Modular smart furniture system for independent living of elderly - user experience study

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Abstract

Introduction The ageing of population represents a significant challenge, however is also a huge potential driver for innovation. Technology development capabilities are rapidly increasing, which enables new, innovative solutions when considering the aging population. However to promote successful development and implementation of new technologies (in this case, smart furniture), positive user feedback and experiences are required. **Methods** In this study, several modular smart furniture prototypes were developed, offering a potential solution to several challenges associated with ageing. The aim was to investigate which features positively affect user experience and consequently form the basis for smart, ageing-friendly furniture design guidelines. The smart furniture systems consisted of five prototypes: Fall Detection system with assistive Mobile Robot, ReAbleChair, Magic Mirror, smart gaming chair and 3D printed handles. These prototypes were presented to seniors in a home-like environment, after which participants completed a questionnaire and were interviewed. The themes used in the semi-structured interview followed the structure of Jesse Garrett's user experience framework. **Results**. The most essential feature was found to be modularity, or the ability to customize solutions according to the end user's capabilities and needs. In addition, results highlight that smart furniture should be aesthetically pleasing whilst still serving its primary purpose (as an item of furniture). Administrative components of the software should be removed from the end user's User Interface (UI) and integrated in a separated UI, to keep the end user's interaction with the technology as simple as possible. The installation and customization services, as well as value-adding services (i.e. monitoring), were seen to offer potential. Finding a true need and "understanding the bigger picture", was also considered important. **Conclusions** In general, the user experiences were positive. Smart features were readily accepted as part of the furniture prototypes, with hidden technologies offering the opportunity to design functional furniture to assist elderly. In particular, smart furniture offers the potential to foster independent and high-quality living, without the stigma often associated with senior-targeted assistive devices. In addition to proving feedback on the smart furniture prototypes, information gathered provided an excellent foundation for future smart furniture guideline development.

Keywords: smart furniture, serious games, fall detection, design for elderly, active and assistive living, assistive technologies

INTRODUCTION

Today's seniors are typically not a tired, passive population. On the contrary, people over 65 years old often live active lives (Marhánková, 2011; Vik, Lilja & Nygård, 2017). However, ageing is a physiological process, which eventually brings some functional limitations (Seals, Justice & LaRocca, 2016). These result in decreased ability to perform activities of daily living (ADLs) and often injuries, with falls being the leading cause of injuries amongst the elderly (Alexander, Rivara & Wolf, 1992). Technology can be of huge help in enabling elderly individuals to live to full capacity, despite some limitations (Andrich et al., 2013). Early adaptation of assistive solutions can increase the quality of life and support active ageing. Despite the potential help that technology offers, the technology solutions targeted for seniors may possess an associated stigma, affecting potential acceptance (Kang et al., 2010). Instead of underlining the need for assistance by providing assistive 'senior' products, assistive functionalities could potentially be embedded into everyday living. As an example, this article relates to furniture, offering additional functionality which is hidden and targeted towards smart living for anybody (and not solely for seniors), thus potentially removing the stigma.

There are already some guidelines for ageing-friendly product design (Pericu, 2017). Senior friendly design guidelines have been reported for web pages (Darvishy, Alireza & Good 2013; Moth, 2013; Senior Friendly Design, 2017) as well as for the physical environment (accessibility) (World Health Organization, 2007; United States, 2010). Smart furniture is somewhat unique, including both ICT (information and communication technology) and physical design dimensions. The aim of this paper is to study elderly user experience (a key question in technology acceptance) to support development of smart furniture related guidelines, as well as piloting a multidisciplinary design approach for smart active-ageing furniture.

A theoretical framework for senior-friendly design has been developed in (Sirkka, Merilampi & Sandelin, 2017). The frame is based on a descriptive literature review of age-related changes in human life. The frame aims to alleviate the effects of ageing on a person's daily life by incorporating customer-centeredness within design processes. According to the framework, the individualized and modifiable design frame requires focus on four main categories: (i) standardization; (ii) putting design thinking into practice; (iii) modular adaptability of furniture, technology and service development and (iv) improved implementation of personal autonomy and value in support systems. With respect to standards and regulations a shift in focus is required, moving away from protecting industrial rights in productization towards protecting users' rights to obtain products and services that are affordable, modifiable and meeting ever-changing real-life needs. The technology industry is challenged to move away from a commerce-centered, production line thinking, towards user-friendly and modular technologies that support users' autonomy and needs. Technology commerce should pay attention to user support services, including them with devices as a holistic product package. In general, older adults or people with special needs should not be seen as marginal groups but rather as an emerging resource with individual human value, life history and capital in society (Sirkka, Merilampi & Sandelin, 2017).

MODULAR SMART FURNITURE SYSTEM AND PROTOTYPES

Smart furniture can be defined as "furniture which brings added value, functionality, comfort and elegance to fit every personalized requirement issued by the user" (Vaida et al., 2014).

A design thinking approach was applied to develop the prototypes under discussion, which were based on real needs in senior lives. In article (Khosravi & Ghapanchi, 2016) eight main challenges of seniors were reported as: dependent living, fall risk, chronic disease, dementia, social isolation, depression, poor well-being, and poor medication management. These real-life challenges were the drivers through the development process of age friendly smart furniture prototypes of this study.

Age friendly product and service design was discussed in an article by Pericu (2017). This study utilizes some key principles, such as:

- the inclusive approach of human-centered design (end users)
- the contribution of medical science to identify problems to be solved (researchers/health professionals)
- the need for a conceptual transition, shifting focus from products to people's experience, trying to find where to simplify and improve interaction between the user and the product / service, with the aid of user-experience design and its tools.

With these principles, the concept of a system, which combines various smart furniture prototypes was developed. This system is based on ICT furniture, which can be unobtrusively integrated into the living environment. It offers support in ADLs and at the same time provides a feeling of security and safety. As functionalities are embedded in the furniture, they reduce the potentially stigmatizing 'senior' label. The core of the system is a server with modular extension capabilities, which facilitates addition and removal of various modules to customize the system according to individual needs and functional abilities. In this article, the prototypes: Fall Detection system with Mobile Robot, Smart Gaming Chair, Magic Mirror, ReAbleChair and customizable 3D-printed handles are introduced in the next section and in *Figure 1*.

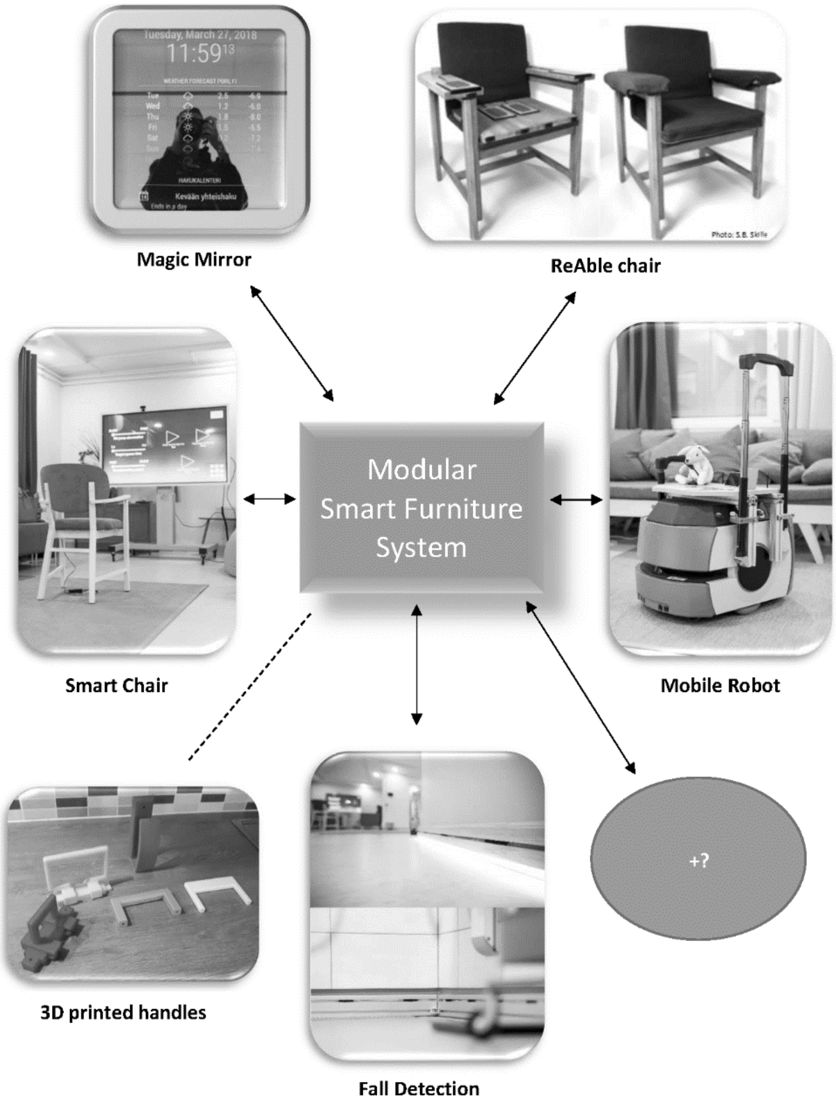

Figure 1. Modular Smart Furniture System allowing embedment of different ICT and non-ICT solutions in furniture.

ReAbleChair

Challenge: As people become older, there is a natural decline in physical function (Cadore et. al., 2013). This decline can lead to insecurity when performing ADLs, most of which occur inside one's home. One of the major fears when experiencing a decline in physical function is the fear of falling and not being able to perform everyday activities independently. In addition to declining functional ability, the associated fear of falling also correlates with increased fall risk (Graafmans et. al., 1996). Therefore, it is important to detect early signs of physical impairment.

Solution: The ReAbleChair was developed to collect high quality quantitative data on physical function, with the purpose to detect warning signs during sit-to-stand and stand-to-sit movements. Such movements can provide valuable insight on physical function and therefore on the capacity to maintain independence in essential everyday activities. The ReAbleChair is a chair with integrated force plates (FP3, Biometrics Ltd, United Kingdom) in the armrests and in the seat. The force plates are hidden, giving the chair a natural look, which promotes natural movements in the home environment. The chair and its ability to collect quantitative data to investigate clinical value on sit-to-stand movement, is described in more detail in (Skille, 2018; Wahl, 2018). The chair is multifunctional, as the sensors can also be used as controls within exercising games to promote increase in physical function.

Fall Detection system and its assistive Mobile Robot

Challenge: In addition to fall risk monitoring, it is also important to detect falls.

Solution: The objective was to create a cost effective and easy to install Fall Detection system solution, which operates using infrared sensors. The Fall Detection system consists of several sensors, which are unobtrusively embedded into the surrounding environment (e.g. in the baseboard). If a fall is detected, most fall detection solutions aim to alert care staff or relatives. Although important, it would also be beneficial if help were available onsite first. This is why a Mobile Robot was integrated as part of the system. The Mobile Robot Pioneer LX Research Platform is able to carry a payload of up to 60 kg and use only a laser range sensor, as well as ultrasound sensors for orientation (Adept MobileRobots LLC, 2013). As the robot does not use any cameras, the data security and personal privacy of the user is ensured, since the robot stores no images or videos. Due to wireless data communication with the Fall Detection system, the Mobile Robot is able to locate a fallen person and bring assistive functions to the fallen person. Via speech recognition, the person can give simple commands verbally to the Mobile Robot. In case of a detected fall, the Mobile Robot moves to the room entrance, and asks if the person requires help. If the help request is confirmed (by saying “yes”), the Mobile Robot enters the room and attempts to offer additional services such as handles (as stand-up support), medication (i.e. nitro) or a phone to call for additional help. Thereby the person can try to help him-/herself before an ambulance, care staff or relative will be alerted. In case the help request is rejected by the fallen person (by saying “no”), the Mobile Robot will ignore the fall alert for a few minutes, before checking again (if the person still lies on the ground). An automated emergency call can be embedded into the system and triggered if the Mobile Robot receives no response within a defined time duration. Once the fall alert stops, the Mobile Robot returns to its docking stations, which ensure that the Mobile Robot stays operable 24 hours per day.

Magic Mirror

Challenge: Ageing also affects cognitive abilities, with high prevalence of memory diseases amongst the senior population (Murman, 2015). Elderly and their relatives may also live far away from each other. This is why relatives would require an easy way to check if everything is all right remotely (i.e. from a distance) without being ‘over-caring’.

Solution: The Magic Mirror was developed for these challenges, without being underlined as a senior security technology. It is based on a modular, open-source platform called Magic Mirror. The mirror can be customized to the user’s preferences and needs, and if equipped with a camera and facial recognition module, it can show different content for each user in the household. Modules can display content like a clock, calendar, weather forecast and news headlines, but other functionalities such as the aforementioned facial recognition can also be added. Furthermore, the mirror can receive messages that are displayed on the screen and the facial recognition can track the use of the mirror. These features can be used as tools for low profile monitoring of the household and its inhabitants.

Smart Gaming Chair and activation games

Challenge: In addition to monitoring, tools should also be developed to promote physical activity, in an effort to reduce or slow the decline of functional abilities.

Solution: An exergame was developed as a potential solution for improving physical abilities, such as muscle strength and balance. The exergame is projected to a large screen and controlled by a smart chair. The exergame was developed for Android devices (in this case a smart TV that has an Android operating system). The chair is connected to the Android device via Bluetooth. The user's movements are measured through nine pressure sensors located under the sitting surface of the chair. Three mini-exergames were developed: (i) ski-jump in which the player must stand up from the chair for the ski-jumper to jump; (ii) snowboarding, in which the player must lean left/right to avoid obstacles and control the player; and (iii) a ball-throwing game in which the player throws balls to targets which appear on the screen. This prototype is described in more detail in article (Merilampi et al., 2019).

3D-printed handles

Challenge: Many older adults are affected by osteoarthritis, weakened compressing power and deteriorated dexterity (Carmeli, Patish & Coleman, 2003). Certain degenerative changes in the hands and fingers are a consequence of underlying conditions such as rheumatoid arthritis. In addition, tremor and spasticity is also common symptom, for example in Parkinson's disease. Impairment to upper extremity function presents difficulties in managing everyday activities such as opening jars, doors, or performing fine-motor tasks.

Solution: To overcome this challenge, examples of custom-made handles were developed, which may be customized according to the user's abilities and requirements using 3D printing technology. All handles provide a larger space between them and the furniture, which they are installed to. They are larger in size and thicker which supports gripping, requiring less dexterity to use/operate than traditional handles. Some enable pulling with a straight hand or forearm (e.g. oval shaped handle), which decreases load/demand on the small joints of the fingers. A "locking handle" consists of a fixed part installed to the cabinet, which acts as an anchor, and a handle part that can be easily attached to the anchor with a simple locking mechanism. This is useful in retirement homes for example, supporting fast and easy replacement of handles customized to new resident's needs.

METHODS

The study was conducted using external contractor Norstat to perform the prototype demonstration and interviews in semi-controlled environment. Neutral facilitators not involved in the prototype development were involved in the research process to ensure objectivity. The volunteer participants were all Finnish, over 65 years old and independently living at home. Recruited people were selected from an external contractor's online consumer panel. In total 22 people (n=22) were recruited, 50% were male (n=11) and 50% female (n=11). The participants were aged 65-69 (n=6), 70-74 (n=7), 75-79 (n=5) and over 80 (n=4). Each participant was contacted in advance to explain the purpose of the research and to validate their suitability related to inclusion criteria (age 65 and above, and living at home). All participants provided informed, written consent prior to participation in the study.

In the test event two interviewers introduced the prototypes, one prototype at the time for two seniors simultaneously. This was followed by an interview with each senior individually, after each tested prototype. The research themes used in the questionnaire followed the basic structure of Jesse Garrett's user experience framework (Garrett, 2010), being: visual design, information and interaction design, functional specifications, and user needs. In addition, general questions were added to give the participants freedom for open feedback and to obtain additional background information.

After all prototypes were evaluated, respondents were asked what they thought about the prototypes and the development of such technology. In the end of the survey, respondents were asked to name their favorite prototype and to describe in their own words why they liked it.

The study answers were analyzed using content analysis, in which the answers to open questions were categorized under the dimensions of Garrett's usability frame (Garret, 2010). The results to the scaled questions (answers were given in scale from 1 (totally disagree) to 5 (totally agree)) were used to support result analysis. From this qualitative material, the researchers were seeking answers to the following research questions (Rq):

- **Rq1: What kind of user experiences (UE:s) did the prototypes evoke in elderly users?**
- **Rq2: Which prototype features influenced user experience?**
- **Rq3: What are the identifiable, key features required for active ageing guidelines associated with smart furniture**?

RESULTS

ReAbleChair

The chair's design followed specific height, backrest and armrest dimensions according to the Timed up and Go (TUG) test requirements as it was used as a tool to collect research data (Kang et al., 2010). The respondents in this study were not informed of the reason for these dimensions. Though this could influence the overall impression of the chair, the primary goal was to assess participants' feedback on how they experience this type of integration of technology. When the ReAbleChair was presented in the field test, the participants understood that it was a technological prototype only after it was presented as one. Before that, it seemed to them like just a normal chair to be used at home. In that sense, the impression of the chair as natural furniture (i.e. without hidden technology) was achieved.

Quantitative results are presented in *Figure 2*. The general impression of the ReAbleChair was good (n=15). The majority (n=17) responded that the appearance indicated the purpose of the prototype 'very well' or 'well'. This was somewhat surprising, as the ReAbleChair was originally designed and developed as a clinical tool, rather than a tool regularly used by older adults. To most respondents, the prototype was meaningful (n=12) or very meaningful (n=2). Furthermore, the purpose was well understood (n=20). Most (n=17) were interested in using the chair in the future.

From the qualitative part of the assessment, the chair's design was highlighted, such as its sturdiness, comfort while sitting, appropriate height and good sized armrests. In addition, the technology aspects were commented upon, with both interest and concerns. As one of the respondents said, "*I'm interested in technology and the information it provides about your own body*". Concerns were expressed with: "*A chair should be a chair and not some test device"*, and *"I see no need for it yet*". This indicates that the purpose of the technology must correspond to a particular need/requirement.

As the ReAbleChair was presented as a prototype to support data-orientated feedback on performance of physical functions, concerns were expressed by the participants. One concern was, being afraid that this type of technology in a chair could replace personal assistance. When asked what the best features with the prototype were, the main responses were on the seating and armrest (being e.g. good to sit on and having a wide enough seat). However, this was also reported by other participants as the worst aspects of the prototype. This indicates that there is a need for individualization of the prototype to meet individual's specific wishes for both the design and the functionality.

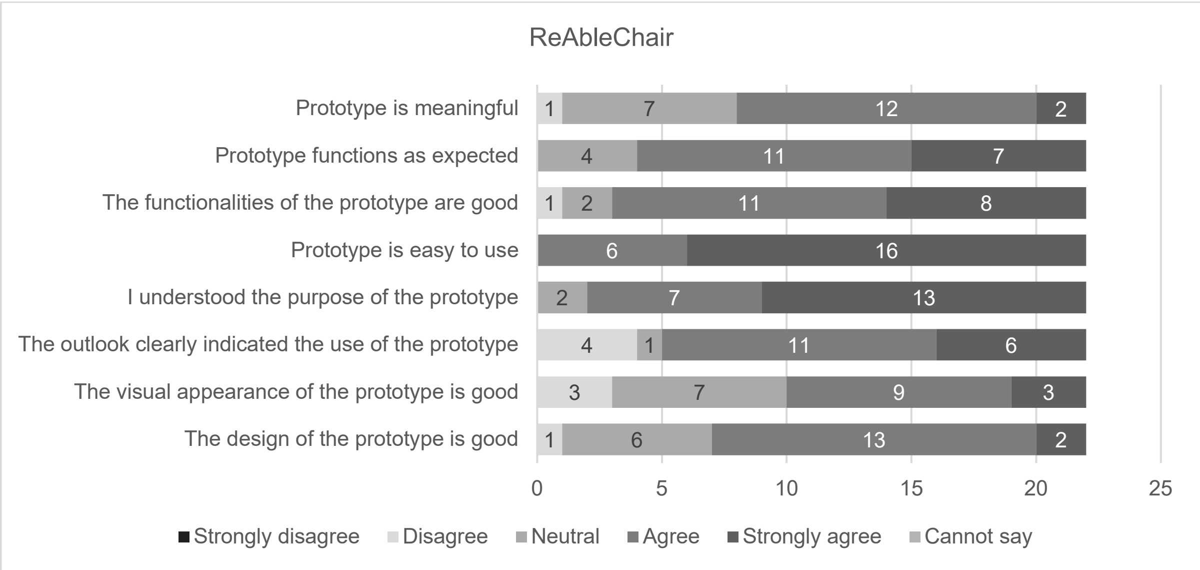

Figure 2. Results for ReAbleChair prototype.

Fall detection system and its assistive Mobile Robot

Feedback on the design of the Fall Detection system and its assistive Mobile Robot was generally positive, with 13 respondents expressing that the design of the prototype is good, and 9 respondents with a neutral opinion (see *Figure 3*).

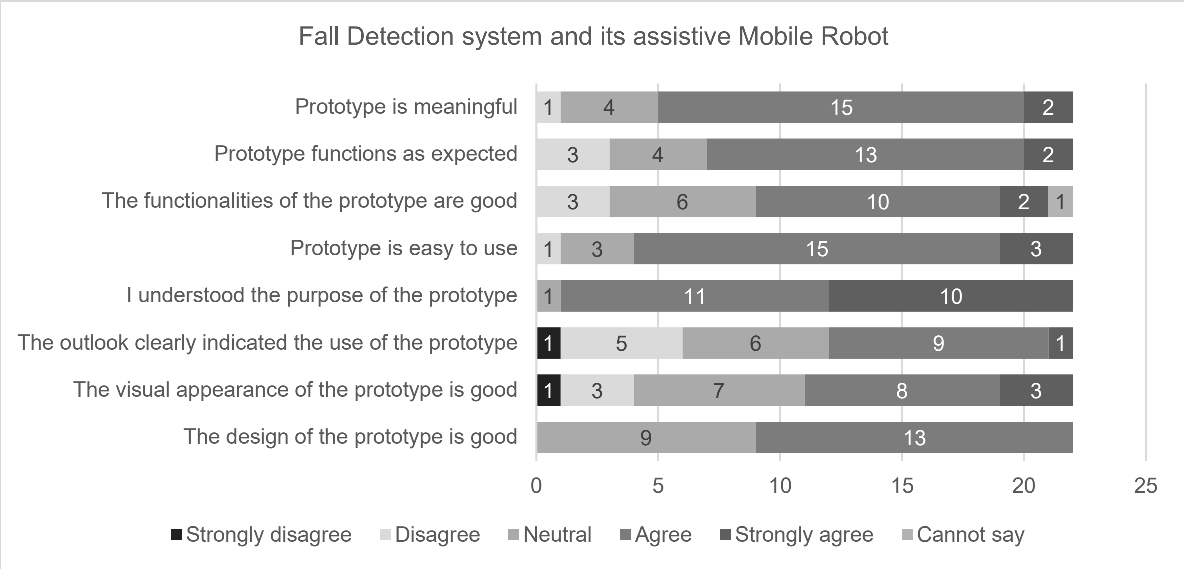

Figure 3. Results for Fall Detection system and its assistive Mobile Robot

Another very important aspect for elderly targeted ICT solutions is usability (user-friendliness), i.e. of the robot and associated automated alert of the robot via the Fall Detection system. *Figure 3* highlights usability of the Fall Detection system and its wirelessly interfaced assistive Mobile Robot, with 15 subjects (out of 22) identifying usability as easy, and 3 even as very easy. Slightly more women than men identified easy or very easy use with respect to usability of the prototype. Only three individuals had a neutral impression, and 1 female evaluated the prototype as difficult in its handling. This positive evaluation could be contributed to the autonomous running system, which interacts via voice control and offers more natural/intuitive operation option for elderly.

The meaningfulness of the prototype to the testees was also investigated (see *Figure 3*). The majority of individuals expressed that the prototype is important or even very important. Here, males and females had a similar impression, with nine males and eight females evaluating the prototype as important or very important.

The evaluation (Norstat, 2018) indicates a positive usability experience, with testees viewing the developed Fall Detection system, linked to an assistive Mobile Robot, as an important tool. Only the design related questions resulted in a neutral impression (n=9), while the rest (n=13) evaluated the design as good. This slightly less positive result comes from the Mobile Robot, which was in the foreground of the testee's perception, since the mobile platform is quite large and heavy and most elderly mistrust technology and domestic robots (Scopelliti, Giuliani & Fornara, 2005). On the contrary, the design of the unobtrusive Fall Detection system compensated for the weaker design of the Mobile Robot as it was commented to be very nicely designed (open questions). Finally, the combination of both technologies, which enables increased feelings of security, lead to the positive overall evaluation of the design.

In the qualitative interview (Norstat, 2018), two major questions were discussed openly with the respondents. These related to: (i) whether the senior would use the prototype at home, and why; and (ii) what the user liked/disliked of presented prototype. The respondents stated that they would use the prototype to increase their feeling of safety, to bring their phone or medicine, and to call for first aid. Furthermore, respondents understood that the prototype aims to support households with seniors living alone. Respondents mentioned that they would not use the prototype unless they were in need (e.g. when their health condition deteriorates). Also, some elderly prefer the help of a human, rather than a robot, however would use the robots to alert for help in case of an emergency.

Regarding preferences of the seniors, the qualitative interview shows that the testees were dissatisfied that the Mobile Robot cannot lift someone up, or open doors automatically. The offered stand up support and the robot's ability to move on ground, as well as the ability to carry objects (e.g. smartphones), left a strong positive impression according to (Norstat, 2018). Also positively mentioned by the test persons was the ability to help care staff in their daily work. Overall, the feedback in the qualitative interview was positive, particularly with respect to improved feelings of security for elderly living alone.

Magic Mirror

During field tests, the Magic Mirror was on display for a shorter period of time than other prototypes, so there were only 11 respondents (instead of 22). Due to this, the remaining 11 question forms have the Magic Mirror related questions answered as "cannot say" (please refer to *Figure 4*). The prototype's visual design was perceived as good (n=7) or very good (n=2). Most of the respondents (n=10) thought the outlook of the Magic Mirror clearly indicated the use of the prototype, and many (n=7) liked the functionalities of the Magic Mirror.

The Magic Mirror was fairly well received with respect to visual design, where the wooden frame was liked in particular. The visual appearance of the prototype can be customized to suit individual's preference by using a different looking frame and changing what modules (content) are shown on the mirror. Most of the respondents thought the outlook of the Magic Mirror clearly indicated the purpose of the prototype.

Feedback on Magic Mirror indicate that the information on the mirror was easy to read and see, however adding or changing content was considered difficult. Streamlining this process would definitely need to be addressed, if the prototype was used and customized by the same person (rather than having a technician controlling content).

The calendar and weather forecast features were the most positively received features of the Magic Mirror. One comment referred to transferability of the tool for other user groups, stating "*it'll probably also serve a busy person, who may not be an elderly person*". One comment referred to the prototype, in general was that "*it lets you view your notes and you don't have to write on paper*". Some concerns arose regarding facial recognition when having multiple people standing in front of the mirror. Improvement ideas were also proposed, such as speech recognition, the possibility to customize text size, the ability to reply to messages, and adding radio channels.

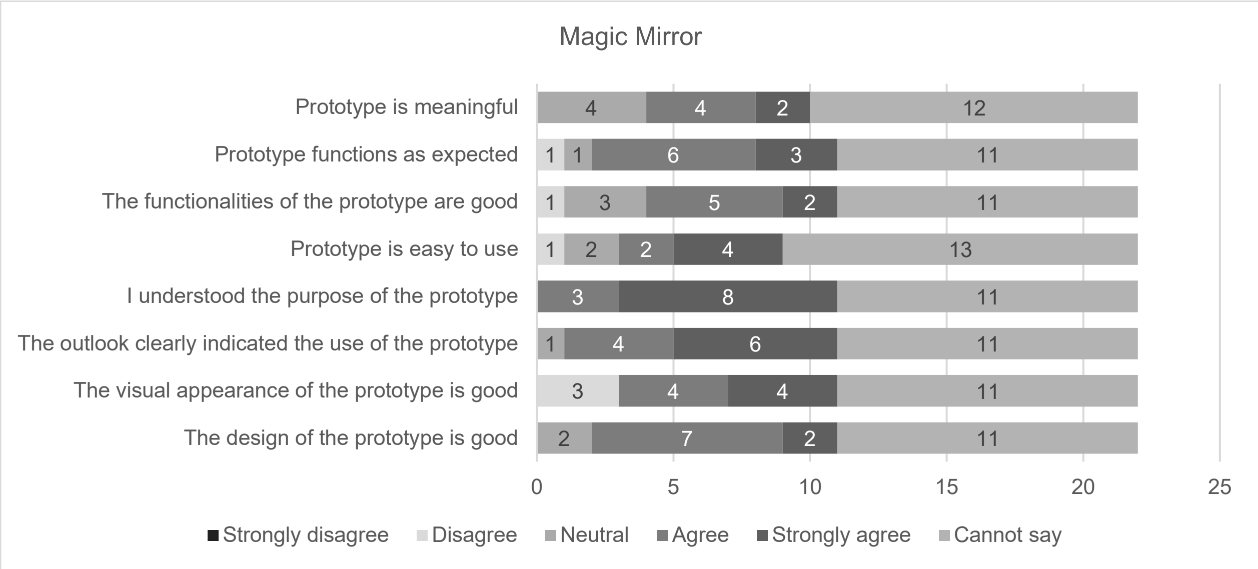

Figure 4. Results for Magic Mirror prototype.

Smart gaming chair and activation games

In general, participants liked the design (n=21) and visual appearance (n=18) of the smart gaming chair (see *Figure 5)*. Also, meaningfulness (n=18) and functionalities (n=19) were well perceived. The purpose of the prototype was well understood (n=20), however two respondents also disagreed about this. One reason could be that the respondents did not expect the chair to possess additional functions, as they perceived it as a regular piece of furniture.

In the test event, the smart gaming chair-controlled game was played on a big screen (65'). No complains about poor visibility etc. were mentioned. In the open questions, no negative comments were raised with respect to visual design. This indicates rather good successes.

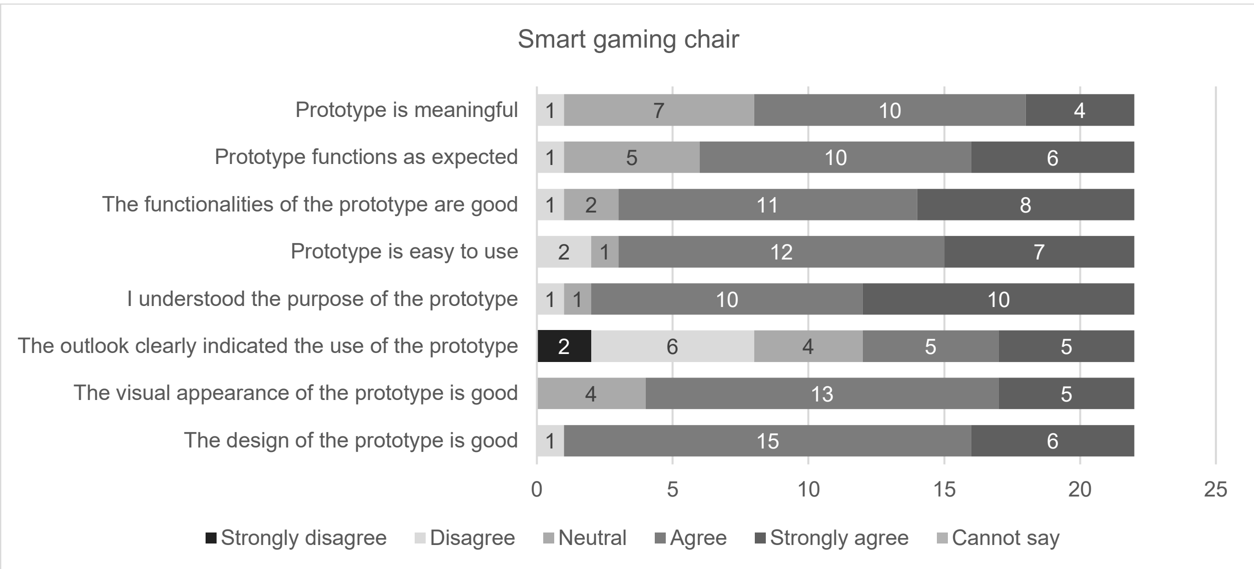

Figure 5. Results for Smart gaming chair prototype.

The open questions offered insight into the features and meaning of the prototype. The expressions “works well” and “easy to use” were repeatedly mentioned. The idea of a chair being used as a game controller was also complemented. Positive comments related to the software/game were: “versatile”, “ski jump theme was nice”, “big screen is good, I can see the game well”, “unusual idea”. The games were designed to be intuitive, which might be one of the reasons for having almost no complaints related to usability. The only negative comment was about the tilt-accuracy, which was hoped to be improved in the future. The theme in the games was winter sports (ski jumping and snowboarding) and ball-throwing, which are very familiar to Finns. The gameplay mimicked the user’s movements, so that the user did not have to learn any difficult controlling methods. The game menus were in the native tongue of the participants, which simplifies game set-up (no complaints about the adjustments were given, as in case with the Magic Mirror). In the test event, the game was also already switched on and the facilitators were modifying the game settings, so the answers/feedback only relates to playing (not the set-up which might affect impact overall impression). The player also received instruction prior to gameplay. The results indicate: familiar theme, intuitive real-life mimicking of controls, clear instructions (in mother tongue) and support from the facilitator (“training service”).

Negative comments related to the limited amount of content available. Some suggestions were given to add different games with more variability. On one hand, this highlights shortages in the demo, but on the other hand it demonstrates that users comprehend the prototype idea and could imagine additional uses for the tool. Some concerns were related to indirect features. The price was mentioned multiple times as people were guessing this concept is expensive. This is a very good point when considering accessibility and service design. In addition, the space requirements for the prototype was identified as a potential challenge, as seniors might not have big apartments. Some persons were also mentioning other game-equipment (for example, Nintendo Wii) as a competitor, which indicates some interest towards games.

The chair itself also received positive comments. Positive expressions related to the chair were: good to sit on (basic function of chair), sturdy, good armrests, good backrest, and appropriate height. Negative thoughts were raised, relating to the height of the chair and difficulties to adjust the height and other dimensions. The armrests also received some criticism. Half of the respondents did not find anything bad about the chair/game. To conclude, the most commonly discussed functional improvements related to adjusting the chair dimensions. The games contained an adjustment/settings menu, so the software could be adjusted according to the player. This functionality could also be beneficial for the chair, especially if the game is used in public places where players have varying physical capabilities and requirements.

The best features of this concept (receiving the most comments) related to meaningfulness were: “it offers physical exercise”, “it brings joy/fun/smiles”; “it offers cognitive exercise”. In addition, safety of the chair-gaming was mentioned as a positive aspect. Some comments suggested that the meaningfulness would increase, if users were no longer able to exercise regularly (e.g. walking). This is supported by answers from people who would not use prototype, as they informed that they regularly exercise, so the chair game concept would not have additional value for them. Regarding improvements, the most common ideas related to creating more games with different controlling methods (to target different muscles). In addition, memory training games were suggested. The only negative comments related to meaningfulness were the concern of games being addictive and the lack of hand exercises. One respondent preferred to exercise in other ways than having any new equipment in the house.

3D-printed handles

There were seven handles displayed in the kitchen test environment, two of which were installed on cabinets and the rest placed on the kitchen counter. The respondents could inspect the visual appearance and design, sturdiness and size, as well as test their functionalities and suitability. The environment also provided the possibility to compare prototypes and the conventional handles installed on the remaining cabinets. As *Figure 6* shows, the handles were meaningful to most respondents (n=20), the purpose was well-understood (n=21) and they functioned according to expectations (n=19). The visual appearance and design were well received, although not liked by everyone.

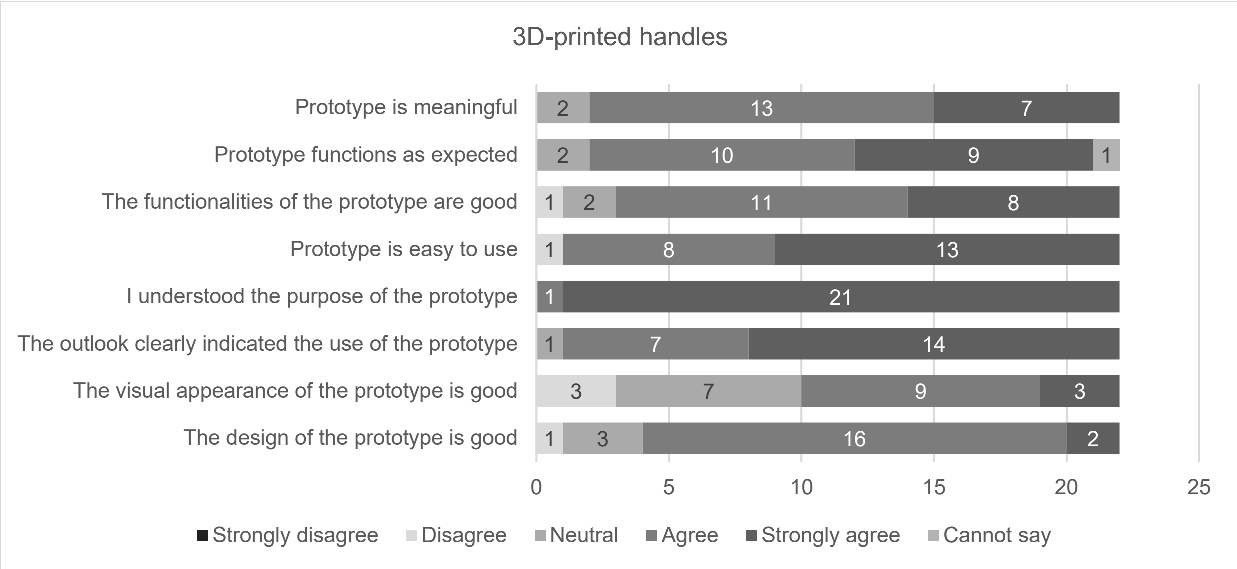

Figure 6. Results for 3D-printed handles.

The design of an oval-shaped handle, which extends over the kitchen cabinet and can be pulled with a forearm, was the most liked. All but one respondent thought that the handles were easy to use. In addition, half the respondents would use the handles if they were readily available. Some were willing to buy the handles if they were available to purchase.

The majority of respondents agreed that the functionalities of the prototypes were sufficient and regarded them as meaningful. These handles would most often be used if the user has special need for them (e.g. underlying health condition, inability to use conventional handles).

In contrast to other prototypes in the test environment, the handles were a set of prototypes and the feedback referred to all of them in general. Some feedback related to individual handles was also expressed. The respondents liked the possibility to produce different sized handles in various colors, their affordability and practicality. Some of the negative comments were related to color (wood color was preferred), material (plastics were disliked), visual appearance (sharp edges) and installation of one particular handle. It was well understood that all sizes, colors and models can be produced quickly. Future development proposals concerned, for example, the design; suggesting that the handles should be more rounded. Some would prefer individual specific design (“specific handle for a specific problem”), whereas others proposed a design for all concept (“more versatile to suit needs of more users”).

Common features in different prototypes that affect user experience

The feedback from the various prototypes was compared, to analyze the elements affecting user experience (Rq2). This is further used to find answers to the main research question (Rq3). In general, the user experiences were extremely positive. This is seen in Table 1, which illustrates the average scores given to the various prototypes. None of the average scores was below 3 (3 = neutral).

Table 1. The average scores for the user experience questionnaire, all prototypes.

	Mobile robot and Fall detection	Smart chair	ReAbleChair	Magic Mirror	3D handles	**Average**
I understood the purpose of the prototype	4.4	4.3	4.5	4.7	5.0	**4.6**
Prototype is easy to use	3.9	4.1	4.7	4.0	4.5	**4.2**
Prototype functions as expected	3.6	4.0	4.1	4.0	4.3	**4.0**
The functionalities of the prototype are good	3.5	4.2	4.2	3.7	4.3	**4.0**
The design of the prototype is good	3.6	4.2	3.7	4.0	3.9	**3.9**
The outlook clearly indicated the use of the prototype	3.2	3.2	3.9	4.5	4.6	**3.9**
Prototype is meaningful	3.8	3.8	3.7	3.8	4.2	**3.9**
The visual appearance of the prototype is good	3.4	3.4	3.5	3.8	3.5	**3.6**
AVERAGE ALL GRADES	**3.7**	**4.0**	**4.0**	**4.1**	**4.3**	**4.0**

From the scoring, the purpose of the handles, Magic Mirror and ReAbleChair was the easiest to understand. The visual appearance of the Magic Mirror and handles described the use of the concept the best. The ReAbleChair and handles were the easiest to use, as they require no technology-specific activities (just “normal use”). The Smart Gaming chair, ReAbleChair and the handles were ranked as the best when it comes to functionality of the prototype. The most critic was directed towards the Mobile Robot, as it is an extra device requiring space (and not resembling furniture).

The design and visual appearance of the Smart Gaming Chair and the Magic Mirror were liked the most. These prototypes were designed by furniture designers, which illustrates the importance of making the prototypes not only functional, but also aesthetically pleasing.

Key, highlighted features for each prototype include:

- Smart Gaming Chair: physical activation, fun, relaxing, brain activation, combines joy and benefits, fit for many
- Mobile Robot and Fall Detection system: multifunctional, security, assistance
- 3D-printed handles: easy to grip, modifiable, great form, beautiful design
- Magic Mirror: easy access to information, helps to remember, calendar function is useful, weather info is useful
- ReAbleChair: multifunctional, giving personal functional information, combining a natural chair with functional measuring device

DISCUSSION

Towards developing active ageing guidelines for furniture

The previously outlined research questions were designed to provide information and identify elements that foster positive user experiences (with respect to smart furniture). This section summarizes the findings and serves as a starting point for building guidelines associated with ageing-friendly smart furniture design (Rq3).

One of the most important features, which was found to positively affect user experience, was the *modularity or ability to customize solutions according to individual users*. In prototypes where personalization was not implemented, many comments highlighted this restriction (such as the set dimensions of a chair). This indicates a positive correlation between customizability and user experience, where users hoped the ability to adjust the prototypes according to their needs/wishes.

One potential way of providing customizable products is through the *addition of support services*, which utilize technology. In the test event the prototypes, as well as potential use cases, were introduced and explained by the researchers. As such, there were no challenges noted in learning to use the technologies. In real-world use, this work should be offered as a service, to ensure prototypes are clearly understood. Some ideas were discussed in relation to adjustment of the prototypes, to simplify use. These services may be supportive, such as instructions how to use the prototypes, how to interpret the data they provide (ReAbleChair, games, Mobile Robot and Fall Detection system) or adjusting the features of the software or hardware (Magic Mirror content, game adjustments, designing handles, Mobile Robot and Fall Detection system's functionalities). In the test event, the researchers performed/modified settings for the user.

In addition to supportive services, the prototypes and their associated data might be integrated into the health care service system, or lighter services outside the official care system (for example, offering new possibilities for relatives to monitor the user's condition. As most technologies require some form of customization or installation (such as the Magic Mirror user interface, game difficulty adjustments, Mobile Robot's and Fall Detection system's configuration, and use cases etc.), these *administrative parts of the software* could be *separated to its own user interface (UI)*, to keep the end user's UI and technology use as simple as possible. The *installation and customization service* would thus play crucial role in successfully implementing these types of solutions.

The prototypes received positive feedback relating to their ability to effect on multiple functions (i.e. physical, cognitive, social). This highlights the importance of a *holistic design approach* when considering smart furniture. The prototypes receiving the most positive feedback contained multiple elements, such as beautiful/aesthetic design, physical exercise, cognitive training etc. Furthermore, many prototypes were judged based on their original/typical use, such as how good the gaming chair was to sit on. This implies that attention has to be paid to the basic function of the smart furniture, in addition to its incorporated technology. This supports the pre-assumption *that functional furniture has to be aesthetic whilst also serving its primary purpose*.

When it comes to the information design, the basic *usability guidelines* (Nielsen & Molich, 1990) offer a good starting point. However, when targeting products towards seniors, additional aspects require attention. In this study, certain aspects were seen to be helpful for seniors. *Technology* was more or less *hidden* to the end user, and *no special attention/instruction was required to understand the use* of most of the prototypes. *Intuitive use which mimics real-life application* (game controls, using a chair, looking at mirror) might have positively affected the results, as no complaints were highlighted in relation to the use logic or learning how to use the prototypes. The *large size and clear fonts/graphics* were appreciated. In the case of the mobile robot, *speech recognition* was well understood and offers an alternative and intuitive method of controlling technology, as people typically answer to speech through conversation.

If external systems such as the Fall Detection system with the Mobile Robot are implemented in home use, it is preferable that extra equipment is multifunctional, serving multiple purposes. In addition, systems should be compact, as well as affordable, without being too difficult to install or to use. The Mobile Robot was considered too ugly and expensive in contrast to the added value it offered (i.e. the functionality). In addition, according to the study results unnecessary/surplus functions which would require extra learning should be avoided, unless they fulfil a specific purpose (including assistive functions) or added value. This again supports the need for a modular and customizable design approach (i.e. attempting not to serve everybody with the same solution). This highlights that *finding and developing for a true need, and "understanding the bigger picture" (also in marketing) is important*.

In general, the user experiences related to smart furniture concepts were positive. It was interesting to see that the Smart Gaming Chair was considered the favorite prototype, although it had the lowest score with respect to meaningfulness. One potential reason for the favor of the Smart Gaming Chair concept is that it possesses both health benefits (physical or cognitive training) and gamified elements that promote feelings of joy. Both factors are very important when considering well-being. All the other prototypes were offering important functions, but did not contain this entertainment element. Additionally, it was pointed out that the aesthetic issues play a role. To conclude, the best user experience was achieved when the prototype had a meaningful function, but also provided something additional, such as gamification or a nice outlook.

Open answers also encouraged developers to keep designing innovative solutions for the elderly. In addition, the developer's work was seen as meaningful and the testing found to be fun. The inclusion of elderly into the development process not only guarantees that designs address a real/specific need, it also promotes usability, ensuring designs are suitable for seniors and offer meaningful content. Future work should concentrate more on data collection and data analytics, which would add value and usage possibilities to smart furniture concepts. In addition, development of service models utilizing this data is in future work.

CONCLUSION

In this study, five smart furniture prototypes were developed, and elderly user experiences were investigated through demonstration and interview. Information gathered formed the basis for future smart furniture guideline development. In general, the user experiences were positive. Smart features were readily accepted as part of the furniture, with hidden technologies offering the opportunity to design functional furniture to assist elderly. In particular, smart furniture offers the potential to foster independent and high-quality living, without the stigma associated with senior-targeted assistive devices. That being said, smart furniture also has to fulfil a primary purpose (i.e. its primary role as an item of furniture). The most essential feature (based on the results) was found to be modularity, or the ability to customize the solution according to the end user's capabilities and needs. Functional furniture also has to be aesthetically pleasing. Administrative components of the software should be removed from the end user's UI and integrated in a separated UI, to keep the end user's interaction with the technology as simple as possible. Installation and customization services, as well as value-adding services (i.e. monitoring), were seen as having potential. To summarize, multidisciplinary, inclusive development was found to be essential to the successful development of the smart furniture prototypes. The user feedback serves as an excellent starting point for developing senior-friendly guidelines for ICT-embedded furniture.

Acknowledgement

The BaltSe@nioR project is co-financed by the European Union (European Regional Development Fund) within the INTERREG Baltic Sea Region.

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Captions of figures