Our mistakes are invisible: What smart technology designers can learn from visually impaired users

Merel Vermeeren
TU Eindhoven, Industrial Design
Eindhoven, The Netherlands
m.h.m.vermeeren@student.tue.nl

ABSTRACT

Smart technology has the ability to be both an aid and an obstacle to blind people. Despite its great contributions to their autonomy and convenience, mainstream smart technology design often fails to regard blind users in its practices. This paper discusses accessibility as a broader practice and resources for its implementation, and addresses the lack of such resources specifically for smart technology designers which specifically facilitate a design's accessibility for blind users.

This paper provides insights for these designers into the blind user group's experiences and habits, and into our own practices that lead to accessibility problems. Combining these two perspectives, it is found that accessible design principles for blind users strongly relate to usability principles, and can specifically address weak aspects of a design. This results in the creation of an evaluation tool for designers that facilitates the application of these principles in design for a broader user group.

Author Keywords

Smart technology; smart design; usability design; accessibility; visual impairment.

INTRODUCTION

Blind people have a great interest in smart technology. It can offer them more personal autonomy and convenience in everyday life, and can be an appealing alternative for costly assistive technology (Morris & Mueller, 2014; Leporini & Buzzi, 2018). However, many smart devices are difficult or impossible to operate for blind users. It seems like disabled users are often forgotten in the development of mainstream smart products (Klironomos et. al. 2006), with the notable exception of specialized smart design targeted at disabled users only (Chang et. al., 2005; Vovos et. al., 2005). Although specialized tools to aid visually disabled users are useful and desirable, broader accessibility in smart technology is essential to their digital inclusion and social participation (Klironomos et. al. 2006).

There are many guidelines and initiatives to increase digital and technological accessibility for visually disabled users, which are further discussed in the Related Works section of this paper. These largely subscribe to the principles Design for All (DfA) and Inclusive Design, which emphasize accessibility for a wider range of users, including those with disabilities in the target group, rather than placing an exclusive focus on visually disabled people. A prominent argument for this approach is that providing greater accessibility, by reducing the capability demands for users, improves the overall usability of the design (Theofanos & Redish, 2003; "Why do inclusive design?" 2007)

Despite the availability of these current resources and their potential value, they are not universally adopted in industry practices and design education. A publication of EDeAN (Klironomos et. al. 2006) explains this as follows: "In the Information Society, the adoption and practice of DfA, although advocated by many actors in the field, still presents significant challenges, due to the inherent characteristics of the sector, and in particular the established industry practice of designing mainstream products targeted to the so called 'typical' user.". It is stated that accessibility is commonly seen as a separate practice rather than a standard requirement of usability design, and therefore excluded from the design and development process. Although these resources aim to include these principles in usability practices, their exclusive focus on accessibility could be a contributing factor that separates them from this practice. This suggests a need for resources that can be more easily integrated into the established norms.

Furthermore, (as is addressed in the "Related Works" section of this paper) these resources are not specifically created for smart technology designers. They don't provide simple, field-specific guidelines and evaluation tools that can be easily implemented. This paper therefore aims to contribute to the creation of such field-specific guidelines and tools.

This paper also addresses another practical issue regarding the accessibility of smart technology for blind users: While recognizing the importance of a broad approach to technological inclusion, the complete integration of blind users into a more general "disabled target group" can also be a disadvantage for smart technology designers aiming to include blind users specifically. This paper therefore first aims to narrow its scope and provide insight into the experiences, habits, and struggles of blind users of smart technologies, the specific elements that create or hinder accessibility, and how the current approaches of designers facilitate these elements. These are then reintegrated into the larger context of accessible design for a broader user group, resulting in the creation of an evaluation tool for smart design that applies to a wide range of users, promoting the inclusion of accessibility principles in usability design for smart products.

RELATED WORKS

Accesibility Guidelines and Tools

The eEurope 2002 and 2005 action plans[1] recognize the compelling need for "an information society for all" and aim to increase the digital accessibility for those with disabilities. This resulted in the creation of the European Design for All e-Accessibility Network (EDeAN), connecting European organizations and projects to coordinate the development and adoption of accessible products and services. There are three attitudes about achieving DfA: 1) design of products suitable for every user, 2) design of products that are compatible with accessibility tools, and 3) the design of customizable products to suit different user needs (Bühler & Stephanidis, 2004). Many guidelines for designers are based on this approach (Maybury, 2001; Nicolle & Abascal, 2001) for technological product design, but do not specifically address either smart technology or blind users.

The World Wide Web Consortium (W3C) is an important contributor to digital inclusion in information products through their Web Accessibility Initiative (WAI)[2], which publishes accessibility standards and guidelines, most of which ascribe to the second principle of DfA. While these are specifically applicable to smart and digital products, they are aimed at programmers rather than designers, and do not specifically address blind users.

The University of Cambridge Online Inclusive Design Toolkit ("Inclusive Design Toolkit", 2007) provides guidelines and tools for evaluating and expanding the accessibility of products through the inclusion of disabled users in the target group, similar to the first and third principle of DfA. These describe or simulate the interaction experiences and needs of people with various disabilities. Furthermore, their Exclusion Calculation Tool[3] can increase understanding of the capability demands of a design, and assesses the amount of users in the British population to whom it is inaccessible (Waller et. al., 2013). While the toolkit is aimed at designers and can be applied specifically to blind users, it does not specifically apply to smart products.

Alternative methods for communication with graphical interfaces for blind people

The popular adoption of graphical user interfaces has caused great concerns about inaccessibility in the blind community (Boyd, Boyd, & Vanderheiden, 1990). Similar concerns were prominent around the development of smartphones and touchscreens, but following the first introduction of a screen reader function on iOS systems, smartphones became widely adopted amongst blind users (Morris & Mueller, 2014). Screen reader software for touchscreen devices has become a standard for operation amongst blind users, and has promoted the inclusion of blind people in technology and society.

The audio translation of information from visual interfaces has long been considered the ideal method for communication (Mynatt, 1998). Although less commonly used, alternative methods for the translation of graphical interfaces that mix audio and tangible information have the ability to provide a more engaging and intuitive interaction (Van Hees, Kris, & Engelen, 2005).

In the development of specialized smart (home) technology for blind users speech operation and feedback has been the prominent standard for interaction (Ciabattoni et. al., 2018; Vovos, Kladis, & Fakotakis, 2005). The additional inclusion of tactile communication methods is also prominent, especially for smart products outside the home (Chang et. al., 2005; Liu, Bacon, & Wilson-Hinds, 2007).

METHODS

Semi-structured interviews with blind users of smart technology

To provide an understanding of the target group in the broader context of accessible smart technology, four semi-structured interviews were conducted with blind participants who have experience with smart (home) technology in their everyday lives, as displayed in table 1. The duration of each interview was approximately 90 minutes, and took place in their own home environment. These interviews were recorded for transcription.

These interviews aimed to provide a realistic insight in how blind people use and experience smart technology and to what extent designers have met and could meet their needs and preferences. These insights are used to evaluate how to meet these needs and support their habits of use, which can help to bridge the previously addressed absence of specific guidelines for smart technology for designers.

A wide range of topics were discussed with the participants relating to both (smart) technology and their everyday life. These topics included their use of and approach to (smart) technology, its perceived value and accessibility, everyday experiences and habits, interaction preferences, personal attitudes, specialized design for blind users and universal

[1] http://europa.eu.int/information society/eeurope/2005/all about/action plan/index en.htm

[2] https://www.w3.org/WAI/

[3] http://calc.inclusivedesigntoolkit.com/

Parti-cipant	Gender/ age	Visual impairment	Occupation/hobbies	Living situation	(Smart) devices and specialized aides
A	Male/72	Blind, has gradually lost visual ability though life	Retired instructor of English teachers, involved with Oogvereniging and NVDA, walks short distances	Lives with sighted partner	Google Assistant, smart lightbulbs, Android smartphone with TalkBack, Windows computers with screen reader software, Trekker, Buzz Clip, talking kitchen scale, cane
B	Female/43	Blind from birth	Braille teacher for Visio, has designed braille puzzle book and blind guided art tour	Lives with sighted young child	Google Assistant Mini, smart lightbulbs, smart TV, iOS smartphone with VoiceOver, iOS smart watch, Windows computer with braille display and screen reader software, color scanner, guide dog
C	Female/48	Blind from birth	Administrative assistant, informal consultant for VI workplace tools and smartphone use, amateur radio broadcaster and musician	Lives with sighted partner	iOS smartphone with VoiceOver, iOS tablet, Windows computer with braille display and screen reader software, smart thermostat, DAISY reader, Webbox, cane
D	Male/52	Blind from birth	Systems architect, IT workplace accessibility advocate and consultant, gadget enthusiast	Lives with sighted partner	Google Assistant, smart lightbulbs, video doorbell, smart TV, iOS smartphone with VoiceOver, Windows and Linux computers with braille display and screen reader software, media streaming devices, smart speakers, smart solar panels, remote-controlled shutters, DAISY reader, cane

Table 1. Overview of interview participants.

Evaluation	Framework	Participants	Project type	Design description
1	Iteration 1	Group (4)	Design research	Embodiment of remote for home security, digital and physical abstract remote controls
2	Iteration 1	Individual (1)	Design	Smart navigation for blind users, embodied interaction with wrist watch, smartphone app
3	Iteration 1	Individual (1)	Design	Communal solar energy sharing, embodied artifact for energy management, smartphone app.
4	Iteration 2	Group (2)	Design research	Automation of music volume and sharing, flexible embodied interface.
5	Iteration 2	Individual (1)	Design	Awareness of energy use, embodied artifact for energy transportation to devices.
6	Iteration 2	Individual (1)	Design	Personal items as storage for memories, physical interface broadcasting media from items to smart screens.

Table 2. Overview of design students participating in evaluation workshops

accessibility, and their wishes regarding (smart) technology in the present and future. To gain more in-depth information, the researcher steered the conversation with open questions such as "How do you approach the obstacle you described?", and "How would you prefer to interact with this smart device if it was redesigned for you?". The researcher also asked the participant to demonstrate certain interactions with (smart) technology, adaptations to devices and their home environment, the use of assistive devices, and other relevant information. To record relevant insights and observations notes were made by the researcher and pictures were taken with respect to the privacy of the participant.

Analysis and design

A qualitative analysis was conducted from the interview transcriptions, insights, and observations in which these findings were grouped and sorted into themes. After the analysis of the data, the resulting categories and connections were discussed in-depth with another industrial design student to evaluate them in a greater context involving our own practices, and create specific guidelines applicable to smart technology and relevant to smart technology designers. These findings and guidelines were translated into a framework for the evaluation of smart design and its specific attributes. This framework is meant as an analysis and starting point for adaptions that include the target group in smart design.

A follow-up study was conducted to evaluate this framework in the intended context of smart home design, and improve its suitability and overall quality. The framework was employed through 6 workshops with Industrial Design students from the squad "Designing for Growing Systems in the Home", who are displayed in table 2. These workshops consisted of an introduction to the research purposes and findings, after which the students evaluated their own designed prototypes with the framework. This was followed by a joint discussion of the results, a brainstorm about eventual changes and additions to the design, and a joint discussion about the framework and methodology.

After the third workshop, a second iteration of the framework was developed from the students' feedback as well as relevant literature. The second iteration of the framework was deployed in three more workshops following the same structure.

RESULTS

Interview Analysis

A qualitative analysis was conducted from the collected interview data, in which the data was sorted in categories. The most relevant categories and findings are described below, along with relevant quotes from participants to illustrate these findings. A full overview of the themes and analysis can be found in Appendix C.

Independence through technology

Participants value the independence and convenience that they have gained through technological developments. Many specialized assistive devices exist to translate visual information from or interact more easily with their environment, digital information is made accessible through braille displays and screen reading software.

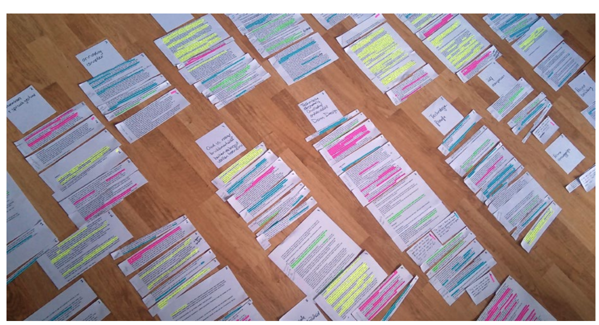


Figure 1. Qualitative analysis of the interviews in progress.

Many apps are easier to operate than desktop websites because they provide a clearer overview and structure, which increases digital accessibility. Smart technology and smartphone apps can also offer appealing alternatives to assistive devices, that are often expensive and bulky. The smartphone offers information about the user's surroundings through apps for navigation, public transportation, image-to-text translation, news updates, and more. Smartphone apps that control smart devices in the home allow users access to many kinds of technologies that were previously difficult or impossible to operate without aid from a sighted person.

"In the past you were very dependent on what sighted people decided was appropriate to translate into braille- or audiobooks. These days you can just buy any .epub and read it yourself with a braille display or screen reader software." – Participant D

"Back then you could only use internet [at home on your desktop computer], and if you went out and something unexpected happened, as a blind person you were dependent on other people around you. Now that the smartphone exists you have a lot more grip on things." – Participant C

"I'm very happy with [my smart thermostat] because I can change the program settings myself. I don't have to rely on someone's help to operate it, or to tell me if the batteries are empty (...) I just check if there's an app that I can use." – Participant C

"At a certain moment the computer was introduced [at work]. For me this meant that I was suddenly able to do my job for a much longer amount of time." – Participant A

Participants also address the limitations of smart technology. Users rely on guesswork and memory when information is not available to them, for example, how far they turned a dial, if the food in their fridge is still good, or if a device is displaying an error message.

"Some devices I can navigate by feeling the interface (...) There are devices that only have a touch interface, I can't use those if there is no spoken feedback." – Participant A

"[This app] is not as accurate as a scanner, but it's very useful for knowing if you're indeed doing what you think you are doing." – Participant C

"It would be useful to know if there was an app that could tell me if my bread or my cheese had expired. I usually remember, but when I forget I can't always tell those things by smell." – Participant B

Screens can be made operable by providing information through speech, either as a part of the device's function, or through an app or connection with a smart home assistant.

Opinions are divided about the use of voice commands, some find them very convenient but others have privacy concerns.

"If something can talk I can work with it. However, being able to work with a device is different from being able to work pleasantly with it." – Participant C

"Our coffee maker shows everything on a screen, but that information is useless to me. If it were possible to interface with my Google Assistant… It would be useful to know what happens." – Participant A

While participants value their independence and autonomy, they recognize their own limits and struggles. In some situations they ask a sighted person for help, in others they prefer to spend more effort on a task by themselves.

"If I'd ask my wife she'd be able to tell me [this information] in a second, whereas it would have taken me maybe one and a half minutes to find this out. However, if I can do it, I prefer to do these things by myself. Even if it takes longer." – Participant A

"Sometimes I wonder if it's necessary to solve every problem you have with technology, or if you need to accept that your handicap doesn't allow you to do something and ask others for help. Those are deliberate choices you need to make." – Participant B

Figure 2. Illustration of a blind user operating an inaccessible smart oven through a smartphone app.

Philosophy and attitude towards technology

Participants have a positive attitude towards smart technology and technological developments. One factor is personal interest in these gadgets, but there is also a strong awareness about the benefits of following these developments as a blind person.

"I'm still tinkering a little with [my Google Assistant]. It's often faster to use an app, and we prefer not to leave the device on all the time. This is more about figuring out what such a device can do. If I become invested in this I will buy a Homey, that one can talk to all kinds of devices." – Participant D

"I like to keep track of these things because I like them, but also because I know nowadays it's a huge benefit as a blind person to know a lot about technology" – Participant C

The price of a design is one of the main reasons users are hesitant to adopt new smart- and specialized devices. These are not always useful enough to make up for the high costs attached.

"It is of course useful for knowing the time, but you can also just buy a braille watch or talking watch instead of an expensive smartwatch. If it hadn't been a gift I wouldn't have bought one myself. (...) Although it's fun to track my fitness goals or measure my heartrate, I find it an expensive toy." – Participant B

Many household appliances are considered unnecessarily complex, because of the many options available through the menu that are not used. Participants often don't know what to expect from new technology, even when it is specifically designed for them. They either experiment themselves or wait for others to discover the usability and usefulness.

"It would be nice to be able test these things in advance. I haven't bought a smart washing machine yet, because I'd hate to buy such an expensive device only to find out that I can't work with it." "The same thing applies to the special talking washing machine, (...) I'd rather buy a regular cheaper machine of better quality, and hire a domestic help for laundry." – Participant B

Falling behind (old vs. new)

Many new (smart) devices are difficult or impossible to operate for users, but they are very hopeful that smart technology and apps will make it easier for them to operate devices in general. The lack of non-visual information about user interaction with the device is the main reason for this inaccessibility (i.e. rotary dials turn forever, silent and smooth touch interfaces). Many older devices are used that contain physical buttons because these are easier to navigate, but these interfaces are rare in modern products. Users hope that connecting smart devices in the house to smart home assistant or smartphone apps can provide them with audio feedback and input.

Although they state innovation offers more freedom and convenience, participants fear future technology will be inaccessible. They have difficulty finding modern devices they can easily operate. Special adjustments such as software and hardware changes are quite expensive because of the limited market. People are also unsure if new technologies are covered by health insurance.

"The introduction of Apple's Talkback was incredible. When touch screens were first introduced, blind and visually impaired people were afraid we would be left out." – Participant A

"I have chosen this washing machine explicitly for its dial with an physical indication of the arrow, that way you know what program you're selecting. I also placed some tactile stickers on it. When you're buying something new many devices are excluded because you can't use them. A device like a [luxury coffee maker with touchscreen interface] I can't buy, no matter how much I like it or how highly it's rated, because I cannot do anything with it since it can't be operated as a smart device, there's no app for it." – Participant C

"Some things cannot be operated. We own a microwave oven that I cannot operate myself, because it has a touchscreen. I use a spare old one when I'm home alone." – Participant D

Technological obstacles

Participants talk a lot about design choices and attributes that make a product inaccessible or difficult to use.

It is difficult or impossible to operate devices without physical or audio feedback (for example, rotary dials that turn forever, smooth and silent touch interfaces, and silent visual notifications). People find this missing information annoying, it impacts the usability of the design. Often there are no accessibility settings on the device or different methods to interact with it (for example, voice controls, connection to an accessible smartphone app, remote controls). It is not always possible or useful to place tactile stickers on devices or make other adjustments to work around this.

A lot of digital information is not compatible with screen reading software because of messy coding. Programming mistakes made in a hurry are often not noticeable by sighted users, but cause problems for screen readers (for example, alt text for links is missing, buttons are not classified as buttons and not recognized). Participants think that programmers are not aware such things cause problems for accessibility, and are often not aware of blind users at all

Users have trouble when buying new technology, because many devices are difficult to use or not operable because of the interface design. Smart devices can also be less practical compared to the current devices and methods they use.

"The old model was popular amongst blind people, but the new model isn't usable. They replaced the buttons with a touch screen." – Participant D

"I want to control a device by myself without needing to think of a trick to make it work" – Participant C

"A screen can look very nice, but the information that supports it is invisible to the eyes. (...) It's fun that I'm able to find different mistakes than my sighted colleagues, because I rely purely on the underlying information." – Participant D

Menus can be difficult to navigate because they contain many steps and information is missing. This problem occurs for both digital and embodied design. Another common problem is that the function of buttons and interface items can change during the interaction. Users have to memorize steps they need to take or the function of unlabeled items, which often means they use few of the device's functions. This also requires a lot of guesswork and workarounds.

"If a smart device contained something for orientation then I think I can probably operate it, for example, hearing sound feedback or having a small button. That can even be practical for sighted users." – Participant D

"If there are one or two [unlabeled] buttons it's not that bad, but if no buttons are labeled then it's quite annoying to memorize them." – Participant C

Participants do not mind making small adaptions to devices or using alternate ways to control them. Orientation of devices can be improved by adding tactile information.

"Designers can decide to always use physical buttons, that's an option [to increase accessibility]. You can also decide that when you're designing a touch display interface, you make sure there is an app for to offer an alternative method to control the device. That would appeal to an extra target group." – Participant C

"Most devices that can be I can control through an app I operate with apps. I also have a lot of "dumb" devices, those I can't use as easily. I'll have to find a solution for those. For example, you can guess the location of a button on a touch interface through the length of your finger." – Participant D

"I have Apple TV, but I don't use it often because I'm trying to figure out how to control all these devices with one remote. It's probably possible, but someone else would need to program it for me." – Participant B

Universal accessibility

Participants mention the principle that accessible design creates more user-friendliness for all users. Some cited examples are the Webbox, Google Assistant, and accessible software.

They think developers and designers often forget to consider them rather than deliberately excluding them form the target group. Participants suggest that a lot of accessibility problems can be avoided if the methods and standards used by make it easier to take accessibility principles into account.

"If you have good tools, you won't forget [including users]. There are many types of forgetfulness, I mentioned the factor of time, which is a universal boogeyman. It depends on budget, interest, intention, quality standards, and the requirements that are stated at the start of a project." – Participant D

"I'm a good braille reader, but I think that improving the accessibility of operating a smart TV would be more useful and cheaper with voice commands. This is also a more common technology that is suitable for users who are blind, visually impaired, mentally impaired, dyslectic, and so on, than braille feedback. There are also many visually impaired people who cannot read braille." – Participant B

"For example, the Google Assistant is something that anyone can use. (…) It is more inclusive than most products that are specifically designed for blind, visually impaired, or physically impaired users. If you can help people with [targeted design] of course you should, but if it's possible, take the largest possible target group into account when starting development." – Participant A

Designer Discussion

When discussing these results and comparing them with our own experiences and practices, we were initially aiming to discover how we could make our work more inclusive for blind users. However, we came to a few unexpected insights that suggested the opportunity for a broader application of this work.

The problem with our practices

Firstly, designers often forget to take the usability of disabled people into account. Our "standard" target user is not disabled, therefore accessibility is often considered a low priority. We recognized the tendency to view accessibility as a separate practice from usability design. Because of this, seeking out accessibility guidelines and toolkits seems irrelevant to our goals, and our tools and methods don't require us to work according to accessibility guidelines.

Secondly, our haste causes a lot of issues for blind users, but also for ourselves. Minimum viable products, design sprints, and hackatons encourage hastily constructed code that cuts corners and skips accessibility testing. This type of code contains flaws that go unnoticed in a visual interface but cause problems for screen reader software. By prioritizing fast results, we produce code that is difficult to maintain on a long-term basis. This also means later changes to increase accessibility take a tremendous amount of work.

Thirdly, we often focus on designing one perfected interaction method. While it seems practical to refine one interaction method with a smart product before considering others, this also imposes limitations. Allowing multiple interaction alternatives and compatibility with many devices enables a wider possibility for integration in the smart home, which also offers blind users alternative interaction methods. Taking the possibilities of multiple interaction methods into account early on in the process can also ensure freedom of choice between different interaction methods for the user, which addresses different user preferences.

Requirements and opportunities

We noticed that a lot of the difficulties blind users experienced when interacting with these products could be solved by small changes to the design. For example, presenting visual information in a different manner, adding tactile information to a smooth interface, or providing alternative methods to interact with the design.

When discussing the users' experiences and struggles, we noticed many of these related closely to common usability principles. Blind users' needs and preferences often overlap with those of the "standard" demographic designers appeal to. However, when the designer fails to meet these needs, the consequences often go beyond a simple inconvenience or unpleasant interaction experience, and make the design inaccessible to a large degree.

A lot of accessibility problems seem to indicate deeper underlying issues in our work and practices, which impact other target users or the quality of the work. As visually unimpaired designers we rely heavily on our eyesight, which causes us not to notice certain aspects of the work we deliver that cause problems to blind users. The perspective and experiences of blind users can be used as a starting point to address these aspects to designers.

By grouping the experiences, needs, and habits of blind users and smart product design principles, guidelines can be constructed to create accessible design, but also an opportunity is found to improve the usability and general quality of the design through such guidelines. The creation of these guidelines and the evaluation framework is discussed in the next section.

DESIGN

Creation of Guidelines

Communication of non-visual information

Firstly, the heavy reliance on visual communication with a design stands out. Users addressed the lack of non-visual information available to them as a prominent obstacle. This also impacts the experience of sighted users, albeit to a lesser degree.

Because the reliance on exclusively visual feedback requires constant cognitive attention from users (Stepp & Matsuoka, 2010) and multi-sensory feedback benefits the interaction with physical objects for non-disabled individuals (Huang, Gillespie, & Kuo, 2007), it is a desirable practice to communicate to the user through more types of information than visual. Rich interaction (Frens, 2006) addresses feedback and feedforward through the integration of form, interaction, and function in a design, relating to tangible interaction and the user's own skills. This type of interaction opposes the principle of "flat" interfaces in the design of smart products, allowing multiple different types of information to be communicated to the user through embodiment.

Complexity of interaction

This also relates to the complexity of the interaction with a design. Designers aim to create intuitive interactions that require little effort from the user. The unnecessary complexity of an interaction often comes to light during user evaluations and testing. The lack of available information for blind users in a complicated interaction shows this even more prominently.

Because they often rely on memory and limited information, lengthy interactions consisting of many small steps are considered difficult, especially if the function of locations or buttons changes throughout the interaction.

Code quality

Another insight is that the quality of the code structure directly impacts the accessibility of digital design. A prominent problem for blind users is the incorrect classification of objects. Another issue is that programmers have difficulty reading and making later changes to hastily constructed code, which makes increasing accessibility a difficult task. Creating awareness for designers about the programming quality can help them improve their code's maintainability and reliability, with the added benefit of improving screen reader accessibility.

Alternative methods of communication and interoperability

The participants' prominent use of workarounds and alternative methods to interact with devices was an important insight into the role of smart design in creating accessibility.

Inherent accessibility settings allow users to tailor experiences to their preferences and needs (Morris & Mueller, 2014). Alternative interaction methods such as voice recognition, or speech-to-text/text-to-speech, enables control without the requirement of sight or touch, contributing to blind users' proficiency with the device. If a design is inoperable by itself, connection to another device can offer such an alternative interaction method suitable to the user by different actions or methods to provide feedback and feedforward.

The need for universal communication between smart devices is extremely relevant for the usability and accessibility of blind users (Liu, Bacon, & Wilson-Hinds, 2007), as well as other demographics such as mobility-impaired users (Bekiaris et. al., 2009). This supports the concept of the interoperable smart home (Harper, 2003) that offers extreme user convenience.

Furthermore, the design of products that are compatible with accessibility tools, and the design of customizable products to suit different user needs are addressed in the implementation of Design for All (Bühler & Stephanidis, 2004). This addresses the value of multiple interaction alternatives and compatibility with many devices to appeal to a wider range of users, with or without disabilities.

Adaptation and flexibility

Another interesting insight from this research were the adaptations made by users and their desire to tinker with devices to create accessibility. Users expressed the desire to add different types of information to devices or change the methods with which they controlled them, through either inherent changes or connections with other devices.

This strongly relates to the principle of resourcefulness, which are the practices through which users adapt, repurpose, and appropriate existing artefacts (Kuijer, Nicenboim, & Giaccardi, 2017). Resourcefulness can be encouraged through allowing a greater degree of flexibility in the interaction with a design. Flexible interfaces and modular design have similar benefits to the earlier mentioned principles of tailored preferences and interoperability in the sense that they provide a broader appeal to different users' preferences and capabilities.

Overview of Guidelines and Framework

The complete framework can be found in Appendix D.

1: Connectivity. The design can easily interact with other (smart) devices.

a. Integration support; b. Completeness of exchanged information (information, control);

The other (smart) devices that the design can connect to determine the degree of integration in the smart home and availability of alternative interaction methods. When addressing the need for connectivity between smart products, it is valuable to consider what type of information is exchanged between these devices, and to what extent the user can operate the design through them.

As can be seen in figure 3, the framework provides an overview of these connectivity aspects for the designer.

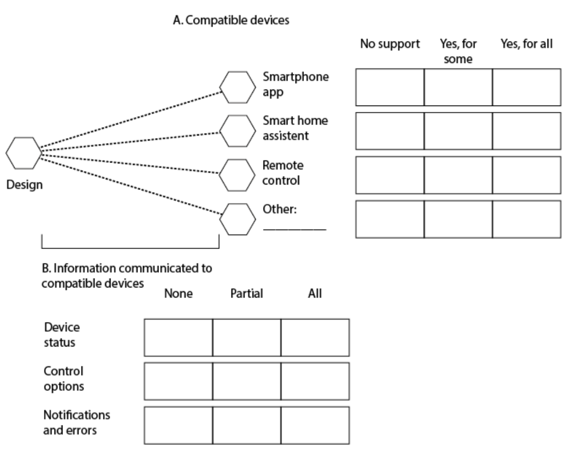


Figure 3. Framework guideline 1: Connectivity.

2: Device to user communication. The design communicates to the user through multiple types of information (visual/physical/tactile/sound)

a. Direct from interface; b. Alternative settings and means; c. External other devices

The information communicated between the user and the device can be divided into the categories of feedforward and feedback, and into types of information that are communicated to the user. This model defines them as follows:

Feedforward: Device status is any information that indicates the device's current actions. *(Interface) functions* indicate what the device is capable of, and how the user can interact with it. *Notifications and errors* concern information about status changes and errors.

Visual feedforward is communicated through (digital) static or interactive elements like colors, icons, text, and lights. *Physical feedforward* is communicated through mechanical characteristics like the design's shape, physical state, present (interface) elements, and location of (interface) elements.
Tactile feedforward is communicated through the embodied characteristics of physical elements like the texture, shape, and size.
Sound feedforward is communicated through the inherent and augmented sounds of the device like jingles, speech and voice descriptions, and operational noises.

Feedback: Interaction feedback is the information in response to communication with the device interface. *Operation feedback* is the information observable by the user when a task is executed.

Visual feedback is communicated through changes in (digital) (interface) elements like colors, icons, text, and lights.
Physical feedback is communicated through direct or indirect changes of mechanical characteristics like the design's shape, physical state, movement of (interface) elements, and location of (interface) elements.
Tactile feedback is communicated through haptic responses from the embodied or digital characteristics of (interface) elements like clicks, mechanical resistance, vibration, and operational haptic information.
Sound feedback is communicated through inherent and augmented audio responses like jingles, speech and voice descriptions, and operational noises.
The inclusion of multiple types of information in this overview allows the designer to evaluate its extent and diversity. The categories and types of feedback and feedforward are laid out in columns to assess the total variety of the information.

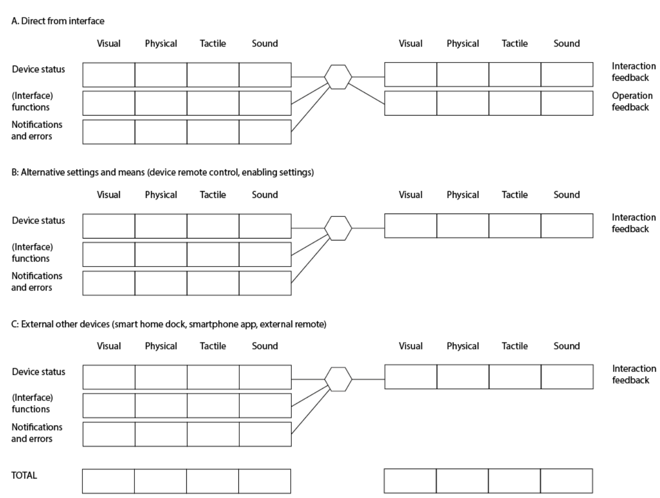


Figure 4. Framework guideline 2: Device to User communication.

This guideline, shown in figure 4, provides an overview of not only the direct interaction between the user and the standard device interface, but also of the other means of interaction that are common for blind users: alternative (accessibility) settings and controls included in the device, and through the use of external other devices. By creating such an overview of information from each method, designers can gain a more holistic view of its possible communication to the user.

For example, a design's direct communication to the user can be largely visual through its touchscreen interface, but through a connection with a smart home assistant audio information is added, which can provide a more engaging and intuitive experience. In their assessment, designers are able to "find the gaps" in the design's communication to the user, and address them in the design itself or through a connection with another device.

3: User to device communication. The user can communicate to the design through many types of methods (visual/physical/tactile/sound)

a. Direct from interface; b. Alternative settings and means; c. External other devices

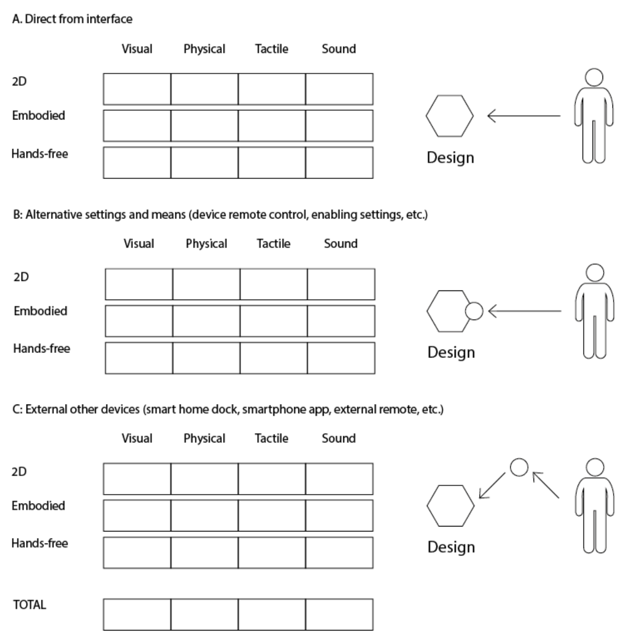


Figure 5. Framework guideline 3: User to Device communication.

This guideline provides an overview of the methods through which the user can communicate to the device, as shown in figure 5. These methods are possible through direct interaction or other means, and rely on different types of information to operate, as are both defined in the previous guideline. Three main methods of interaction are defined as follows:

Two-dimensional interaction describes interaction with flat surfaces and digital interfaces. For example: tapping touchscreen items, touchscreen gesture commands, and touching smooth interfaces. These interactions mainly rely on visual information, and can contain augmented sound- or tactile information.

Embodied interaction describes the physical manipulation of a tangible artifact. For example: pressing buttons, twisting dials, moving artifacts, placing artifacts. This relies mainly on physical information, often paired with tactile information, but can include all types.

Hands-free interaction refers to interaction methods that require no manual actions, like speech commands, gestures, and location of the user. The types of information they rely on are dependent on the method.

4: Interaction simplicity. Interactions are simple and straightforward.

a. Steps; b. Function allocation variation; c. Duration

Up to four interactions can be analyzed through this guideline. The simplicity of an interaction is described in three aspects:

Steps refer to the amount of smaller actions needed during the interaction to complete a task.

Function allocation variation is defined as changes in functionality of interface elements during the interaction, like the meaning of a button press or the appearance or disappearance of menu items on a touchscreen.

Duration refers to the amount of time it takes (in seconds) to complete an interaction.

The meaning of these aspects depends largely on the context and characteristics of the design, which leaves it to the designer to interpret them.

5: Code durability. Code is maintainable and reliable.

a. Structured and properly labeled code (readable, maintainable, accessible); b. Stable connection to other devices to allow complete interaction

This guideline aims to make designers roughly aware of bad coding practices that cause issues for themselves and accessibility. They are asked to estimate to what extent their design's code embodies the following statements derived from the participants' experiences with screen reader accessibility and the discussion:

The overall clarity and readability of the code is high.

The code is commented appropriately.

All items are labeled correctly and contain alt text.

The consistency of the code is high.

The code's maintainability for future development is high.

The reliability of the prototype's functioning is high.

The stability of the wireless connection is high.

These estimates are subjective to the designer and serve as a starting point for awareness and discussion.

6: (Optional) Flexibility and adaptability. Flexible interfaces are supported by the design.
a. Integrated settings in the design allow different alternatives for the communicated information types and/or interaction methods; b. Open access for tinkering allow users to make changes to allow di-fferent communicated information types and/or interaction methods

This guideline addresses the presence of accessibility settings in the design and the possibility for users to make adjustments to the design. Designers are asked to examine which types of feedforward and feedback are made possible through accessibility settings, creating a more detailed overview of guideline 2b exclusively about these settings. This can help designers estimate the type of accessibility settings needed to provide a large variety of information.

Designers are asked to estimate how easily users can add and change aspects of the device according to the following gradations:

Users can make surface-level adjustments to the device to provide information, such as applying tactile stickers to a flat surface for tactile navigation, or pasting text labels under buttons to indicate their function.

Users can make mildly-invasive adjustments to the device to provide information, such as swapping out an LED for a sound chip, or adding a microcontroller relay for remote control of switches.

Users can make invasive adjustments to the device to provide information, as supported by modular design principles that allow users to change the mechanical and digital functionality, such as swapping digital and physical interfaces, or swapping spoken and haptic responses.

This guideline is categorized as optional in the assessment since these factors are not often included in the scope of student projects. Its inclusion in the framework is intended to address a prominent aspect of blind users' interaction methods with products, and create awareness amongst designers about these factors.

Overview Results and Brainstorming

An overview of the evaluation results is provided as the basis for a discussion and brainstorming session. The purpose of this brainstorming session is to assess to what extent the design embodies these guidelines, which guidelines are desirable for the design to embody in respect to its operation and purpose, and insights for changes and additions to the design.

CONCLUSION

This paper aimed to address the need for integration of accessibility principles for blind users into the usability design of smart products. This study first provided insights into this user group and the difficulties caused by this current lack of this integration. It was found that experiences and habits are strongly connected to current design practices and attitudes, but also to the broader perspective of usability principles and problematic aspects of design that impact its operation and general user interaction.

From these insights and discussion, guidelines were created for more generic usability which includes accessibility for this target group. A designer-oriented framework was created to help identify the manner and extent in which smart technology design meets these users' needs, and to identify opportunities to identify problematic aspects of the design.

DISCUSSION

During the deployment of this framework, workshop participants mentioned they found this tool useful for shaping the interactions of a design, especially guideline 2 was received positively for this purpose as it gave an overview of the information types and categories a design can communicate. The guidelines were generally agreed to involve good design practice or be an interesting insight. In this manner, it can be assumed that the framework is indeed applicable to a more general user group.

For further development of the framework, it is desirable to redesign the evaluation methods of guideline 5 and 6 to more specifically assess these guidelines. Throughout the study these were difficult to assess for students, as they lacked information about the subjects, which prevented their further development due to lack of feedback. Method 5 can be further developed by basing its assessment on the W3C standards to substantiate its methodology. Method 6 can be improved to include design principles for promoting resourcefulness.

Ideally, the next iteration of the framework could be in the form of an interactive web tool, to increase its availability to other designers.

ACKNOWLEDGEMENTS

I would like to thank Lenneke Kuijer for her coaching and support throughout this research project. Special thanks go out to the interview participants for both their hospitality and valuable contribution, Daphne Muller for her help evaluating results and our following discussion, and the students of Designing for Growing Systems in the Home squad for their help testing the framework and their feedback.

REFERENCES

1. Bekiaris, E., Kalogirou, K., Mourouzis, A., & Panou, M. (2009). An interoperable concept for controlling smart homes - The ask-it paradigm. In *HCI 2009: Human-Computer Interaction. Ambient, Ubiquitous and Intelligent Interaction* (pp. 377–386). San Diego, CA, USA. https://doi.org/10.1007/978-3-642-02580-8_41
2. Boyd, L. H., Boyd, W. L., Vanderheiden, G. C. (1990). The graphical user interface: crisis, danger and opportunity. *Journal of Visual Impairment and Blindness*, 496—502.

3. Bühler, C., & Stephanidis, C. (2004): European Co-operation Activities Promoting Design for All in Information Society Technologies. In *Proceedings of the 9th International Conference on Computers Helping People with Special Needs (ICCHP 2004)*, Paris, France, 7-9 July (pp. 80-87). Berlin Heidelberg: Springer-Verlag.
4. Chang, T.-H., Ho, C.-J., Hsu, D. C., Lee, Y.-H., Tsai, M.-S., Wang, M.-C., & Hsu, J. (2005). iCane – A Partner for the Visually Impaired BT. In T. Enokido, L. Yan, B. Xiao, D. Kim, Y. Dai, & L. T. Yang (Eds.), *Embedded and Ubiquitous Computing – EUC 2005 Workshops* (pp. 393–402). Berlin, Heidelberg: Springer Berlin Heidelberg.
5. Ciabattoni, L., Ferracuti, F., Foresi, G., & Monteriu, A. (2018). Hear to see-See to hear: A smart home system user interface for visually or hearing-impaired people. In *IEEE International Conference on Consumer Electronics - Berlin, ICCE-Berlin* (Vol. 2018–Septe, pp. 10–12). https://doi.org/10.1109/ICCE-Berlin.2018.8576163
6. Frens, J.W. (2006). *Designing for Rich Interaction: Integrating Form, Interaction, and Function.* Unpublished Doctoral Dissertation, Eindhoven University of Technology, Eindhoven, the Netherlands. (Retrievable from: https://pure.tue.nl/ws/files/1743335/200610381.pdf)
7. Harper, Richard. (2003). *Inside the Smart Home*. https://doi.org/10.1007/b97527
8. Huang, F. C., Gillespie, R. B., & Kuo, A. D. (2007) Visual and haptic feedback contribute to tuning and online control during object manipulation," *J Mot Behav*, *39*, 179-93
9. Inclusive Design Toolkit. (2007). Retrieved from http://www.inclusivedesigntoolkit.com/
10. Klironomos, I., Antona, M., Basdekis, I., & Stephanidis, C. (2006). White Paper: Promoting Design for All and e-Accessibility in Europe. *Universal Access in the Information Society*, *5*(1), 105–119. https://doi.org/10.1007/s10209-006-0021-4
11. Kuijer, L., Nicenboim, I., & Giaccardi, E. (2017). Conceptualising resourcefulness as a dispersed practice. In *DIS '17 Proceedings of the 2017 ACM Conference on Designing Interactive Systems*, Edinburgh, UK, June 10-14, 2017 (pp. 15-27). Association for Computing Machinery, Inc. https://doi.org/10.1145/3064663.3064698
12. Leporini, B., & Buzzi, M. (2018). Home Automation for an Independent Living. In *W4A Conference'18, April 23–25, 2018* (pp. 1–9). Lyon, France. https://doi.org/10.1145/3192714.3192823
13. Liu, Y., Bacon, J., & Wilson-Hinds, R. (2007) On smart-care services: Studies of visually impaired users in living contexts. In *1st International Conference on the Digital Society, ICDS 2007* (pp. 2–6). Guadeloupe, French Caribbean. https://doi.org/10.1109/ICDS.2007.31
14. Maybury, M. T. (2001). User Interfaces for All. User Interfaces for All - Concepts, Methods, and Tools.
15. Morris, J., & Mueller, J. (2014). Blind and Deaf Consumer Preferences for Android and iOS Smartphones BT. In P. M. Langdon, J. Lazar, A. Heylighen, & H. Dong (Eds.), *Inclusive Designing* (pp. 69–79). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-05095-9
16. Mynatt, Elizabeth. (1998). Transforming Graphical Interfaces Into Auditory Interfaces for Blind Users. *Human-Computer Interaction. 12.* https://doi.org/10.1207/s15327051hci1201&2_2 .
17. Nicolle, C., & Abascal, J. (2001). Inclusive Design Guidelines for HCI. Taylor & Francis.
18. Stepp, C. E., & Matsuoka, Y. (2010). Relative to direct haptic feedback, remote vibrotactile feedback improves but slows object manipulation. In *2010 Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBC'10* (pp. 2089–2092). https://doi.org/10.1109/IEMBS.2010.5626120
19. Theofanos, M. F., Redish, J. (2003). Bridging the gap: between accessibility and usability. *Interactions, 10*(6), 36—51.
20. Van Hees, Kris, & Engelen, Jan. (2005). Abstract UIs as a long term solution for non-visual access to GUIs. In *Proceedings of the 3rd International Conference on Universal Access in Human-Computer Interaction*, The 3rd International Conference on Universal Access in Human-Computer Interaction, Date: 2005/07/22 - 2005/07/27, Location: Las Vegas, Nevada, USA
21. Vovos, A., Kladis, B., & Fakotakis, N. (2005). Speech operated smart-home control system for users with special needs. In *9th European Conference on Speech Communication and Technology* (p 193–196).
22. Waller, S. D., Bradley, M. D., Langdon, P. M., & Clarkson, P. J. (2013). Visualising the number of people who cannot perform tasks related to product interactions. *Universal Access in the Information Society, 12*, 263-278.
23. Why do inclusive design? (2007) Retrieved from http://www.inclusivedesigntoolkit.com/why/why.html

APPENDICES

A: Personal reflection

In this project my main goals were to gain an in-depth understanding of an unfamiliar user group, and to develop new skills in the context of smart home technology. (Main competencies: User & Society and Technology & Realization.) In the context of contributing to the field of smart product design, I chose to focus my research on the target group of blind people, and in what way designer can improve their experiences with such technology.

My approach to this project was very user-oriented, and focused on understanding the users and their needs throughout the process in accordance to my vision: I believe good design should come from a perspective of practicality and respect for the user's capabilities and experiences. In the context of design research, this means that understanding and valuing users' experiences and capabilities can offer valuable insights about the deployment of our work, and inspire the rethinking of our interpretation of a user group. This requires a thorough understanding of not only the target group, but also the larger social context in which they exist.

To gain such a holistic understanding of this target group, I conducted an extensive orientation study, consisting of a benchmark of current (smart) design for blind users and assistive (smart) devices, industry attitudes towards these users, popular accessibility frameworks and tools, and general information from organized interest groups for blind and visually impaired persons in the Netherlands. This helped me shape the direction of the project to promote the inclusion of this target group in mainstream smart product design rather than specialized design.

To gain further insight into the target group's capabilities and experiences I conducted user interviews and observations with blind people in their home environment, putting to use last semester's experiences setting up a structured study. I had planned to conduct two more interviews, but due to a scheduling conflict and time constraints this was not possible. Although I was able to gain a lot of interesting insights and information from these interviews, my research could have been more substantiated if I had taken these factors into account earlier in the process. In future projects will therefore approach the target group sooner to ensure availability. Another useful way to ensure this could be collaboration with another student involved with a similar target group, in which we can aid each other with finding participants for a user study.

Throughout this project I realized that I could make a more valuable contribution to the field by using these experiences and perspectives as a basis for an evaluation framework to assess how we interpret users' needs in smart design, in regards to usability. In my vision, I address the need for accessibility through the design of specialized products, but this opportunity to promote accessibility as an easily graspable concept for designers is an opportunity I had not considered much before despite its importance. I therefore chose to create an evaluation tool for designers rather than design recommendations specifically for this target group.

To achieve this, design students were treated as an informal second target group in this project, in which I aimed to appeal to their experiences and expertise through discussions and workshops, and relate this back to the blind users' perspectives and guidelines.

This was my first semester in the DIGSIM squad. At the beginning of this project I was largely unfamiliar with working in the context of the smart home. Initially I had planned to create and deploy a research prototype in this study, which would allow me to develop new skills and gain experience working in this context. However, throughout the process it became clear that the direction of the research required no deployment of such a prototype.

My development in this context is therefore largely related to the understanding and evaluation of smart designs and their interconnectivity from both current smart technology and student projects. An interesting aspect of this was the greater awareness regarding the communication of information between the design and user, and between designs themselves. This has made me consider interaction design from a more interconnected perspective, and helped me identify specific requirements and desirable practices. Furthermore, I have a greater insight into interaction design in regards to the kind of information communicated to the user, and the relevance of this information for the usability of a design. Both my user research and the study of frameworks and principles like Interaction Frogger (Wensveen, Djajadiningrat, & Overbeeke, 2004), Rich Interaction (Frens, 2006), and alternative communication of visual information (Van Hees, Kris, & Engelen, 2005).

Last semester I found that it was sometimes a challenge to communicate my ideas clearly through visuals and presentation materials. Color use and visual language played a large role in this. This semester I set out to improve the quality and clarity of my visuals at the demo day. Despite the lack of a present demonstrator, I found that my visuals allowed me to communicate my research focus and goals effectively to others, and demonstrate the habits and experiences of users clearly. I also specifically asked workshop participants for feedback regarding their understanding of the framework, through which I was able to improve the clarity of the guidelines' use and presentation.

A personal development goal was to devote attention to improving the planning and documentation structure of my work process. I have struggled with this in previous individual projects due to both health concerns and planning difficulties, and have worked to develop more sustainable studying methods that respect my physical limits. During this research project I experienced a few setbacks that affected both my health and schedule, which were mainly related to the increased workload compared to last semester. Despite the adjustments in my planning, a deadline extension was needed. Although this is regrettable, it has become clear how much work that I can realistically take on, which will be valuable experience approaching my next semester.

References

1. Frens, J.W. (2006). *Designing for Rich Interaction: Integrating Form, Interaction, and Function.* Unpublished Doctoral Dissertation, Eindhoven University of Technology, Eindhoven, the Netherlands. (Retrievable from: https://pure.tue.nl/ws/files/1743335/200610381.pdf)
2. Van Hees, Kris, & Engelen, Jan. (2005). Abstract UIs as a long term solution for non-visual access to GUIs. In *Proceedings of the 3rd International Conference on Universal Access in Human-Computer Interaction*, The 3rd International Conference on Universal Access in Human-Computer Interaction, Date: 2005/07/22 - 2005/07/27, Location: Las Vegas, Nevada, USA
3. Wensveen, S. A. G., Djajadiningrat, J. P., & Overbeeke, C. J. (2004). Interaction frogger. *Proceedings of the 2004 Conference on Designing Interactive Systems Processes, Practices, Methods, and Techniques - DIS '04*, (January 2004), 177. https://doi.org/10.1145/1013115.1013140

B: Consent forms user research

Toestemmingsformulier gebruikersonderzoek

Ik ben Merel Vermeeren, een masterstudent Industrial Design op de Technische Universiteit Eindhoven. Ik doe onderzoek naar het ontwerpen van smart home technologie voor mensen met een visuele beperking.

U bent uitgenodigd om deel te nemen aan een onderdeel van deze studie waarin onderzoek wordt gedaan naar uw ervaringen met smart technologie in het dagelijks leven. Het doel van deze test is om een beter inzicht te krijgen in uw dagelijkse gewoontes en de manier waarop u (smart home) technologie gebruikt.

Methodes
In dit onderzoek wordt een interview afgenomen in uw eigen thuisomgeving over uw dagelijkse ervaringen met (smart home) technologie, en uw meningen over dit onderwerp in het algemeen. De onderzoeker zal ook vragen om activiteiten te mogen observeren, zoals bijvoorbeeld een interactie met een smart apparaat.

De onderzoeker zal aantekeningen maken van deze gesprekken en observaties. Ook zal er een geluidsopname gemaakt worden van het interview om dit later in tekst vast te leggen. Mogelijk wordt deze transcriptie later vertaald in het Engels.
De onderzoeker zal mogelijk ook uw toestemming vragen om foto's te nemen ter ondersteuning van een relevante observatie. Vanwege de bescherming van privacy mag u niet herkenbaar afgebeeld worden op deze foto's. Dit betekent dat u niet of maar gedeeltelijk zichtbaar bent, bijvoorbeeld doordat alleen uw handen in beeld gebracht worden.

Vertrouwelijkheid en privacy
De informatie die verzameld wordt tijdens dit onderzoek zal niet gedeeld worden buiten de Universiteit Eindhoven en alleen gebruikt worden voor onderzoeksdoeleinden. Uw informatie zal niet gekoppeld zijn aan uw naam of persoonlijke gegevens, waardoor deze niet naar u terug kan worden geleid.
U geeft met ondertekening van dit formulier wel toestemming om op anonieme wijze quotes en observaties te gebruiken in verslagen en presentatiemateriaal.

Recht tot terugtrekking
U bent niet verplicht om vragen van de onderzoeker te beantwoorden. Indien u zich wil terugtrekken van het onderzoek kunt u dit te allen tijde aangeven aan de onderzoeker. Alle informatie zal als vertrouwelijk worden behandeld.

Contact
Als u vragen en/of opmerkingen heeft mag u ze nu of later stellen. U kunt hiervoor contact opnemen met de volgende personen:

Merel Vermeeren
m.h.m.vermeeren@student.tue.nl
06 553 439 36

Lenneke Kuijer, UD, begeleider van dit onderzoeksproject.
s.c.kuijer@tue.nl

Verklaring van deelnemer

Ik heb het 'toestemming formulier' begrepen, en de mogelijkheid gehad vragen te stellen. Ik neem vrijwillig deel aan dit onderzoek.

Naam van deelnemer ______________________________

Handtekening van deelnemer ______________________________

Datum ______________________________

Verklaring van onderzoeker

Ik heb de deelnemer gevraagd om het formulier door te nemen en deze een (digitale) kopie van dit formulier verstrekt. Ik verklaar dat de deelnemer de mogelijkheid geboden is om vragen te stellen over de studie en dat ik deze vragen naar mijn beste vermogen heb beantwoord. Ik verklaar dat de toestemming vrijwillig is verleend door de participant.

Naam van onderzoeker ______________________________

Handtekening van onderzoeker ______________________________

Datum ______________________________

C: Analysis of interviews (complete version)

The main categories are: independence through technology, philosophy and attitude towards technology, falling behind, technological obstacles, and universal accessibility.

1: Independence through technology

Technological developments have offered blind people a lot of independence and autonomy. Participants value the independence and convenience that they have gained through technological developments. Many specialized assistive devices exist to translate visual information from their surroundings or interact more easily with the environment, whereas digital information is made accessible through braille displays and screen reading software. The development of smartphones and smart devices have made similar contributions to this independence and autonomy.

Many apps are easier to operate than desktop websites because they provide a clearer overview and structure, which increases digital accessibility. Smart technology and smartphone apps can also offer appealing alternatives to assistive devices, that are often expensive and bulky.

The smartphone offers information about the user's surroundings through apps for navigation, public transportation, image-to-text translation, news updates, and more. Smartphone apps that control smart devices in the home allow users access to many kinds of technologies that were previously difficult or impossible to operate without aid from a sighted person.

"In the past it you were very dependent on what sighted people decided was appropriate to translate into braille- or audiobooks. These days you can just buy any .epub and read it yourself with a braille display or screen reader software." – Participant D

"Back then you could only use internet [at home on your desktop computer], and if you went out and something unexpected happened, as a blind person you were dependent on other people around you. Now that the smartphone exists you have a lot more grip on things." – Participant C

"I'm very happy with [my smart thermostat] because I can change the program settings myself. I don't have to rely on someone's help to operate it, or to tell me if the batteries are empty (...) I just check if there's an app that I can use." – Participant C

"At a certain moment the computer was introduced [at work]. For me this meant that I was suddenly able to do my job for a much longer amount of time." – Participant A

"I use [my Trekker] every day, not to navigate but for orientation (...) I already know approximately when a side-street is coming up on my route, but I could start feeling around for it with my cane when it's still 60 meters ahead. With this device I'll know immediately when I'm there." – Participant A

Visibility

By using public transportation apps they no longer need to rely on broadcasted announcements about changes and delays. Users can find out if their smart lightbulbs are switched on or off through an app or smart home assistant.

Smart technology is often used to communicate or replace visual information from the environment, but participants also address the limitations of smart technology.

Users rely on guesswork and memory when information is not available to them, for example, how far they turned a dial, if the food in their fridge is still good, or if a device is displaying an error message.

"The current temperature, humidity, if the lights are turned on or off, if everything in the house is operating normally. (...) I find it important that I can keep up with things through smart technology." – Participant D

"[This app] is not as accurate as a scanner, but it's very useful for knowing if you're indeed doing what you think you are doing." – Participant C

"There are many things you need to guess in the moment [a device behaves unexpectantly], in those situations it would be ideal to have spoken feedback." – Participant A

"It would be useful to know if there was an app that could tell me if my bread or my cheese had expired. I usually remember, but when I forget I can't always tell those things by smell." – Participant B

"Some devices I can navigate by feeling the interface (...) There are devices that only have a touch interface, I can't use those if there is no spoken feedback." – Participant A

Screen readers and voice (operated) interfaces

This user group has a general preference for iOS smartphones with VoiceOver over other devices because of familiarity and wide adoption by the blind community. Incoming messages are often read out loud as they arrive.

When operating a computer or tablet generally a combination of screen reader software and braille display is used, depending on the situation and task. Spoken information is slow.

Screens can be made operable by providing information through speech, either as a part of the device's function, or through an app or connection with a smart home assistant.

Opinions are divided about the use of voice commands, some find them very convenient but others have privacy concerns.

"If something can talk I can work with it. However, being able to work with a device is different from being able to work pleasantly with it." – Participant C

"[Voice commands for smart devices] are the easiest, although I am also content to work with a touchscreen, but it needs to have spoken feedback." – Participant A

"Our coff-ee maker shows everything on a screen, but that information is useless to me. If it were possible to interface with my Google Assistant… It would be useful to know what happens." – Participant A

Limits and asking for help

While participants value their independence and autonomy, they recognize their own limits and struggles. In some situations they ask a sighted person for help, in others they prefer to spend more effort on a task by themselves.

"If I'd ask my wife she'd be able to tell me [this information] in a second, whereas it would have taken me maybe one and a half minutes to find this out. However, if I can do it, I prefer to do these things by myself. Even if it takes longer." – Participant A

"Sometimes I wonder if it's necessary to solve every problem you have with technology, or if you need to accept that your handicap doesn't allow you to do something and ask others for help. Those are deliberate choices you need to make." – Participant B

2: Philosophy and attitude towards technology

Participants have a positive attitude towards smart technology and technological developments. One factor is personal interest in these gadgets, but there is also a strong awareness about the benefits of following these developments as a blind person.

The participants have quite an universal attitude towards technology: it needs to make your life easier, not more difficult. This is reflected in their main considerations when adopting new technology.

"I'm still tinkering a little with [my Google Assistant]. It's often faster to use an app, and we prefer not to leave the device on all the time. This is more about figuring out what such a device can do. If I become invested in this I will buy a Homey, that one can talk to all kinds of devices." – Participant D

"I like to keep track of these things because I like them, but also because I know nowadays that it's a huge benefit as a blind person to know a lot about technology" – Participant C

High costs

The high price is the main reason users are hesitant to adopt new smart devices.

Design of specialized devices for blind users is expensive, it is not always useful enough to make up for the high costs attached. The talking microwave oven and the iCane are often quoted as examples of this.

"It is of course useful for knowing the time, but you can also just buy a braille watch or talking watch instead of an expensive smartwatch. If it hadn't been a gift I wouldn't have bought one myself. (…) Although it's fun to track my fitness goals or measure my heartrate, I find it an expensive toy." – Participant B

Unnecessarily complex design

Many household appliances are considered unnecessarily complex, because of the many options available through the menu that are not used.

Many smartphone apps exist for outdoor navigation and text recognition from pictures. It can be difficult to choose between many similar apps because of the lack of in-depth reviews, people rely on others' recommendations.

Wait and see

Participants often don't know what to expect from new technology, even when it is specifically designed for them. They either experiment themselves or wait for others to discover the usability and usefulness. They also express uncertainty if a device or app remains accessible after an update.

"It would be nice to be able test these things in advance. I haven't bought a smart washing machine yet, because I'd hate to buy such an expensive device only to find out that I can't work with it." "The same thing applies to the special talking washing machine, (…) I'd rather buy a regular cheaper machine of better quality, and hire a domestic help for laundry." – Participant B

"The ORCAM glasses can read text in real-time and recognize familiar people's faces (…) but I think you need to have a lot of remaining visual ability to use it." – Participant A

"It's not always because of the update itself [that an app can become inaccessible], it can also depend on the programming language or operating system." – Participant D

"It's useful to know the color of something, but I feel that [color scanner apps for smartphones] aren't accurate enough." – Participant B

3: Falling behind (old vs. new)

Interesting divide: Many new (smart) devices are difficult or impossible to operate for users, but they are very hopeful that smart technology and apps will make it easier for them to operate devices in general. The lack of non-visual information about user interaction with the device is the main reason for this inaccessibility (i.e. rotary dials turn forever, silent and smooth touch interfaces). Many older devices are used that contain physical buttons because these are easier to navigate, but these interfaces are rare in modern products. Users hope that connecting smart devices in the house to smart home assistant or smartphone apps can provide them with audio feedback and input.

Interesting divide Although they state innovation offers more freedom and convenience, participants fear future technology will be inaccessible. Expensive and bulky flatbead scanners have been replaced by smartphone apps to scan, recognize, and read written text much faster. Users are waiting for self-driving cars that can offer more freedom than current transportation. Many were afraid that touch screen devices and smartphones would not be operable for them, but became very interested in them after the implementation of VoiceOver.

They have difficulty finding modern devices they can easily operate. Special adjustments such as software and hardware changes are quite expensive because of the limited market. It is unsure if new technologies are covered by health insurance.

“The introduction of Apple’s Talkback was incredible. When touch screens were first introduced, blind and visually impaired people were afraid we would be left out.” – Participant A

“It would be useful to see through an app what you have selected on, for example, your oven, microwave, or even washing machine.” – Participant C

“I have chosen this washing machine explicitly for its dial with an physical indication of the arrow, that way you know what program you’re selecting. I also placed some tactile stickers on it. When you’re buying something new many devices are excluded because you can’t use them. A device like a [luxury coffee maker with touchscreen interface] I can’t buy, no matter how much I like it or how highly it’s rated, because I cannot do anything with it since it can’t be operated as a smart device, there’s no app for it.” – Participant C

“Some things cannot be operated. We own a microwave oven that I cannot operate myself, because it has a touchscreen. I use a spare old one when I’m home alone.” – Participant D

“You’re drinking coffee from a very simple Senseo with physical buttons. It’s possible that in 10 years they’ll only make coffee machines with displays, then I can no longer make coffee.” – Participant B

4: Technological obstacles (dumb design)

Participants talk a lot about design choices and attributes that make a product inaccessible or difficult to use.

It is difficult or impossible to operate devices without physical or audio feedback (for example, rotary dials that turn forever, smooth and silent touch interfaces, and silent visual notifications). People find this missing information annoying, it impacts the usability of the design. Often there are no accessibility settings on the device or different methods to interact with it (for example, voice controls, connection to an accessible smartphone app, remote controls). It is not always possible or useful to place tactile stickers on devices or make other adjustments to work around this.

A lot of digital information is not compatible with screen reading software because of messy coding. Programming mistakes made in a hurry are often not noticeable by sighted users, but cause problems for screen readers (for example, alt text for links is missing, buttons are not classified as buttons and not recognized). Participants think that programmers are not aware such things cause problems for accessibility, and are often not aware of blind users at all, despite IT being a popular field of work for blind people.

Specialized designs to help blind people are often expensive and not covered by insurance, or not high on usability.

Users have trouble when buying new technology, because many devices are difficult to use or not operable because of the interface design. Smart devices can also be less practical compared to the current devices and methods they use.

“The old model was popular amongst blind people, but the new model isn’t usable. They replaced the buttons with a touch screen.” – Participant D

“I have tried the iCane. It was very expensive, but what especially bothered me was its weight. My arm would get very tired from moving the cane. I didn’t buy it mainly because of that, partly because I prefer my guide dog. Insurance didn’t cover the device so not many people bought one.” – Participant B

“I would find it useful if many devices that I currently cannot use, that lack information because of a touchscreen or endless rotary dial, were operable in another way. For example by adding spoken interface feedback or connecting it to an app.” – Participant C

“I want to control a device by myself without needing to think of a trick to make it work” – Participant C

“All of this is described in accessibility standards, but those are usually forgotten if they aren’t aware of us.” – Participant C

“Accessibility is a kind of sub-branch of usability. It’s also budgeted separately, so you often have to make an effort to get money for it.” – Participant D

“A screen can look very nice, but the information that supports it is invisible to the eyes. (…) It’s fun that I’m able to find different mistakes than my sighted colleagues, because I rely purely on the underlying information.” – Participant D

Memorizing and guessing

Menus can be difficult to navigate because they contain many steps and information is missing. This problem occurs for both digital and embodied design. Another common problem is that the function of buttons and interface items can change during the interaction. Users have to memorize steps they need to take or the function of unlabeled items, which often means they use few of the device's functions. This also requires a lot of guesswork and workarounds.

A common problem is the installation of new devices, which is difficult and often requires help from a sighted person.

"If a smart device contained something for orientation then I think I can probably operate it, for example, hearing sound feedback or having a small button. That can even be practical for sighted users." – Participant D

"Because my wife will be away for a few days I have to practice using this remote to operate the blinds. For me it's always a guess if they are closing or not. If I could do this with a switch or universal remote, and see in an app if it worked…" – Participant D

"Those are functions that are a standard part of the device, but that we don't use because they are behind a menu. (…) I didn't feel like memorizing all of those menu interactions by heart." – Participant C

"If there are one or two [unlabeled] buttons it's not that bad, but if no buttons are labeled then it's quite annoying to memorize them." – Participant C

Adapting devices & workarounds

Installing new devices is often difficult for blind users, because a lot of information is only visually available.

Participants do not mind making small adaptions to devices or using alternate ways to control them. Orientation of devices can be improved by adding tactile information.

"Designers can decide to always use physical buttons, that's an option [to increase accessibility]. You can also decide that when you're designing a touch display interface, you make sure there is an app for to offer an alternative method to control the device. That would appeal to an extra target group." – Participant C

"That's the fun thing about Arduino, you can create a kind of relay-connection to an interface that makes it possible to operate it." – Participant D

"Most devices that can be I can control through an app I operate with apps. I also have a lot of "dumb" devices, those I can't use as easily. I'll have to find a solution for those. For example, you can guess the location of a button on a touch interface through the length of your finger." – Participant D

"I have Apple TV, but I don't use it often because I'm trying to figure out how to control all these devices with one remote. It's probably possible, but someone else would need to program it for me." – Participant B

Universal accessibility

Participants mention the principle that accessible design creates more user-friendliness for all users. Some cited examples are the Webbox, Google Assistant, and accessible software. (Webbox was designed for the elderly but appeals to many others because of the simple interface, voice commands are more universal to use than braille remotes because more people know how to operate it, having both audio and visual interaction makes it suitable for blind or deaf users, small buttons can also be selected with keyboard combinations.)

They believe it's better to take accessibility into account early on in the development of a product rather than to make adjustments in a later stage.

Participant mention that they think developers and designers often forget to consider them rather than deliberately excluding them form the target group. Participants suggest that a lot of accessibility problems can be avoided if the methods and standards used by make it easier to take accessibility principles into account. For example, messy programming makes websites and apps difficult to view with a screen reader.

"If you have good tools, you won't forget [including users]. There are many types of forgetfulness, I mentioned the factor of time, which is a universal boogeyman. It depends on budget, interest, intention, quality standards, and the requirements that are stated at the start of a project." – Participant D

“A while ago I got a Webbox. Even though my partner can see he uses it much more often than I do, to listen to the radio for example.” – Participant C

“I’m a good braille reader, but I think that improving the accessibility of operating a smart TV would be more useful and cheaper with voice commands. This is also a more common technology that is suitable for users who are blind, visually impaired, mentally impaired, dyslectic, and so on, than braille feedback. There are also many visually impaired people who cannot read braille.” – Participant B

“Someone thought it would be interesting to operate [radio broadcasting devices] with a computer, and when developing the software for this they took into account that blind or visually impaired amateur broadcasters existed. I was very pleasantly surprised by that!” – Participant C

“For example, the Google Assistant is something that anyone can use. (...) It is more inclusive than most products that are specifically designed for blind, visually impaired, or physically impaired users. If you can help people with [targeted design] of course you should, but if it’s possible, take the largest possible target group into account when starting development.” – Participant A

“I think if [non-disabled people] can’t use the accessible aspects that’s fine, as long as they aren’t bothered by them.” – Participant A

Other

Annoyances from sighted people

Participants have shared stories about sighted people’s assumptions and ignorance regarding blindness, which resulted in their needs being treated as inconveniences or forgotten.

“My neighbors thought I wasn’t home a few times because my lights were switched off. People tend to forget I am blind, possibly because I’m very well-adjusted. Colleagues have given me printed books to read.” – Participant D

“They were annoyed because they thought I was simply unwilling to use their website. (...) I don’t mind working digitally, but it’s quite annoying this is the only option.” – Participant C

Involvement in research

A user remarked that it was a pity that projects they participated in as a test user didn’t keep them in the loop after their involvement.

D: Framework (complete version)

1: Connectivity

The design can easily interact with other (smart) devices

a. Integration support
b. Completeness of exchanged information (information, control)

2: Device to user communication

The design communicates to the user through multiple types of information (v/p/t/s)

a. Direct from interface
b. Alternative settings and means
c. External other devices

3: User to device communication

The user can communicate to the design through many types of methods (v/p/t/s)

a. Direct from interface
b. Alternative settings and means
c. External other devices

4: Interaction complexity

Interactions are simple, straightforward, and clear to the user

a. Steps
b. Function allocation variation
c. Duration

5: Code durability

Code is maintainable and reliable

a. Structured and properly labeled code (readable, maintainable, accessible)
b. Stable connection to other devices to allow complete interaction

6: (Optional) Flexibility and adaptability

Flexible interfaces are supported by the design

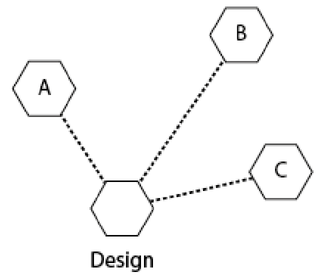
a. Integrated settings in the design allow different alternatives for the communicated information types and/or interaction methods
b. Open access for tinkering allow users to make changes to allow different communicated information types and/or interaction methods

1: Connectivity

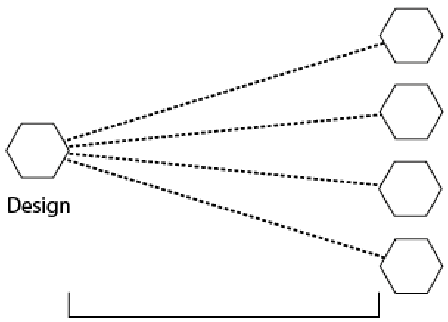
The design can easily interact with other (smart) devices

a. Integration support

b. Completeness of exchanged information (information, control)



A. Compatible devices



	No support	Yes, for some	Yes, for all
Smartphone app			
Smart home assistent			
Remote control			
Other: ___________			

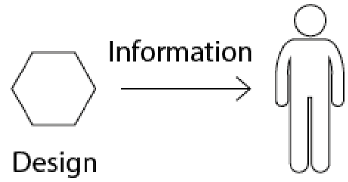
B. Information communicated to compatible devices

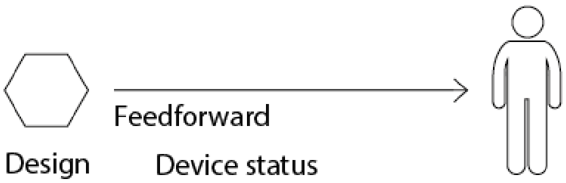
	None	Partial	All
Device status			
Control options			
Notifications and errors			

2: Device to user communication

The design communicates to the user through multiple types of information (v/p/t/s)

a. Direct from interface
b. Alternative settings and means
c. External other devices





Device status
What is the design doing at this moment?

(Interface) functions
What can the device do, and how can the user interact with the device?

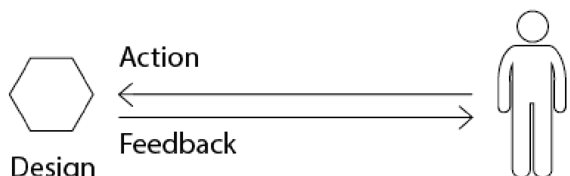
Notifications and errors
What information about status changes and errors is communicated?

Visual feedforward is communicated through (digital) static or interactive elements like colors, icons, text, and lights.

Physical feedforward is communicated through mechanical characteristics like the design's shape, physical state, present (interface) elements, and location of (interface) elements.

Tactile feedforward is communicated through the embodied characteristics of physical elements like the texture, shape, and size.

Sound feedforward is communicated through the inherent and augmented sounds of the device like jingles, speech and voice descriptions, and operational noises.



Interaction feedback
Responses to communication with the device interface.

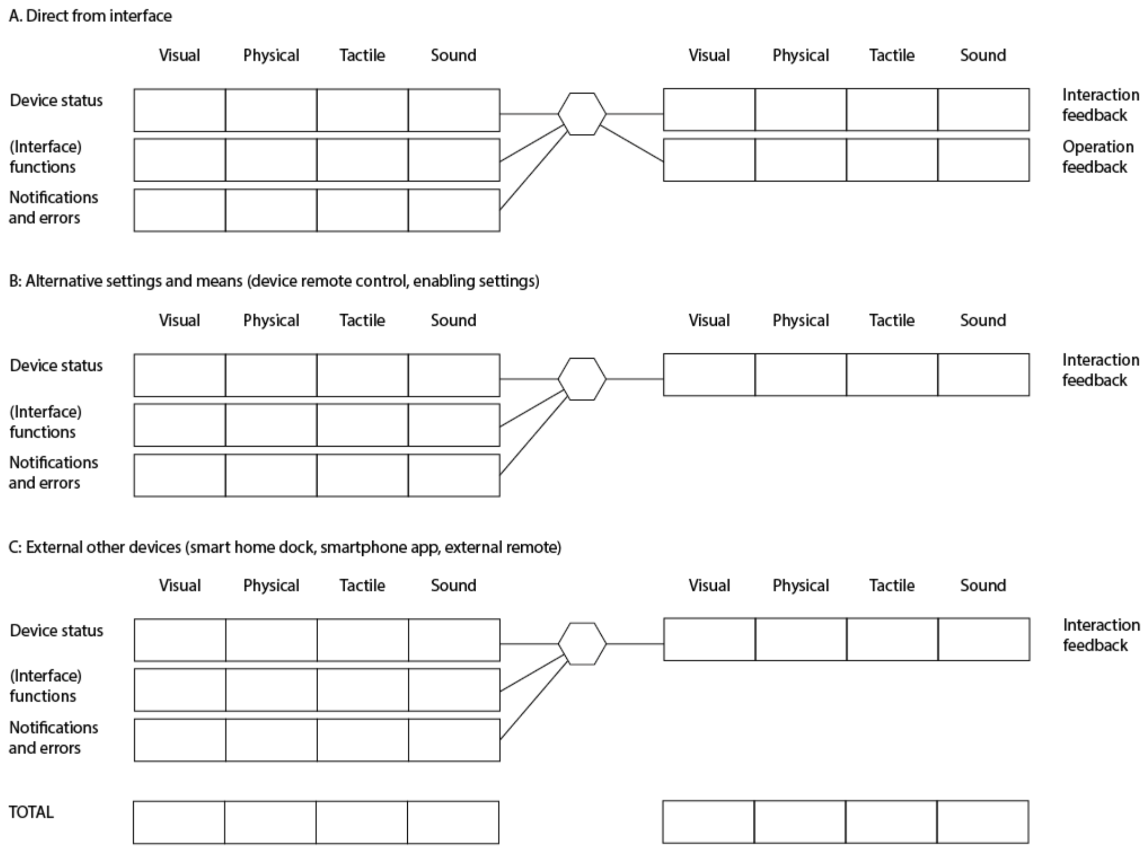
Operation feedback
Information observable by the user when a task is executed.

Visual feedback is communicated through changes in (digital) (interface) elements like colors, icons, text, and lights.

Physical feedback is communicated through direct or indirect changes of mechanical characteristics like the design's shape, physical state, movement of (interface) elements, and location of (interface) elements.

Tactile feedback is communicated through haptic responses from the embodied or digital characteristics of (interface) elements like clicks, mechanical resistence, vibration, and operational haptic information.

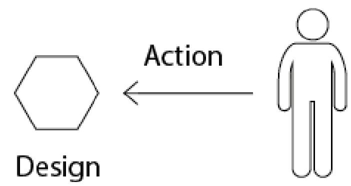
Sound feedback is communicated through inherent and augmented audio responses like jingles, speech and voice descriptions, and operational noises.


A. Direct from interface
Visual
Physical
Tactile
Sound
Visual
Physical
Tactile
Sound
Device status
(Interface) functions
Notifications and errors
Interaction feedback
Operation feedback
B: Alternative settings and means (device remote control, enabling settings)
Visual
Physical
Tactile
Sound
Visual
Physical
Tactile
Sound
Device status
(Interface) functions
Notifications and errors
Interaction feedback
C: External other devices (smart home dock, smartphone app, external remote)
Visual
Physical
Tactile
Sound
Visual
Physical
Tactile
Sound
Device status
(Interface) functions
Notifications and errors
Interaction feedback
TOTAL

3: User to device communication

The user can communicate to the design through many types of methods (v/p/t/s)

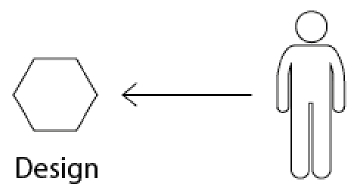
a. Direct from interface
b. Alternative settings and means
c. External other devices



Actions	Examples	Feedback types
Two-dimensional	Tapping touchscreen items, touchscreen gesture commands, tapping/touching smooth areas	Visual, (haptic), (sound)
Embodied	Pressing buttons, twisting dials, moving parts, placing parts	Physical, haptic, (visual), (sound)
Hands-free	Speech commands, gestures, prescence	Any

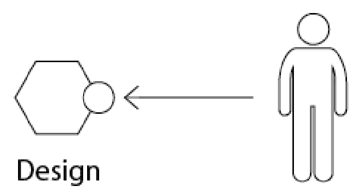
A. Direct from interface

	Visual	Physical	Tactile	Sound
2D				
Embodied				
Hands-free				



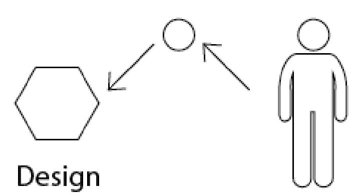
B: Alternative settings and means (device remote control, enabling settings, etc.)

	Visual	Physical	Tactile	Sound
2D				
Embodied				
Hands-free				



C: External other devices (smart home dock, smartphone app, external remote, etc.)

	Visual	Physical	Tactile	Sound
2D				
Embodied				
Hands-free				

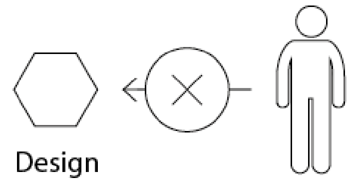


TOTAL				

4: Interaction complexity

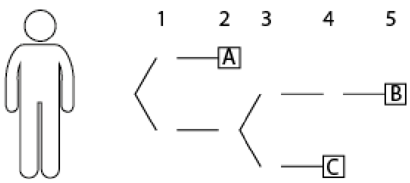
Interactions are simple, straightforward, and clear to the user

a. Steps
b. Function allocation variation
c. Duration



Steps

Number of steps needed to execute actions.



Function allocation variation

Changes in functionality of interface elements, like the meaning of a button press, the appearance or disappearance of menu items on a touchscreen, etc.

Duration

Duration if interaction in seconds.

Core tasks of the device analyzed

	Task A:	Task B:	Task C:	Task D: ....
Steps				
Function allocation variation				
Duration				

1	2	3	4	5	6	7	8	9

5: Code durability

Code is maintainable and reliable

a. Structured and properly labeled code (readable, maintainable, accessible)
b. Stable connection to other devices to allow complete interaction

Judge the durability of the design's code

	Low	Medium	High
Clarity			
Labeled items %			
Consistency			
Commented			
Maintainability			
Reliability			
Connection stability			

6: (Optional) Flexibility and adaptability

Flexible interfaces are supported by the design

a. Integrated settings in the design allow different alternatives for the communicated information types and/or interaction methods
b. Open access for tinkering allow users to make changes to allow different communicated information types and/or interaction methods

Integrated settings allow (refer to: examples 1,2)

	Visual	Physical	Haptic	Sound
Device status				
Interface functions				
Interaction feedback				
Notifications and errors				
Control method				

Device supports tinkering

	Yes	No
Non-invasive		
Mildly invasive		
Very invasive		
Total:		

E: Tables 1 and 2

Participant	Gender/ age	Visual impairment	Occupation/hobbies	Living situation	(Smart) devices and specialized aides
A	Male/72	Blind, has gradually lost visual ability though life	Retired instructor of English teachers, involved with Oogvereniging and NVDA, walks short distances	Lives with sighted partner	Google Assistant, smart lightbulbs, Android smartphone with Talkback, Windows computers with screen reader software, Trekker, Buzz Clip, talking kitchen scale, cane
B	Female/43	Blind from birth	Braille teacher for Visio, has designed braille puzzle book and blind guided art tour	Lives with sighted young child	Google Assistant Mini, smart lightbulbs, smart TV, iOS smartphone with Voiceover, iOS smart watch, Windows computer with braille display and screen reader software, color scanner, guide dog
C	Female/48	Blind from birth	Administrative assistant, informal consultant for VI workplace tools and smartphone use, amateur radio broadcaster and musician	Lives with sighted partner	iOS smartphone with Voiceover, iOS tablet, Windows computer with braille display and screen reader software, smart thermostat, DAISY reader, Webbox, cane
D	Male/52	Blind from birth	Systems architect, IT workplace accessibility advocate and consultant, gadget enthusiast	Lives with sighted partner	Google Assistant, smart lightbulbs, video doorbell, smart TV, iOS smartphone with Voiceover, Windows and Linux computers with braille display and screen reader software, media streaming devices, smart speakers, smart solar panels, remote-controlled shutters, DAISY reader, cane

Table 2. Overview of interview participants

Evaluation	Framework	Participants	Project type	Design description
1	Iteration 1	Group (4)	Design research	Embodiment of remote for home security, digital and physical abstract remote controls
2	Iteration 1	Individual (1)	Design	Smart navigation for blind users, embodied interaction with wrist watch, smartphone app
3	Iteration 1	Individual (1)	Design	Communal solar energy sharing, embodied artifact for energy management, smartphone app.
4	Iteration 2	Group (2)	Design research	Automation of music volume and sharing, flexible embodied interface.
5	Iteration 2	Individual (1)	Design	Awareness of energy use, embodied artifact for energy transportation to devices.
6	Iteration 2	Individual (1)	Design	Personal items as storage for memories, physical interface broadcasting media from items to smart screens.

Table 2. Overview of design students participating in evaluation workshops