A Literature Review on the Design of Smart Homes for People with Dementia Using a User-Centred Design Approach

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The number of people with dementia is rising every year, and it is getting more expensive to provide care for them in specially designed care centres. Furthermore, some people with dementia prefer to live independently, and to be accompanied by informal and family caregivers. One way to meet this requirement of people with dementia is to place them in smart homes. Smart homes facilitate extra care for people with dementia with automated and semi-automated support. However, smart homes need to be designed in a way that addresses the specific needs of people with dementia. One suggested approach is the user-centred design method, which involves the participation of people with dementia and their caregivers during the design process. This paper presents a literature review of smart homes for people with dementia and user-centred design. The paper attempts to provide a sound review, which can be useful for designers and developers of smart homes for people with dementia.

1. INTRODUCTION

The world population is getting older. Estimates show that in 2015, 900 million people were aged 60 and over, and this number will increase to 2 billion by 2050 (World Health Organisation 2015a). Reports suggest that such a rapid growth of the elderly population and its associated requirements for care will continue to exist, and therefore, it will be difficult to have dedicated caregivers for every elderly person (Augusto et al. 2007). Consequently, and as a result of this lack of human resources, some elderly people have to be able to live independently, which increases the likelihood of being affected by dangers at home (Department of Health-UK 2016).

One group of elderly people, however, is very vulnerable in terms of independent living. This group consists of people who have been diagnosed with dementia. Dementia is a family of chronic diseases that leads to permanent and gradual cognitive decline. Alzheimer’s Disease is the most common type of dementia. As the cognitive abilities of people with dementia diminish, it becomes harder for them to live independently inside their homes, and their need for constant care increases.

Dementia is a serious disease amongst the elderly people, affecting more than 47 million people in the world in 2015, and it is expected to increase to more than 140 million people by 2050 (World Health Organisation 2015b). World Health Organisation describes the personal, social and economic consequences of dementia as follows (World Health Organisation 2015b):

“The personal, social and economic consequences of dementia are enormous. Dementia leads to increased long-term care costs for governments, communities, families and individuals, and to losses in productivity for economies. The global cost of dementia care in 2010 was estimated to be US$ 604 billion: 1.0% of global gross domestic product. By 2030, the cost of caring for people with dementia worldwide could be US$ 1.2 trillion or more, which could undermine social and economic development throughout the world.”

The progress of dementia has been classified into seven stages (Reisberg et al. 1982), starting with people with no cognitive decline at stage one, people with very mild cognitive decline at stage two, people with mild cognitive decline or mild cognitive impairment (sometimes referred to as MCI) at stage...
three, people with moderate cognitive decline or mild dementia at stage four, people with moderately severe cognitive decline at stage five, people with severe cognitive decline at stage six, and people with very severe cognitive decline at stage seven. While in this paper we will use the word people with dementia, our study is centred around people with MCI.

Ambient intelligence is defined as a paradigm based on artificial intelligence which can potentially influence the daily lives of people positively (IST ADVISORY GROUP 2003). It attempts to enrich a space, such as a house or a bus station, with sensors in a way that a decision-making system can provide benefits to the people using that space based on the data acquired from those sensors. Smart home is one of the examples of ambient intelligence.

Smart homes are homes which are equipped with improvements in the sensor technology, wireless communication and remote monitoring. These new technology developments have made several breakthroughs in the domain of healthcare, and one of them is the provision of alternative forms of healthcare provision in smart homes. They have also facilitated the aid of the elderly people, including those who are diagnosed with dementia (Augusto et al. 2007).

The use of smart homes for people with dementia has been extensively researched in the literature (Amiribesheli et al. 2015). A smart home is a reasonable option for people with dementia, as it helps them live independently. At the same time, the sensors used in a smart home can detect their activities, send them to a central database, and then healthcare providers and informal care givers can access and view the data through web and monitor the person with dementia (Skubic et al. 2009). As a result, their independent living is also monitored by caregivers and other relevant stakeholders.

One problem, however, in the design of smart homes is that developing a smart home without getting the actual requirements of its potential users can lead to poor acceptance. This, in turn, is often because smart home developers have much expertise about technicalities, but a limited insight into smart home users’ real requirements (Scheermesser et al. 2008). To overcome this problem, the use of user-centred design has been proposed in several papers (Röcker 2013; Ravishankar et al. 2015; Jozam et al. 2012).

User-centred design is an approach in which the requirements of end users (in this case people with dementia) of a service or product (in this case the smart home) are paid extensive attention to during the design process. The utilisation of user-centred design brings several advantages to the smart home end users and to manufacturers alike. For people with dementia, user-centred design means the smart home is designed with design concepts that consider the old age of its users and also it is fashioned with design ideas that take into account the cognitive limitations of people with dementia (Lumsden 2008). For manufacturers, it brings financial advantages, as it reduces the costs of adapting technical concepts and service functionalities in early design stages (Vahs and Burmester 2005).

The rest of the paper is organised as follows. In Section 2, we will investigate the literature on the topics of the concept of smart homes, how they can help their users, especially people with dementia, devices used in smart homes, and how they can intervene in the lives of people with dementia. In Section 3, we discuss the application of user-centred design in smart homes for people with dementia, the ethical and pragmatic issues that may arise, and possible solutions to those issues. We conclude the paper in Section 4.

2. SMART HOMES FOR PEOPLE WITH DEMENTIA

The benefits of smart homes for their users have been extensively investigated in the literature. For example, it is discussed in (Augusto et al. 2007) that smart homes can bring the following advantages to their users:

- Safety and security: For example, when monitoring the lifestyle of the inhabitant reveals that a dangerous situation is going to happen.
- Comfort: For example, when the room temperature is adjusted automatically for the inhabitant.
- Saving money: For example, when lights in empty rooms are automatically turned off.

Similarly, it is stated in (Berlo 2002) that smart homes can assist their users in the following ways:

- Safety and security: Such as access control, intruder alarm, smoke alarm, automatic lighting at night, and automatic cooker switch off.
- Care: Such as providing an active person alarm, a passive person alarm, and authorised access to the smart home for the care worker.
- Comfort: Such as automatic control of lighting, curtains and screens.
2.1. Specific Needs of People with Dementia

People with dementia, like other ordinary users, can benefit from the facilities provided to them by smart homes, increasing their independence and helping them to age in place. However, the analysis and outcome of a study on smart home requirements of people with dementia (Orpwood et al. 2005) revealed the following concerns:

- It is difficult for people with dementia to learn to use new devices at their homes.
- New devices installed at homes should look similar to devices they have seen previously.
- New devices should help people with dementia to maintain control over their environment.
- Caregivers need to evaluate the new devices before people with dementia can use them.
- Caregivers need to be supported through prompts and reminders.

Furthermore, in order to give people with dementia the independence they want in their life, several risks to their safety and health should be addressed in the design of smart home. These risks might present themselves in several forms, for example, in the form of falls, sensory impairment, immobility, isolation, and non-compliance in taking medication (Demiris et al. 2004).

Another important issue that must be considered in the design of smart homes for people with dementia is how people with dementia perceive the technology used in smart homes, because their age and their disabilities may affect the way they use the devices in smart homes. In one study, the authors ran several focus group sessions to evaluate the perceptions of the elderly people about the technology used in a smart home (Demiris et al. 2004). They found out that there are several major categories where smart home technologies can provide useful assistance to their older adult residents. Examples of such categories are listed in Table 1.

While the study illustrates that people with dementia can benefit from the implementation and deployment of these devices in smart homes, such an implementation is not cost free, and may also introduce new concerns and worries for people with dementia. For example, the study by Demiris et al (Demiris et al. 2004) revealed some of the main concerns of the elderly people about the use of technology. The study showed that there are privacy concerns regarding the use of cameras at different locations in a smart home. There was also a concern that as a result of using the smart home technology, human assistance would decrease and they will lose contact with their caregivers at certain times. Another concern was about the user-friendliness of these devices, as their use could sometimes become confusing or irritating. Furthermore, it was deemed difficult to train older learners to work with these new devices.

2.2. Smart Home Services for People with Dementia

The services provided by smart homes to people with dementia can be classified into two groups (Lundström et al. 2016):

- Services provided at ordinary times, such as reminder services and smart home management services
- Services provided based on anomaly detection in the behaviour of the person with dementia.

In case of anomalies, four types of abnormal behaviour in smart homes have been detected (Tran et al. 2010):

- A normal behaviour which is done at an abnormal time (e.g., the person with dementia waking up, dressing and leaving the home after midnight)
- A normal behaviour with an abnormal duration (e.g., the person with dementia spending too long in the bathroom)
- A normal behaviour with an abnormal spatial context (e.g., the person with dementia sleeping on the sofa during the night)
- A deviation from normal behaviour patterns (e.g., the person with dementia falling on the way to bedroom)

2.3. Smart Home Devices for People with Dementia

Installed devices in a smart home have been generally classified into five groups (Stefanov et al. 2004), though the authors state that not all these device categories might be deployed in a smart home:

- Devices for automation and control of the home environment: for example, automatic kitchen equipment, door controllers, and home security devices;
- Assistive devices: for example, robotic devices for movement assistance, devices for indoor navigation and specialised human-machine interfaces;
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Table 1: Where Smart Homes Are Useful to Elderly Residents

<table>
<thead>
<tr>
<th>Categories where smart home technologies provide useful assistance to elderly residents</th>
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<tbody>
<tr>
<td>- Emergency help</td>
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<tr>
<td>- Temperature checking</td>
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<tr>
<td>- Automatic lighting</td>
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<tr>
<td>- Security of the premises</td>
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<tr>
<td>- Intruder alarm</td>
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<tr>
<td>- Monitoring the physiological factors (e.g., blood pressure, glucose levels)</td>
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</tbody>
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- Devices for health monitoring of important vital parameters: for example, non-invasive and wearable sensors, wireless signal transmitters, and waterproof sensors;
- Devices for information exchange, for example systems for information access and telecommunication and systems for tele-inspection and remote control;
- Leisure devices: for example, virtual reality systems and emotional interactive entertainment robots (Shibata and Tanie 2001).

Another type of categorisation for devices in a smart home has been proposed by (Riboni et al. 2015), and is based on the core functionality of these devices, namely, sensing, reasoning, and reporting.

**Devices which are used for sensing:** These devices are used to monitor an individual's interaction with the smart home. Some examples of sensor devices are magnetic contact sensors, RFID tags, and passive infrared sensors.

**Devices which are used for reasoning:** These devices are used to decide the best action to take for the individual at home, based on the information obtained from monitoring devices. For example, the reasoning device, upon obtaining information about a fall detection of the elderly person, may decide to call emergency, or call a caregiver. For the reasoning device to work properly, it should store and utilise some background knowledge. For example, to reason whether an elderly person is taking their medicine in enough dosage, it should know what the prescribed dosage is, or to know whether a person with dementia has misplaced an item, it should know where the original location for that item is.

**Devices which are used for reporting:** These devices are used to prepare and present reports on the individual using the smart home and on the (mal)functionality of the devices. Reporting devices may use mobile technologies (e.g., the smartphone application developed by eCAALYX (Boulos et al. 2011)) or web technologies (e.g., the eCare for Eldercare secure web application (Steis et al. 2012)).

2.4. Smart Home Intervention Types in the Lives of People with Dementia

The smart home can engage in the lives of people with dementia in several ways (Amiribesheli and Bouchachia 2015). The types of intervention, which are modelled from caregivers’ supporting approaches, are inviting awareness, suggesting, prompting, urging, and performing.

**Inviting awareness:** Inviting awareness happens when the person with dementia (or their caregivers, nurses or doctors) should be reminded of something, without necessarily suggesting them to do some actions. For example, a person with dementia can be made aware that she is constantly repeating her questions. This is done by collecting data from the sensors (in this example, the microphone) and then sending the data to the reasoning device, which analyses the data and decides the best intervention type is inviting awareness.

**Suggesting:** Suggesting happens when the person with dementia should be given suggestions on their daily life activities and for an action. For example, a person with dementia may forget to drink enough water during the day and might get dehydrated as a result. The smart home can therefore suggest that they drink water at a specific time. This is done by collecting data from certain body sensors and sending them to the reasoning device for making a decision on suggesting to the person with dementia to drink water.

**Prompting:** Prompting happens when the person with dementia should be informed of what he is doing and should be checked whether they have complied with the prompt. For example, at a certain time, the smart home prompt the person with dementia to take their pills, and wait for their action. If they take the pill,
the smart home does no further action, but if they do not, the smart home take the action further, maybe by calling a caregiver. In this example, sensors, such as time sensors and pill sensors, and a reasoning device are involved.

**Urging:** Urging happens when the smart home immediately performs an action which is necessary for the well-being of the person with dementia while notifications are also usually given to them. For example, if a person with dementia starts wandering in the house and decides to get out of the house in the middle of the night, the smart home will lock the door immediately to keep her safe, while she is notified of the time and told to get back to her bed. Here, sensors such as movement sensors and time sensors are involved, and the reasoning device is responsible for activating the door lock trigger.

**Performing:** Performing happens when the smart home performs an action automatically based on the data they have gathered, usually without any notifications to the person with dementia. For example, the smart home may decide to turn on the heating when the temperature drops to a certain degree to keep the person with dementia warm, or turn off the lights in rooms with no occupants to save energy and costs for the person with dementia. In this example, temperature and light sensors are used along with the reasoning device that determines when these actions should be performed.

### 3. USER-CENTRED DESIGN FOR THE DESIGN OF SMART HOMES FOR PEOPLE WITH DEMENTIA

User-centred design aims at building a system or a product that meets the requirements of its users and is usable by them (International Standards Organisation 1999). User-centred design involves users in the design process and collects their feedback on the system or product and its usability. During user-centred design, prototypes are usually used for the users to see, work with, and evaluate, and then the designs are modified based on the user feedback.

A user-centred design is important in the development of smart homes because devices and sensors used in a smart home, such as video recorders and heating controllers, can be misused or under-used when understanding and operating them are difficult (Haines et al. 2005), and the situation is aggravated in the case of people with dementia. Through the involvement of users during the design phase, a user-centred design approach ensures this variety of devices can be used by people.

### 3.1. Applying User-Centred Design in Smart Homes for People with Dementia

The use of user-centred design for the development of smart homes is a common approach amongst the developers of assistive technologies (Poulson et al. 1996). However, there are some concerns about involving people with dementia into the process of user-centred design. These concerns can be ethical or pragmatic. From an ethical perspective, it may not be appropriate to expose people with dementia to devices at an early stage of development, because early prototypes are faulty and not completely effective, and when they fail, it may cause anxiety in the people with dementia (Poulson et al. 1996). Since people with dementia tend to have a low self-confidence, working with devices that inevitably fail (as a result of being in the early stages of development) will make people with dementia feel even less able (Bjørneby et al. 1999). Pragmatically, it is challenging for people with dementia to be involved in the process of smart home design because of the peculiarities of dementia disease symptoms such as memory constraints and mobility difficulties (Amiribesheli and Bouchachia 2015). For this reason, it has been suggested that people with dementia be involved only for the evaluation of smart homes (Orpwood et al. 2005).

To overcome the problem of involving people with dementia in a user-centred design approach for the design of smart homes, it has been suggested that formal and informal caregivers can be involved instead (Amiribesheli and Bouchachia 2015). The reason is that they are well-informed of the requirements and preferences of people with dementia and can therefore provide valuable insights. However, involving caregivers is not without a cost either. Sponselee et al (Sponselee et al. 2007) mention that most caregivers, unlike smart home designers, are technophobic, partly because they are afraid of giving away personal contact with people with dementia through a technology intervention, and also because they consider a decrease in time spent with people with dementia as a decline in the quality of care (Raappana et al. 2007).

User-centred design approaches are diverse and each one of them has their own advantages. Haines et al (Haines et al. 2005) provide a comprehensive list of user-centred approaches, including photo studies, focus groups, card sorting, paper prototyping, and the use of diaries. They also list 17 Human-Computer Interaction and usability principles which are refined for smart home applications, as listed in Table 2:
### 3.2. User-Centred Design Tools

A smart home for people with dementia needs to be adaptive (i.e., its behaviour should change in response to the actions of the person with dementia) and personalised (i.e., its behaviour should be tailored to the needs of the person with dementia) (Casas et al. 2008). In order to design such an adaptive, personalised smart home, tools which support user modelling are required.

The tools used in a user-centred design approach are mainly personas, scenarios, and use-cases (Aoyama 2005). Personas are fictional characters based on real stakeholders in a smart home. Scenarios are details of a stakeholder’s interaction with the smart home and the environment. Use cases are based on personas and scenarios and illustrate a list of stakeholders’ actions and the corresponding world reactions. Together, these tools are often used as a means of eliciting, refining, and documenting the needs of people with dementia and their caregivers in a smart home.

### 3.3. Evaluating the User-Centred Design of Smart Homes

Any smart home designed for people with dementia has to be evaluated from several points of view: the end users’ point of view (i.e., people with dementia), the professional point of view (i.e., social and formal caregivers and the medical professionals), and the technological point of view (i.e., the technology used in the design of smart homes) (Kleinberger et al. 2007).

Usability testing is a well-known technique used in user-centred design for the purpose of evaluating whether end users are able to use the product successfully, which is usually referred to as “summative testing” (Maguire 2001). Usability testing can also be used to enhance the usability (and consequently, the acceptability) of a product that is being tested (Dumas and Redish 1999). This is sometimes referred to as “formative testing” (Maguire 2001). The following criteria are commonly used in usability testing:

- Effectiveness: whether end users can successfully complete tasks and achieve goals
- Efficiency: the amount of effort end users require to complete tasks and achieve goals
- Satisfaction: what end users think and how they feel about their experience

It must be noted that due to the unique characteristics of people with dementia, design guidelines and recommendations, although very useful, are still not sufficient. For people with dementia, system must be understandable and easy to use, but also they should learn how to use the system while also learning what the system can do for them (Castilla et al. 2013). Consequently, evaluation of the smart home in its early stages is recommended.

### 4. CONCLUSION

In this paper, we conducted a literature review on the design of smart homes for people with dementia by using a user-centred design approach. While the literature review is not exhaustive, it tries to provide a reasonable overview of three main concepts of dementia and people with dementia, smart home technologies, and user-centred design methods and tools.

We discussed the advantages that the application of smart homes can bring to the lives of people with dementia, and discussed some of the key challenges and obstacles on such applications. We discussed how the smart home can help people with dementia and what concerns they or their caregivers may have about smart homes. We also highlighted the benefits of user-centred design approaches in the design of smart homes for people with dementia, and outlined difficulties and possible solutions for those difficulties. We also stated some of the ethical and pragmatic issues for the involvement of people with dementia in the process of user-centred design.

Several issues in the design of smart homes for people with dementia remain to be explored, such as privacy, security, acceptability and trust. The subject, therefore, remains open for future research.
REFERENCES


