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A Case Study for Universal Design in the Internet of Things

Trenton SCHULZ [a] Kristin Skeide FUGLERUD [a] Henrik ARFWEDSON [b] Marc BUSCH [c]

[a] *Norwegian Computing Center, Gaustadalléen 23a, NO-0373, Oslo, Norway*
[b] *Sweden Connectivity, Torshamnsgatan 30B, 164 40 Kista, Sweden*
[c] *CURE —Center for Usability Research & Engineering, Businesspark MARXIMUM, Modecenterstraße 17/Objekt 2, 1110 Vienna, Austria*

Abstract. The user-centered design process helps ensure the requirements of the users are met throughout the development of a product or service. Universal design is an approach that makes sure that the needs of people with disabilities are incorporated. While many have suggested combining user-centered design and universal design, we demonstrate how it can be done in the development of prototypes and mobile apps for the Internet of Things. Applying the user-centered and universal design process allowed us to identify complex issues with user interaction that would not have been found only using accessibility guidelines. We recommend focusing on technical accessibility, performing user evaluations with persons with disabilities, and having an accessibility champion for advocating universal design issues throughout a project.

Keywords. Internet of Things, mobile apps, universal design, user-centered design, accessibility

Introduction

It is important to ensure that ICT products and services are usable by as many people as possible, regardless of users' ability. Universal design is a process that aims to do this. The Riga Declaration [1] sets the universal design of ICT as a priority in Europe, and countries including Norway [2] and Spain [3] have written universal design into laws guaranteeing citizens the right to access ICT technologies.

How do designers and developers integrate this new requirement for universal design into their development processes? Regulations point to guidelines for making content accessible, but is that enough? Subasi, Leitner, and Tscheligi [4] propose a workflow for web services that helps include the needs of the elderly, and Keates and Clarkson [5] provide a method for integrating knowledge of people with disabilities into a user-centered design process. These authors offer a possible process, but there is little information on how these processes work in practice.

We provide a case study to show this process in a project with both hardware prototypes and mobile apps. We describe experiences and provide insights how developers and designers can structure their own processes. First, we provide background on both universal design and user-centered design. Next, we present our case and how the universal design process mapped onto each step of the user-centered design process. Then, we present findings and offer some discussion of the case. Finally, we provide some recommendations for designers and developers.

1. Universal design and user-centered design

Architect Ronald Mace introduced universal design in the mid-1980s; since then, it has been adopted in many fields, including more recently to the design of ICT [6].

Many think of universal design as design for people with disabilities. Yet, the general intention of universal design and similar approaches, such as Universal Usability [7], Design for All [8], and Inclusive Design [5], is to design ICT so that it can be used by as many people as possible, i.e., mainstream technology for everyone, including the elderly and people with disabilities. The emphasis is on counteracting unnecessary special solutions and to provide equality and equal opportunities to participate in the society [9].

Universal design as a concept has two important aspects: a process and a result. That is, universal design denotes (*a*) a design process or an approach and (*b*) a normative goal of the resulting design, i.e., that it can be used by as many people as possible.

The universal design process should be holistic [9] and included in each part of a project. Therefore interdisciplinary planning, follow-up, implementation, and assessment of the design is important. Important aspects of a universal design process include: (*a*) holistic and interdisciplinary, (*b*) based on *user-centered design*, (*c*) adopt and apply accessibility guidelines and standards, (*d*) iterative development, (*e*) focus on *users with diverse accessibility needs* and their usage contexts early and throughout the development process, (*f*) empirical evaluations with the elderly and people with disabilities, and (*g*) focus on the whole user experience.

There is broad consensus that following accessibility standards and guidelines is a precondition for universal design. Yet, a solution that conforms to accessibility standards and guidelines may, without consulting users, be so difficult to use for certain user groups that it is hard or even impossible to use in practice [10]. Therefore it is generally agreed that universal design and similar approaches should be based on a user-centred design process including empirical evaluation with disabled people [11–14].

The user-centered design process (Figure 1) is defined in ISO 9241-210:2010 [15]. The process puts the user in the center of the design process by integrating the user into each aspect of the process. The user-centered design process is divided into four steps: (*1*) understand and specify the user context, (*2*) specify the user requirements, (*3*) design and produce solutions to meet the user requirements, and (*4*) evaluate the solution against the requirements. The process encourages iteration until a product or service meets the requirements of the user. An iteration does not necessarily require starting at Step 1; starting at Step 2 or Step 3 may be sufficient depending on different factors such as time, resources, or completeness of requirements.

Gulliksen, Göransson, Boivie, Blomkvist, Persson, and Cajander [16] suggest that a project should have a *usability champion*, a person or group of people who are responsible for usability. We will extended this by having an *accessibility champion* to be an advocate for universal design issues. The concept of an accessibility champion also makes it easier to see specific actions for universal design in each step. We refer to the accessibility champion as one person below, in reality it was a group of people.

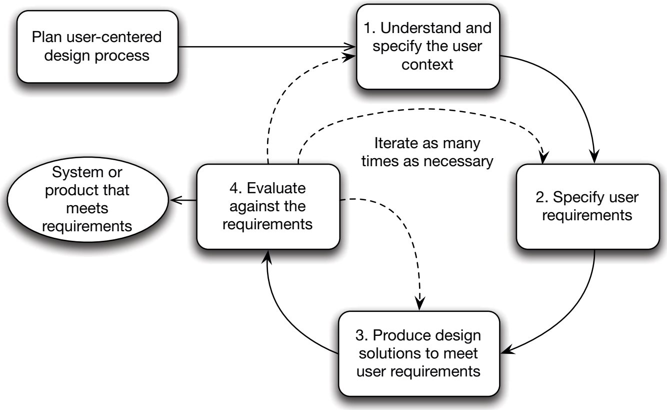

Figure 1. The user-centered design process based on ISO 9241-210:2010 [15, p. 11].

2. Case: Trust in the Internet of Things

We applied the universal design process to a project that measured trust in the Internet of Things (IoT). The IoT is a concept of many everyday objects communicating with each other in an Internet-like structure [17]. For the IoT to succeed, people will need to know that their data is protected and that their privacy is protected. [18] Yet, this is difficult when people use the technology in different and changing environments and some interactions happen automatically. People should be able to make an informed decision on whether or not to *trust* the IoT. The goal of the project was to create a *security assistant* to present the security and privacy information in a usable and trustworthy manner. This includes people with disabilities. The project used the trust definition introduced by Döbelt, Busch, and Hochleitner [19]: “A user’s confidence in an entity’s reliability, including that user’s acceptance of vulnerability in a potentially risky situation.”

Since the IoT is still an emerging technology we decided to create our own prototypes for both objects in the IoT and the apps to display the information. To assist in gathering input from users with disabilities, two non-profit organizations, the Norwegian Association for the Blind and Partially-Sighted (NABP) and Dyslexia Norway (DN), were committed to providing advice on accessibility and recruiting participants for focus groups and evaluations. We therefore had a focus on making our prototypes accessible for people with vision impairment and people with dyslexia.

3. Mapping universal design to the user-centered design process

Our design process went through two iterations. Let’s examine the different steps.

3.1. Step 1: understanding and specifying the user context

How and in what situations will people use the IoT? We began our investigation by holding focus groups. Different groups of people were recruited. Participants were presented with various ideas about what the IoT could look like and different scenarios that would raise trust and privacy issues for participants. These focus groups helped us get a picture of the mental models people had about the IoT and the security, trust, and privacy issues they have in these environments.

For finding the needs of people with disabilities, the accessibility champion held three focus groups: two with people with different levels of vision impairment and one with people with dyslexia. Among the concerns of these participants were possibilities for surveillance in the scenarios and the need to rely upon a device to work in every situation. They felt there needed to be backup plans (e.g., what happens when the phone has a dead battery or is forgotten?) Others—especially the vision impairment groups—were interested in the new technology because it could be designed for everyone from the start, and they appreciated the opportunity to provide input to the design.

3.2. Step 2: specify the user requirements

The focus groups helped us to understand how people would work with the IoT. Then, we started creating the user requirements. To help us focus on the needs of the users, we created *personas* and *scenarios*.

Lindgren, Chen, Amdahl, and Chaikiat [20, p. 461] describe personas as "... a hypothetical archetype of real users described in great detail and defined by their goals and needs, rather than just demographics." We followed a process adapted from Adlin and Pruitt [21] to develop five personas. With help from the accessibility champion, we used a process documented by Schulz and Fuglerud [22] and made three personas with disabilities: one persona with 20% vision, one with dyslexia, and an elderly persona with little interest in technology and low ICT skills who was beginning to develop dementia. All personas would periodically provide stories to remind everyone about the needs of people with disabilities. For example, one persona presented problems she had logging into a website when using a screenreader and how she overcame these issues.

At the same time as the personas were being developed, we wrote scenarios for activities in a smart home, smart office, and e-voting. Examples of the tasks included: (*a*) using a tablet to adjust settings of different IoT things in the household, (*b*) sending a time-restricted smart key to a house cleaner's smartphone, (*c*) taking correct medicine from a smart medicine cabinet, (*d*) presenting at a meeting at a smart office and printing handouts, and (*e*) voting electronically at a housing cooperative. We used the personas to make the activities in the scenarios come alive. For example, the elderly persona had recently been put in a smart home, his son was using the technology to make sure that things were all right with him, and our vision-impaired and dyslexic personas were voting electronically in the housing cooperative.

In addition, we also investigated different ways users could be informed about trust issues using different human senses [23]. These were used to help inform the design in Step 3. After the first round of evaluations (Section 3.4), guidelines were created for both regular design and accessibility issues [24].

3.3. Step 3: design and produce solutions to meet the user requirements

With the scenarios defined and the personas reminding us of the issues different kinds of users had, the next step was to start development. Creating IoT prototypes involved both hardware for creating the "things" in the environment and software for the user interfaces. For the IoT prototypes, the hardware work needed to begin before the software.

For hardware, we determined what needed to be constructed for the different scenarios. For the smart home we needed a door lock with wireless key management system and a medicine management and control system in a cabinet; the smart office needed a smart receptionist for registration and connecting to infrastructure; and the e-voting scenario needed voting infrastructure. Technical requirements were written for the different prototypes and hardware and software were selected.

The interfaces were designed based on the requirements and personas' needs along with adopting relevant literature on trustworthy interface design [25, 26]. Additionally, the interfaces were based on principles from the Android Design Guidelines [27]. We picked appropriate typefaces, colors with good contrast, and wrote text in an understandable and non-technical way with consequences and recommendations. Finally, we included multimodal feedback (audio, visual, and tactile) where it was appropriate, ensuring that any alerts or changes in security were conveyed in multiple modalities to be better picked up by different groups of users.

During the first iteration, the accessibility champion examined the available assistive technology for the Android platform since it was chosen for building the prototypes. TalkBack is the Android screen reader [27]. Depending on the version of Android, TalkBack has different capabilities; this has implications for the user experience and the accessibility of the application. At the beginning of the first iteration, the version of TalkBack was designed for phones with keyboards [28], but the phones (and tablets) that provided the best experience for developing IoT prototypes were touchscreen-only. There was concern about how well this version of TalkBack would work for people with vision impairment. Before the second iteration began, the Android operating system and TalkBack added new features that allowed it to work on touchscreen devices. However, one of the prototypes, the medical cabinet, used a tablet that was older and couldn't be upgraded to later versions of Android.

After the first evaluation, we designed new interfaces (Figure 2). The accessibility champion checked both the software interface design and hardware setup for potential accessibility issues for people with dyslexia and people with vision impairments. When the interfaces were complete, the accessibility champion went through the mock-up screens and documented elements that would need alternative text (text description for images), suggestions for the alternative text, suggestions for how to group elements to be more understandable to a screen reader, and what objects should be invisible to a screen reader. These items were then passed on to the software developers working on integration.

As the development of the hardware and software neared completion, the accessibility champion tested the technical accessibility by installing the applications and activating TalkBack to see how well they worked on the different devices. This uncovered labels and controls that were missing a description or needed a different description to be more understandable. The accessibility champion also worked on the phrasing of security information to make sure that it was short and easily understandable, including when it was translated into the different languages where the evaluations would be held.

3.4. Step 4: evaluate the solution against the requirements

The evaluations marked the end of each iteration. The evaluations were conducted in two rounds including people *with* and *without* disabilities. The first evaluation was in VR; the second was in three environments: a lab, a smart home apartment, and VR. Here, we focus on the evaluations that included people with disabilities.

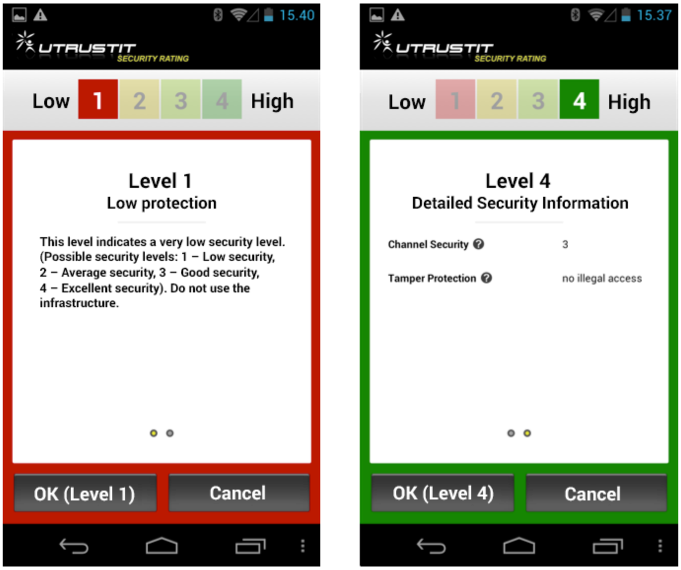

Figure 2. The security assistant interface for the second evaluation.

We performed the first evaluation in VR because it allowed us to get earlier feedback on the software prototypes before the hardware prototypes were ready. Tasks in a smart home and smart office were created for the evaluations based on the requirements that were written in Step 2 and the tasks from Section 3.2.

For accessibility testing in the first round, we used a portable VR system and recruited members from DN and students with problems reading and writing from a local vocational school. Unfortunately, the 3D stereoscopic effect makes VR difficult for people with vision impairment, so this group was not included in the VR evaluation. The results were fed back into the second iteration of Step 2 and Step 3.

In the second round of evaluations, we recruited users from NABP, DN, and a user organization for senior citizens that helps seniors learn about technology and the Internet. For the accessibility evaluations, we had 23 participants: 12 with some kind of vision impairment, five from the senior citizen organization, five persons with reading and writing difficulties (two from DN, three from an adult learning center), and one who was the representative of the local dementia organization.

These evaluations took place at a model smart home apartment that contained different examples of current smart home technology. Special attention was given to the practicalities of participation, such as accessible information materials, directions, and offering transportation to and from the evaluation location. At this location, a test leader and a note-taker were present. Each evaluation was video recorded. Besides the smart home and smart office tasks from the first evaluation, an e-voting scenario was added. As participants worked on tasks, the note-taker captured issues and comments related to use and perception of the prototypes such as usability, accessibility, security, and privacy.

After the evaluations were completed, researchers entered the notes from each user session into the digital system. The descriptions included observed behavior and utterances from the participants. We used an open-code process, often used during the first steps of a qualitative analysis as described by Crang and Cook [29, p. 137]. Each researcher went through their notes and *tagged* them. That is, they picked words to identify what each comment was talking about; this allowed comments from different participants to be easily grouped together. Once this tagging was completed, the researchers met together and reorganized, renamed, and grouped the tags into common themes. These themes were then used as the basis for writing the accessibility evaluation report.

4. Findings

By following a user-centered design process, it was possible to see where universal design was needed for each step. Involving persons with disabilities early in the process gave us insight in understanding how they would approach the IoT and what sort of features they would expect (Step 1). This informed how we specified the scenarios and what were important properties to highlight in the personas (Step 2). During the design and implementation stage (Step 3), focusing on assistive technology and the technical accessibility of the scenarios and devices made it possible to evaluate the solutions (Step 4) with people with disabilities. This meant that making things work for people with disabilities was part of the entire project. If we had not considered persons with disabilities at a each step through both iterations, the solution might not have been universally designed and it could have been costly to fix.

The extension of the Gulliksen et al. [16] usability champion to an accessibility champion was important for the process to succeed. Since the accessibility champion's duty is to ensure that the needs of people with disabilities are included, their needs become the champion's needs. It also helped others in the project to know that there was someone they could talk to about accessibility and universal design, and it resulted in the accessibility champion being invited to many different discussions for accessibility and universal design advice. This helped ensure that we did not run into any surprises while specifying the requirements, building the prototypes, or evaluating them. The accessibility champion's expertise in assistive technology helped in discovering and addressing issues that appeared in Step 3. This expertise was also helpful in testing the technical accessibility during the second iteration.

Were the prototypes usable and accessible? We found accessibility and usability issues in our evaluations. For example, the medicine cabinet, which had an older version of Android and TalkBack, made it impossible for some participants with vision impairment to complete the task without help. Another example was the information about security levels and TalkBack. This information was presented in a concise manner, but it was followed with detailed information that was always read aloud before getting to the buttons to continue or cancel an action. Participants could skip this reading aloud on the smartphone, but they still had to consciously skip over the text. A solution would be to provide some way to easily skip the text after getting the security level and jump to the buttons in the hierarchy was needed. There was also confusion among some participants about being able to change the security level when getting the security information (this was *not* possible). Finally, while we choose good text size and contrast for typical smartphone and tablet usage, some devices have different screen capabilities and were used in different situations (e.g., a tablet used as a display in the medicine cabinet).

Yet, even though these issues arose during the evaluations, most participants with disabilities were able to complete all the tasks. These participants, even the ones that could not complete all the tasks, felt that the usability and learnability of the prototypes were better than other systems that they had encountered [30]. The universal design in a user-centered design process likely helped to make this possible.

This also shows that doing the technical accessibility check in Step 3 was important. Even though developers had followed the guidelines and information provided by the accessibility champion, there were still some issues in how this was presented on the screen. The technical accessibility check was also necessary because of the different versions of TalkBack on the devices. As mentioned in Section 3.3, we were able to upgrade TalkBack to provide a better experience for people with vision impairment. This still resulted in three different versions of TalkBack to test because of limitations on the different devices. Each version had different capabilities and required users to interact with the system in different ways. Checking technical accessibility on the apps with TalkBack on the devices made it possible to run a successful evaluation. If these issues had not been addressed before the evaluation, the evaluations would have wasted everyone's time as the participants would have been stopped by superficial accessibility issues, and we would have not found the deeper accessibility issues.

This work also helped prevent at least one usability issue for those with vision impairment. As mentioned above, some participants were confused about being able to change the security level. This happened because the label presenting the security level looked like a button (Figure 2). However, TalkBack properly identified the security level as a label, while many sighted users mistook the numbers as buttons they could press to change the security level. This shows that properly "labeling" controls (whether visually or for assistive technology) is important for users to interact with them properly.

The accessibility evaluations had benefits for everyone. For example, people with dyslexia alerted us to the length and complexity of text in the first evaluation. The concise, easy-to-understand text in the second evaluation was used for everyone. Many also benefit from having the text presented in a good text size and in good contrast.

5. Discussion

We presented the development and evaluation process for our prototypes in the IoT. Did we really follow a universal design process? The process included the aspects outlined in Section 1. It was a holistic and interdisciplinary user-centered design process; we followed accessibility guidelines when developing the mobile apps; we went through two iterations; early in the project, we focused on diverse user groups with the development of personas; we did evaluations with people with disabilities; and, by conducting the evaluations in a smart home apartment, we focused on the whole user experience.

Ideally, we would have liked to include more groups of people with disabilities, since making the prototypes accessible for some groups does not necessarily make it so for the others. Without the expertise and help of the NABP and DN, it would have been difficult to recruit enough participants with disabilities for the focus groups and the user evaluations. Securing commitment from other user organizations while defining the project might have made it possible to include more groups during the project.

It is important to remember that there are different levels of impairment. Not every person with vision impairment used TalkBack. In our evaluation with twelve persons with vision impairment, seven used either a magnifying glass or relied on the devices having large enough text and good contrast. The solutions need to work well for partially sighted people not using a screen reader as well. The evaluation with people with disabilities helped us identify these issues.

Another point is that defining technical requirements and developing solutions take time. Eventually, it is necessary to finalize certain parts. In our project, once the hardware was decided upon (e.g., the medicine cabinet), it would have been costly to change it. As mentioned in Section 3.3, this had consequences on possible choices of assistive technology and versions of software.

Finally, since the needs of people with disabilities were included from the beginning, meeting the needs of people with disabilities became part of regular development. Some issues, such as alternate ways of providing feedback, became requirements for the prototypes. This was likely a better use of time and resources than creating custom, specialized solutions for each scenario.

6. Recommendations

To participate in the information society and access and use mainstream ICT solutions is a human right [31]. Integrating universal design into a development process makes it a part of the overall product or service rather than addressing the needs of people with disability at the end of the process or designing custom, special solution that can be seen as extra work. This should help keep development costs down and allow for new and better methods to emerge. We have the following points to consider when integrating universal design into a project: (*a*) Determine level of user involvement when defining the project: Having user organizations or other groups pledging support makes it easy to include, plan, and structure user involvement activities. (*b*) Have an accessibility champion: The accessibility champion will be an advocate for universal design and ensure the needs of people with disabilities are included. (*c*) Be aware of complexity of assistive technology: Different hardware and software combinations means it is important to test solutions on different configuration. (*d*) Pay attention to technical accessibility: Making sure that things work with different assistive technology is a precondition for good user evaluations. (*e*) Perform user evaluations including people with disabilities: The user evaluations are necessary to determine if a solution works for people with disabilities.

These points should help designers and developers include the needs of people with disabilities and develop solutions that meet those needs.

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