An Extended View on Benefits and Barriers of Ambient Assisted Living Solutions

Christina Jaschinski[1,2] and Somaya Ben Allouch[1]
Research Group Technology, Health & Care
Saxion University of Applied Sciences[1] , University of Twente[2]
Enschede, The Netherlands
{c.jaschinski, s.benallouch}@saxion.nl

Abstract— **Motivated by the older adults' desire to age in their trusted home environment and the increasing financial pressure on the healthcare system, Ambient Assisted Living (AAL) technologies are designed to facilitate healthy and autonomous aging in place. To aid the acceptance of these still immature technologies, one first need to understand how prospective users perceive AAL technologies. Following this objective two studies were conducted. Study I contains an extensive literature of 26 AAL papers, which resulted in eight benefit categories and ten barrier categories. Study II attempted to validate and specify these benefits for a conceptual AAL application called SONOPA (Social Networks for Older Adults to Promote an Active Life). Focus groups and interviews were conducted with older adults and elder care professionals in Belgium, France and the UK. The results of these studies were translated into several design guidelines for SONOPA and related AAL applications.**

Keywords-Ambient Assisted Living; elderly; benefits; barriers; design.

I. INTRODUCTION

With the rapid increase of Ambient Assisted Living projects, we need to put more focus on how these applications are perceived by their prospective users. Initial insights on this topic were presented at AMBIENT 2014 [1]. The current paper forms an extension to this paper and provides an extended view on the benefits and barriers of AAL technologies.

Worldwide the proportion of elderly people is increasing. With 18.2% of the population being 65 years or older in 2013, Europe has one of the highest shares of elderly people in the world [2]. It is expected that this proportion will rise to almost 30% by 2050 [3]. This goes along with a sharp increase in the old-age dependency ratio, meaning that the number of potential recipients of health and pension funds rises (65 years and older), while the number of potential providers of funds belonging to the working age population (15-64 years), continues to decline [3][4]. While global aging can be considered as a great accomplishment of today's socially and technologically advanced culture, it creates immense challenges for governments in terms of healthcare regulations, pension schemes and state budgets [3].

A. AAL Technologies

To meet these challenges, the concept of AAL was introduced. AAL is an umbrella term for innovative Information and Communication Technology (ICT) based products, services and systems, which support healthy and active aging at home, the community and at work [5]. AAL technologies cover a broad field of applications including smart homes, assistive robotics and mobile and wearable sensors. Various algorithms and computational techniques such as activity recognition, context modeling, location identification, planning and anomaly detection are used to support the older adults' physical (e.g., detecting falls, medication reminders) and psychological well-being (e.g., facilitate interaction with peers and family members) [6]. By promoting a healthy and autonomous lifestyle, AAL technologies meet both the older adults' desire to remain independent and age in place and the demand for controlling healthcare cost [7][8].

Despite the fact that AAL technologies offer a promising perspective on independent aging, it is uncertain if older adults are ready to adopt and use these technologies [9][10]. Usability problems [8][11], the lack of perceived benefits [7][10][12] and self-efficacy [10][13] can form, among other factors, severe barriers to technology adoption among elderly people. In addition, older adults form a highly divers target group with regard to their health, activeness, social involvement and technological skills [9]. In our view, this heightens the need for a user-centered approach when designing AAL technologies, to access the wishes and needs of the intended user and identify potential benefits and barriers at an early stage of development.

B. SONOPA Project

The presented work is part of the SONOPA project [14] which is carried out in the framework of the AAL Joint Programme. The aim of the SONOPA project is to empower elders to stay active, autonomous and socially connected and consequently support and unburden family caregivers. SONOPA will achieve this objective by combining a social network with activity recognition techniques in a smart home environment to stimulate and support activities and daily life tasks. The SONOPA system consists of three major subcomponents (see Figure 1). Firstly, a simplified smart home environment for providing assistance to the older adults and obtain information about their activities.

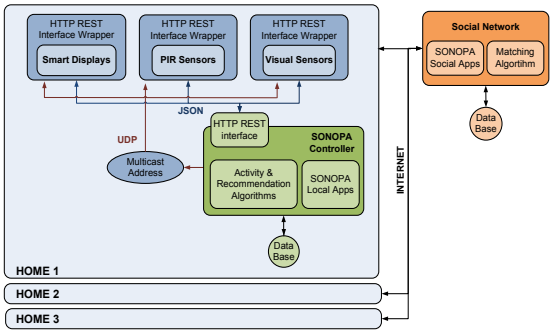

Figure 1. SONOPA System Architecture

Secondly, a module for intelligent behavior analysis which derives activity information from raw sensor data and finally, the social network application which manages the communications between users and their caregivers, and promotes activities. All these components communicate via a WLAN network setup in the home environment. The behavior analysis module, user interface and the middleware which connects with the social network are installed on a computer at the user's home – the SONOPA controller. The controller will collect the sensor data received from the visual sensors and passive infrared sensors. The user interacts with the smart home environment and the social network through the audio/video calling system and the smart wall displays. The smart wall displays are a touch-enabled display that provides spontaneous communication in any room in the home. The video messaging system enables a rich communication between the elder and their friends, relatives and caregivers. The SONOPA controller provides access to the social network application hosted in the cloud, which connects the different homes of the elders in the neighborhood.

C. *Overview*

In this paper, several design guidelines for AAL technologies are identified. Findings are based on both insights from an extensive literature study (study I) and a user-requirement study conducted as part of the SONOPA project (study II). Section II provides an overview of the conducted literature study. The design of the user-requirement study is described in Section III. The combined results of both studies with regard to the perceived benefits and perceived barriers of assisted living technologies are described in Section III. Together, these insights led to several design guidelines, that are directive for the development process of SONOPA and related AAL applications. These guidelines are described in Section IV. Section V provides general conclusions and implications for the future work with regard to the SONOPA system and related AAL technologies.

II. STUDY I: LITERATURE STUDY

To get an insight in the perceived benefits and barriers of AAL technologies, relevant literature about AAL and related technology applications designed for the purpose of healthy and active aging in place was reviewed. We searched several scientific databases (Scopus, Web of Science, Google Scholar) with keywords such as 'older adult', 'assistive technology', '(ambient) assisted living', 'smart home' 'robots' 'monitoring', 'independent', 'adoption', 'use' or synonyms of these words. After initial screening of titles and abstracts, we included (n = 26) papers applying the following criteria :

- Peer – reviewed
- English language
- Published between 2000 - 2015
- Systematic review, qualitative study, quantitative study or mixed method approach
- Research focusing on factors which influence the adoption and use of technology applications designed for healthy and active aging

The selected papers studied different AAL applications such as sensor and monitoring technologies (n = 11), social network applications (n = 2), domestic robots (n = 3), smart health technologies (n = 1), an intelligent mobility aid (n = 1) or the more general concept of technologies for aging in place (n = 8) (see Appendix I). With a few exceptions, participants in the sample were aged above 60. The sample size ranged from 1-1518. Some of the included studies focused on older adults in good health, while other studies included participant with physical and cognitive limitations. Accordingly, the living situation of the sampled participants varied as well. Several studies (n = 10) also included the perspective of informal caregivers and health care professionals. While some studies investigated the technology in a more conceptual phase, some technologies (mostly prototypes) were tested in the field. We also included two systematic reviews. The selected studies were conducted in the US (n = 12), EU (n = 10), Australia (n = 1) and Canada (n = 1).

We extracted the perceived benefits and barriers from the selected papers and grouped them into categories. Consequently, eight benefit categories and ten barrier categories for AAL technologies could be identified.

III. STUDY II: USER-REQUIREMENT STUDY

To evaluate the perceived benefits and barriers identified from the literature study in the context of the SONOPA technology, a user-requirement study with older adults and elder care professionals was conducted.

Three focus groups (UK: n = 8; FR: n = 5; BE: n = 9) and semi-structured interviews (n = 21) were conducted in the UK, France and Belgium. In total, 28 older adults aged between 55 and 86 (M = 71.36, SD = 9.45) participated in the study. Six older adults participated in both focus-groups and in-depth interviews. Of all participants, twelve were male and sixteen were female. Nine participants lived on their own, while the other participants lived with a partner, family members or a friend. The older adults lived independently and without the regular help of a formal or an informal caregiver. A few seniors depended on their family members or external help for certain chores such as cleaning,

transport, grocery shopping or gardening. Although their self-reported physical well-being showed some variation, the majority felt fairly healthy. Overall, participants also felt fairly active, ranking their own activity level at an average of 7.06 (SD = 2.07) on a 10-point scale. Moreover, the majority of the older adults felt socially involved, ranking their own level of social involvement at an average of 7.32 (SD = 1,59) on a 10-point scale.

The Belgium focus group was conducted with four male and five female elder care professionals. The professionals were aged between 36 and 61 years (M = 46.50, SD = 9.89) and had an average of M = 14.44 years of work experience in the care sector (SD = 6.32).

A video was used to visualize two potential user-scenarios of the future SONOPA technology. Subsequent questions targeted the following topics:

- Problems related to ADLs and the level of social involvement
- Opinion about the SONOPA solution
- General level of technical skills and design requirements for technology for elderly

The recorded material was then coded according to the benefits and barriers perceived by the participants.

IV. RESULTS

Based on the conducted literature study (Study I), eight benefit categories and ten barrier categories for AAL technologies could be identified (see Table I). Almost all of these benefits and barriers were supported in the user-requirement study (Study II) with regard to the conceptual SONOPA technology. This section presents the combined results of both studies and provides a detailed description of all benefits and barriers.

A. Perceived Benefits

1) Health and Safety

Health and safety are prerequisites for aging in place [7]. Hence, the literatures study showed that responding to emergencies [7][8][16]-[21], detecting and preventing falls [7][8][16][18]-[23] and monitoring physiological parameters [7][8][19][24] were regarded as vital features of AAL technologies. Other valued features included health management tools such as fitness tracking and medication management [20][24], property security [8][18] and detection of safety hazards, e.g., fire or unlocked doors [18][25]. In sum, the literature study showed that AAL technologies can provide older adults with an increased sense of safety, security and peace of mind.

Safety was also a valued user-requirement with regard to the future SONOPA technology. Older adults and elder care professionals both felt that embedded sensors could provide added safety and security by detecting abnormal behavior such as falls or other emergencies, and automatically contact help. Thus, paralleling the findings from the literature study, fall-detection and emergency response were identified as key features. Another feature that was suggested to be incorporated to the SONOPA system was a reminder for turning off the stove.

TABLE I. BENEFITS AND BARRIERS OF AAL TECHNOLOGY

Benefits	Papers (n=)	References
health and safety	23	7, 8, 15-26, 32, 37, 39, 41-44, 48
independent living and aging in place	11	7, 16-19, 22-24, 26, 41, 44
support carenetwork	9	16-19, 22, 24, 26, 30, 32
social involvement	8	16, 26, 30-32, 37, 47, 48
support with daily activities	7	8, 18, 20, 24, 25, 37, 39
enjoyment and leisure	6	25, 26, 31, 32, 37, 47
education and information	2	24, 32
self confidence and status	2	21, 26
Barriers	**Papers (n=)**	**References**
privacy, intrusiveness and controle	18	8, 15-18, 20, 22-24, 26, 32, 37, 39-43
perceived need and perceived usefulness	15	7, 8, 16, 17, 19, 21, 22, 24, 32, 37, 39, 41, 43, 47 48
Usability	13	7, 8, 17, 18, 22, 24, 32, 37, 39-41, 43, 47
lack of human interaction	10	7, 8, 19, 22, 24-26, 32, 37, 42
social stigma and pride	9	7, 8, 17, 19, 21, 39, 41-43
technology anxiety, technology experience and self-efficacy	8	7, 8, 17, 18, 24, 32, 41, 43
reliability and trust in technology	8	7, 8, 17, 18, 22, 41, 42, 44
cost	8	7, 8, 16,17, 22, 37, 41, 43
burden others	3	8, 17, 19
health concerns	2	7, 17

In the literature study automatic and around-the-clock monitoring was viewed as a major advantage of sensor-based assistive living technologies in comparison with existing solutions, such as an emergency button or a human caregiver [7][18][19].

The user-requirement study showed that automation was also regarded as a main advantage of the future SONOPA technology, as becomes clear in this statement by a female older adult participant: “I have a panic button on my mobile […]. But as far as I’m concerned it is practically useless. Because if something serious happens it is either going to be on the other side of the room, or in your hand bag, or you’re not capable to press the button. So really what you are talking about, is a lot more helpful”.

2) Support Care Network

According to the literature study, both informal caregivers and the elderly people themselves perceived AAL technologies as good tools to support the care network because they can provide some peace of mind and can reduce the overall burden of family caregivers [16]-[18][22][24][26]. With the help of in-home monitoring, professional and family caregivers can gain a better overall understanding of the elderly person’s well-being,

immediately react in emergency situations and detect functional and cognitive decline at an early stage [19].

Similar findings resulted from the user-requirement study. The older adults stated that SONOPA could be very valuable to support the care network and provide peace of mind for the relatives. One male senior participant regretted that a similar technology was not available when he was an informal caregiver: "When my mother was older I looked after her to be sure she is well. And I think this kind of solution would have been very valuable in that situation".

3) Social Involvement

Another benefit of AAL technologies which resulted from the literature study concerns the improvement of the user's social involvement. Social connectedness has been described as a key element of a good quality of life [27][28] and successful aging [29]. Several of the reviewed projects demonstrated that AAL technologies can help elderly to feel closer to family members and combat social isolation and loneliness [26][30][31]. Huber et al. [26] showed that the tested technology gave the elderly and their family members "windows into each other's daily lives" (p. 450) and provided new topics of communication while eliminating monitoring questions. Similarly, the field trial of the 'Digital Family Portrait' project [30], revealed that the female participant felt less lonely, knowing a family member was watching over her. AAL technologies can also provide opportunities to connect with peers. In the 'Building Bridges' project [32], elderly people met fellow seniors via online calls and chat to discuss a broadcast they had commonly listened to. Participants stated that they were very keen to arrange real-life meetings and get to know their conversations partners.

In the user-requirement study, social involvement was also perceived as an important advantage of the future SONOPA technology. The participating older adults and professional caregivers liked that the social network feature of the technology would allow elderly people to make new friends and strengthen the neighborhood network, as stated by one male senior: "It's like a social club." They also valued that one could stay in touch with family and other existing contacts. Participants appreciated that contact would be one-on-one and could lead to real-life interaction. They concluded that SONOPA could prevent social isolation by getting people outside the house, motivate them to participate in social life and therefore, give them back a sense in life. By aiding social involvement, SONOPA could simultaneously stimulate the elderly people's activity level. As stated by one female senior participant: "If you meet someone, you get ready, you clean the house and you get busy with other daily chores. And in this way this kind of technology could contribute to staying active". While this is in line with some studies from the literature study, it contradicts findings from Steele et al. [7] who found that their elderly participants strongly rejected the suggestion to incorporate social aspects in an assisted living technology. However, one female elder care professional in our user-requirement study argued that particularly these social aspects could be the reason that the more healthy and active elderly people would be interested in SONOPA: "For some people safety would not be such a big problem at first, and if that is all there is, they probably would not get [the technology] installed. But it also includes some social elements which could maybe convince people to get it installed anyway. This way they get familiar with [the technology] […] and by the time it is needed for safety purposes than there is already a good [activity] profile of this people and that I consider a strength". Mynatt and Rogers [46] also implicated that the more technologies can be incorporated in the homes of fit elderly, the more likely they will be to adopt more advanced assistive technologies when their health declines.

4) Support with Daily Activities

With older age physical, cognitive and sensory impairments such as muscle stiffness, memory decline and poor vision increase [33]-[36]. AAL technologies can help elderly people to compensate for these deficits and help them with their daily activities. Indeed, Smarr et al. [25] found that elderly people would value the assistance of domestic robots in helping them with chores such as cleaning, fetching objects or reminders. With those tasks robotic assistance is even preferred over human assistance. Similarly, Demiris et al. [8] found that older adults identify assistance with impairments and a reminder function as potential advantages of assisted living technologies.

In line with these findings from the literature study, assistance with chores and reminders (e.g., medicine, important appointments) was a much appreciated feature among older adults and elder care professionals in the SONOPA user-requirement study. A few older adults liked the possibility to get personal advice from peers or family members via video-chat. One female senior participant even suggested to use SONOPA to recruit help for chores through the social network feature: "But imagine if you want to decorate your kitchen and you put it on there, you could have five people come around and you could go shopping and come back and it would all be done".

5) Enjoyment and Leisure

According to the literature study, enjoyment was identified as another benefit of AAL technologies. Several older adults reported to have fun when interacting with the tested technologies [26][32]. They also recognized that AAL technologies could stimulate leisure activities. For example, in the study of Beer and Takayama [37] older adults suggested to use the tested virtual presence robot to attend concerts or sport events from the comfort of their own home.

When discussing the conceptual SONOPA technology during the user-requirement study, several participants imagined that using SONOPA would be fun and enjoyable. Several older adults also saw the SONOPA social network feature as an opportunity to share common interests. As one female participant stated: "I do watercolor painting, I might find somebody who wants to come in with me once a week and sit."

6) Education and Information

Opposed to common stereotypes, a good proportion of elderly people are still capable of learning new things and is still fairly active and productive [38]. This was confirmed by the results of the literature study. In the 'Building Bridges'

Project [32], participants were very excited about the educational element of the tested device. Similarly, Joe et al. [24] found that elderly people would like their tested AAL technology to include features like 'learning something new' and 'keep up with the news'.

In line with these findings some of the user-requirement study participants were interested in informational and educational features for the future SONOPA technology. For instance, one participant suggested to incorporate online classes or educational videos in the SONOPA system.

7) Independent Living and Aging in Place

In the literature study, independent living and aging in place were perceived as essential benefits of AAL technologies. Several studies reported that independence is of utmost importance to elderly people, and technology which can facilitate autonomous living is therefore perceived as useful, e.g., [7][18][19]. Many elderly people are attached to their own homes because of their possessions, past memories and the familiar neighborhood [17][18]. Consequently, they often have a negative view on nursing homes and regard institutionalization as a last resort [7][17][18]. The desire for independent living was so strong, that it often superseded other concerns, such as privacy and intrusiveness [19].

Independent living and aging in place was not explicitly mentioned in the user-requirement study with regard to the future SONOPA technology. A possible explanation is that SONOPA was already presented as a conceptual technology for healthy and independent aging at home. Consequently, participants might have felt that this was an obvious advantage and therefore, unnecessary to recall. However, various statements made clear that independence is very important to the participants. This and the fact that it was a major advantage in previous studies lead to the conclusion that independent living and aging in place indeed should be emphasized as a benefit of AAL technologies

8) Self confidence and Status

Finally, it was recognized in the literature study that AAL technology could built up the self-confidence of older adults [21] and even serve as a status symbol [26]. However, 'self-confidence and status' was not a very prominent benefit.

Therefore, it is not surprising that it was not mentioned in the SONOPA user-requirement study. However, we still think it would be a desirable benefit for AAL technologies as low self-esteem is a common problem among older adults [45].

B. Perceived Barriers

Besides benefits, several barriers that could interfere with the successful adoption of AAL technologies were extracted from both studies. The insights on those barriers are discussed below.

1) Privacy, Instrusiveness and Controle

Concerns about privacy, security and possible intrusion were perceived as important barriers to the adoption of AAL technologies. Elderly people were worried that their personal information can get in the wrong hands and be misused [15][24]. Some were reluctant to the monitoring aspect of assisted living technologies, as it felt like surveillance to them [22][23]. Especially, the use of cameras, was strongly rejected [8][20]. In contrast, some studies found that privacy is just a minor concern to their elderly participants [7][19]. They regarded some loss of their privacy as a valid trade-off for their safety, independence and health. Another reason could be the lack of awareness of potential security risks. Moreover, older adults were worried that technologies are too visible in their home environment [17][39], and could interfere with their normal routine [23][32][39]. Indeed, some participants in the study by Van Hoof, Kort, Rutten and Duijnstee [18] complained about visible cables, annoying sounds and interference with other devices, such as the TV. Others worried about having to dress up and keeping their home clean for video calls [23].

Following these findings, the participants of the user-requirement study considered the loss of privacy as a negative aspect of the future SONOPA technology. Some of SONOPA's potential functionalities were also regarded as intrusive. Several senior participants felt that the SONOPA technology would invade their personal space, and that they would feel observed as becomes clear in this statement by a female participant : "I think it is big brother, being watched all the time". The older adults worried that they would feel restricted in their freedom and loose spontaneity as argued by another female older adult: "But I don't know whether you would creep around the house, thinking oh dear they can see me […] That would be horrible, sort of spy on the wall". Some of the older adults were concerned that the data could get in the wrong hands. However, the majority of the older adults found the idea of sensors acceptable because they perceived them to benefit their personal well-being and safety at home, as this male participant stated: "When I know that the sensors are installed in my home for my well-being, I don't have any problems with them being in my home". Furthermore, most of the participants who were comfortable with sensors, were comfortable to have them in every room of the house as falls could happen everywhere. However, a few older adults would not like to have sensors in the toilet, bathroom and bedroom.

According to the literature study, the level of user control was a matter of concern to the elderly user. Most elderly people wanted to have some level of control about the technology, e.g., turn it off manually [17][40]. Consequently, the lack of user control is perceived as a barrier. On the other hand, some elderly people argue that a monitoring system cannot assure safety, unless it is switched on all the time. Emergencies could happen when the system is switched off or when users forget to switch it back on [7]. A low level of user-control would also be more suitable for people who are not very confident in interacting with technologies [8].

In line with these findings, most older adults from our user-requirement study wanted to be able to switch the future SONOPA system on and off, be aware of which data are shared and decide with whom the data are shared. On the contrary, other participants thought that the system would only work to its full potential, when it could not be switched off.

2) Perceived Need and Perceived Usefulness

The subjective need and the perceived usefulness of a new technology are essential for elderly people to adopt it. Consequently, the literature study showed that the lack of subjective need and perceived benefits forms a major barrier to accepting assisted living technologies. The subjective need for AAL technologies seems to be influenced by the elderly person's perceived well-being in terms of health, activity and social involvement. Steele et al. [7] found that elderly persons with good social ties were less likely to feel the need for such a technology. Greenhalgh et al. [39] discovered that their participants saw no value in assistive technologies if they had never needed to use it before. However, many elderly people struggled to imagine future deterioration where they might benefit from features such as monitoring [19]. Others simply did not want to admit the need for assistive technology [21]. This is confirmed by Peek et al. [17] who concluded that many elderly people talk about a hypothetical older person who could benefit from assisted living technology rather than themselves. The use of existing technologies, such as an emergency button and the help of family members or a spouse can also reduce the perceived need for assisted living technologies [17]. This is contributed by the fact that many elderly people did not fully understand the additional benefits assisted living technologies can provide [7][39]. While the perceived benefits were more abstract, the concerns related to those technologies were very specific [17].

Similar results were found in the user-requirement study. Although the majority of the older adults liked the general idea of SONOPA, many felt no need for it in their current situation. They found the concept of SONOPA more beneficial for people who are less independent, active and healthy; and who are more isolated as becomes clear in this statement of an older couple: "I mean we're not in the position at the moment to need any of those things. But thinking of other people, I think it is marvelous". They also found it hard to imagine that they might feel less healthy in the near future and would need more assistance. Like in the study of Peek et al. [17], it was observed that many older adults talked about a hypothetical older person who could benefit from SONOPA, rather than themselves. However, eleven older adults indicated that they have no need for it at the moment, but could imagine to use it in the future, when they felt less healthy and active, or in case they would lose their partner. Some older adults found that the future SONOPA technology would not offer a lot of added benefits. Several older adults indicated to already use a paper diary for overlooking their appointments, or a pill-box to remember to take their medications. However, it also became clear that the concept of the technology was still quite abstract and therefore, some of the participants did not fully understand all benefits the SONOPA technology could offer to them.

3) Usability

In the literature study, many elderly were worried about the user-friendliness of AAL technologies. They feared that those technologies will be difficult to use and not adapted to their specific needs as older adults [17][24]. Indeed several field studies encountered usability problems with regard to the tested AAL technology, e.g., [18][32].

As in many previous studies from the literature review, older adults in the SONOPA study were worried about the potential complexity of the SONOPA interface, and how much user participation is needed to operate the system as becomes clear in this statement by a female participant: "But if you got to go to an iPod thing and should do tututututu [push buttons] before you find out what you are supposed to do, that is not helpful".

4) Lack of Human Interaction

According to the literature study, the lack of human interaction was also a matter of concern to the elderly target group. They thought that AAL technologies cannot and should not replace human assistance and human interaction, but should be used as a supplement to human care [7][8][19][22][26][32][37]. Indeed, Smarr et al. [25] revealed that while robot assistance is accepted for certain tasks, human assistance is preferred for personal care tasks (e.g., wash hair), leisure activities (e.g., entertaining guests) and most health related tasks (decide which medication to take). Similarly, Joe et al. [24] found that their participants preferred in-person communication with their physician over technology-mediated contact. On the other hand, in the study of Huber et al. [26] it was found that despite concerns about monitoring technologies reducing the contact with family caregivers, the quality and quantity of communication actually improved during the field trial with the technology. However, this does not change the fact that older adults are concerned about technology replacing human care.

In line with these findings, older adults and professional caregivers from the user-requirement study stated that SONOPA could not and should not replace human care and human interaction, as becomes clear in this statement by a male older adult: "For me human contact is still most important […] Thus, I prefer no computer". A female senior participant pointed out: "The negative point is that this person's family and the environment cannot fully rely on this application. Because the application cannot replace the human".

5) Social Stigma and Pride

The literature study showed that social stigma was also a potential barrier to the acceptance of AAL technologies. Many elderly people were hesitant to use technologies that could stigmatize them as frail or needing assistance [8][17][21][41]. Pride and embarrassment were often the reason for not using assistive devices [7][19][21]. Consequently, older adults indicated that AAL technologies should be as discreet and unobtrusive as possible [7][42][43].

Similar findings resulted from the user-requirement study. While assistance with chores was well perceived by a few older adults, others felt no need for assistance and almost felt insulted by the idea as this statement by a female participant indicates: "I don't need anybody to tell me how to make a stew". We observed that some older adults were very proud of their independence and therefore, rejected anything which would imply otherwise. Indeed, one older adult pointed out that seniors might be resistant to accepting that

they need assistance and therefore, would not want to use technology that stigmatizes them as frail and dependent.

6) Technology Anxiety, Technology Experience and Self-Efficacy

According to the literature study, several elderly people were apprehensive towards technology and worried about their abilities concerning technology use [7][8][24]. They perceived technology to be very complex and inaccessible for elderly people who miss the necessary skills and experience [32]. Making mistakes when interacting with the technology, was a major concerns. However, some of them were willing to undertake training and believed that this knowledge could make the interaction with the technology easier [7].

In line with these findings, the older adults from our user-requirement study were worried about the complexity of the future SONOPA technology. It was repeatedly emphasized that they did not grew up with technology and therefore, might lack the necessary skills, experience and confidence as this statement by a male senior participant shows: "I think a lot of our generation are computer shy".

7) Reliability and Trust in Technology

The literature study showed, that many elderly people worried about the reliability of AAL technologies and questioned the accuracy and ability of those technologies in ensuring the health and safety of the user [7][17][22][41]. They worried about interruptions in energy supply [7][44] and the occurrence of false alarms [7][17][18][42]. Indeed, several studies testing monitoring systems reported false emergency alarms during field trials, e.g., [18][22]. While some participants were annoyed by these false alarms [18][22], other participants perceived false alarms as a reassurance that the systems is actually working [18][30].

In accordance with these findings, older adults in our user-requirement study were concerned about the reliability of the future technology, especially the sensors. They worried that SONOPA could give false alarms as becomes clear in this statement by a female participant: "It might just go off with your natural things". Two seniors regarded the activity recommendations as ineffective: "I am not convinced that a single technology application and especially a screen can motivate people to do stuff". Older adults also wondered if all parts of the system could be installed in different domestic environments as becomes clear in this statement by a female participant: "I can't honestly visualize it to be a possibility. Not in an old house".

8) Cost

Another barrier concerns the cost of assisted living technologies. In the literature study, several elderly people have stated that, due to their limited income, such systems would either not be affordable to them [7][8][22][37][41], or they would not to be willing to spend a lot of money on such technologies[7][22]. Elderly people also mentioned that cost should be subsidized by the government [7].

Although cost came not up as a top-of-the-mind concern among the older adults in the user-requirement study, it became clear that the SONOPA technology has to be affordable for a person living on a pension. Several French and Belgium seniors demanded that the government would have to cover parts of the costs.

9) Health Concerns

Finally, the last barrier regards health concerns. In the literature study, several elderly people worried that electromagnetic radiation caused by wireless sensors could cause health problems [7][17].

Although our user-requirement study participants were not worried about electromagnetic radiation, one older adult stated that SONOPA could potentially provide too much assistance and make people less active and healthy because then they do not have to go outside the house to have social contact: "It could be that you shackle them behind the computer".

10) Burden Others

The literature study showed that, while support for caregivers was identified as a potential benefit of AAL technologies by several older adults, others perceived AAL technologies to put an additional burden on relatives as family caregivers [8][17][19].

This barrier was not mentioned in the context of the SONOPA user-requirement study. Nevertheless, we should keep in mind that some older adults might worry to burden their family when using AAL technologies.

V. DESIGN GUIDELINES

Based on the findings from the literature study and the SONOPA user-requirement study, we formulated several design guidelines which are discussed below.

A. Clear, Specific and Flexible Benefits

To stimulate older adults and their caregivers to use AAL technologies, these technologies must not just offer added benefits to its users, but at the same time those benefits have to be clear, specific and profound. The benefits that should be targeted by AAL technologies include the following areas: health and safety, independence, support for the care network, social involvement, support with daily activities, enjoyment and leisure, education and information and self-confidence. Especially, social, leisure and educational benefits should not be overlooked, as some older adults are still very active and fit, and therefore, might not feel an immediate need for a technology which is mainly focused on health, safety and support. Because the concept of AAL technologies is often perceived as abstract, elderly should be able to try out or experience a technology without being obliged to buy it first.

In the context of SONOPA, a central element of the first prototype is the social network which helps the user to connect with peers and family members and offers leisure and informational features such as personal interests groups and event information. By emphasizing social, leisure and educational benefits we try to target the still healthy and active, older adults. During the upcoming pilot phase, two demo sites will be equipped with the SONOPA prototype, so a large number of potential users can experience the system and get a better understanding of its benefits.

B. Ensuring Privacy, Security and Unobtrusiveness

AAL technologies often collect sensitive data such as personal health and activity records. Therefore, measures must be taken to ensure the secure storage of this sensitive information. By giving the user control over whether the system is active, where potential sensors are placed and which data are shared and with whom, privacy concerns can be reduced. However, the level of user control has to be weighed against the proper working and reliability of the AAL technology. In case of a monitoring system, a time limit for deactivation could be applied, to avoid that people forget to switch the system back on. Furthermore, caregivers could be informed when the system is switched off for a longer period of time. To counter obtrusiveness, it is recommended to embed the hardware in the elderly people's home environment and blend it with the surroundings. Moreover, the system should be able to communicate wirelessly, without noise, and no interference with other devices in the home environment.

For the SONOPA pilot phase we will take all necessary measures to ensure safe data storage. Moreover, we will try to reduce the number of sensors and collect feedback on the design to make the system less obtrusive. Within the social network environment the users can control which data they want to share and with whom.

C. Simplicity and Familarity

The interaction with an AAL technology should be simple, consistent and easy to use and learn. The interface has to be intuitive and clearly structured. Technical slang should be avoided and textual elements should fit the elderly's frame of reference. The challenge is to create a simple design but not limit the functionality [32].

The SONOPA prototype is designed to be simple and easy to use. During the pilot phase we aim to collect detailed feedback to further improve the user-friendliness of the system.

D. Training and Low Level of Active Interaction

To simplify the interaction with AAL technologies, it is suggested to automate most processes and to opt for a minimal level of active user interaction, if desired by the user. Special training programs should be designed to teach the elderly how to use a technology and thereby improve the perceived ease of use and the confidence in their skills.

Many features of the SONOPA prototype are automated and require little user interaction. During the pilot phase the participants will receive a short training for using the more 'active' features such as the social network environment. Moreover, we will try to improve the usability of these features with the help of the user's feedback.

E. Emphasizing Abilities rather than Disabilities

When designing and marketing AAL technologies like SONOPA, emphasis should be put on the abilities rather than the disabilities of the target group. This can be achieved by further developing and embedding social, leisure and educational features and positioning AAL technologies as a wellness tool rather than a assistive device. Functionalities of AAL technologies should be helpful but not patronizing and be flexible to the wishes of the still healthy and active user.

As mentioned earlier, social, leisure and educational features are a central element of the SONOPA prototype. This features will help to market SONOPA as a wellness tool rather than a assistive device. During the pilot testing, we will investigate if the recommendations provided by SONOPA are perceived as patronizing and adapt this feature accordingly.

F. Reliability and Technial Support

Given that the average experience with technology in the elderly target group is rather low, robustness to mistakes is another important demand for designers to keep in mind. Furthermore, sensors should be accurate and reliable to avoid false alarms. Technical support in form of a helpline or a well-written manual should be available to all users to minimize technology anxiety and promote a successful interaction with the technology.

For SONOPA, we conducted a technical test in two home environments prior to the pilot studies, to test the integration between the different technical elements and ensure that all elements are working properly and in a reliable manner. During the pilot phase, the technical installation in each pilot site will be monitored remotely by the responsible technical partners and if technical problems occur, they will intervene directly at the pilot sites. The participants can contact their end-user contact person at any time if they experience technical problems. The insights from the pilot study will be used to further improve the reliability and proper functionality of the SONOPA system.

G. Flexibility and Adaptiveness

AAL technologies should be adaptive to differences in physical constraints, personal preferences, technological skills, context and environment. By offering high flexibility in content, functionalities and level of control, AAL technologies can appeal to the different needs of this highly divers target group.

With regard to SONOPA, we aim to offer the system in different modes. One mode is tailored to the active and healthy older adults with an emphasis on the social aspects and only a few sensors. The other mode will target the older adults who start to experience physical problems and put more emphasis on health and safety with a denser sensor installation.

H. Promoting not Replacing Social Interaction

AAL technologies should promote and not replace social interaction. For instance, it is recommended to use a local social network so that face-to-face interaction is a possibility.

We expect that the SONOPA social network and event recommendations will improve the contact with family and peers and stimulate the creation of new social connections online and offline.

I. Low Cost and Spread Payments

Keeping in mind that the average income in parts of the intended target group is rather low, costs should fit into the

available resources of the users. Also, a monthly payment scheme is recommended. Furthermore, one should keep in mind that users might expect that costs are partially covered by social security means.

By offering different modes of the SONOPA system and keeping the hardware requirements to a minimum we try to minimize the costs of the SONOPA system. We also plan to use a different monthly payment scheme for the different modes of the SONOPA system. This way, we can adapt to different user needs.

VI. Conclusion and Future Work

AAL technologies offer a promising prospect on independent aging and managing health care costs. However, it remains unclear if older adults are ready to adopt these new technologies. In this paper, we identified eight benefits and ten barriers of AAL technologies as perceived by the elderly user and their caregivers. These benefits and barriers were the result of an extensive literature study and a user-requirement study of a conceptual AAL application called SONOPA. Together the results of both studies led to the following design guidelines: (1) clear, specific and flexible benefits, (2) ensuring privacy, security and unobtrusiveness, (3) simplicity and familiarity, (4) training and low level of level of active interaction, (5) emphasizing abilities rather than disabilities, (6) reliability and technical support, (7) flexibility and adaptiveness, (8) promoting not replacing social interaction, (9) low cost and spread payments.

Our approach is not without limitations. The benefit, barriers and consequent design guidelines are still based on qualitative data. However, the initial study was extended [1] and our preliminary results were verified. Moreover, recently another SONOPA user-study was conducted, and the first results seem to confirm the findings of this paper. Also, a recent content analyses of AAL deliverables, showed similar benefit categories and also provided some theoretical background for these found benefits [49].

Future work will focus on integrating the found benefits and barriers into a model for AAL acceptance and gather quantitative data to test the conceptual model. The SONOPA system will be tested in the field and the user feedback will be used to further adapt and improve the system according to the user's needs.

Although design guidelines need further evaluation, they form a valuable directive for the developers of SONOPA and other AAL technologies.

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APPENDIX I OVERVIEW SELECTED PAPERS

Ref.	Technology Category	Test User Characteristics						Test Country	Applied Method
		Number	*Age*	*Gender*	*Health Status*	*Living Situation*	*Caregivers involved*		
7	sensor network/monitoring	n = 13	65+	6 males 7 females	n/a	independently	no	Australia	focus groups
8	technologies for aging in place	n = 15	65+	7 males 8 females	n/a	independently and assisted living and nursing home	no	US	focus groups
15	sensor network/monitoring	n = 119	80+ m = 83	22% males 78% females	average or better health n = 92 with normal cognitive function n=27 with MCI	independently	no	US	field trial with questionaire
16	technologies for aging in place	n = 9	70+	2 males 7 females	normal cognitive function	assisted living	no	US	focus groups
17	technologies for aging in place	sample size range: 7-1406	60+	n/a	n/a	independently	n/a	mostly US (67%)	systematic review
18	sensor network/monitoring	n = 18	63+	4 males 14 females	The majority of participants deal with a variety of comorbidities, n = 7 mild to moderate psychogeriatric health problems including dementia	independently and assisted living	informal caregivers	Netherlands	field trial with observational data and interviews
19	sensor network/monitoring	n=23 elderly n=16 informal carers	66-9 1 m=80.6	n/a	stable health, no signs of dementia	n/a	informal caregivers	US	focus groups
20	sensor network/monitoring	n = 6	60-85+	n/a	some participants had partial physical or cognitive impairments	assisted living	no	Netherlands	participatory design activities, interviews, questionaire
21	Intelligent mobility aid	n = 19	67-86	n/a	mobility problems	n/a	informal carers	UK	focus groups, observation and interviews
22	sensor network/monitoring	focus groups: n = 28 field trial: n = 22 elderly and n = 20 informal caregivers	65+	Equal gender distribution	n = 8 had a significant healthproblemand n = 9 reported minor healthproblems	assisted living	informal caregivers and care professionals in focus groups and informal carers in field trials	UK	focus groups and field trial with interviews and questionaires

Ref.	Technology Category	Test User Characteristics						Test Country	Applied Method
		Number	*Age*	*Gender*	*Health Status*	*Living Situation*	*Caregivers involved*		
23	sensor network/monitoring	n = 12	61-95 m = 75.6	3 males 9 females	mean of 3.75 chronic conditions and n = 5 relying on an assistive device to function within the home	n/a	no	Canada	interviews
24	sensor network/monitoring	Three group with 7-15 participant n = 7 sheltered housing wardens	n/a	n/a	Some studies included healthy older adults, while others included participants with neurological deficits.	n/a	informal carers and sheltered housing wardens	UK	focus groups with scenario based drama
25	domestic robot	n = 21	65-93 m=80.25	6 males 15 females	good health	independently	no	US	focus groups, questionaires
26	sensor network/monitoring	n = 6	73-86 m = 82.17	6 females	good to excellent (self-rated)	retirement community	informal carers	US	field trial with datalogs and interviews
30	sensor network/monitoring	n=1 elderly n=1 informal caregiver	76	1 female	good health	independently	informal caregivers	US	field trial with interviews, diaries
31	technologies for aging in place	n = 14	62+	6 males 8 females	n/a	retirement community	no	US	focus groups and questionaires
32	social network application	field trial n=15	60+	n/a	n/a	n/a	Professional carers	Ireland	home visits interviews focus groups workshops field trial
37	domestic robot	n = 12	63-88	5 males 7 females	excellent:17% very good: 33% good: 42% fair: 8% poor: 0%	independently	no	US	interviews
39	technologies for aging in place	n = 40	60 – 98 m=81	13 males 27 females	various medical conditions	independent and sheltered housing	no	UK	Various ethnographic techniques: interviews cultural probes field notes home tour
40	smart health technology	group 1: n = 7 group 2: n = 35 group3: n = 40	group 1: 40-50, m = 45.5 group 2: 51-65, m = 58.6 group 3: 66-92, m = 74.1	group 1: 45% males and 55% females group 2: 43% males and 57% females group 3: 45% males and 55% females	n = 39 suffer chronic diseases	n/a	no	Germany	questionaire

Ref.	Technology Category	Test User Characteristics						Test Country	Applied Method
		Number	*Age*	*Gender*	*Health Status*	*Living Situation*	*Caregivers involved*		
41	technologies for aging in place	n = 30 aging service leaders and policy advocates	40-75	13 males 17 females	n/a	n/a	aging service leaders and policy advocates	US	workshop and focus groups
42	ambient display with social network application	n=1 elderly n=8 informal carers	88	1 female	n/a	n/a	informal carers	n/a	field trial with interviews
43	technologies for aging in place	group 1: n = 762 group 2: n = 756	group 1: 45-64 group 2: 65+	499 males 1019 females	both disabled and nondisabled adults	n/a	no	US	survey
43	technologies for aging in place	sample size range: 1-78	mostly 65+	n/a	hetereogenous	heterogenous	4 studies included informal carers and care professionals	Mostly North America and Europe	Systematic review, interviews
47	domestic robot	Exp. 1: n = 40 Exp. 2: n = 88 Exp. 3: n = 30 Exp. 4: n = 30	Exp. 1: 65-89 Exp. 2: n/a Exp. 3: 65-94 Exp. 4: 65-89	Exp. 1: : 18 males and 22 females. Exp. 2: 28 males and 60 females. Exp. 3: 8 males and 22 females. Exp. 4: 16 males and 14 females.	n/a	n/a	no	Netherlands	4 experiments
48	sensor network/monitoring	n = 40	56-8 8 m = 70.3	n/a	n/a	n/a	no	Italy	experiment and questionaire