running without considerable support from researchers or the vendors' support channels (hotline and live chat support).

The most common problem touched on that of pairing devices with the gateway – a necessary step for Z-wave based components. The whole process raised serious issues and was a task many participants felt uneasy accomplishing.

"For me, installation was very … complicated. I mean you always think its like plug and play. Meaning: I will just try bevore reading the instructions. And that didn't work at all. Then I read the manual and thought I had understood it. But this still wasn't the case and looking closer to the manual, you found half a sentence you missed and then it worked." (multi-person household)

Moreover, the reason for having to undergo the process was unclear to participants unfamiliar with the technology; they expected the smart home to be plug and play compatible.

"Retrospectively, I would prefer to simply put the devices where they should be and then they should make themselves visible automatically somewhere and then you just ascribe them instead of having to wait and do all these steps." (multi-person household)

Introductory screens and overlays, described with highlights, arrows and text boxes, were deemed not especially helpful. The overlays were often quickly removed and, in fact, not read at all. When the overlays' informative character was subsequently described, reactions were more positive:

"If you haven't ever done this before and you don't know [how to], you would probably search, search, search. In this way, it is prescribed to you: Oh yes, you have to click

here, to start the timing. I think that actually is quite okay." (multi-person household)

For pairing devices, in ordert to include them into the system, rules for automated behavior in an if-this-then-that style needed to be defined by users. Identifying these concrete procedures necessitated considerable reflection:

P1: "I find it especially hard to set up rules…And setting them the way I want them to work. I don't manage to do this myself."

Interviewer: "So what did you do?"

P2: "I always try. Let's look [into the system]. A rule is for example: In case the thermostat measures 23 degrees Celsius, shut down the heating. That's a rule, right?"

P1: "If one thing happens, the other thing must follow. That's a rule. I never manage to do this."

P2: "When the window is open, I get an email. We tested this down here: opening and closing. Then I tried to include that it would only write an email after 10 minutes or so, because we only need a reminder when we have forgotten it. And I dind't find it and eventually gave up. "

Noticeably, households typically defined rules in a step-by-step manner. For example, when wanting a light to switch on depending on sensed movement: First, coupling the motion sensor with the smart plug was set and tested as a rule by moving in front of the sensor. After success, the period of time where the light was to remain turned on was set and tested again. Finally, the restriction that light should only be turned on when ambient light is low was added. In one case, darkness was simulated by putting the sensor under a cushion or covering it with a hand to get immediate results. This example makes two challenges explicit: First, users had a need for immediately testing rules due to either lack of trust in their own accurate understanding of rules or in the system's interpretation. In other instances, automatic timers were defined to trigger certain actions during testing. Households explicitly used fake times to get feedback about whether their idea of implementing the rule was correctly reflected in the system. Second, and more importantly, the problem of thinking about daily routines in algorithmic structures is not an everyday task for many households, resulting in inconveniently having to set up rules incrementally to make them work and fit actual needs.

„But the rule, such that I can say: 'The door sensor measures certain brightness and it should turn on the lights.' I still don't know how to get there. But I have followed the chat in the group and Dave is really good at this." (multi-person household)

Tech-savvy households with basic experience in configuring IT-systems and pairing processes often figured out troubleshooting for themselves and supported others, for instance, by setting up rules or suggesting use cases, with hints in meetings and within the instant messaging chat group.

Domestification and Daily Use

In the following months, participants used their individually configured smart home in more routinized ways. Within this phase, participants reported a considerably reduced interaction on the software interface level, due to having found their optimized configuration.

Regular and permanent home awareness demands

Despite households' general desire for background automation, we also found various demands for explicit information and awareness. In particular, permanent demand for historical data was mentioned. One household, for instance, which already manually kept track of gas and electricity consumption on sheets of paper wanted to digitalize and improve monitoring:

"For example, when I have invested let's say into my heating, I want to know: Does it pay off? Or when changing my heating settings. [..] I want a conclusion: Did it pay off or not? Therefore, I need to measure. If I don't, I can't change anything. I am not a control freak, but I want to know." (multi-person household)

This permanent home awareness mechanism targeted not only support consumption optimization, but also security aspects regarding the whole home:

"When I'm on vacation or just gone for a week, then you want to know what has happened." (multi-person household)

In particular, instead of having an interest in every single event, households tended to look for groups of events, which they were able to identify as a "normal" amount or sequence. Identifying patterns such as activities and times of absence, one could assess whether everything was okay at home or not.

Coming or leaving home were two very common scenarios in which households wanted to check on things or set devices to a certain state. For example, the same household with cats had installed a safety mechanism for their pets:

"It is dangerous for our cats if we let the window open when we leave the house because they could get hurt by getting stuck in a partly opened window." (multi-person household)

For this purpose, they connected a small light to a smart plug next to the entrance door which switched the light on when windows are open. Similarly, another households set up an awareness system for the dryer which was positioned in the basement, by connecting a smart plug to the machine and defining a rule that a smart plug in the living room should make a light blink when power consumption of the dryer dropped. After presenting his idea at a regulars' table meeting, this solution was adopted by others, too. Other demands for information related to security issues, such as checking for open windows or making sure all electronics were switched off.

A second kind of permanently demanded information related to system awareness:

"I check the system to see if something has failed, like my heating control at the beginning?" (multi-person household)

Related to system awareness, users showed relatively little concerns in privacy, though some users wanted to know what information was being transferred to the vendor (or 3rd parties). That is, they demanded a degree of awareness:

"For now, I don't see any way of misusing my data that could turn out to be my downfall. [...] It would be nice, however, to see what data is transferred or stored. If I can control this, its on me to decide what may be transferred or used." (single-person household)

Moreover, we found that most households did not understand the potential of information that could be deduced by third parties analysing data. However, if users understood, e.g that smart home logs provide strong hints as to whether anyone was at home at a given time, awareness and caution grew:

"After looking at the diary widget, I realized what information the smart home collected. Especially, in terms of motion profiles, because these are safety-critical information." (multi-person household)

One-time and temporal home awareness demands

During summer, in particular, a set of temporal or seasonal information demands became apparent. With longer daylight and higher temperatures during the summer season there was simply less to be managed in the house and interest in checking the temperature for heating was less sought. During the summer, however, a two-person household with cats for example wanted to check the room temperature whilöe they were abroad:

"[..] We could control if it was too hot for the cats at home." (two-person household)

Several information demands were limited to a special event or timespan. This could be due to activities of members of the households or due to a change of infrastructure: for example, to gain an understanding how much energy the new washing machine consumed. After tracking the machine for a while, there was no further interest in a long-term consumption evaluation.

Controlling the home

The physical smart home switch was considered a great way of controlling the home, and many households appreciated the possibility of simply positioning switches whenever a smart home command was used regularly. For example, several households positioned a switch, which was supposed to be put on a wall, on their living room table to change light settings when sitting on the sofa despite aesthetic considerations. The switch was only available in white, since it was built for wall mounting, and was seen as intruding on the interior decoration.

Although also a frequently used interface when at home, the mobile application was primarily used abroad. Here, use cases serving a demand for security awareness prevailed. Simulating presence by switching on and off lights manually was especially considered a benefit. While traditional timers were already used by some participants, their static programmable time slots were perceived as a limitation and easily detectable by potential burglars. Either random timers or randomized timeslots were mentioned as possible solutions.

While core use cases seemed to be identified, the routinization phase points towards the complexity and heterogeneity of households' ecosystems. Even though comfort, security and energy savings might motivate households to have an interest in a smart home on a global level, concrete use cases are highly individual and changed noticeably depending on seasonal factors, changing infrastructure or (irr-)regular events and households' evolving routines. Many use cases only arose in a later phase after households had the systems installed.

Becoming an Expert: Reconfiguration and Extension

In our first reflective interviews after four months of smart home use, participants told us about having integrated their smart home into their households to varying extents. Upon asking about the system's cost and its relation to the market price, however, the smart home was valued more as an expensive 'nice to have' gadget, rather than as a vital part of the home. However, no household took the offer to remove the system; they all wanted to participate further.

With households getting used to the system, its limitations became more evident. These, in part, stemmed from the sensors and actors not included within the system. For example, flush mounted switches or IP cameras were not available. While disappointing in principle, households understood that the product was still new and its landscape was to be extended. Other limitations of the smart home, however, were less anticipated and less accepted.

First, many users perceived Z-wave as a strictly standardized protocol and thought that any Z-wave-based sensor or actor was supposed to work with the system, too. Therefore, as an alternative to missing sensors and actors in the system, more technology-experienced households themselves tried to include third-party devices into the system. In most cases, and to varying extent, this failed due to differing interpretation of the communication standard. One participant found a third-party device that included several sensors which he wanted to be shown on his dashboard. Athough compliant to the Z-wave standard, including the sensor was hard work and only partially worked:

“Well this (...) small bowl [I got] (...) It was kind of a jack of all trades device including earthquake sensor, motion detection and temperature (...). After four weeks, I managed [to include] it, but it only offered me the motion detection function.” (multi-person household)

The only way to know whether a product would work, even within the same standard, was to either find out by word-of-mouth or by trial and error. Thoughout the smart home market official whitelists are seldom to be found.

Second, users found limits in the product itself, posing a barrier for their intended use. For example, some configurations of includable sensors were not possible, e.g. defining the sending rate of a light detector was not possible because of the vendor’s battery saving intentions. This however, limited adaptability and led to feelings of helplessness and frustration:

“I guess you have to think twice whether it is the right component to fulfill your wish? [..] But I think it is kind of an issue, when expectations of users differ from what the vendor was thinking.” (single-person household)

Users also naively thought that other systems they used would be interoperable with a smart home, especially the ones promising “smartness”. For example, some households had smart meters installed, which they thought would easily go with a smart home system – in fact they were considered a vital part of it. Similarly, other smart systems such as smartphones or audio systems were expected to be able to have an interface for sensors and actors, such that e.g. the smart home would be able to react to the GPS of the phone or the battery of an electric vehicle.

DISCUSSION AND CONCLUSION

In the 18-month Living Lab study, we identified 3 potential ways of fostering appropriation of smart home technology. We provide significant empirical detail, showing not only that users experience certain kinds of barriers but also *in what circumstances and when* they are likely to do so. Secondly, the extensive qualitative research undertaken demonstrates how these barriers are significant at particular stages of the appropriation process and suggests that designers need be mindful of this evolving set of conditions. Thirdly, we have shown, in and through the Living Lab study, that the various barriers to use should not be treated as separate matters, but need to be addressed in a holistic manner. In particular, the heterogeneous ways in which households demanded configuration forms, and the degree of knowledge required in order to do so, was identified. Throughout the study, the most common and severe problems arose in the fields of (a) a disconnect between users’ expression of demands and the systems’ capability to understand and process them. This became visible in the system setup phase and during installation and configuration, (b) maintaining awareness in routine use and and finding suitable visualizations for feedback demands, and (c) system extension beyond the home as a place. We discuss these practice-based phenomena and outline promising ways of addressing these issues.

Setup and configuration with practices and routines

Despite being interested in buying a smart home product, all households in our Living Lab mentioned having experienced problems identifying a suitable solution. The market is evolving quickly, and new products are being continually offered, making it hard to gain an overview. Most importantly, a smart home system was understood to be a significant investment, thus requiring it to be extendable in the future [10]. Here, the implications of choosing a particular system were not transparent in relation to future extensibility of the communication protocols and third-party sensors or actors. In this regard, our observations here were similar to Mennicken et al. [41]. Our findings go further, however, in highlighting that households actually did have ideas of what a smart home is supposed to provide, but often failed to map their interest to suitable technological setups. When asking, what could be improved or automated in the home, households often came up with what smart homes already offer. However, the step towards choosing the right technology was where our households reported feeling undecided and lost. We believe that orienting towards practices, routines and use cases to be supported will help users better understand what kind of technological setup they might need.

This disconnect between what users desired and how to map this to the system also was a major theme during installation and configuration, too. Although in the past even experts struggled to get distributed digital systems to work [57], new interfaces and web technologies promise plug and play even for “ordinary” users. This is in line with several attempts to make the smart home plug-and-play compatible [1,8,35,47]. Taking into account the individuality of user demands, End-User-Development (EUD) is known to pose a promising strategy for making complex systems work for non-experts, and should be relevant to the smart home [32,60].

We now argue that it is especially useful to support the operationalization of behavior and routines into events measurable for sensors. Smart homes, we argue, should be sensitive to local and changing, routines by affording more obvious and flexible (re-)configuration possibilities [44]. The typically proposed if-this-then-that style posed major challenges to households not familiar with algorithms in their everyday life. Reflecting on household practices in such a way that they could be matched to technology behavior was a serious challenge. Here, systems could more actively support users, e.g. by being pre-paired and preconfigured [47]. For example, products could be adapted to users during the buying decision by them reporting about routines. This way, the workload of algorithmically reflecting about daily routines would be transferred into a non-technological language, while still allowing rules and dependencies to be deduced and use cases to be suggested.

This would allow the vendor to include rules into the system upfront, thus relieving the user of a task and fostering the plug and play character.

Design for evolving visualization demands

During sustained and routine use, households checked up on their smart home, in the main for three reasons: (a) Maintaining control and awareness of what has been going on in the home and how it performs (i.e. in terms of energy consumption), (b) system check (i.e. whether the smart home does what it should), and (c) for temporary or specific event-driven information demands. Although, generally, the system worked in the background autonomously, usable means for maintaining sovereignty in the home were demanded. Regardless of the reason the concrete requirements on what exactly households wanted to check were highly individual and changed over time. In the field of energy consumption, these are known phenomena [51], calling for software to allow for continuous change and adaptability [32,33]. EUD [5,38] could support the users' journey from a novice to an expert user by allowing for adaptable information dashboards and information widgets for evolving or temporary demands.

Extending the 'home'

After getting used to their system, some households explicitly tested boundaries or came up with new use cases that included other electronic devices, such as smart meters, photovoltaic systems, smartphones, IP-based gardening equipment, cameras or car-mounted GPS-sensors. The isolation of these smart systems was counterintuitive to users and often led to frustration when different smart systems were not interoperable. This separation was not reduced to single appliances and protocols [10], but rather spanned across ecosystems. On a UX and usability level, the single access points to the systems lacking coherence in wording, style and control.

Households increasingly perceived their smart home interface as the central point for managing their home and wanted a single management system that also included e.g. their garden electronics and connection to external sensors and actors such as the smartphone. In this regard, the home is more than a location [17]. One promising solution is unified dashboards and control centers of distributed information sources from cyber-physical systems in household environments, similar to what Few [24] describes for business dashboards. For respective measures to be effective, this also calls for action on the middleware level [20]. If respective APIs and interfaces for protocols are provided, user interfaces may make use of them.

Limitations

Our findings might in part be due to system peculiarities. Even so, having conducted a market analysis and lab-based test of several platform-based systems we believe that most findings are not bound to a specific product. For smart home systems, Z-wave is a widespread standard, as are dashboards and IFTTT mechanisms for rule definition. All of which have implications for setup, running and maintenance that our system shares with many others. Also, market complexity and limitations in interoperability are not product-related. More sensors might have improved the smart home experience. However, at least for surface-mounted solutions, an evolving growth of the smart home system better represents the actual way of buying such systems. Moreover, most inexperienced participants ran into major problems making their smart home work with about ten existing sensors. In limiting the amounts of sensors, we supported a steady appropriation and found newly developed use cases over time. Finally, our research was of a qualitative nature, which also sparks typical limitations. For further evaluating validity and classifying the relevance of each problem dimension identified, further quantitative research could and should be conducted.

CONCLUSION

Our Living Lab-based case study has identified design guidelines addressing challenges during the process of smart home appropriation. Overall, we argue that smart home so far has targeted the home primarily as a technological space, rather than a a place formed by routines and interaction [29]. By becoming more sensitive to the routines and practices of users, four challenges could be addressed: Regarding the challenges of setting up and configuring the smart home, we stress the importance of daily routines as a metaphor which households can cope with, in contrast to technical detail or algorithmic patterns. For supporting operation and maintenance of a smart home, evolving visualization demands call for flexible user interfaces, adaptable to both temporary and permanent information demands on home and system awareness. Finally, smart home systems could unlock more of their potential when going beyond typical place-related boundaries, incorporating floating and interweaving practices which are not limited to the home as a building.

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