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

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Abstract

Background: The ageing of the population represents a significant challenge, however, it is also a huge potential driver for innovation. Technology development capabilities are rapidly increasing, which enables new, innovative solutions when considering the ageing population.
Objective: To promote the 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 (i.e. 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 separate UI, to simplify the end user's interaction with the technology. Installation and customization services, as well as value-adding services (i.e. monitoring) were seen to offer potential.
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 the older adults. 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, the information gathered provided an excellent foundation for future smart furniture guideline development.

Keywords: Smart furniture, serious games, fall detection, design for older adults, active and assistive living, assistive technologies

Introduction

People over the age of 65 years often live active lives (Marhánková, 2011; Vik, Lilja & Nygård, 2017). Although ageing is a natural, physiological process, the associated decline in physical and cognitive capabilities represents a significant challenge (Seals, Justice & LaRocca, 2016). Reduced functional capacity can lead to decreased ability to perform activities of daily living (ADLs) and injuries, with falls being the leading cause of injuries amongst the older people (Alexander, Rivara & Wolf, 1992). The emergence of modern technology can enable older individuals to live to full capacity, in spite of functional limitations (Andrich et al., 2013). Early adoption of assistive solutions can increase quality of life and support active and healthy ageing. Healthy ageing, as defined by World Health Organization, is a "*process of developing and maintaining the functional ability that enables wellbeing in older age*" (World Health Organization, 2007). Despite the potential help that technology offers, technology solutions targeted towards seniors may possess an associated stigma, affecting potential accept-

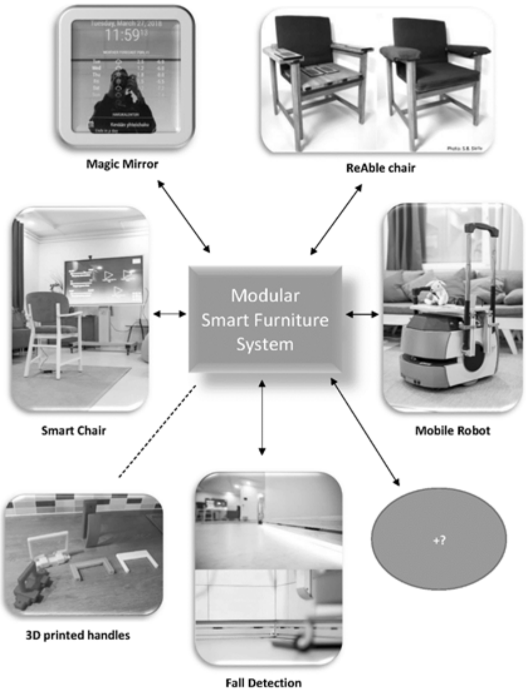

Figure 1. Modular Smart Furniture System.

ance (Kang et al., 2010). Instead of underlining the need for assistance by providing assistive '*senior*' products, assistive functionalities could potentially be embedded in everyday living. As an example, this article relates to furniture, offering additional functionalities which are hidden and targeted towards smart living (for all demographics, not just seniors).

The '70s saw the first steps towards user-centred product design, incorporating ergonomics into the furniture design process (Bürdek, 2015). In recent years, user involvement and user experience have guided product development. The importance of user involvement and user-centred design has also been highlighted in software development, impacting requirements analysis through to testing (Canziba, 2018). Ageing has become a consideration in development, resulting in guidelines for ageing-friendly product design (Pericu, 2017), web pages (Darvishy, Alireza & Good 2013; Moth, 2013; Senior Friendly Design, 2017) and physical environments (World Health Organization, 2007; United States, 2010). Attention has also been directed towards age-friendly environments, with a focus on cities and communities by increasing their accessibility, inclusiveness, equitability, safety, security, and support (World Health Organization, 2007). Smart furniture is somewhat unique, as it combines both ICT (information and communication technology) and physical design dimensions. This paper aims to study the user experience of older users, 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 a customer-centered design process. According to the framework, individualized and modifiable design requires to 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, and moving towards protecting users' rights to obtain products and services that are affordable, modifiable, and meeting ever-changing real-life needs. The technology industry needs to be challenged to move away from a commerce-centred, 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 home technology utilizes basic and assistive devices to build an environment in which many features in the home are automated and where devices can communicate with each other. Such devices can collect physiological and movement data, which can be used for early detection of age-related changes (Barei, 2018).

Smart furniture can broadly 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). It is usually equipped with an intelligent system or controller operated with the user's data and energy sources. Its purpose is to improve the quality of life through the ability to communicate and anticipate the user's needs, with the help of sensors and actuators inside the user's environment (Krejcar et al., 2019). In this article, smart furniture prototypes: Fall Detection system with Mobile Robot, Smart Gaming Chair, Magic Mirror, ReAbleChair, and customizable 3D-printed

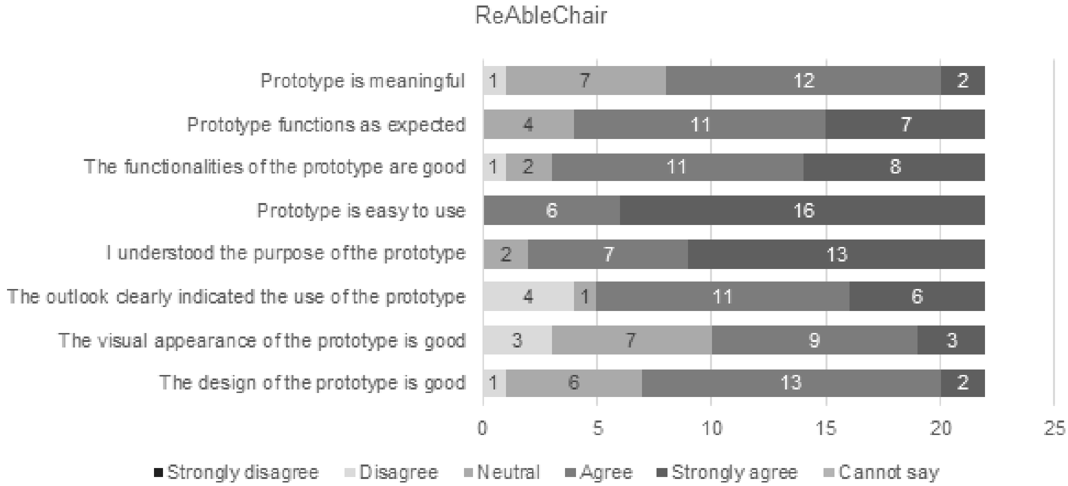

Figure 2. Results for ReAbleChair prototype.

handles are introduced in the next section and *Figure 1*. These prototypes were selected as they contribute to various areas of functional ability and present several technological possibilities. By testing different prototypes, the aim was to find similarities that positively affect user experience. Commercially available products were not used in the study as the feedback from the study would possess limited ability to improve the devices further. Instead, this study shall contribute towards the user-centered development/refinement of the prototypes, as part of the Interreg BaltSe@nioR 2.0 project (Priedulena, Fabisiak & Hogeforster, 2019). The designs are publicly available and actively presented to enable commercialization of the products by industry in the future.

Khosravi & Ghapanchi (2016) presents eight main challenges impacting senior's quality of life: dependent living, fall risk, chronic disease, dementia, social isolation, depression, poor well-being, and poor medication management. These real-life challenges were drivers throughout the development process of furniture prototypes in this study. In addition, ageing-friendly product and service design was discussed in an article by Pericu (2017). This study utilizes some of the key principles of Pericu (2017), such as:

- the inclusive approach of human-centred design (end users);
- the contribution of medical science to identify problem areas (research/health professionals);
- the need for a conceptual transition, shifting focus towards an individual's experience, to improve the interaction between the user and the product/service (with the aid of user-experience design and tools).

With these principles, the concept of a system that 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 for ADLs, while also providing a feeling of security and safety. As functionalities are embedded within the furniture, they reduce the potentially stigmatizing 'senior' label. The core of the system is a server with modular extension capabilities, which facilitates the addition and removal of modules to customize the system according to individual needs and functional abilities. The modular design of serious games was presented in Merilampi, Koivisto & Sirkka (2018) and considered the development of serious games for special user groups. In this study, modular design was found to be beneficial, particularly for user groups whose capabilities differ. This modular approach may also be applied to senior users. *Figure 1* presents the modular smart furniture concept and the prototypes used in this study.

ReAbleChair

Challenge: As individuals age, 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 the home. One of the major fears when experiencing a decline in physical function relates to falling. In addition to declining functional ability, a fear of falling also correlates with increased fall risk (Graafmans et. al., 1996).

Solution: The ReAbleChair was developed to collect high-quality quantitative data on physical function, supporting the detection of warning signs during sit-to-stand and stand-to-sit movements. Such movements can provide valuable insight in relation to physical function. The ReAbleChair is a chair with integrated force plates (FP3, Biometrics Ltd, United Kingdom) in the armrests and seat cushion. The force plates are hidden, giving the chair a natural look, which

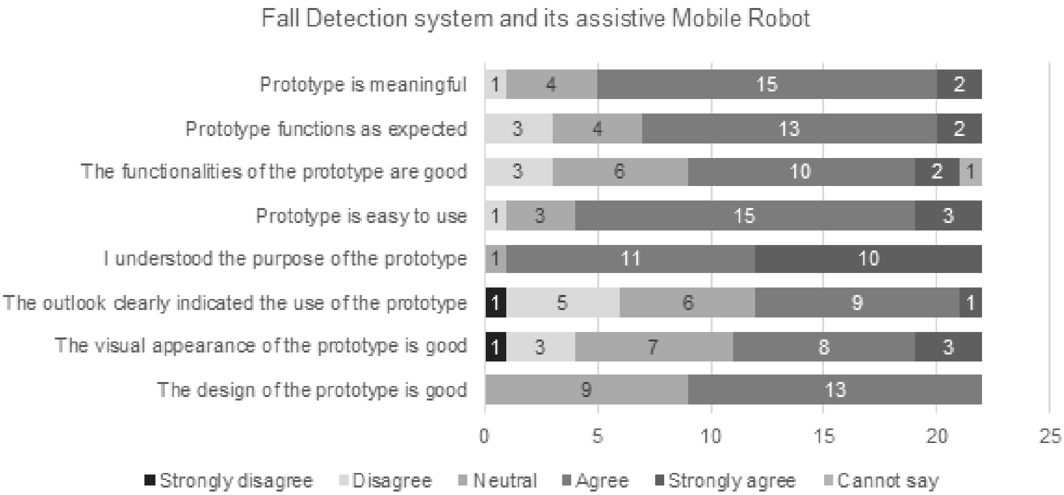

Figure 3. Results for Fall Detection system and its assistive Mobile Robot.

promotes natural use within the home environment. The chair and its ability to collect quantitative data to investigate the clinical value of sit-to-stand movements is described in more detail in Skille, 2018, and Wahl, 2018. The chair is multifunctional, as the sensors can also be used as controls within exercising games to promote physical rehabilitation/exercise.

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, 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 to provide onsite support. Therefore, a Mobile Robot was integrated within the system. The Mobile Robot Pioneer LX Research Platform is able to carry a payload of up to 60 kg, using a laser range sensor and ultrasound sensors for orientation (Adept MobileRobots LLC, 2013). As the robot does not use cameras, the data security and personal privacy of the user is enhanced. Due to wireless data communication with the Fall Detection system, the Mobile Robot is able to locate a fallen person and provide them with assistance. Via speech recognition, individuals can give simple verbal commands to the Mobile Robot. In a detected fall event, the Mobile Robot moves to the room's entrance and asks whether the person requires help. If the help request is confirmed (by saying "*yes*"), the Mobile Robot enters the room

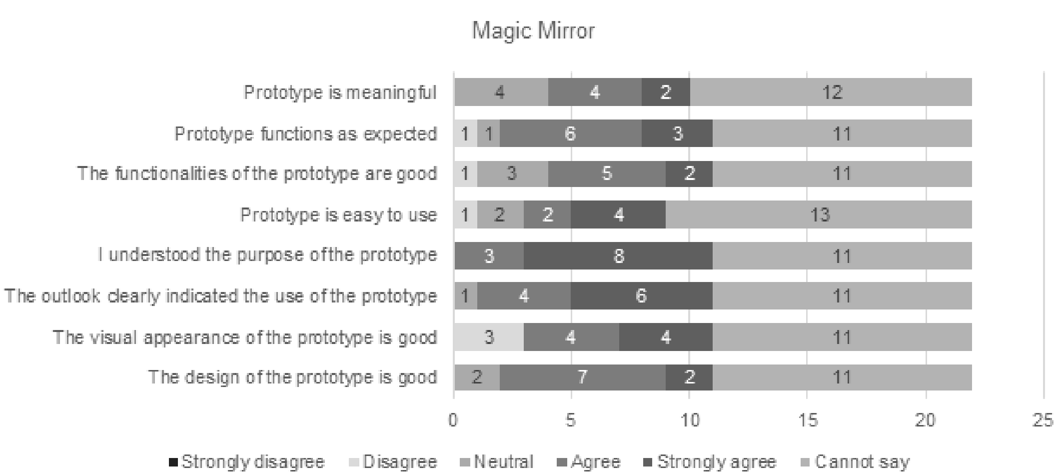

Figure 4. Results for Magic Mirror prototype.

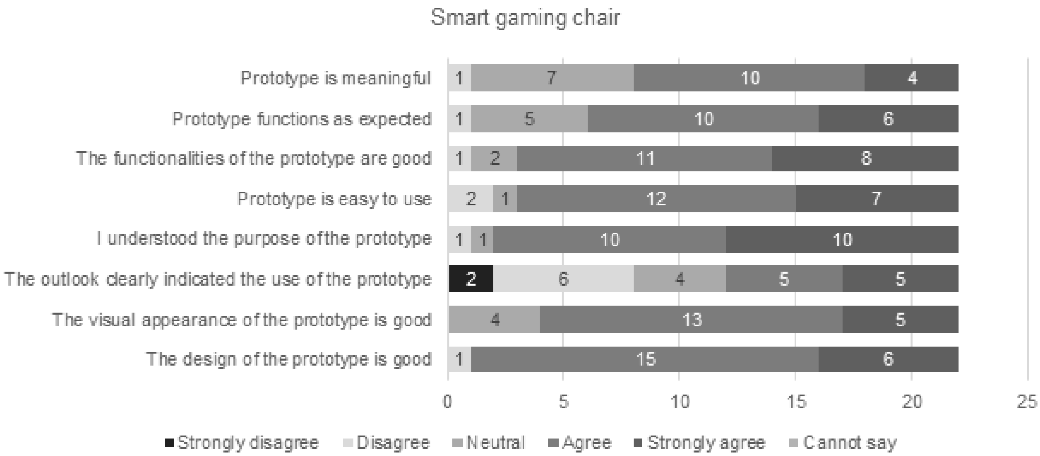

Figure 5. Results for Smart Gaming Chair prototype.

and attempts to offer additional services such as handles (as stand-up support), medication, or phone (to call for additional help). Thereby an individual can attempt to help him-/herself before an ambulance, care staff or relative will be alerted. If a help request is rejected by the user (by saying "*no*"), the Mobile Robot will ignore the fall alert for a few minutes, before checking again (if the person is still lying 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). When in standby, the Mobile Robot returns to its docking station to ensure availability 24 hours per day.

Magic Mirror

Challenge: Ageing can also impact cognitive ability, with a high prevalence of memory diseases developing amongst the senior population (Murman, 2015). Older individuals and their relatives may not live close to each other. Therefore, a tool to easily check-in remotely (i.e. from a distance) without being '*over-caring*' could be beneficial.

Solution: The Magic Mirror was developed to address 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/needs, and if equipped with a camera and facial recognition module, it can display personalised content for each user in the household. Modules can display varying content, such as clocks, calendars, weather forecast, and news headlines. Furthermore, the mirror can receive and display messages on the screen. The facial recognition functionality can also be used to track usage. These features may be used as tools for low profile monitoring of the household and its inhabitants (i.e. is the mirror used on a daily basis), in addition to supporting independent living (reminders, messages etc.).

Smart Gaming Chair and activation games

Challenge: In addition to monitoring, tools should also be developed to promote physical activity, in an effort to promote health and reduce the impact of age-related decrease in functional ability.

Solution: An exergame was developed to promote physical abilities, incorporating movements to promote muscle strength and balance. The exergame is projected onto a large screen and controlled via a smart chair. It 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, requiring the player to perform a sit-to-stand movement as the control input (i.e. initiating the ski-jumper to jump); (ii) snowboarding, in which the player must lean left/right to control the player, and avoid obstacles; and (iii) a ball-throwing game in which the player throws balls at targets which appear on the screen. This prototype is described in more detail in the 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 a 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.

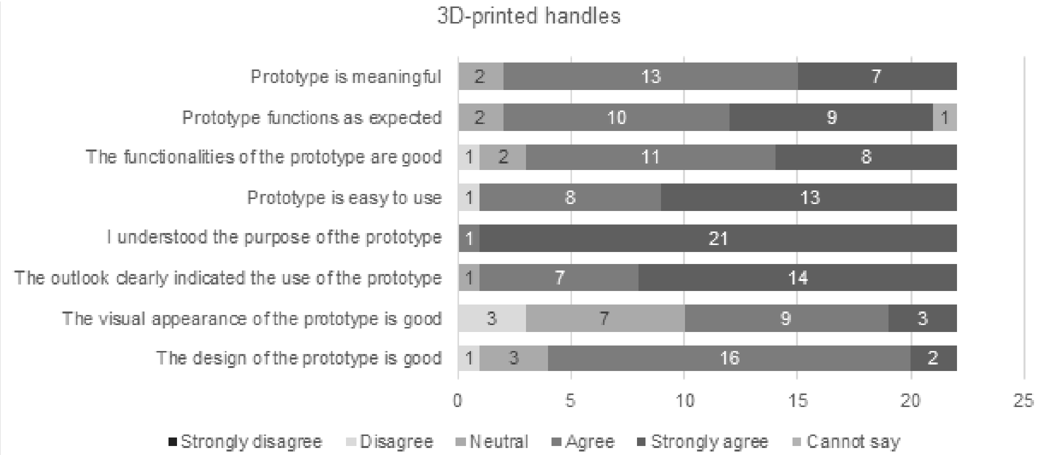

Figure 6. Results for 3D-printed handles.

Solution: To overcome this challenge, examples of custom-made handles were developed using 3D printing technology, which may be customized according to the user's capabilities and needs. All handles were designed to provide a larger size (increased surface area) to support gripping, requiring less dexterity compared to traditional handles. Some handles support pulling with a straight hand or forearm (e.g. oval shaped handle), which decreases loading/demand on the small joints of the fingers. Some handles consisted of two components: (i) a "*locking handle*" fixed/installed to the cabinet, which acts as an anchor; and (ii) the "*interaction component*" 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 an external contractor (Norstat), who performed the prototype demonstrations and interviews in semi-controlled environment. Neutral facilitators not involved in the prototype development were involved in the research process to ensure objectivity.

Participants

The volunteer participants were all Finnish, over 65 years old, retired, and independently living at home (thus not requiring any specific home care services). Recruited participants 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 ensure they met the inclusion criteria (age 65+, living independently at home). All participants provided informed written consent prior to participation in the study. The study obeyed ESOMAR and Finnish Market Research Association ethical and national rules/laws.

Study setup

In the test event, two interviewers introduced and demonstrated the use of the prototypes, one prototype at the time, for two seniors simultaneously. After testing of each prototype, seniors were interviewed individually. 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. Garrett's framework is a guideline for prototype design and feedback, providing a wider scope for analysing user experience (compared to measuring how "*easy-to-use*" a product is). In particular, this research aimed to assess the prototype's impact to meaningfulness. In addition, general questions were added to give the participants freedom for open feedback and to obtain additional background information. After all the prototypes were evaluated, respondents were asked to provide free comments on the prototypes and the development of such technologies.

Data analysis

Closed-form questions utilised a five-point scale (1 = totally disagree, to 5 = totally agree) to support analysis. Responses to open form questions were analysed using content analysis, in which responses were categorized under the dimensions of Garrett's usability framework (Garret, 2010). Quantitative results from the closed form questions are presented in percentage format (in parentheses within the text). Qualitative results from the open form questions were organised into categories and are also presented in percentage format. Three researchers performed content analysis of the qualitative input as a group, to increase objectivity of the study. From the qualitative material, researchers were seeking answers to the following research questions (RQ):

- RQ1: What kind of user experiences (UE:s) did the prototypes evoke in older 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

The following section presents the quantitative and qualitative results for each of the prototypes: ReAbleChair, Fall Detection system and its assistive Mobile Robot, Magic Mirror, Smart chair, and 3D-printed handles.

The participants' general level of interest in technology was as follows: five respondents (23%) answered that they were very interested in technology; 14 respondents (64%) answered that they were somewhat interested, and three respondents (13%) answered that they were not interested at all. The common conception was that "*technology is for the next generations*". Respondents were more interested in familiar technologies (mobile phones, TV, home appliances etc.), rather than modern/unfamiliar technologies.

ReAbleChair

The chair's design adhered to the Timed up and Go (TUG) test requirements for height, backrest, and armrest dimensions, as the TUG was used 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 technology integration. When the ReAbleChair was presented in the field test, participants understood that it was a technological prototype only after it was presented as one. Prior to this, it appeared to be a regular chair. 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*. Overall, the general impression of the ReAbleChair was good (68%). The majority (77%) responded that the outlook clearly indicated the purpose of the prototype. This was somewhat surprising, as the ReAbleChair was originally designed and developed as a clinical tool. To most respondents, the prototype was meaningful (55%) or very meaningful (9%). Furthermore, the purpose was well understood (91%). Most (77%) were interested in using the chair in the future.

From the qualitative part of the assessment, the chair's design received positive feedback in its sturdiness (19%), comfort while sitting (19%), appropriate height and width (26%), and well sized armrests and backrests (22%). Negative comments related to the lack of adjustability in dimensions (43%), visual design (33%), and unsuitability for the living room environment (9%).

Areas for improvement related to the visual appearance (25%), size adjustability (50%), and the inclusion of measurement functions (2 %). This highlights the need for individualization to meet each individual's specific design and functionality requirements.

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 (59%) respondents expressing that the design of the prototype was good, and 9 (41%) respondents with a neutral opinion (*Figure 3*).

One particularly important aspect for older adults targeted ICT solutions is usability (user-friendliness). Figure 3 highlights the usability of the Fall Detection system and its wirelessly interfaced assistive Mobile Robot, with 68% of respondents identifying usability as easy, and 14% as very easy. Only 14% had a neutral impression, and one person evaluated the prototype as difficult in its handling. The majority (77%) of individuals expressed that the prototype was either meaningful or very meaningful. This positive evaluation could be contributed to the autonomous running system, which interacts via voice control, potentially offering more intuitive operation.

Overall, the evaluation indicates a positive usability experience. Only the design-related questions resulted in a neutral impression (41%), while the remaining participants (59%) evaluated the design as good. This slightly less positive result may be due to the Mobile Robot, which is quite large, heavy, and requires storage/housing space. On the contrary, the design of the unobtrusive Fall Detection system received positive feedback during the open questions. Finally, the combination of both technologies, which enable increased feelings of security, leads to a positive overall evaluation of the design.

Positive comments (n=34) related to an increased sense of security (15%), ease calling for first aid (26%), quiet movement of the robot (15%), the ability provide access to phone/medicine (6%), physical appearance (9%), automatic recognition of emergency (6%), and use of handles (6%). With respect to the Mobile Robot, positive feedback related to: the device's ability to be directed to one's location, use of the local language (Finnish) when communicating with the device, and the ability to help care staff in their daily work.

Respondents understood that the prototype aims to support households with seniors living alone. They would not use the prototype unless they were in need (e.g. when their health condition deteriorates). Also, some older adults would prefer the help of a human, however would still use the robot as an alert for help during an emergency. Negative comments (n=18) related to the attachment of the handles (22%), lack of additional functions such as lifting a person up or opening doors automatically (22%), visual appearance and size (17%), general doubts about such technology (17%), high price (11%) and the robot's slow reactions and movements (11%). Overall, the feedback in the qualitative interview was positive, particularly with respect to improved feelings of security for older adults 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"* (*Figure 4*). Of the eleven respondents, the prototype's visual design was perceived as good (64%), or very good (18%). Most of the respondents (90%) thought the outlook (visual appearance) of the Magic Mirror clearly indicated the use of the prototype (that is, clearly understanding the use and purpose of the prototype), and many (64%) liked the Magic Mirror's functionalities.

The Magic Mirror was fairly well received with respect to visual design (the wooden frame was particularly liked). The visual appearance of the prototype can be customized to suit the individual's preference. For example, the frame style can be modified and the displayed modules (i.e. content shown on the mirror) can be altered. Feedback on Magic Mirror indicates that the information displayed on the mirror was easy to view and read, however adding or changing content was considered difficult as it requires programming knowledge.

Most positive comments (n=15) related to the calendar function (27%), weather information (20%), size and design (2%), and messaging function and reminders (20%). Although the Magic Mirror's functionalities were well received by most participants (*Figure 4*), there were also comments criticizing the Mirror's usefulness. Two comments in particular described the mirror as pointless and redundant. Most of the information that the Mirror displayed within the testing environment was also accessible via other devices since data/information was obtained from the Internet. Users who felt the Magic Mirror was pointless likely had access to a smartphone or a computer. Single negative comments related to the difficulty in changing the mirror's content and text, redundancy of certain functions, or the device itself. Some concerns arose regarding facial recognition when having multiple people standing in front of the mirror. Improvement ideas were also proposed by single comments and thus not calculated as percentages, such as the addition of speech recognition/voice control, the possibility to decide the content, adjusting text size, the ability to reply to messages, the option for audio content, adding an option to browse the calendar, and adding radio channels.

Smart Gaming Chair and activation games
In general, 95% of participants liked the design (n=21) and 82% liked the visual appearance (n=18) of the Smart Gaming Chair (*Figure 5*). In addition, the meaningfulness (n=18) and functionalities (n=19) were well perceived. The purpose of the prototype was well understood by 91% of participants (n=20).

In the test event, the Smart Gaming Chair-controlled game was played on a big screen (65'). No complaints about poor visibility etc. were mentioned. In the open questions, no negative comments were raised with respect to visual design.

The open questions offered some additional insight into the prototype. Comments related to both the software and chair. Positive comments relating to the software/game were (n=13): *"versatile"* (15%), *"ski jump theme was nice"* (8%), *"big screen is good/I can see the game well"* (15%), *"unusual idea"* (15%), *"works well"* (15%) and *"easy to use"* (15%). Users also liked the idea of the chair being used as a game controller (15%). 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 concerned the tilt-accuracy (single comment), which was already identified as a potential future improvement prior to the trial. The winter sports theme in the games was familiar to the participants (i.e. 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 participant's native tongue, which simplified 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 controlled the game settings, so answers/feedback only relate to gameplay (not the set-up which may impact overall impression). The player also received instruction prior to gameplay. Positive results related to the familiar theme, intuitive real-life mimicking of the controls, clear instructions (in mother tongue), and support from the facilitator ("*training service*").

Most criticism is related to variability, with respect to the number of games available and ability to exercise different body parts (50%). 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 related to indirect features, such as the price (21%), with participants guessing that this concept would be expensive. In addition, the space requirements for the prototype were identified as a potential challenge (14 %), as seniors might not have large apartments. One person also mentioned other game-equipment (for example, Nintendo Wii) as a competitor, which indicates some interest in games. One negative comment referred to the fear of creating an addiction to games.

Regarding improvements, the most common ideas related to creating additional games, using alternative controlling methods to target different muscle groups (67%). Adding sound was also mentioned (22%). Memory training games were also suggested (single comment).

The chair itself also received positive feedback. Positive expressions relating to the chair (n=16) were: "*good to sit on*" (43%); "*sturdy*" (12.5%); "*good armrests*" (19%); "*good backrest*" (12.5%); and "*appropriate height*" (12.5%). Negative thoughts were raised (n=15), relating to the height of the chair and difficulty adjusting the height and other dimensions (80%). The armrests also received some criticism (20%). 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's 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.

Open form feedback relating to meaningfulness included: "*it offers physical exercise*" (50%); "*it brings joy/fun/smiles*" (37%); "*it offers cognitive exercise*" (13%). In addition, the safety of the chair-gaming was mentioned (single comment). Two comments suggested that the meaningfulness would increase if users were no longer able to exercise regularly (e.g. walking). This was supported by feedback from participants who would not use the prototype, as they exercise on a regular basis (the prototype concept would have limited value).

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 functionality and suitability. The environment also provided the possibility to compare prototypes and the conventional handles installed on the remaining cabinets. As Figure 6 highlights, the handles were meaningful to most respondents (91%), the purpose was well-understood (95%) and they functioned according to expectation (86%). The visual appearance and design were well received, although not liked by everyone.

The design of an oval-shaped handle, which extends over the kitchen cabinet and can be pulled using the 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 for purchase.

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. The respondents liked: the ability to customize the size, colour and design (32%), their affordability (16%), the fact that they are easy to use and to clean (8%), and recyclability (8%). In particular, the oval-shaped handle was well received, with users finding the design pleasing (16%) and highlighting its multifunctionality (8%). Some of the negative comments (n=11) were related to design (27%), and individual comments on colour (wood colour was preferred), material (plastics were disliked), visual appearance (sharp edges), and installation (of one particular handle). It was well understood that all sizes, colours and models can be produced quickly. Future development proposals concerned the design, suggesting that the handles should be more rounded (25%), and use more durable material (33%). 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 analyse common elements affecting user experience (RQ2). This was further used to find answers to the main research question (RQ3). In general, the user experiences were extremely positive. *Table 1* illustrates the average

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

	Mobile robot and Fall Detection	Smart Chair	ReAble Chair	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**

scores given to the various prototypes. Average scores did not fall below 3 (3 = neutral).

From the results, the 3D-printed handles, Magic Mirror and ReAbleChair were the easiest to understand. 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. The Smart Gaming Chair and the Magic Mirror were the highest ranked for design and visual appearance. These prototypes were designed by furniture designers, which illustrates the importance of making the prototypes not only functional but also aesthetically pleasing.
Some 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 information is useful;
- ReAbleChair: multifunctional, giving personal functional information, combining a natural chair with functional measuring device.

Discussion

Towards developing active ageing guidelines for smart furniture

The previously outlined research questions were designed to identify elements that foster positive user experience (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.

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 prototypes. 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 on how to use the prototypes, how to interpret the data they provide (ReAbleChair, games, Mobile Robot and Fall Detection system) or adjusting the software/hardware features (Magic Mirror content, game adjustments, designing handles, Mobile Robot and Fall Detection system's functionalities). In the test event, the researchers performed and modified the 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, use cases etc.), these administrative parts of the software could be separated into 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 a crucial role in successfully implementing these types of solutions.

The prototypes received positive feedback relating to their ability to effect 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 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. This is further reinforced by previous studies, where hedonic attributes have been demonstrated to be an important aspect in product design (Diefenbach & Hassenzahl, 2011).

When it comes to the information design, the basic usability guidelines (Nielsen & Molich, 1990) offer a 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 readily understood and offers an alternative and intuitive method of control, as people typically answer speech through conversation.

If external systems (such as the Fall Detection system with the Mobile Robot) are implemented in-home use, extra equipment should be multifunctional. 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). This is consistent with the study results by Melenhorst and colleagues, which demonstrates that the benefit obtained from technology is what affects opinion, more so than cost (Melenhorst, Rogers & Bouwhuis, 2006).

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 add 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, user experiences related to smart furniture concepts were positive. It was interesting to see that the Smart Gaming Chair was considered the favourite prototype, although it had the lowest score with respect to meaningfulness. One potential reason for the favour of the Smart Gaming Chair concept is that it possesses both health benefits (physical or cognitive training) and gamified elements. Both factors are very important when considering well-being. All the other prototypes were offering important functions, however, did not contain this entertainment element.

To conclude, the best user experience was achieved when the prototype had a meaningful function, whilst also adopting a more holistic design approach (such as an aesthetically pleasing appearance, or gamification element). Perceived usefulness (meaningfulness) and perceived ease of use affected respondent's attitude towards technology, which supports the Technology Acceptance Model (TAM) theory on how users accept and use a technology (Davis, 1986; Venkatesh & Bala, 2008; Venkatesh & Davis, 2000). Additionally, it was highlighted those aesthetics play a role when considering smart furniture.

Open answers also encouraged developers to continue designing innovative solutions for the older adults. In addition, the developer's work was seen as meaningful and the testing was found to be fun. The inclusion of older adults into the development process not only guarantees that designs address a real/specific need, it also promotes usability, ensuring that designs are suitable for seniors and offer meaningful content. Future work should concentrate more towards 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.

Study limitations

The first limitation of the study related to the small number of participants. In addition, as the participants were not screened for functional ability prior to prototype testing, participant capabilities could have potentially influenced study results. This will be taken into consideration in future studies.

Conclusion

In this study, five smart furniture prototypes were developed, and older user experiences were investigated through demonstration and interview. Information gathered formed the basis for future smart furniture guideline development. In general, 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 older users. In particular, smart furniture offers the potential to foster independent and high-quality living, without the stigma often 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. In future iterations of the prototypes, administrative components of the software should be removed from the end user's UI and integrated into a separate 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 future 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.

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