Slimmer dimmer, a case of inclusive smart home design

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Contents

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Introduction

Smart homes have existed for decades, with Bill Gate's home built in 1997 being a notable example. The rapid developments in technology have made all electronics cheaper and made the Internet of Things possible. The Internet of Things has brought many new products and services to the market and revived the dream of a "smart home" for the average person.

There seem to be two main types of smart home systems. The first type of smart homes are built using proprietary, subscription-based services and “black box” hardware devices that work exclusively with these services (e.g. Nest and Sonos). This type takes less time to set up, but offers little ability to customize, adapt and control the system. This type also has limited possibilities of combining hardware and services from different vendors, while raising questions about data transparency and privacy.

The second type are smart home systems based on open source software (e.g. OpenHAB and Home Assistant), which are typically used by enthusiasts. This type requires a lot of time and specialized knowledge to set up and use, but gives the enthusiasts a lot of control, transparency and full ownership of the system and collected data.

While these days enthusiasts have access to a lot more products to build their smart home, they are rarely the sole inhabitants and their co-habitants are not likely to share the same level of enthusiasm for new technologies. Instead of a home making their lives easier, they encounter automated systems that are not tailored to their behavior and that don't react the way they would expect, causing confusion and exclusion.

Neither of the two types of smart home systems offer sufficient support for being used and adapted by multiple users with varying needs and skills (such as different family members or roommates). **This project investigates how a smart home may combine the control and flexibility of an open source platform with the convenience of a proprietary service-based system, while inclusively catering to a diverse group of inhabitants.**

Project relevance

Previous research focused on the technical execution of smart homes, such as connecting devices and network infrastructure (Cook, 2012). This project focuses on the experience of users, which is a comparatively novel perspective. Preceding literature does exist and it generally supports the angle of this project.

Preceding literature
Seven social barriers to the adoption of smart homes could be described (Balta-Ozkan, Davidson, Bicket, & Whitmarsh, 2013). Most barriers touched on practical aspects, such as reliability of systems and ease of installation. They also described a relevant barrier as follows: “fit to current and changing lifestyles”.

In 2014, more directions for home automation research were published (Mennicken, Vermeulen, & Huang, 2014). The following is a fitting research direction: Households are socially complex and routinely involve breakdowns, improvisations, compromises and conflicts (Davidoff, Lee, Yiu, Zimmerman, & Dey, 2006). Smart homes should be able to deal with the ‘mixed messages’ created by these situations or from inhabitants with different preferences. These directions are described and their importance is mentioned, but they have not sufficiently been tackled yet.

Research in the field
In 2018, the first long-term qualitative research in adoption of smart home technologies was published (Hargreaves, Wilson, & Hauxwell-Baldwin, 2018). This research was conducted to uncover possible energy savings and to see how people learn to live with a smart home.

The research confirmed previous literature and added that smart home technologies are disruptive for domestic life. The smart home technologies even tend to undo adoption of existing products in the home.

Market growth
Forecasts of the market also contributes to the relevance of this project. The forecasts vary greatly, but all show growth.

Statista is forecasting a 25% annual growth of the worldwide market, reaching 122$ billion by 2022 ("Smart home - worldwide," 2018). Strategy Analytics is forecasting a slower growth of 10%, but their estimates start from a larger current market, which results in a 143$ billion market by 2022 ("Strategy Analytics," 2018).

Alongside the financial growth of the smart home industry, there is also a visible growth in IoT connected devices. IHS is forecasting there to be 42 billion connected devices by 2022, see figure 1. This is more than double the connected devices in 2017.

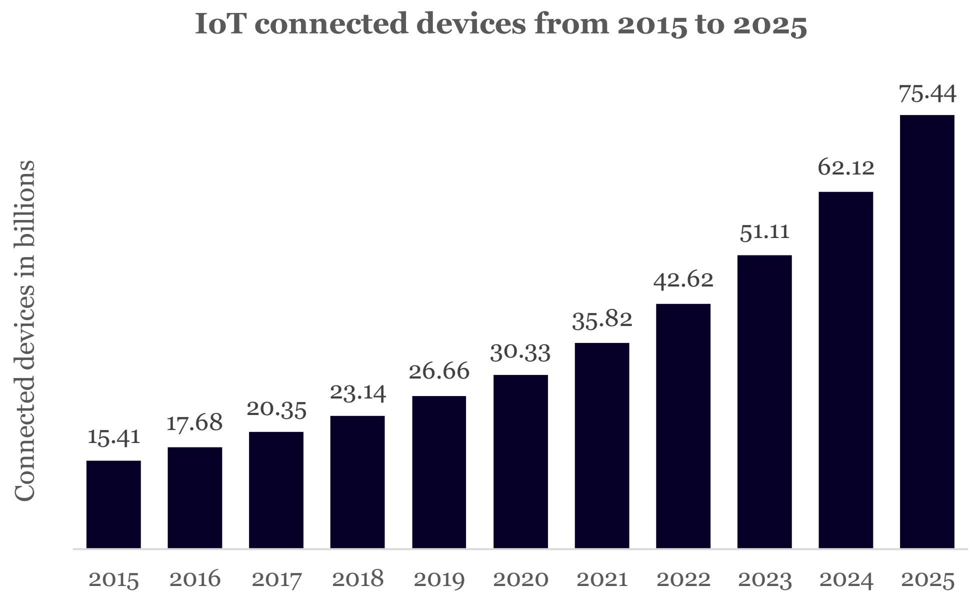

Figure 1: Forecast of devices ("Connected devices worldwide 2015 - 2025," 2018)

Concluding

The preceding literature shows that other researchers see problems with the adoption of smart home technology. These problems are similar to those described in the introduction. Research in the field confirmed existence of the problems by encountering them during a long-term qualitative research. The market growth suggests that more people will encounter IoT devices and smart home products, introducing more people to the issues described. Combining these findings makes the relevance of this project evident.

Understanding the smart home ecosystem

This chapter provides an insight into the definition of a smart home, the different values smart homes might add and the different ecosystems that exist. With these insights, the ecosystems are compared and a choice is made for which ecosystem will be the focus of this project. Additionally, a smaller scope of smart products is chosen for more focused prototyping and testing.

Smart home terminology

Both smart homes and home automation surround the use of connected devices. **Connected devices** are those that can be controlled by or provide information to a remote computing device. An example is the smart washing machine from Samsung that can be controlled remotely and can notify the user when it’s done, see figure 2.

Home automation is the control of devices with a focus on reducing user action. This includes controlling multiple lights with one switch or enabling lights when walking into a room. This behavior is always the same and provides a consistent experience. A good example are the power plugs that can enable lights based on a schedule while you are on vacation, see figure 3.

Smart homes are homes with connected appliances that can be controlled from a smartphone, computer or any other input device. Smart homes include home automation, but add additional information to the system. By providing additional information, automatic behavior can be tailored to specific situations. This does mean the behavior changes and can be less consistent.

Figure 2: A connected washing machine that can be fully controlled from a smartphone. (samsung.com)

Figure 3: A plug that allows to schedule appliances on a daily cycle (aliexpress.com)

Smart home promises

There are many products that fit inside the smart home, but it can be hard to see how they relate to each other and what value they add. This chapter provides an overview and divides the market into the type of value the products promise. This report assumes three main promises: security, energy efficiency and comfort. See appendix A for a more comprehensive overview

Security
The first promise is meant to provide inhabitants with an improved sense of security. This includes smart locks, connected cameras and door/window sensors, see figure 4 for an example.

Energy efficiency
The second promise is a reduction in energy usage and as a result a reduction of energy costs. These products mostly control heating systems, some attach to a heater and some replace the wall thermostat, figure 5 is an example.

Comfort
The last promise contains products that make your home more fun, flexible or generally more comfortable to be in. This is a broad promise and products in the security and energy efficiency categories might fall within this category as well. This promise contains smart lights, media devices, but also alternative interfaces and sensors, see figure 6 for an example.

Figure 4: Nuki is a smart lock system that allows you access to your home with your phone, as well as give friends access to your house with their phone. (nuki.io)

Figure 5: The Nest thermostat, which learns from and adapts to your behavior. (cnet.com)

Figure 6: Philips Hue bridge and bulbs, introduced in 2012. (amazon.co.uk)

Closed and open ecosystems

Closed systems

Some of the examples mentioned on the previous page are products developed by large companies to which services are attached. These companies do not want you to switch services and therefore create closed ecosystems. Communicating between services is only possible when the company specifically builds this functionality.

Millionaire systems

Before all these segmented brands existed, there were fully integrated systems. These systems are incredibly expensive, but they are made to last and keep data inside the home. A company will integrate all your appliances with the system, assuring the devices can communicate.

Open systems

Another way to build a smart home is by using open source systems. These systems are made to be flexible and integrate with as many products as possible. They do not depend on external services or make it easy to switch between services. They focus heavily on privacy and automating behavior, which is likely to become more prevalent for closed systems in the coming years. Figures 7 and 8 show what could be attached to an open ecosystem.

Some large companies do make their products accessible for open source systems. For example, many smart lights use the open source Zigbee protocol. This allows users to control their *IKEA TRADFRI* lights with the *Philips Hue* bridge and app or with an open source alternative such as *zigbee2mqtt*.

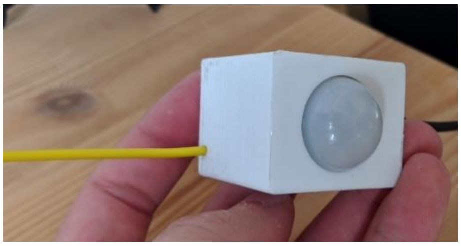

Figure 7: Homemade device with a sensor and radio control actuator.

Figure 8: Homemade switch that utilizes the open MQTT protocol.

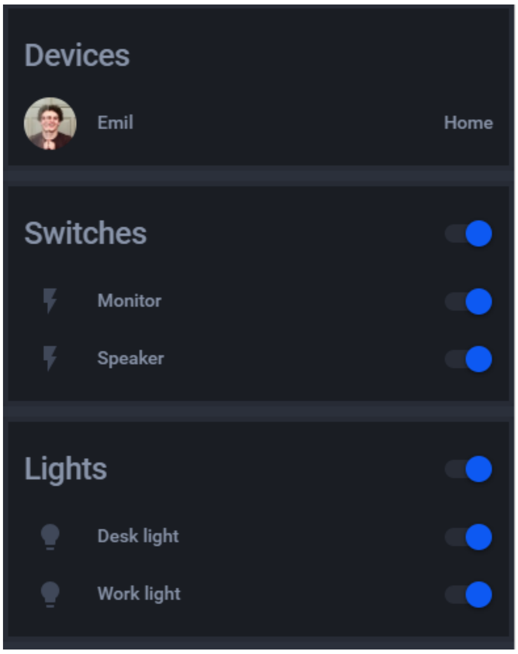

Figure 9: The digital interface for Home Assistant, an open source hub.

Problems of closed ecosystems

The service-based nature of closed systems raises questions about their longevity, privacy and flexibility.

Services closing down
Homes tend to stay around for quite a while, generally much longer than a mobile phone. Then what happens 10 years after installing smart home products that run on similar technology as a mobile phone? Companies might go bankrupt or decide that providing a service is no longer financially viable. Both of these situations have happened already, with the Pebble smartwatch (Verge, 2018) and the Nest Revolv (Verge, 2016) respectively. Because these products have a closed nature, it is generally not possible to switch over to another service. These customers were out of luck and their products, while functioning physically, no longer work because the services were shut down.

Privacy concerns
Placing products in your home with microphones and cameras can be detrimental to your privacy. When these products are connected to an external service for processing, this loss of privacy becomes a certainty. A recent study shows that consumers have reluctantly resigned to the idea of giving up privacy for convenience when it comes to smart speakers (Lau, Zimmerman, & Schaub, 2018). This does create tensions between users of smart speakers, which shows not everyone likes to give away their privacy for convenience.

Not flexible
The last issue with these systems actually builds on the previous problems. Once you buy into a system, it can be hard to switch to another system. Many of these products cannot easily communicate with each other. This requires additional hardware or adding another external service. This could force you to depend on even more services that might shut down or share your private data with yet another company.

Problems of open ecosystems

Compared to closed ecosystems, open systems seem very promising, however there is one big issue. The flexibility that open source offers, also makes it incredibly complex. An open source system might have a friendly interface for regular usage, but is generally unfriendly when it comes to configuration. For example, the open source hub *Home Assistant* uses a programming language to configure devices or to configure automatic behavior.

Complexity can exclude inhabitants from configuration
This creates the situation where very few can configure these systems, generally just one person in a household. This excludes most inhabitants from changing devices or altering automatic behavior that does not work for them. The result of a system that is too complex to alter can be seen in a study conducted in the United Kingdom, as described below.

Study: no energy savings
This study aimed to quantify the energy savings of a smart home, but found that there were many barriers (Hargreaves et al., 2018). At the start of their 9-month trial, the participants did actually have energy savings. But as the test continued, the participants got annoyed by automated behavior. They had no support to fix this and they eventually started shutting down most of the automated behavior. After the 9 month test, there were no energy savings.

The complexity of systems
The test made use of products from 2013, at which point there were no cheap universal systems available. Currently, these systems do exist with the services previously mentioned and they are rather easy to use. The open source systems have not caught up, especially not in configuration. See figure 10 and 11 for a difference in possible complexity between a closed and open system.

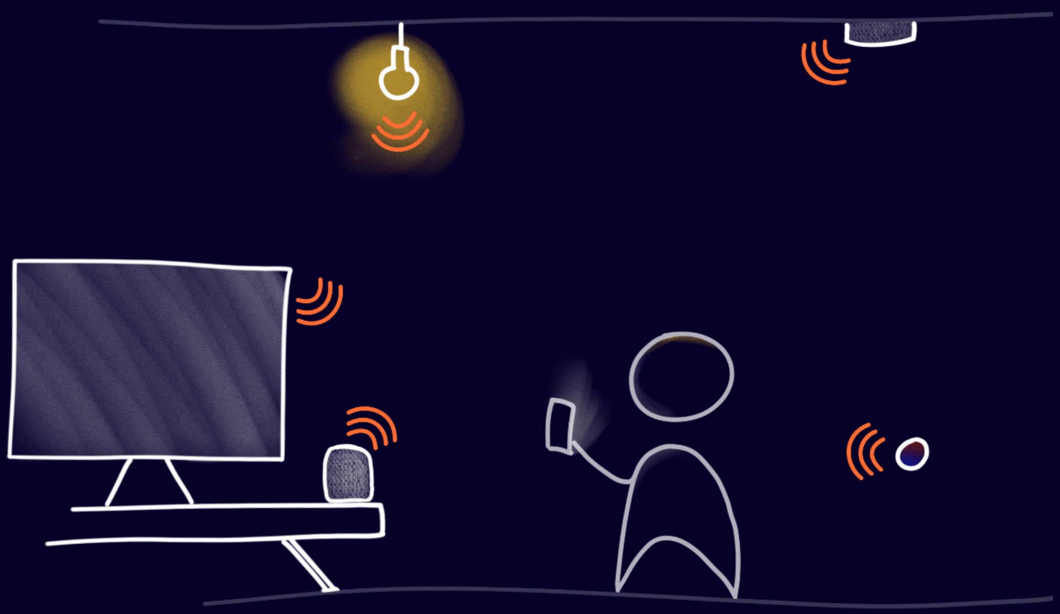

Figure 10: A closed source system, all configured through one hub and app. Devices are limited by the amount of services that can be connected.

Figure 11: An open source system with two hubs and two configuration environments. The number of devices and services that can be connected is much larger.

Concluding: open ecosystems and smart lights

Understanding of the different ecosystems allows this project to continue development with one of them. Additionally, a choice can be made which products to include in the development scope.

Open ecosystems
This project will address the difficulty of involvement with an open ecosystem. Closed ecosystems have many problems, but these are rooted in business decisions. Open ecosystems have design issues, but with focused development, they could rival the experience of a closed system. The open ecosystems also have a focus on automating behavior, something that is not as extensively possible with closed systems.

Additionally, the closed systems are difficult to prototype and test with, as they do not allow tampering in their system. Open ecosystems are in favor of this behavior and have entire supporting communities.

Smart lights
To allow for tangible testing scenarios, this project is limited to the scope of smart lights. Unlike a thermostat or a security system, smart lighting affects a person immediately when they make use of a room. This allows testing scenarios to be limited to first use scenarios, which requires a low involvement of participants.

Smart lighting products are also quite open. Closed source lighting systems can be controlled through open source platforms very easily, which makes prototype development more accessible. It is rather easy to add a light or controller for prototyping purposes to an existing lighting system.

Understanding smart lights

The ecosystem analysis mentioned smart lights as a useful scope for testing and prototyping. This chapter analyzes what functionality the smart lights have and what value they add. Then an overview is made of how lights are controlled digitally, traditionally and in between. Insights are gained and suggestions are made for future lighting control prototypes and tests.

Smart light functionality

At this point there are well-known companies that sell brands of smart lights, Philips Hue and Ikea TRADFRI come to mind. What features do these lights have and how may they be part of a smart functionality?

Brightness, color temperature and full-color spectrum
Because these lights are replacing traditional bulbs, the manufacturers have full control over the light they emit. This results in all bulbs being dimmable, some can change color temperature and some even can emit the entire color spectrum.

Remote control and grouping
These lights can be controlled independently of a switch on the wall. To achieve this, the lights are controlled wirelessly. This allows the user to control one specific light or group them together and control many at once. These choices can now be made in the user interface and not when wiring the wall.

Adapt to a changing context
This flexibility in control of individual lights, groups and light quality, makes smart lights very adaptable to a changing context. An example could be that all lights in a bedroom are used to create a wake-up light. A lamp could also be a mood light, but become a work light when a person works at the desk (figure 12). This requires advanced sensing or some other way to control the lights.

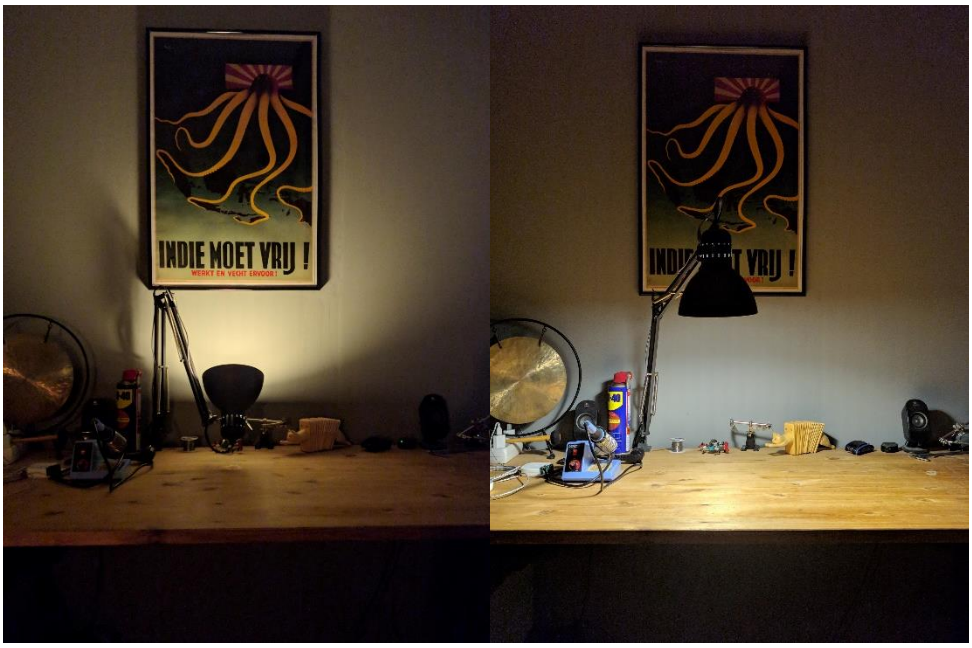

Figure 12: Different qualities of light for different uses. Left a mood light, right a work light.

Lighting control

To gain an understanding of what users might expect of their lighting controls, an overview of the market was made. This overview includes digital control, conventional controls and smart controls. See appendix B for a complete overview.

Digital control

An example of digital control is the Philips Hue app, see figure 13. This app allows users to create groups, create lighting scenes, create lighting schedules and configure automatic behavior. The app is a place for daily control of lighting, as well as where all the features can be configured. Another "digital" way of controlling lights is through voice control.

Physical control

The control that is most familiar to most people can be seen in figure 14. Conventional controls create problems for smart bulbs, as they disconnect the bulb when it is switched off. For this purpose, many smart physical controls exist as well. The vary from conventional (figure 14) to drastically different (figure 15) and somewhere in between (figure 16).

Figure 13: Philips Hue app with lights in a group, scenes and the color picker. (macstories.net)

Figure 14: Gamma dimmer with a big knob and pushbutton. (gamma.nl)

Figure 15: uLux, a complex programmable light controller (smarthomestore.at)

Figure 16: Wemo dimmer, can dim with an indicator and has a programmable long press function. (engadget.com)

Concluding: suggestions

There are big differences between the features available with smart lights and how lights have traditionally been controlled. Smart lights create a lot of freedom and personalization, but traditional control has no way to address these freedoms. Smart lighting controllers have their own ways of dealing with these difficulties, but not all of them are user-friendly. From these insights, several recommendations can be made for developing lighting controls.

Separating configuration and daily usage
As the digital controls provide a place to configure the complex system, it can be worthwhile to keep physical controls separated from this. It allows the physical device to focus on implementing the many daily controls.

Physical feedback for muscle memory
The capacitive touch dimmers have no physical feedback, which makes it a lot harder to use the switches without looking. Physical feedback supports muscle memory being formed and makes first time user fairly familiar.

Visual feedback for immediate response
Sometimes smart systems have delays, but the controller should always provide immediate feedback. This might not be important when using basic controls, but becomes crucial when using more complex functions.

Standard wall socket placement
All the physical controls are similar in size and are placed in similar places. People are likely to expect a light switch of about 80x80mm next to the door at a height of about 120cm. Smart lighting controls should adhere to this standard. Some controls were wireless, which can be combined with this standard by placing a holder for the remote at this place.

Understanding enthusiasts and non-enthusiasts

There are problems with the involvement of inhabitants in open source smart homes. This chapter names these as enthusiast and non-enthusiast inhabitants. After this identification, the chapter analyzes the differences between their motivations and values. Their shared values and motivations are explored as well and turned into opportunities for this project. This chapter is built on knowledge gained through literature research, interviews and a contextmapping session.

Non-enthusiasts and enthusiasts

Enthusiast
With an open source ecosystem, it takes a technically inclined person to bring it into the home. They need to have a high level of technical literacy and be motivated to maneuver through a big swamp of smart home products. Those who meet these requirements are called the enthusiast.

Non-enthusiasts
Non-enthusiasts are the ones who do not intrinsically install smart home products. This will be most people, especially the other inhabitants of a smart home. Non-enthusiasts might still enjoy smart home products even when they would not install them. A non-enthusiast could also be a fellow inhabitant who simply wants lights and other appliances to turn on and off as expected.

Dynamic definitions
It’s important to note that these roles are not attached to specific people, they are more similar to an attitude. Over time the enthusiasm for smart homes might vary greatly. An analogy would be the car enthusiast who might be in a garage every weekend, but when they leave work, they will not enjoy fixing their car before getting home (figure 17).

A non-enthusiast might want to join in on the design, prototyping and testing fun during the weekends. Maybe not with the same level of involvement, but with appreciation nonetheless.

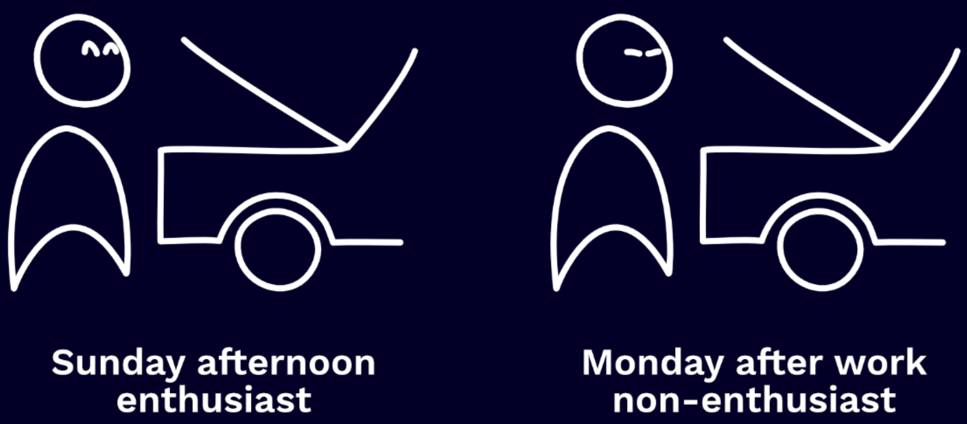

Figure 17: Car enthusiasm is analogous to smart home enthusiasm

Sessions and interviews

To learn about those involved and empathize with their positions, a contextmapping session was held and enthusiasts were interviewed.

Contextmapping session
The contextmapping session focused on the differences in perspectives of technology. Additionally, the contextmapping discussed how people change their routines and what difficulties they run into. Four participants were selected, two had smart home devices and two had none at all. Sadly one of the participants was not mobile during the session and participated through Skype, see figure 18. This turned out to have little impact on the session, see figure 20.

The session made use of contextmapping theory, such as sensitizing the participants with a booklet (figure 19) and developing a creative toolkit for the participant to help express themselves (Sleeswijk Visser, Stappers, & van der Lugt, 2007). Figures 21 and 22 show some materials the participants created during the sessions. See appendix C for a complete overview of methods, tools and transcribed results.

Enthusiast interviews
The enthusiasts in the contextmapping session did not have elaborate smart homes, nor did they live with other people. To uncover any tensions and to better understand their motivations, two enthusiasts agreed to an interview. See appendix D for the transcriptions of these interviews.

Figure 18: The four participants during the creative session.

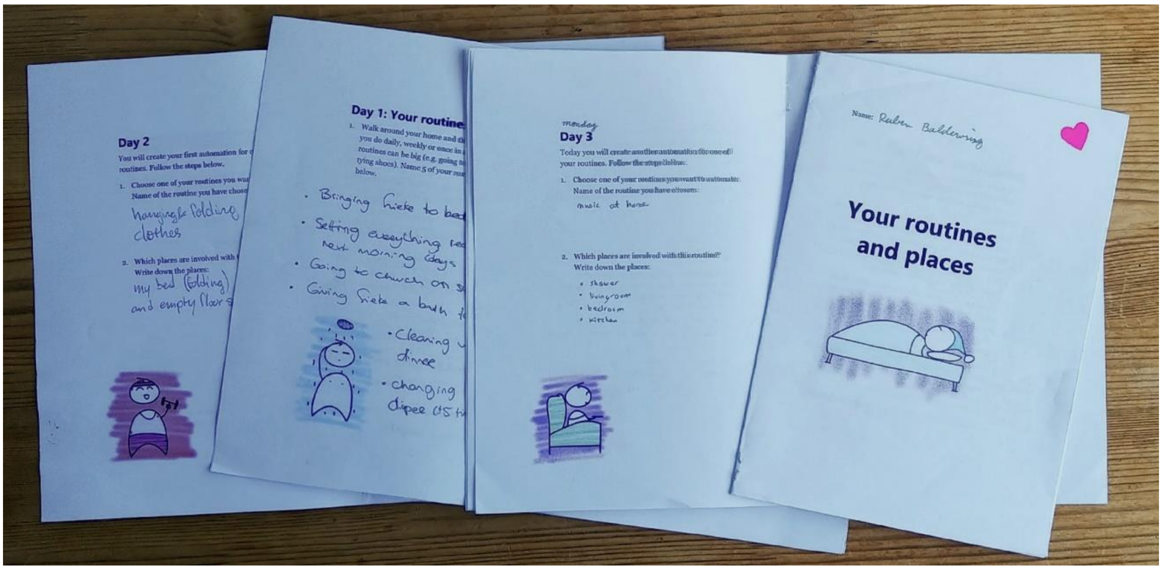

Figure 19: The filled booklets. Every page had a task for the day about their living environment.

Figure 20: The work of the participant on Skype

Figure 21: Good technology collaboration

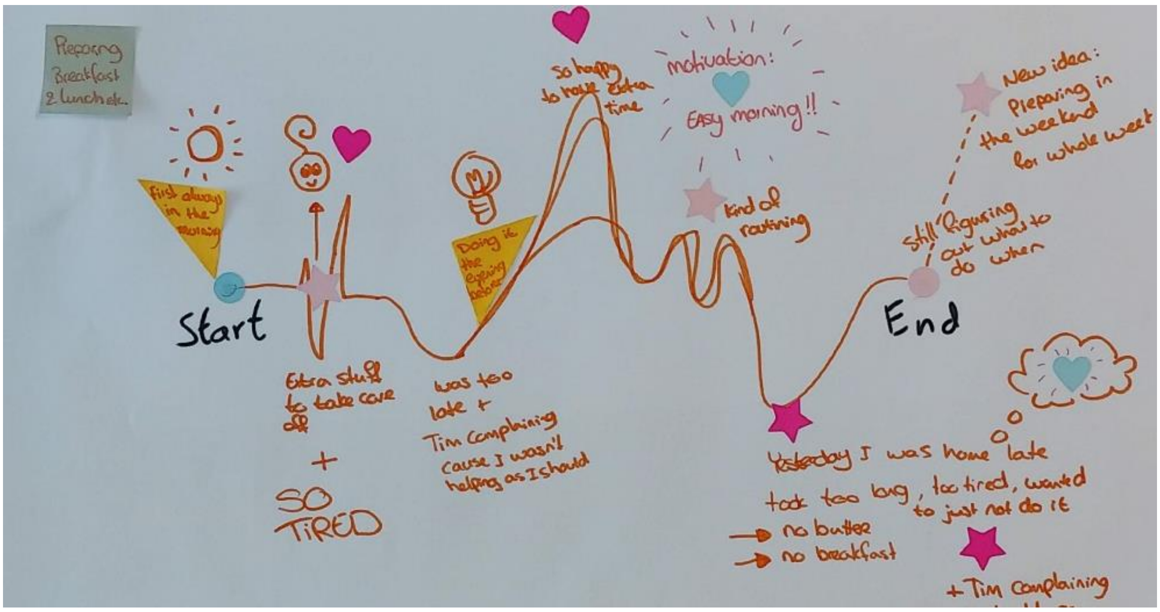

Figure 22: A timeline of a participant who changed a routine

What drives enthusiasts

When directly asking enthusiasts what their motivation is for rigging their homes, they respond in similar ways. They start with a prideful smile and will tell you how much fun they have when developing and seeing their work in action. This is then quickly followed by them explaining their joy when others acknowledge their work.

> *"It's super cool to do! When people come over, I'll show them what's possible!" ~ Enthusiast 2*
>
> *"Every time it's enabled, I think to myself that it's pretty cool. Also, when you have visitors, everyone says wow." ~ Enthusiast 1*

Their explanation contains infectious excitement and shows their motivations are more than just improving the efficiency of their life at home. To gain more insight into this excitement as a motivation, their behavior was described using self-determination theory.

Self-determination theory
SDT (self-determination theory) offers a very broad framework that allows for the study of motivation and personality ("selfdeterminationtheory.org - Theory,"). The most relevant takeaway from the framework for this project are the three core needs for intrinsic motivation. According to SDT, the human needs of *competence, autonomy* and *relatedness* foster the strongest form of motivation and engagement (figure 23).

In a simple form, autonomy is the desire to act based on one's own interests and values, competence is the desire to control the environment and relatedness is the will to experience a connection to others (Deci & Vansteenkiste, 2004).

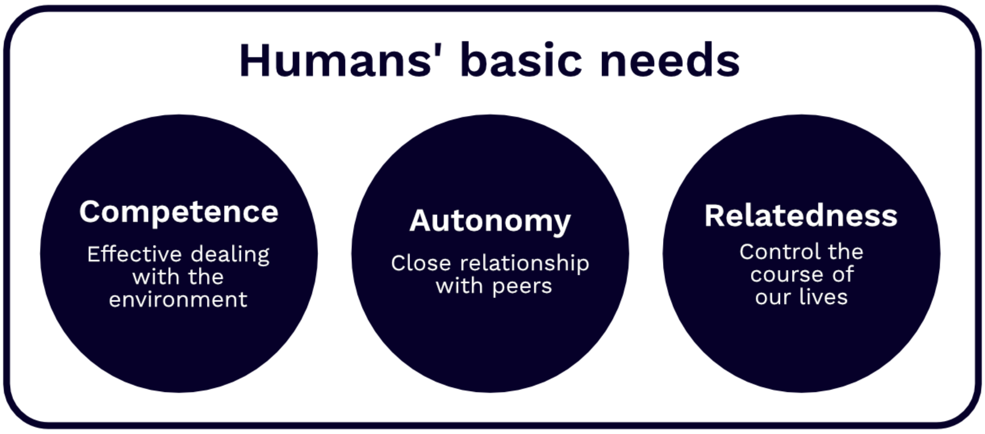

Figure 23: The three basic human needs (Deci & Vansteenkiste, 2004)

Competence

The most direct connection between enthusiasts and SDT is their desire for control over their environment. Smart homes offer a very direct environment on which control can be exerted, frequently making their competence visible. Additionally, this control does not come for free. As described in the previous chapter, setting up automations requires a considerable knowledge and time investment. It is worth noting that enthusiasts do need automations to work properly before they get their sense of competence. They are willing to make their automation simpler if that works better.

> *"We ate on the couch and suddenly we're eating in the dark. So, I added another button to actually trigger it." ~ Enthusiast 1 (E1)*
>
> *"It offers another security layer. I put a lot of time into it!" ~ E2*

Autonomy

When asking enthusiasts what inspires their automations, they disregard outside sources as their main inspiration. This aligns with the need of autonomy in multiple ways. First, they solve specific problems that they find important.

> *"My inspiration I think of myself. I have looked at blogs. Generally, not that interesting." ~ E2*
> *"Normally just stuff that annoys me and I'll try to fix it." ~ E1*

At the same time, they do acknowledge the need to build on the work and knowledge of others. They have a vision for the development of their smart home and will also use fictional characters or other analogies to convey that vision.

> *"You always rely on something or someone." ~ E3*
>
> *"Small things I find very valuable." ~ E1*
>
> *"Jarvis can do everything, I want that this thing can do everything as well." ~ E2*

Relatedness

Another direct relation between enthusiasts and SDT is the experience they seek when showing others their work. It's a moment of connection while showcasing their competence.

Concluding

All components needed for strong intrinsic motivations are present for enthusiasts. Smart homes are a place for enthusiasts to utilize their creative problem-solving skills. This explains their infectious excitement and willingness to spend a lot of time and money on automating seemingly small things in their home.

What shuns non-enthusiasts

It is clear the ingredients are in place to motivate enthusiasts. How does this relate to non-enthusiasts? What causes their general lack of motivation to learn new controls? When asked how they feel about smart homes and technology in general, they are more hesitant and request more context. After providing or describing their own context, they mention fear of losing control and valuable experiences.

> *"I don't want it now, I turn it off."* ~ *Non-enthusiast 1 (N1)*
> *"If technology did that for me, I would lose that experience."* ~ *N2*
> *"You do not dare to turn it off anymore."* ~ *N2*

To gain more insight, their position is also interpreted using SDT. But to get a better understanding of their loss of control, domestication of technology is introduced first.

Domestication of technology
Domestication describes the process of adapting technology into our daily lives and requires three steps. First, the user encounters the technology, then the user learns how to use the technology and finally, they construct meaning and incorporate the technology in their practices (Sørensen, 1996). Figure 24 gives an example of this process.

1. A light switch is introduced in the home.
2. Interact with the switch a few times and understand how to use them.
3. Integrate the switch in your routines, use without thinking.

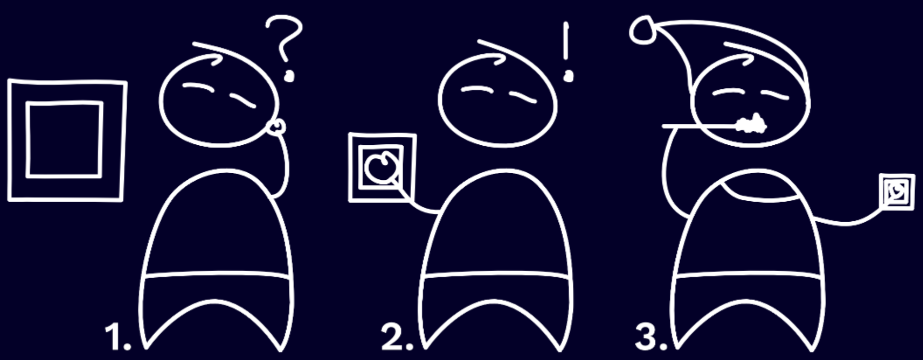

Figure 24: The steps of domesticating technology.

The example also shows how domestication can be reversed. By moving a switch or changing its behavior, a user will need to restart the domestication process. Introducing new technology properly while staying close to domesticated technology is also known as the MAYA (Most Advanced, Yet Acceptable) principle (Dam, 2018).

Competence and autonomy
This reversal of domestication negatively influences two needs described by SDT. When you are not able to turn a light on, which is incredibly well domesticated, it undermines your feeling of competence. You experience this as a loss of ability to control the very basics of your environment.

If you wish to restore your feeling of competence, you will need to domesticate a new technology. If the choice to change the light switch was not yours, the decision to learn something new was made for you. This affects the feeling of autonomy and in turn the motivation to learn this new thing.

> *"If I wanted to turn on a CD, I had to change four different settings, with three different remotes. I don't want to learn that. I don't want to do this." ~ N2*

On top of being coerced to adapt to this change, the non-enthusiasts also mentioned a fear of things changing again. This would require them to domesticate another technology quickly, possibly before fully domesticating the previous one.

> "You need to be able to depend on it if it's going to help you.*" ~ N1*

Concluding
Using domestication and SDT to frame the research findings provides a clear insight into why non-enthusiasts are hesitant to learn new controls. Non-enthusiasts do not get the choice in whether they want to change something or when they want to learn something. Additionally, they have no certainty that their effort will be useful for a longer period.

Tensions that arise

There is a stark contrast in the perspective of enthusiasts and non-enthusiasts, which can create quite some tensions. The enthusiast introduces the house to smartness, thus they are responsible for making it work well. The non-enthusiast is not in a position where they can change the system and this becomes an issue if the enthusiast is not taking their responsibility. These responsibilities can be identified at different times.

The moment something goes wrong
Automations are not perfect and sometimes need to be corrected. If it is a small mistake a non-enthusiast can easily correct, it will not be a large issue. If the non-enthusiast cannot correct this and the enthusiast needs to be involved, it immediately becomes a bigger issue. If the enthusiast is not around when this happens, the automation is not likely to survive this tension.

Implementing maintenance
After tension exists, it is important for the enthusiast to execute the maintenance needed to reduce the tension. If a mistake happens many times, the tension increases every time something goes wrong.

Additions to the smart home
When an enthusiast adds a new product or automation to the system, the non-enthusiast will likely need to learn about it. If previous tensions exist or the timing is unfavorable, the addition can easily create more tension. As enthusiasts tend to keep working on their systems, this can be a continuous source of annoyance.

Between users and technology
These tensions all happen between users because of the technology. Figure 25 shows the parties involved in the tensions. If any of their relations towards each other has issues, there is tension on the entire system.

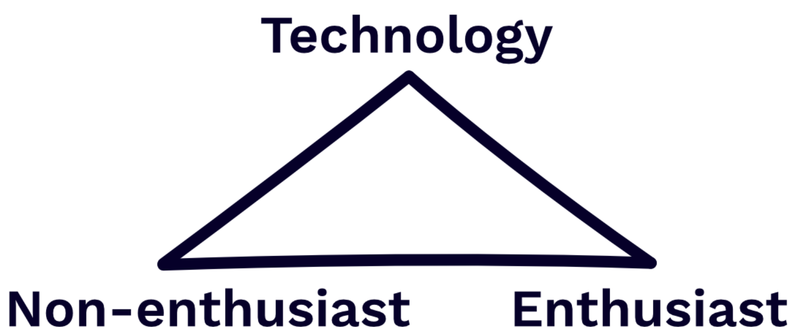

Figure 25: Triangle of tensions

Shared values

Now the differing perspectives and tensions are clear, it seems like there is a gigantic gap to bridge. Fortunately, the interviews and sessions also gave insights into shared values and ways to bridge the issues described.

Get it right
This is not so much a value, as much as it is a requirement for technology. In consumer products, there is no room for device errors. When creating automations at home, it comes into the consumer product environment and must comply with this requirement.

> *"I hate when I do something, and it doesn't work." ~ N2*

Personal
Smart home technology should be aware of the person they are dealing with. Adaptions need to be made depending on what kind of user is involved, thus making it more personal.

> *"If it's a detective and discovers what I want, that would be great as well." ~ E4*

Complementary
Smart home technology should not replace our core activities. The technology should be an addition that adds value to the activity.

> *"The technology is not running for him; the technology helps him to run." ~ N2*
>
> *"It needs to make your life more robust." ~ E3*

Honest
Technology, in general, should not seduce you into behavior you would not do without seduction. Intentions of technology should be clear and made without ulterior motives.

> *"I really hate the technology that makes you addicted to it." ~ N1*
>
> *"It should not make a difference between cultures or create inequality" ~ E3*

Concluding: opportunities

With an understanding of the motivations, tensions and values, many opportunities can be identified. It is clear the enthusiasts are intrinsically motivated and treat their smart home systems similar to a hobby project. The non-enthusiast can run into problems with basic usage of their homes. The enthusiasts cause these problems and the non-enthusiast have likely never asked for this. This causes tensions, as they might not even be equipped to deal with these problems. Luckily all these insights provide a lot of opportunities to shape or guide the design.

Preventing a loss of domestication
Making it easy for a non-enthusiasts to use a new smart home product is a given. This could be achieved by staying close to the experience they know well. This means crucial elements of the experience should be identified and consistently implemented for the non-enthusiasts.

An example of this is the chatbot one enthusiast developed for him and his girlfriend. This chatbot had an interface she was already familiar with and stayed the same as he continued development on the system. This provided her with a short domestication period and a reliable experience after that.

Clear boundaries of an automation
Another enthusiast had developed automations that started at incorrect times. Instead of disabling the automation, it is now manually enabled when needed. This creates a specific period in which certain behavior can be expected by someone who is aware of its use. This protects other inhabitants from unwanted behavior and creates clear boundaries of the automation.

Support the enthusiasts' responsibilities
It might be difficult for enthusiasts to keep up with their responsibilities, especially those of maintenance. An opportunity could be to support the enthusiast in their task of keeping up with maintenance and make sure they consistently squash tensions.

Implementing all shared values
As the enthusiasts and non-enthusiasts agree on the values personal, complementary and honest, it is an opportunity to implement these. When done well, both groups will, at least, appreciate those values.

Design scenarios

The introduction set out a goal for this project:

“Investigate how a smart home may combine the control and flexibility of an open source platform with the convenience of a proprietary service-based system, while inclusively catering to a diverse group of inhabitants.”

This goal was rather broad and with all the gathered information about the context, a more narrowly scoped goal can be defined:

“Provide lighting control that a non-enthusiast is familiar with while supporting an enthusiast in the continuous development of their DIY smart home.”

To make this goal tangible for designing, it is put into scenarios.

Reading light: non-enthusiast battling the system

1. A non-enthusiast is reading with the light turned up.
2. At 22:00 the house goes in evening mode and the light dims.
3. The non-enthusiast can't continue reading.

Figure 26: Reading light scenario

Wake-up light: enthusiast is not always an enthusiast

1. Enthusiast comes home after a party ready for bed, it's very late.
2. The house thinks they just woke up and gives them the floodlights!
3. The enthusiast has burning eyes.

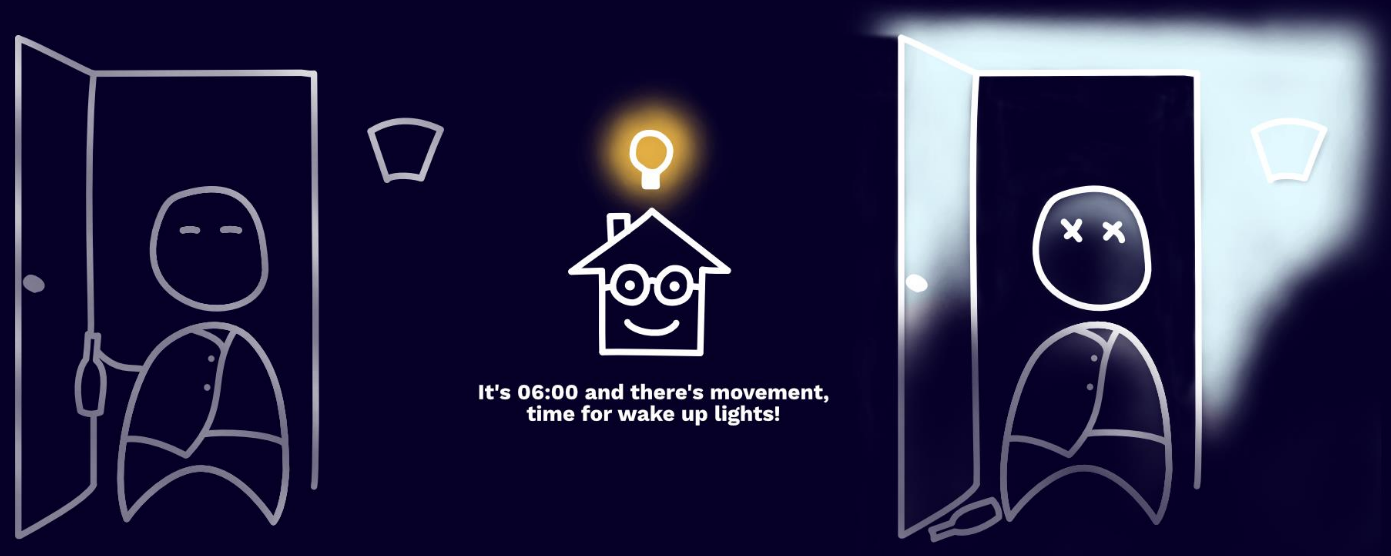

Figure 27: Wake-up light scenario

Process of prototypes

To tackle the design scenarios, this project made use of multiple research and design methods. The main paradigm used was research through design, which resulted in many phases, prototypes and tests. This chapter explains how the paradigm was implemented and which phases it resulted in. The prototypes belonging to the different phases are briefly shown and finally testing methods are shortly addressed.

Research through design

Research through design (RTD) allows designers to engage with wicked problems that cannot be easily addressed through science and engineering methods (Zimmerman, Forlizzi, & Evenson, 2007). Designs are researched to improve the designs, which are then used to conduct better research, see figure 28. The designs are prototypes which act as hypotheses and are tested in their respective environments. Research in context is also being called for in existing smart home literature: "Studying technology in a representative context of use will be crucial to assessing its suitability for everyday use and whether or not it addresses inhabitants' intended goals." (Mennicken et al., 2014)

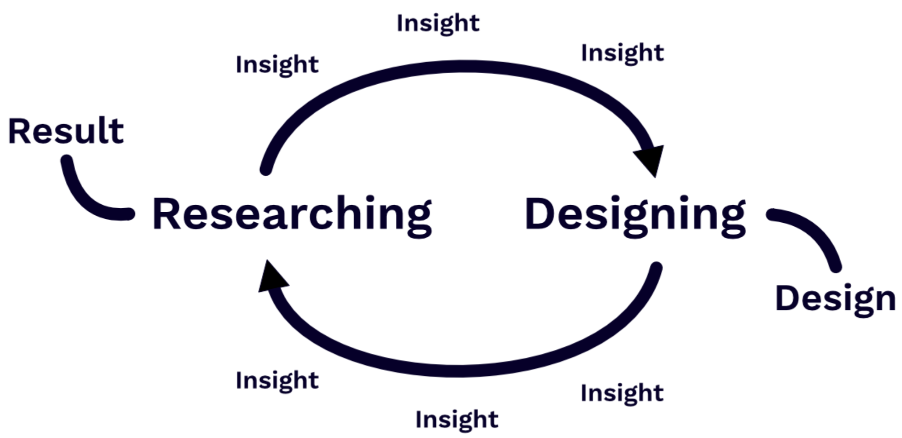

Figure 28: A schematic showing the actions and proceeds of RTD

Pivoting with research through design

Because this project started with a broad scope, it needed a method to narrow this scope as the project continued. Instead of making unfounded decisions at the start of the project, the choices were developed as explorations continued. Three moments were planned where the project could pivot into another direction. As new knowledge was uncovered, fruitful directions could be selected. This resulted in a narrow scope at the end of the project, forged from research knowledge.

Phases and pivots

This project was divided into four phases, see figure 29. The first phase was used to create an understanding of the context and to approach users. The following two phases focused on designing an experience for the non-enthusiast and the last phase focused on the enthusiast experience.

These phases made use of differing exploration and validation techniques. The first phase used literature research, interviews and a contextmapping session. The following three phases made use of prototypes for explorations and tests for validation. The first phase and its results have already been discussed in previous chapters, thus these chapters discuss the prototypes and tests.

Phase	Method	# Participants
Phase 0: Understanding the context		
	Literature research	
	Context mapping session	4
	Enthusiast interviews	2
Phase 1: a minimum level of control for non-enthusiasts		
	Scenario 1	6
	Scenario 2	6
	Scenario 3	6
Phase 2: Usability and accessibility for non-enthusiasts		
	Usability 1	10
	Usability 2	8
	Scenario 4	6
Phase 3: Communicating use and responsibilities to enthusiasts		
	Communication 1	6
	Communication 2	6

Figure 29: Overview of phases, methods and participants

Phase 1: a minimum level of control for non-enthusiasts
This phase focused on solving the reading light scenario for the non-enthusiast. The prototypes developed during this phase made use of the opportunities found in the context analysis. The prototypes in this phase started out with novel principles, see figure 30. Quickly it became clear that users need controls they recognize, both in location and usage. Figure 31 and 32 show the following steps to create control for a non-enthusiast.

Figure 30: Scenario 1, it allowed participants to undo the latest change of the lighting. They were meant to use it when it got too dark to read.

Figure 31: Scenario 2, it was placed next to a light and allowed participants to dim that light. The prototype could also toggle automations on and off.

Figure 32: Scenario 3, it allowed participants to control a light and disable the automations automatically. To enable automations again, the dedicated button had to be pressed.

Phase 2: usability and accessibility for non-enthusiasts
After the previous phase came close to solving the reading light scenario, the project pivoted to refine this design. The requirements for the device were re-evaluated, which resulted in new designs (figure 33 and 34). To evaluate how well participants could understand these designs, they were validated with usability tests. This isolated small changes, making their effect more apparent. After two usability iterations, these changes were put to the test in a scenario test again (figure 35).

Figure 33: Usability 1, a new form factor with different ways to indicate functionality. These indicators were tested against each other, this was the winner.

Figure 34: Usability 2, this prototype reused an old prototype to test the new interface. This was also the point at which the indicators were animated.

Figure 35: Scenario 4, after usability testing the design was tested in the scenario again. This was a new prototype that embodied all the previous learnings.

Phase 3: communicating use and responsibilities to enthusiasts
With the experience of the non-enthusiast validated, it was time to focus on the enthusiast. They had to learn about a complex product, be able to configure it and be aware of their responsibilities. To achieve this, an onboarding app was designed. This onboarding was tested and iterated on, first without context and finally with context. Figure 36 shows the final onboarding prototype and figure 37 shows the final physical prototype.

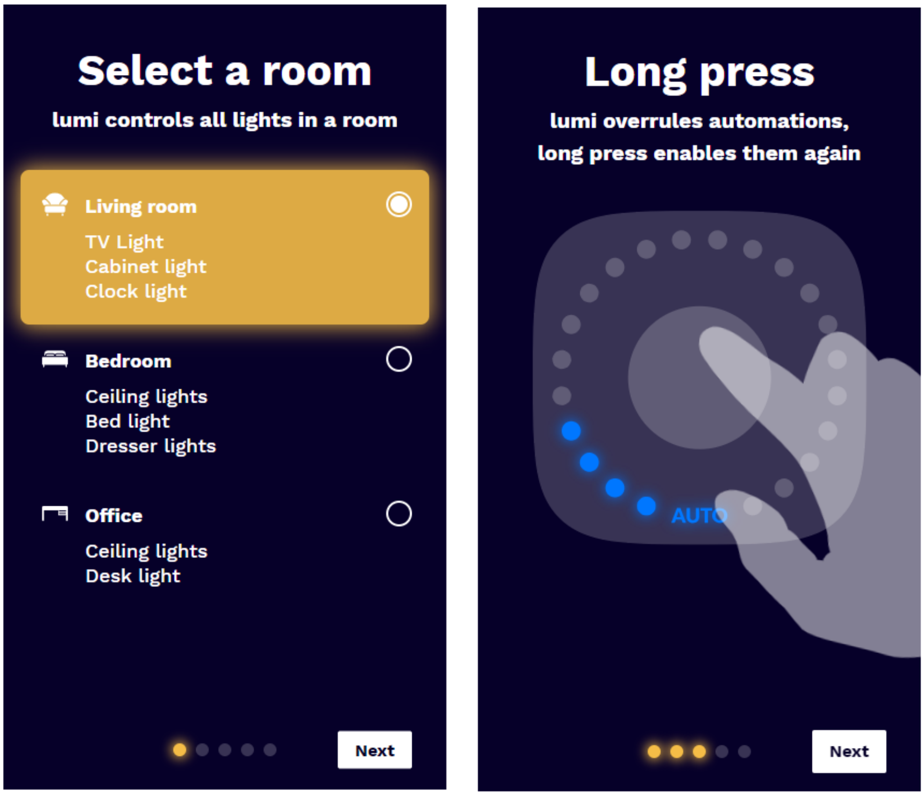

Figure 36: Communication 2, succinct descriptions and targeted information for enthusiasts to understand usage and configuration.

Figure 37: Communication 2, the final physical prototype used with enthusiasts.

Participants

For all these tests, the participants were sourced at the IDE faculty. Using participants from the faculty allowed for weekly tests. These participants did not have to be arranged before the actual testing day. The tests also frequently made use of a testing environment which was at the IDE faculty.

Non-enthusiasts
Using design students does influence their knowledge of testing methodology, as this is part of their studies. This is a limitation of this method and might have skewed results more positive than they would be in a representative participant group. The testing protocols did make sure to provide the participants with very little information, similar to a first time non-enthusiast user.

Tests completed with the scenario method had 6 participants per test. The usability tests had 10 and 8 participants. All tests were completed in one afternoon, limiting the number of participants. The tests in scenarios generally took longer, thus fewer participants were involved.

Enthusiasts
Again, using design students influences their knowledge of testing methodologies and might have skewed results. To make sure the design students approached the knowledge of an enthusiast, they were given a lot of information about the system. The design students were possibly more akin to an enthusiast than a non-enthusiast, as they are technically savvy.

For the final validation, the participants were specifically selected to be technology enthusiasts. This was done to improve the representability of the participant group. Both tests had 6 participants.

Scenario test method

All scenario tests were done in a similar manner. Between tests, the methodologies improved, but the outlines stayed the same. For detailed methods and insights per test see appendix E.

These tests made use of the living lab at the Industrial Design faculty in Delft, see figure 38 and 39. The lab is a living room specifically made for testing in a living room situation. This room was therefore perfect for testing with the reading light scenario.

Figure 38: The living room used as a test setup.

Figure 39: A participant reading in the test environment

Usability test method

The usability tests called for a more sterile environment with less changing variables. This allowed for tests that compared designs or test comprehension from just interface feedback. The details of these tests can be found in appendix F.

These tests were conducted in the main hall of the IDE faculty. During usability 2, participants were positioned directly across the researcher, such that the hands of the participants could be recorded.

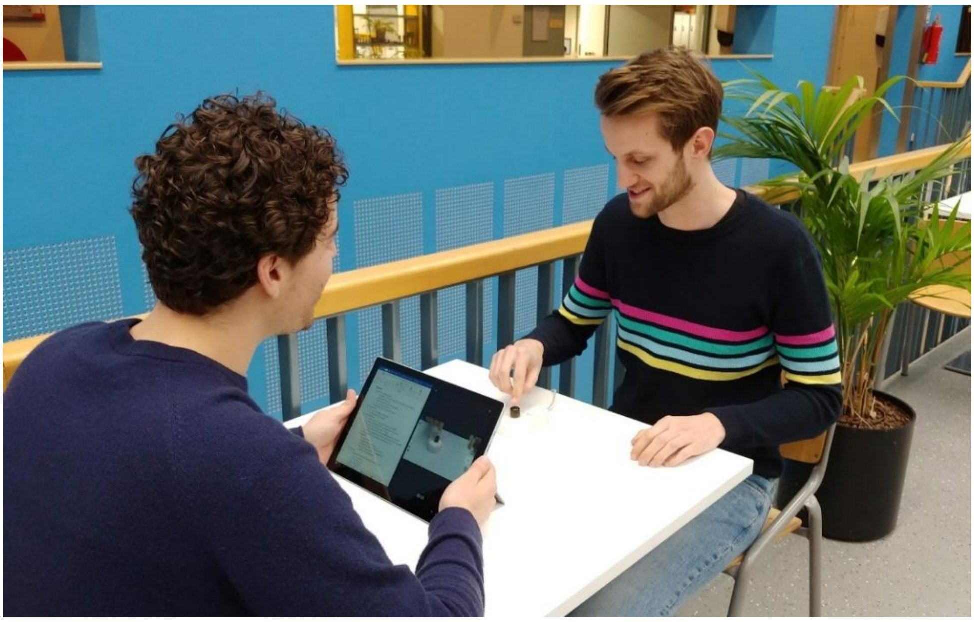

Figure 40: The participants sat straight in front of the researcher, which allowed the hands to be recorded as well as the audio.

Figure 41: This is what the recording looked like, which gave a better understanding of what the participant had difficulties with.

Communication test method

Communication tests with enthusiasts focused on their comprehension. These tests took place in the main hall of IDE and in the living labs of the IDE faculty. The first test focused on communicating concepts and could be done without context. The second test was fully integrated and thus made use of the living environment. See the details in appendix G.

Figure 42: Setup similar to the usability testing, this time with digital interface and a disconnected prototype

Figure 43: Camera footage of the test in context

Figure 44: Participant in context, learning the dimmer through onboarding

Concluding: many validations

By using research through design, this project was steered in a controlled manner. The pivots in this project were planned and executed with the maximum amount of information available at the time.

Three pivots
The first pivot focused on the design scenarios that were developed through the context analysis. This resulted in successful solutions and thus the following phase pivoted to refine these design. The refinement resulted in a tangible solution that solidified a good experience for the non-enthusiast. After this, the enthusiast needed to be brought on board as well. The last pivot successfully designed a way to communicate usage and responsibilities to enthusiasts.

3 methods, 8 tests, 9 prototypes and 54 participants
These pivots made use of three different methods of validation. The methods recreated the design scenarios, isolated usability changes and tested enthusiast comprehension. In total 8 tests were executed resulting in 9 different prototypes, each prototype building on the knowledge of the previous tests and prototypes. The 8 tests had a total of 54 participants.

Research findings and a design
This method created many insights and many designs. The final results of this method are distilled research findings and a design with these findings properly implemented.

Principles for inclusive smart homes

From the analysis and testing done during this project, three main design principles could be identified. They are insights that are not specifically applicable to the design goals nor to the product that was designed. They are general principles that can be used as guidelines to design more inclusive smart home products. This chapter introduces these guidelines and uses the wake-up light design scenario to explain them, see page 32.

Protect domestication

As learned during the context analysis, domestication of technology is the process with which people hear about a technology, learn to use it and integrate it into their routines. This first principle calls to protect any domesticated technologies that smart products might affect. A smart product that is introduced should keep the original routines intact. For this, the traditional control must stay; lights can be controlled with a light switch, the TV can be controlled with a remote, indoor climate can be controlled with a thermostat and a door can be physically locked.

Adding new features
Smart products might introduce features which might collide with traditional functionality. In this case, the traditional functionality should be more easily discovered than the new features.

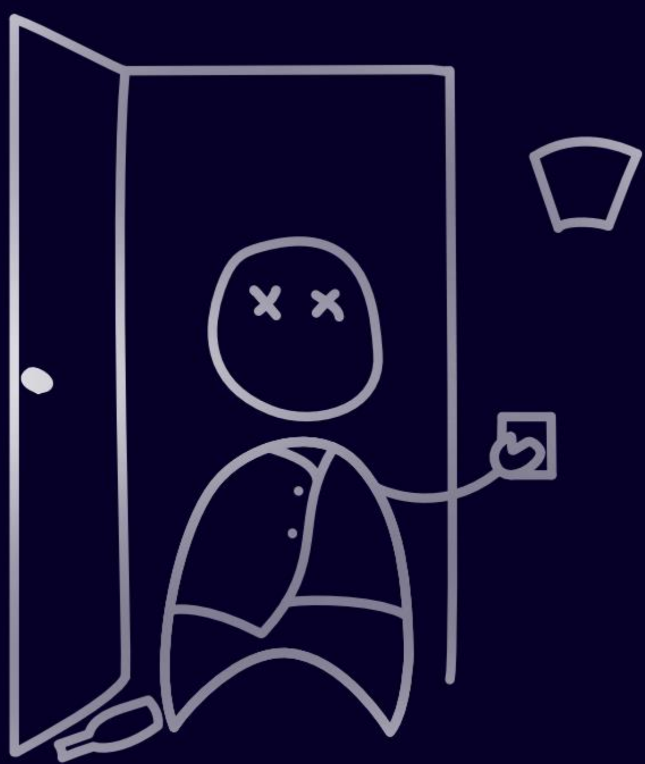

Figure 45: You come home very late after a party, the house thought you just woke up. The lights were full brightness, so you smacked the switch next to the door. Lights are off, just like always.

Give immediate control

Households are socially complex and routinely involve breakdowns, improvisations, compromises and conflicts (Davidoff et al., 2006). We are unpredictable, sometimes we're sick or get home a bit late. This second principle calls to abandon automatic behavior once an exception is found. When a user tries to deal with an exception, they should immediately receive full control. Non-enthusiasts expect to receive full control when manually controlling their environments. When they turn the lights on, the lights are staying on.

Enthusiasts can adapt
When an enthusiast encounters a room that no longer responds automatically, they will wonder why and know how to fix this. They might be annoyed by this, but they can always fall back to their original, well domesticated, technology.

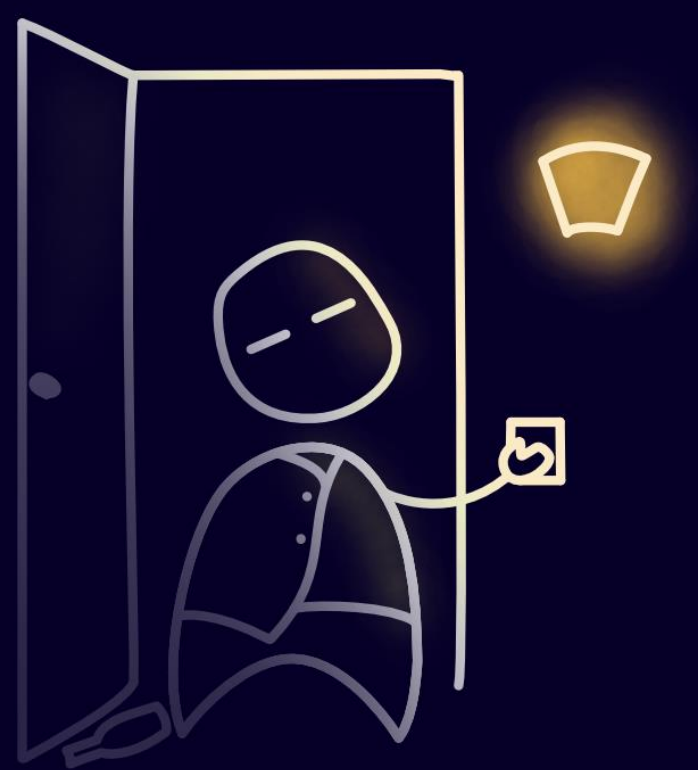

Figure 46: After smacking the lights off, you turn them on very dimly. They stay like this until you turn them off again.

Facilitate adaption

People are unpredictable, but this does not mean exceptions are impossible to solve. When a user deals with an exception, it can be used to learn from. By keeping track of these moments with immediate control, useful insights can be gained. Knowing if an exception happens often, with whom they happen, when they happen and what exactly happens are crucial pieces of information for improvement. Turning this information into actionable insights and making it accessible to the enthusiast, gives them the tools they need to improve an automation.

AI does something similar
This adaption is similar to smart products that have a self-learning system. With the creative problem-solving skills of an enthusiast, actionable insights likely rival or surpass the capabilities of a self-learning system.

Figure 47: After sleeping, you check what actually happened during your morning. You know exactly what happened and how to fix it. You decide to only enable wake-up lights after your alarm has gone off.

Presenting slimmer dimmer

The inclusive smart home design principles were not developed in isolation. They come from a specific context with a specific solution. The slimmer dimmer and an overview of its features are described in this chapter. Then the chapter gives insight into how the principles are integrated in an inclusive smart dimmer. Finally, the future explorations and implications of this product are discussed.

How the dimmer works

The slimmer dimmer was primarily developed to work just like any other dimmer. However, there are additional smart features that are hidden during non-enthusiast use. An overview of the dimmer is provided here.

Manual control/automatic control
The dimmer has two general modes it functions in. When the knob is turned or clicked, it is in manual mode. Manual mode is the first mode any user would encounter and it will disable any smart behavior for lights in the room. To enable these automations again, the button needs to be long pressed. Figure 48 shows the dimmer in manual mode and figure 49 shows when it has been put in automatic mode.

Figure 48: The dimmer in manual mode, activated by clicking or turning

Figure 49: The dimmer in automatic mode, activated by long pressing

Physical overview
Slimmer dimmer is situated in the wall, as a normal light switch would be. Here the slimmer dimmer can easily be found and used by any non-enthusiast. The slimmer dimmer can also be taken out of the wall, it then functions as a remote control. When placed in the wall, the dimmer gets charged. See figure 50 for a typical placement of the device.

The dimmer has one button and a LED ring surrounding it. This one button is used for all control, making some things easy to find and others much harder. The ring will normally indicate how bright the light is set, both in manual and automatic mode. When the dimmer has not been used for 10 seconds, most of the LEDs will turn off and show just one LED that indicates the brightness. When all the lights are off, the dimmer will not show any indicators. See figure 51 for a dimmer that is timed out.

Figure 50: The dimmer placed on a wall next to a door, where it's expected.

Figure 51: The dimmer when the lights are on, but haven't been changed for 10 seconds. This indicator shows the current brightness of the lights.

Custom controls

Because the dimmer is targeted towards DIY smart home enthusiasts, it needs to be configurable. The dimmer can be configured to disable only a few automations or control only half of the lights in a room, but the fun part are the fully configurable controls.

First is a custom button, pressing twice sends a custom command. This command triggers an automation or integrates with a service like IFTTT. Triggering the custom command fills the LED ring, seen in figure 52. The second customization is a custom dimmer function. To use this function, you need to press and turn the knob. In this mode, turning the knob can execute any feature you like. The defaults can control RGB, specific lights, select scenes or color temperature as seen in figure 53.

Figure 52: Custom command when triggered.

Figure 53: Custom dimmer feature used for color temperature control

Onboarding and insights

The dimmer comes with a companion app to configure the device. During the onboarding, the enthusiast is taught how to use the device and introduced to the concept of manual/automatic control. Alongside onboarding and configuration, the app provides the enthusiast with insights. See figure 54 for the onboarding.

These insights are made to help the enthusiast improve their automations. When the device is used, it is a moment that the automatic system is not sufficient. The dimmer gathers all these moments and displays them such, that it is easy to figure out if there are any issues and how big these issues are. Every issue has actionable data available, making it clear with whom, when and how things went wrong. See figure 55 for an example of these insights and actionable data.

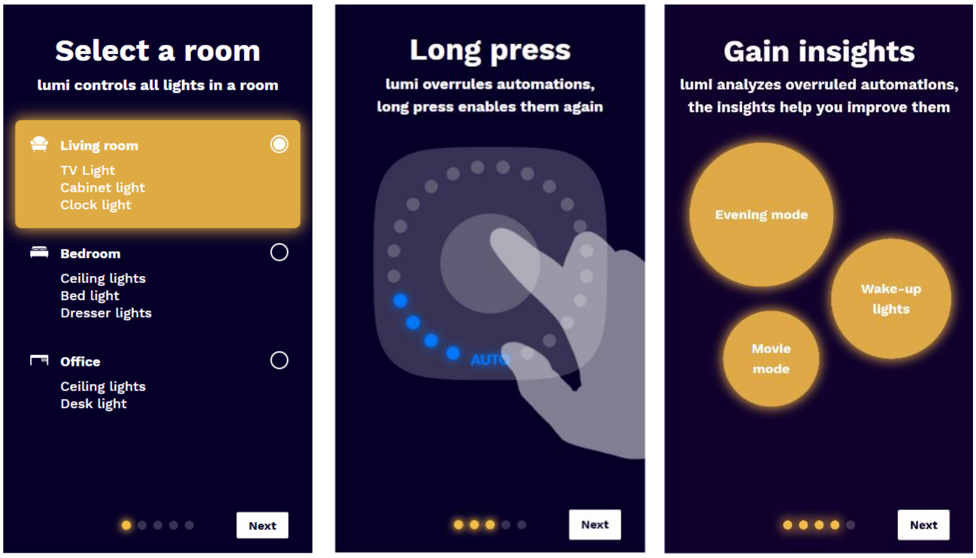

Figure 54: Some steps during the onboarding in chronological order

Figure 55: Some insights to help the enthusiast improve night mode

Incorporation of principles

To provide a better understanding of where the inclusive smart home design principles come from, this chapter will show how they were developed in the slimmer dimmer. First, the application of the principle is explained and then the findings that support the principle are mentioned.

Protect domestication

The slimmer dimmer protects domestication by being in exactly the same place as all other light switches. Somewhere near a door, at a height of about 105 cm. Then, when a user has found the dimmer, it will work similar to all other dimmers they have used. Turning the knob changes the brightness and clicking toggles the lights.

Proper placement solved most issues
During tests in the scenario, it became clear how difficult it was for participants to find non-traditional light controls. As the placement of the prototypes changed, their ability to find the device changed drastically. With the first test, the controller was on the table in front of the participants. They did not relate this device to the lights and tried speaking or waving their arms instead, see figure 56 and 57.

> *"I'm looking for a way to get it brighter again, there is probably a sensor somewhere" ~ Scenario 1*
>
> *"It is a smart living room, hmmm. Please, more light! Can it speak?" ~ Scenario 1*

Figure 57: A participant using gestures to try and control the brightness ~ Scenario 1

Figure 57: A participant turned on the light with the physical switch. The light was too dim to read from the couch. ~ Scenario 1

During the final validation of the non-enthusiast experience, it was clear participants could easily find the dimmer. The device was where they expected it to be and when looking, the device kept their attention by displaying the change of lighting happening in the room. See figure 58 to see this in action.

> *"I see a knob here." ~ Scenario 4*
> *"Button with a light here!" ~ Scenario 4*

Figure 58: Participant using the dimmer while it's on the wall. ~ Scenario 4

Participants used the knob correctly every time

Figure 58 also shows the ease with which a participant is able to use the device. The usability testing showed that turning for dimming and clicking for toggling was very well understood. Even when participants had no feedback from their environment, they used the device correctly every time. Figure 59 and 60 show participants touching the device for the first time.

Figure 59: The first second the participant touched the prototype ~ Usability 2

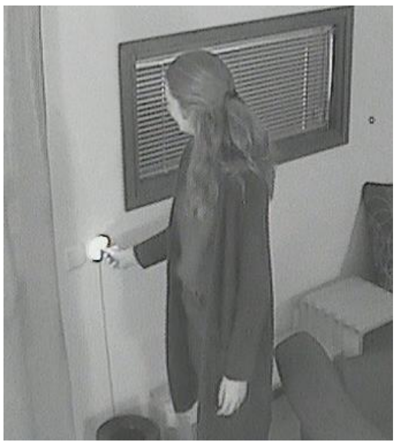

Figure 60: The first turn of the participant was the correct one. ~ Scenario 4

Participants never accidentally used a feature
During usability tests, but also in scenario tests, the participants never accidentally accessed an enthusiast feature. This was done by making it significantly more difficult to find these non-traditional features. This caused them to only find the features they were expecting. See figure 61 for a schematic overview of enthusiasm versus discoverability.

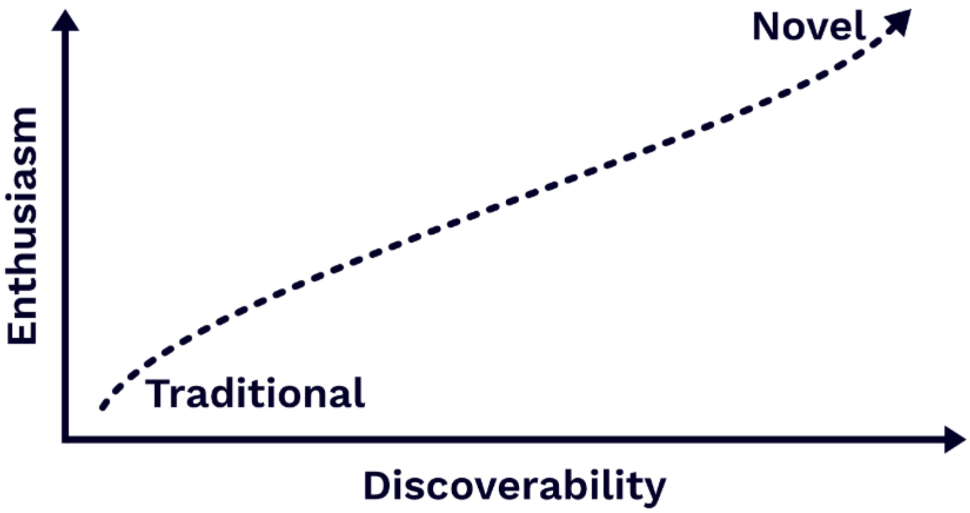

Figure 61: Traditional controls should be easily found for non-enthusiasts, novel controls should only be found by enthusiasts.

Give immediate control

The slimmer dimmer disables any automatic behavior related to the lights you are controlling. This gives the user immediate control when they are using the device.

Users expect control
During scenario testing, participants were confused when they did not get immediate control. They felt out of control when they had given input that the system ignored.

> *"Things going off when I turned them on was definitely not control." ~ Scenario 1*
>
> *"When turning the dial, it should know I don't want it to be automated?" ~ Scenario 2*
>
> *"I didn't expect the light to turn off again, because I felt I had overruled it." ~ Scenario 2*

The following scenario test disabled automatic behavior immediately. Participants were a lot more ambivalent about their feeling of control. Some thought they had control over the situation, others wondered how they can change the system or control different lights. However, the idea that the system is still in charge was no longer a concern.

> *"Definitely, the manual aspect. It gives me a lot of control" ~ Scenario 3*
>
> *"If I have the knowledge to change it, then I have control" ~ Scenario 3*
>
> *"Now, I can control this light, what if I want to change another one?" ~ Scenario 3*

Enthusiasts are the ones who can adapt
Aside from non-enthusiasts gaining control, enthusiasts do not lose anything. During tests with enthusiasts, they were able to understand the behavior of the device in less than a minute. When their automations don't work, they know how to enable them.

> *"You can turn it on/off, dim it, that is in manual mode, to get back to automatic mode, you long press." ~ Communicating 2*
>
> *"The main thing is control lights. You can do it manually. You can also hold the button and set it to self-adjustable mode." ~ Communicating 2*

Facilitate adaption

The slimmer dimmer keeps track of all moments when the dimmer is used. When the dimmer is used, the automatic system is not sufficient. This information is transformed into insights and they are made to help the enthusiast improve their automations. This facilitates them to adapt their system when behavior changes or exceptions are found.

Tensions between enthusiasts and non-enthusiasts
This need was originally found when analyzing the contextmapping session. When enthusiasts do not keep up with fixing the small problems that arise, tensions between inhabitants and technology can increase. Facilitating adaption tackles this issue by giving the enthusiast tools to keep those tensions at bay.

AI does something similar
Literature also mentioned how households are socially complex and routinely involve breakdowns, improvisations, compromises and conflicts (Davidoff et al., 2006). Some closed source products deal with this unpredictability by learning from user behavior, such as the Nest thermostat. The thermostat utilizes AI and implements findings by itself. DIY smart homes don't have AI, but they have an enthusiast. This enthusiast needs similar information as the AI, but presented in a way that is usable for them.

Enthusiasts recognize the need
When communicating these insights to the enthusiasts, they were very receptive. They put these issues in their own words and obviously recognize the need for these insights.

> *"Basically, these devices. They are smart, but not that smart. They don't allow for improvisation. This allows me to overrule that and hopefully train the system behind it to be more adaptive to me." ~ Communicating 2*
>
> *It makes it easier as long as the automations work. And then you can use the insights to improve them. The better you configure the automations, the less you use the device. You just don't need it at some point." ~ Communicating 2*
>
> *"That is very valuable. Those insights." ~ Coaches during green light meeting*

Directions for development

Since the device has been developed into a fully functional prototype, it makes thinking about the next steps very tangible. Could this device be used to teach your home? What happens when you have 10 of these devices in a pile? This chapter gives some answers, mostly open-ended.

Now an enthusiast, later an AI?
The insights are now aimed at an enthusiast, but the insights could also be aimed at an AI that improves your automations. This is not being done for entire homes, but products like the Nest thermostat already adjust their own behavior on a smaller scale.

The insights could also be aimed at both the enthusiast and the AI. Some insights might be easy to implement and could be done automatically, where larger issues might require a change of sensors or actuators.

Training the house
Instead of only learning when mistakes happen, the device could also be used to make suggestions for automations. The device could then be used for a month, without any automations in the home. By carefully looking at your usage of the device, the dimmer could suggest automatic behavior to introduce.

It will likely be a long time before this can actually replace the creative aspect of an enthusiast. An enthusiast thinks of new behavior to add to their house, things that currently can't be measured yet. For an AI to take this role, they need a lot of additional information.

Insights provide an explicit moment to ask permission
Enthusiast systems are very privacy-focused, but sometimes functionality can be received by giving some information away. The insights could be a place where permission for correlating data is explicitly given. When it is clear how the data could improve the system and it asks explicit permission, an enthusiast might be willing to take the step.

What happens when you have 10?
Currently, the vision is that the slimmer dimmer is in every room. Since they are all wireless, you could put them all in one pile and spend a while separating them. This could be solved in multiple ways, with labeling or color coding being the most boring ones.

Since the dimmers have a hole in the wall that doesn't move, they could be paired to any room by placing the dimmer in the hole. This makes the remotes interchangeable per room. This also makes it possible to use all of them at the same time in one room!

The dimmer could also determine its position by checking signal strength towards the lights around it. This could triangulate the room you are in and automatically control the correct lights.

Controlling specific lights
In addition to determining a room through signal strength, the dimmer could also use this to control specific lights. A user could walk up to a lamp and whichever lamp is closest, is then controlled by the dimmer.

Extra controls
Currently the dimmer only supports double-clicking for a custom button and press turning for custom control. This could be expanded to triple clicks or more. This can definitely be implemented, but is not as easy to use. However, since the dimmer is aimed at enthusiasts, it is probably best to implement this feature.

Concluding

With the context, process and results presented, this project can be concluded as successful. The original research goal was to investigate how a smart home may combine the control and flexibility of an open source platform with the convenience of a proprietary service-based system, while inclusively catering to a diverse group of inhabitants.

The project achieved an answer to this goal by using the research through design method. This method provided many moments of validation and reflection, finally resulting in research findings. These research findings were presented in a distilled manner as the following design principles: protect domestication, give immediate control and facilitate adaption.

The findings were also presented through a design, the Slimmer Dimmer, which dealt with a specific scenario. The principles and the design were developed in unison and only separated at the end of the project. This assured both the principles and the design were properly validated in context. It also made the principles tangible for other designers and provided options for further development of the slimmer dimmer.

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