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Developing an Intelligent Environment to Support People with Early-Stage Dementia: from User-Needs to a Real-Life Prototype

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Abstract. Intelligent environments can offer support to people with early-stage dementia, who often experience problems with maintaining their circadian rhythm. The focus of this work is developing a prototype of an Intelligent Environment for assisting these people with their daily rhythm while living independently at home. Following the four phases of the Empathic Design Framework (Explore, Translate, Process, and Validate), the needs of people with dementia and their caregivers were incorporated into the design. In the exploration phase, a need assessment took place using focus groups (N=12), observations (N=10), and expert interviews (N=27). Then, to determine the requirements for a prototype of an intelligent environment, the second phase, Translate, used three co-creation sessions with different stakeholder groups. In these sessions, Mind Maps (N=55) and Idea Generation Cards (N=35) were used. These resulted in a set of 10 requirements on the following topics: context-awareness, pattern recognition, adaptation, support, personalization, autonomy, modularity, dementia proof interaction, costs, data, and privacy. Finally, in the third phase, the requirements were applied to a real-life prototype by a multidisciplinary design team of researchers, (E-Health) tech companies, designers, software engineers with representatives of eight organizations. The prototype serves as a basis for further development of Intelligent Environments to enable people with dementia to live longer independently at home.

Keywords. intelligent environments, dementia, ambient assisted living, ubiquitous computing, pervasive computing, elderly, healthcare

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Ethics: Research approved by the internal ethics committee of the partner healthcare institution. All participants included in the research signed together with their informal and professional caregiver informed consent. During the whole research professional caregivers were present. All research was voluntary.
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1 Introduction

Every year nearly 10 million people are diagnosed with dementia [1]. It is important that these people can remain living at home as long as possible. Living in a familiar environment is an important determinant of successful aging as it improves independence, quality of life, and allows people with dementia to stay part of society [2–4]. Unfortunately, for many people with dementia, living independently at home comes with challenges and risks due to declining cognitive abilities [5], such as fire hazards, falling incidents, malnutrition, and dehydration [6–8]. This not only negatively affects the lives of the persons with dementia but also places a burden on the already understaffed (in)formal care [9, 10].

Although the living environment of people with early-stage dementia can present challenges, it can become a supportive environment, for example, by integrating smart technological innovations. Innovations in the fields of artificial intelligence, wireless networking, and sensor technologies (e.g., smart floors or printable sensors) enhance the possibilities to support people with dementia through intelligent assistive technologies [11, 12]. New developments take these technologies even a step further and try to integrate them into the homes of people with dementia [13–16], creating intelligent environments or so-called “health smart homes”. These are intelligent environments with a focus on assistive health technologies that provide support by monitoring environmental factors, activity patterns, and/or physiological signs [11, 12, 17–19]. Based on the data collection in the home, these systems use their computational abilities to search for deviations in daily activity patterns and can send messages to (informal) caregivers when needed. In recent years many of these intelligent environments are being developed. The European Ambient Assisted Living program [20] is one of the driving forces for developing smart technologies for older adults including intelligent environments [11, 21, 22]. Some known projects are ORCATECH [23], The Rosetta project [24], SPHERE [25], eWare project [26], MIT ageLab [27].

Despite these numerous intelligent environment designs many are not widely used and accepted by people with dementia and their caregivers [53, 56]. This could be an indication that many developed smart home technologies do not meet the user’s needs [53]. Often because intelligent environments are developed from a technological point of view and people with dementia are not directly involved in the development process. Morrisby and colleagues (2018) [30] found in their literature review that only 2 of the 11 studies included the needs suggested by seniors with dementia themselves e.g., [31, 32]. Suijkerbuijk and colleagues’ review (2019) [28] found similar results. However, gathering the needs of people with dementia and incorporating them into the technical requirements is an important aspect of developing accepted and useful intelligent environments, especially when designing for vulnerable target groups such as people with dementia [33, 34].

The primary goal of this research is therefore to include people with dementia during the whole development process of a real-life prototype of an Intelligent Environment that focuses on the needs of people with dementia regarding support and stimulation in their living environment. Furthermore, we will focus during this research on the inclusion of people with dementia when designing user-system communication. With current intelligent environment designs, user-system communication is often limited to messaging deviations to the (informal) caregiver, ignoring the people with dementia. However, much is possible considering current technological innovations, the intelligent environment could, for example, give sensory cues to people with dementia when deviations are found. The intelligent environment is being developed into a just-in-time adaptive intervention (JITAI) [35]. Extending the systems with effectors in the home (e.g., smart lights and speakers) enables the system to offer personalized support to the user the moment they need it [36, 37]. For example, directing lights at kitchen cabinets when it is dinner time [38], giving auditory reminders [39], or using guiding lights [40].

Embedding these effectors in the home environment of people with dementia can create an Intelligent Environment that can support people with dementia and could be the next step in healthy smart homes.

In this paper, first, the methods used to develop the Intelligent Environment are presented and the results of applying these methods are discussed. Thereafter the prototype of the Intelligent Environment is presented. The discussion presents the plans to further develop the prototype into an Intelligent Environment that can support people with dementia in their living environment.

2 Methods

The prototype of our Intelligent Environment has been designed using the first three of the four phases of the Empathic Design Method [13] (Fig. 1). This method mainly focuses on the design of living environments that meet the needs of the user and can thus promote the user's well-being. Working through the design phases researchers and/or designers are steered to develop cognitive empathy so that they can learn and understand people with dementia and adapt the design for their living environment accordingly. Stakeholder and user involvement is crucial in this research to ensure the elicitation of valid requirements and a valid prototype.

In this research during the exploration phase, a need assessment with people with early-stage dementia was performed. Thereafter in the translation phase, these needs were translated into design requirements for the prototype of an Intelligent Environment involving the different user and expert groups. In the processing phase, the design team consisting of different disciplines such as care professionals, designers, and technical Small and Medium-sized Enterprises (SME), designed and developed the prototype in a demonstration home [1]. This home is a fully functional family house where the feasibility of the requirements specified by the experts and the technical feasibility of the prototype can be tested. Throughout the whole process, the end user's needs are considered either by involving them directly or using personas based on the need assessment.

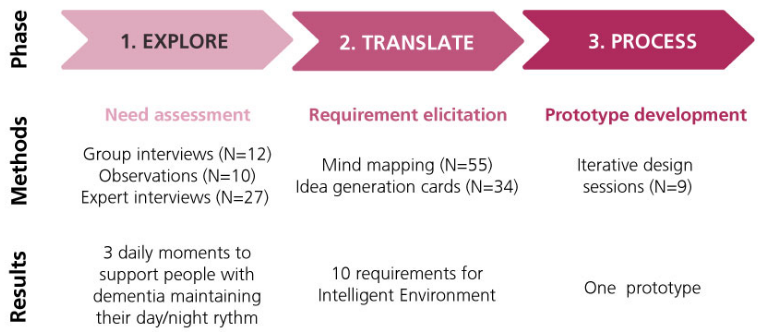

Fig. 1 Research approach, following the first three phases of the Empathic Design Method.

[1] https://www.empathischewoning.nl/en/

2.1 Phase 1 Explore – Methods

The goal of the first research phase was to map out the needs of people with early-stage dementia. In collaboration with care professionals, different qualitative methods were chosen to conduct the research, while taking into account the capabilities of people with dementia. First focus groups were conducted in which the researchers could directly talk to people with dementia in a safe (social) environment and collect subjective needs [27]. Subsequently, direct observations were performed to get a more objective view of the needs of people with dementia in their home environment. Additionally, expert interviews were conducted to obtain an expert view on when and where people with dementia need extra support.

a) Focus groups

Two focus groups were conducted with people with dementia (N=5) and informal caregivers (N=7). Participants were informed about the research through for them familiar care professionals. The research was voluntary. Informed consent was given by the informal caregiver in collaboration with the people with dementia themselves. During the research, an informal caregiver and/or familiar care professional was present to support people with dementia. If the accompanying caregiver noticed any discomfort or struggles the research was placed on hold immediately. To offer a comfortable research environment for the people with dementia the study was conducted in a for them familiar meeting space. Furthermore, the participants of both groups were part of a long-term research program of the affiliated care organization, participants were already acquainted with each other from earlier gatherings, resulting in a safe, open, and informal atmosphere. This trust within the group is important for people to honestly reveal their thoughts and needs [41]. Different themes were discussed: sleeping problems, hobbies, being home alone. During the session, images were presented on-screen to support people with dementia with voicing their thoughts and ideas. Interviews were recorded and analyzed using qualitative content analyses.

b) Observations

The second method performed was direct observation (N=10). Participants were informed about the research through for them familiar care professionals. The research was voluntary. Informed consent was given by the informal caregiver in collaboration with the people with dementia themselves. During the research, a familiar care professional was present to support people with dementia. Participants were observed by a researcher/trainee nurse during the care moments they received from a professional home care nurse known to the participants. No personal information was recorded, and no questions were asked by the researcher/trainee nurse. Data was collected by writing down observations, which were later incorporated into descriptive stories [42] and analyzed using qualitative content analyses.

c) Expert Interviews

Lastly, expert interviews (N=27) were conducted. The experts were contacted through email via the affiliated care organization. All participating experts had different roles within the dementia care system e.g., case manager, nurse, general practitioner, geriatric psychiatrist. All interviews were conducted at work locations. An interview lasted approximately one hour and consisted of 9 open-ended questions about the needs of people with dementia. With given consent interviews were recorded and analyzed using qualitative content analyses.

2.2 Phase 2 Translate – Methods

In the second phase of the Empathic Design Method, the needs of people with dementia (Phase 1) were translated into design requirements for an Intelligent Environment prototype using two subsequent idea generation methods: a) Mind Mapping and b) Idea Cards. Mind Mapping [32] is chosen as the first explorative step because it is an accessible idea generation method that is suited for both smaller and larger groups. The Idea Cards method [43] is an idea generation method used in different stakeholder groups for a more in-depth analysis of the requirements set-up. To make sure the needs of people with dementia (results of phase 1) are sufficiently incorporated in the design solutions generated in the idea generation sessions three different personas were developed. Els, Jacob, and Marie are fictive persons based on the personal characteristics, needs, and wishes of participants of phase 1. They each have a problem with maintaining their circadian rhythm each persona needs support at a different time of the day (*waking up, eating & drinking, going to bed*). Presenting the personas to the participants made sure they could incorporate the wishes and needs of people with dementia into the design solutions.

a) Mind mapping

Mind mapping was used in two workshop sessions, during the conference on new living and housing ideas in 2019 (N=48) and as part of a lecture series at the HAN university of applied sciences (N=7). Participants were informal caregivers and professionals who amongst others worked for care organizations, municipalities, and housing corporations. After a brief introduction to intelligent environments, participants were introduced to the personas. Thereafter participants were divided into pairs and provided with an A3 paper portraying a house as a visual aid (Fig. 2a). Participants were given 15 minutes to write down as many ideas and thoughts on how an intelligent environment should work to support Els, Jacob and Marie, and other people with dementia at home with maintaining their circadian rhythm. The session concluded with a plenary discussion about the different mind maps created. In the end, 28 mind maps were generated. The solutions were analyzed using qualitative content analyses and divided into sense, plan and, act functions and collected in one Excel overview.

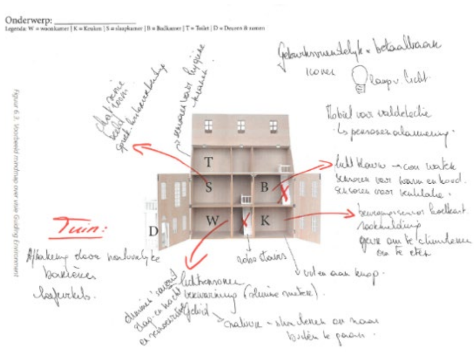

Fig. 2a An example of a completed mind map. **Fig. 2b** Example of a design solution for an intelligent environment. Containing problem solution cards (pink), critical issue cards (orange), and system component cards (multi-colored).

b) Idea cards

After the explorative mind mapping sessions, five workshop sessions with specific stakeholder groups were organized: care professionals (N=6), architects and designers (N=7), ICT experts (N=3), electrical installers (N=11), interdisciplinary design team consisting of researchers, designers, and technical SME (N=8). These sessions aimed to transform more abstract solutions from the mind mapping sessions into more concrete and technically feasible design concepts for an intelligent environment prototype that can support people with early-stage dementia with maintaining their circadian rhythm at three different moments during the day. After a brief introduction to intelligent environments, participants were introduced to the personas. Thereafter participants were randomly divided into pairs/trios and provided with a card set as an idea generation aid (Fig 2b). The cards were generated based on the results of phase 1 and the mind mapping sessions and consisted of three different card categories:

- The set of problem domain cards consists of 3 cards representing common problem domains for people with early dementia: waking up, eating & drinking, going to bed. These domains are corresponding with the personas and are based on the results of phase 1. Participants chose one problem domain card to further develop their design.
- The set of system component cards provides suggestions for technological solutions for the different components of the Intelligent Environment. This set is divided into six smaller thematic sets: communication, content, data input, location, detection, data sharing. The cards are based on the results of the mind map sessions. Empty cards are available to add additional components. The components could be placed together to form one solution for an Intelligent Environment (Fig. 2b).
- The set of critical issues cards is used to evaluate a solution on aspects such as privacy, costs, or scalability of the system. The topics are derived from the results of phase 1.
- After 30-45 minutes of setting up the design, a plenary discussion was held. The critical issue cards were used to discuss the positive and negative aspects of each design proposal. All proposals were photographed (Fig. 2b), and the discussions were annotated. The annotations of the discussions and the intelligent environment concept proposals were categorized into sense, plan and act functions using qualitative content analyses and added to the results table of the mind maps. The different solutions were compared and reviewed by the authors. This led to a list of 8 requirements for the Intelligent Environment prototype.

2.3 Phase 3 Process – Methods

In the third phase, the 8 requirements elicited in phase 2 were implemented into a prototype for an Intelligent Environment using iterative prototype development. A design team iteratively co-created a real-life prototype of the Intelligent Environment in a demonstration home, considering the technical feasibility of the generated ideas. The design team consisted of representatives of 9 organizations including 3 research institutes, 5 technical SMEs (with expertise in areas such as sensor development, data, and user interaction), and a care organization, who collaborated in the context of a two-year funded project. Throughout the project, regular co-creation sessions in smaller groups were organized resulting in a working prototype of the Intelligent Environment. Iteratively, the design team discussed the different aspects of the prototype in 8 plenary sessions of approximately 2-3 hours. Several methods and media were used to elicit discussion on concept development such as creative toolkits, personas, interactive presentations, and several evaluation sessions in the demonstration home for a technical evaluation of the prototype in support of the decision-making process.

3 Results

The results will be presented for the first three phases of the Empathic Design Method (Fig. 1).

3.1 Phase 1 Explore – Results

All three methods of the need assessment (focus groups, observations, and interviews) conclude that *maintaining a circadian rhythm* is a serious problem, encountered by many people with early dementia. A disturbed circadian rhythm negatively affects people with dementia and reduces the possibility of living independently. This challenge of maintaining a circadian rhythm is also supported by literature e.g., [44], [45]. Disturbances in circadian rhythm are caused by various dementia symptoms such as apathy, memory problems, reduced ability to plan, and disorientation in time [6], [46]. As a result, there is a greater chance that people with dementia will forget to perform certain activities. This is bothersome when it comes to forgetting social activities which can lead to loneliness. However, it can become problematic, for example, when people forget to eat or drink resulting in malnutrition and dehydration. Participants of the need assessment indicate that forgetting to eat is a problem they regularly encounter:

"Well, he [pointing at partner with dementia] sometimes forgets to eat. Then I ask, 'have you already eaten?' and then he doesn't know. So yes, that is difficult." – Informal caregiver

An issue that also often arises because of disturbances in circadian rhythm is irregular sleep patterns. This can lead to sleep shortages which lead to negative health effects like increased risk of falling, developing anxiety, negative impact on the immune system, and amplifies loneliness [47], [48]. To prevent these circadian rhythm disturbances, it is important to support a sense of time and offer a day structure to people with dementia. These findings are supported by care professionals who participated in the need assessment. Care professionals make sure clients eat three times a day, take their medicines, and do not forget their appointments. However, this is very time-intensive and if the care professionals leave the house, they are unaware of what is going on. If an Intelligent Environment could provide support with maintaining the circadian rhythm of people with dementia, many problems and health issues can be prevented which can promote the self-reliance of people with early-stage dementia.

In short, a disturbed circadian rhythm negatively impacts people's health because of physical decline related to inactivity, sleep irregularities, malnutrition, and dehydration which is why these disturbances should be prevented as much as possible.

From the results, three key moments in the day were appointed to support circadian rhythm: *waking up, eating and drinking, going to bed*. Indicated by experts as well as people with dementia, these are often the moments during the day where the rhythm goes ‘wrong’. Offering extra support on these moments can prevent major disturbances that negatively affect the health of people with dementia. When designing the prototype of an Intelligent Environment extra attention will be paid to these three moments.

3.2 Sensory cues to support circadian rhythm

During the need assessment participants were also asked about which sensory cues could be given (by technology) to support people with dementia during the day. Participants with dementia indicated that automatic lights are very effective in supporting them with certain activities, for example, going to the bathroom by following a blinking automatic light. Care professionals confirm these findings that light can support people with dementia. However, light is not the only sensory cue. Sounds and images (projections) can also help support people with dementia during the day. Another suggestion often used by care professionals is to use voice commands:

“People like voice-activated things (…) just say what needs to be done. If you only give a beep, then you already assume that the person can remember what that beep means. Instead, if you say, ‘it is time for a sandwich’ it is clear.” – Case manager

Unfortunately, until this moment there is no consensus about which (combination of) cues are most successful; more research is needed. However, all participants agreed on the need for personalization and just-in-time interventions. Dementia is an individual and progressive condition. Therefore, the support given by an Intelligent Environment should offer personalization of sensory cues. Furthermore, to stimulate self-reliance sensory cues should only be offered when people with dementia need them most using just-in-time interventions.

3.3 Phase 2 Translate – Results

The results of phase 1 showed that people with dementia need support maintaining their circadian rhythm. The support needs to take place during three moments of the day: *waking up, eating, drinking, going to bed.* How the Intelligent Environment can provide this support at the right moments was further investigated in phase 2.

The participants (N=90) of the idea generation methods (Mind Maps and Idea Cards) formulated in total 39 concepts of an Intelligent Environment that can support people with early dementia with maintaining their circadian rhythm. Using qualitative content analyses the solutions were analyzed and divided into sense, plan and, act functions and collected in one Excel overview. In this overview, the different solutions were compared on similarities and categorized into eight design requirements by the authors. When developing the prototype, the multidisciplinary design team (N=11) added two additional requirements to the list. This resulted in a list of *ten requirements* for the Intelligent Environment prototype. Table 1 shows which participant groups suggested the different requirements.

- *Context-Aware*. Over one-third of the participants (N=38) mentioned the use of a sensor network to monitor movements and activities that take place in the home and the detection of pattern deviations as a base for the Intelligent Environment.
- *Support*. From the results, it became clear that people with dementia need extra support with maintaining their day-night rhythm. The system can offer support

with daily activities like sleeping and rising on time, eating, and drinking enough, preparing food, and remembering appointments. Users can get support from the system with these activities with the use of different effectors. Participants suggested using light signals and projections (N=48), sound signals (N=25), scent (N=19), and temperature (N=20). Other suggestions included automatic curtains (N=10), medicine dispensers (N=4), and videos (N=7).

- *Pattern Recognition.* More than half of the participants (N=58) stated that data gathered by the sensor network and/or added personal data can be used for pattern detection. The system can detect deviations in these patterns and respond to them. For example, the system can detect whether the user slept enough or whether the person slept at abnormal times based on his/her normal patterns and preferences.

- *Adaptation*. A frequently named requirement is the adaptability of the system by autonomously changing the type of support for the person with dementia based on pattern deviations.

- *Personalization.* Many participants (N=72) put extra emphasis on the fact that the system should offer additional personalization options. Providing personal information, for example, a person's normal sleeping and eating patterns enable the system to give personalized support that fits the user and therefore can be more effective.

- *Data & Privacy.* During the critical discussions held during the Idea Card session (N=35), several additional requirements emerged, including that data and privacy issues should be considered when designing the Intelligent Environment. When data is collected in the home, privacy and data security must be ensured. Careful consideration must be given to who has access to the data: does the whole family have access or only one member? The same applies to any healthcare organization involved.

- *Cost of the system*. Another issue is related to the cost of the system (N=35), as an increasing number of features can make the system more expensive while people do not always have much to spend, nor do they always want to. The system should be affordable for most and if possible covered by health insurance.

- *Autonomy.* This requirement emerged from the discussion about the trade-off between an autonomous system versus the autonomy of the user. On the one hand, an Intelligent Environment should respond and adapt to the users' needs without difficult system interactions such as buttons, lights, and menus (autonomous system). On the other hand, the system should not take over the user's life. A person with early dementia must remain in control over their own lives (autonomous person).

- *User interaction*. For the user to remain in control over the system, a suitable interface needs to be present considering the cognitive impairments associated with dementia (N=11). Participants gave multiple suggestions on how the system can interact and offer support to people with dementia using effectors such as light, sound, and projections. The signals given by the system's effectors should not overstimulate the people with dementia and should be comprehensible for their changed senses.

- *Modularity.* Dementia is a progressive and individual condition that makes the symptoms different for every person and changes over time. To adapt to these different needs the system is divided into different functional modules (N=11). Some people have difficulties with going to bed on time and others with eating enough. Based on these needs, different support modules can be (automatically) switched on or off. The system should also be modular in adding additional sensors and effectors.

Table 1. Requirements for an Intelligent Environment to support people with early dementia. *Methods used: 1) mind maps, 2) cards, 3) design team

Requirements*	**1**	**2**	**3**
Context-aware: A sensor network can monitor movements and activities that take place in the home.	X	X	
Support: Using different effectors the system can support the user with daily activities.	X	X	
Pattern recognition: Pattern deviations in daily activities can be automatically recognized.	X	X	
Adaptation: Based on pattern deviations the system can change its support.	X	X	
Personalization: adding personal preferences to the system makes it possible to offer personalized support	X	X	
User interaction: the system has a suitable interface taking into account the cognitive impairments associated with dementia.			X
Autonomy - *of the system*: the system works autonomously based on the data analyses; no difficult interface is needed to switch the system on/off. - *of the user*: the system will fade out if the user does not react, it will not pressure the user only to guide them gradually.		X	
Costs: the system is accessible for all.		X	
Data & Privacy: Data should be stored locally; the system should ensure the privacy of the user.		X	
Modularity: The system should be modular in functionalities, sensors, and effectors			X

3.4 Phase 3 Process – Result

Based on the results from phase 2 the design team started with the prototype development of the Intelligent Environment. Two years of iterative design and development sessions resulted in a technically working prototype that was installed in a demo-home. This section describes the prototype design and discusses how the requirements are embedded in the prototype.

a) Prototype Design

A prototype is developed based on the results of the first two phases. Fig. 3 depicts a conceptual overview of the prototype design. The prototype consists of different parts based on the framework of other intelligent environments [31]; a) the sensor network in the home to retrieve data, b) communication network, c) data analyses modules and scenario modules forming the computing and decision-making platform, and d) services, consisting of effectors in the home.

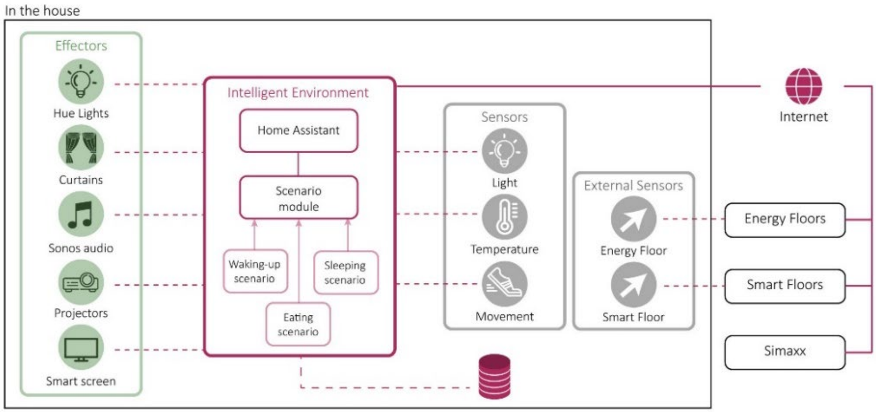

Fig. 3 System architecture of the Intelligent Environment prototype

The communication network and decision-making platform, as the heart of the system, is formed by Home Assistant[2], which is an open-source home automation platform, which runs on a small Raspberry PI that can easily be placed inside the home. The Home Assistant server has been extended with new modules to form the Intelligent Environment prototype. It can be connected to a variety of sensors and effectors, see Fig. 3. The Home Assistant platform forms the base of the system and can be extended using both wired and wireless connectivity and supports protocols such as Bluetooth, Wi-Fi, Z-Wave, Zigbee, and Websockets. The storage component is used to store the data that the sensors generate. This data is stored locally for analyses and/or later retrieval. Optionally, the data can first be filtered, processed, and aggregated before being stored to keep the amount of stored data manageable. In general, the Intelligent Environment can be extended in four ways (Fig. 3):

- *Sensors* – these generate data by sensing its environment
- *Analysis modules* – these modules contain logic to process sensor-data
- *Scenario modules* – these modules implement a scenario that uses analysis, plans interventions, and offers support for people with dementia.
- *Effectors* – these can execute interventions by interacting with their environment

The system also supports the use of external services. In the prototype, examples of external services were smart floors and an external dashboard which can be used as sensors or effectors. These external services can be authorized to use the Home Assistant API over a secure connection. Permission must be explicitly granted by the user of the Intelligent Environment. Using this connection, external services can read out sensors or the stored sensor-data in the storage module and perform their own analysis or present data on their own dashboard. This is useful when external services can provide more advanced analytics relying on external software, or for connecting caregivers to the environment.

Sensors and effectors usually consist of both hardware and software. The hardware is the actual sensor or effector, such as a light sensor or a light bulb. The software typically runs inside the Intelligent Environment and can communicate with the corresponding hardware sensor/effector and passes data and/or instructions between the hardware and

[2] https://www.home-assistant.io/

the analysis modules of the Intelligent Environment. Analysis modules can analyze the data collected by sensors to detect patterns. For example, it can be used to detect the fall risk of a user or if somebody suffers from malnutrition. Based on this information, the system can opt to turn one of the three scenario modules on or off.

The three user scenario modules were developed to offer support at three moments of the day (waking up, eating and drinking, going to bed). A scenario is a predefined decision-tree that is used to determine whether an intervention is necessary based on input from sensors and analyses modules. If an intervention is deemed necessary, appropriate instructions are sent to effectors to execute this intervention. To explain the modules better we will describe one of the three scenario modules: waking up (Fig. 4). First, the system starts the scenario module based on sensor data. The intelligent environment knows the person has not woken up yet. To wake them up effectors are activated, not all at once but one by one the effectors are gradually activated. In this scenario, the smart lights will be activated first (Fig. 4). Light intensity increases over time. The sensor system checks if the person woke up. If this is the case, then the system will be placed in a neutral set-up until it is started up again by sensor input. If the person did not wake up other effectors are activated (e.g., bird sounds, automatic curtains). After three checks the system will not push the person further, but the system will fade out and be placed back in a neutral set-up. This is to prevent the system to take over the life of the person with dementia. A note will be made in the database of the system. If this scenario module was unsuccessful to wake up the person with dementia too many times, a message can be given to the caregiver. The other two modules work according to the same principle only the effectors are different (for example, a projection of a sandwich to guide people to the kitchen, red lights to induce feelings of nighttime, or voice instructions). The effectors which are activated do not only differ for each scenario but can also be varied based on personal preferences.

b) Translation of requirements into the working prototype

This section discusses how the different requirements are integrated into the working prototype. Three requirements (pattern recognition, adaptation, and cost of the system) were not implemented and will be reviewed in the discussion section.

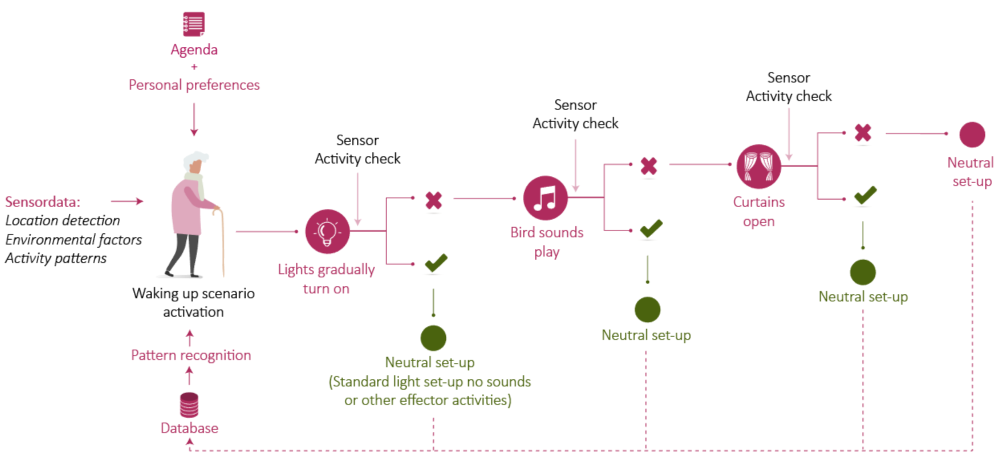

Fig. 4 Example of a scenario module (waking up) using the three-step strategy.

- *Context-Awareness:* The system is made context-aware through its sensors using off-the-shelf sensors that sense light, temperature, and movement. Furthermore, two types of floor sensors are integrated for localization and activity detection using triangulation based on a grid with RFID antennas [49, 50].
- *Modularity:* The system has built-in modularity in its architectural design: via the Home Assistant new sensors and effectors can be added. The system is also modular in its supporting functionalities using scenario modules.
- *Support*: Three scenarios are currently implemented and functional: waking up, eating, and going to bed.
- *Personalization:* The scenario modules can be (manually) parameterized with personalized data from users. For example, the waking-up scenario in Fig. 4, uses the personalized data of when the user normally wakes up. New scenario modules can be developed and easily added to further personalize the system. Another way to personalize the system is by customizing the effectors (e.g., changing the light colors or content on the projector).
- *Adaptation:* Based on the sensor data three different scenario modules can be activated. In the current prototype, the activation of scenario modules is based on location data or can be done manually.
- *Autonomous:* The system can autonomously start a scenario module to support the person with dementia based on the data analyses. Therefore, a person with dementia does not need to learn to activate the system. Autonomy of the person with dementia is ensured by the implemented three-step interaction (Fig. 4). The system does not push the person with dementia but uses a user-centered form of interaction to guide the person. If the person does not want to change certain activities, the system will fade out and leave the person with dementia in his/her own right.
- *User Interaction:* To accomplish dementia-proof interaction, the scenario modules are designed based on a three-step strategy (Fig. 4). Increasing the level of effector intensity in each step, avoiding overstimulation, and ensuring a level of autonomy for the user. The system stops when the action is performed or after a cycle is completed (even if the action is not performed by the user).
- *Data & Privacy:* All generated data is stored locally, and all access to it must be explicitly granted by the user, thus enabling the privacy of the users.

4 Discussion

The exploration phase carried out together with people with dementia, caregivers and experts have led to a solid problem definition – support of the circadian rhythm during three moments of the day – before a start was made on developing the technical prototype. This research tried to involve people with dementia throughout the entire design process. Something that according to different literature reviews does not often occur [28, 30], they are often only partly included for example during co-creation sessions or user tests. As a result, wishes and needs are often not properly incorporated into designs, which leads to technology acceptance issues. In this study, we tried to, directly and indirectly, include people with dementia throughout the whole design process, by involving people with dementia, care professionals, experts, informal caregivers, and personas based on participants from phase 1. As a result, a set of requirements could be drawn up based on the real needs of people with dementia which could be integrated into the prototype. This has led to a prototype that can offer personalized support at a specific moment of the day when people with dementia need it. The system offers autonomy to its users. It does not push people but gradually tries to stimulate them to perform certain key activities for maintaining their circadian rhythm.

However, the prototype is not perfect yet. The text below discusses the validity of the prototype in relation to the requirements and problem statement and discusses which steps should be taken towards having an Intelligent Environment that can interact with the user through different effectors embedded in the home environment of people with dementia. As described in the results section the system is context-aware and can support the user. The architecture of the system facilitates modularity, allowing the easy addition of new functionalities or scenario modules, and personalization. Not all requirements were integrated into the prototype. Pattern recognition could not be implemented yet, as data of actual users are needed to develop more advanced algorithms. The cost of the system was not regarded as a strict requirement as it will take a while before the Intelligent Environment will be a marketable product, and hardware costs will typically drop.

However, the inclusion of technical SMEs ensures the development of an affordable product. Furthermore, it is not yet clear to what extent the Intelligent Environment can also save costs when implemented into the care system. The remaining requirements were all integrated into the prototype to some extent, but there is room for future improvements. Personalization is currently only possible in the back end, but not facilitated by an easy interface for end-users, or by the integration of an Artificial Intelligence (AI)-module. Future implementation of AI modules makes it possible for the system to automatically select which modules are suitable for the end-user [11]. This type of adaptation and pattern recognition can be improved using AI after the prototype has been used in longitudinal data collection in a realistic environment.

Furthermore, the interaction between the system and the user is currently limited, although the system has a selection of effectors and scenario modules to support the user and provide feedback, the user currently cannot explicitly configure or control the environment themselves. This trade-off between the autonomy of the system and the autonomy of the end-user should be further considered when developing the prototype [51, 52]. Together with other concerns related to privacy and data sharing, this should be taken into consideration continuously in further development and eventual implementation [21]. A suggestion is to partly integrate these requirements “by design", for example including a configurable variable of how much the system should act autonomously.

4.2 User involvement

Because people with dementia, (informal) caregivers, and dementia experts were involved from the start of the prototype development needs of people with dementia could be integrated into the design. As expected from the literature [28, 54], it was a challenge to recruit people with dementia to participate in the research project. However, when people decided to partake in the research the collaboration was successful. Participants enjoyed the research activities and were very open in answering the researcher’s questions.

The combination of different methods (e.g., interviews, observation, and focus groups) resulted in a complete image of the needs of people with early-stage dementia because subjective as well as objective needs were gathered. This allowed for designing the prototype in such a way that it can offer personalized support at specific moments of the day when people with dementia need it most. By integrating this information within the sensor technology, the system will only offer support when it is needed.

Due to low participant numbers of people with dementia also other stakeholders were involved in the research. This turned out positively, involving the different stakeholder groups (informal caregivers, care professionals, and dementia experts) resulted in an extensive set of requirements for the development of the prototype and allows us to ensure that the user's needs are properly implemented into the design of an Intelligent Environment which in turn could promote the future adaptation of the technology [28, 29, 33].

In the future, to incorporate the needs of people with dementia even better into the design of the Intelligent Environment the prototype can be used as a design tool. For people with dementia, a decline in abstract thinking and cognitive capabilities makes it harder to express their needs [28, 34, 55], therefore, using the prototype in a real-life home setting can provide valuable insights. For example, the prototype could provide insights on how people with dementia experience the support moments, on finding the personal preferences for the (combination of) signals that are effective in supporting the user's daily structure, both in terms of behavioral change and in terms of acceptance of the system, and on the effectiveness of the system in giving support.

4.3 Continuous development of the Intelligent Environment

Furthermore, the modular nature of the Intelligent Environment provides opportunities for further development. Besides adding other sensors and effectors the prototype is also modular in its functionalities. The modules "waking up", "eating and drinking", "going to bed" are the first modules that are implemented to support the circadian rhythm. In the future also other modules can be implemented, such as modules that provide support for preparing meals, anxiety, exercising, or taking medication. Other fields of exploration are how the Intelligent Environment (on a large scale) affects the clinical practice, responsibilities, costs, and work protocols.

Before further development of the prototype can take place validation of the prototype is needed. Validation, the fourth phase of the Empathic Design Methods, falls out of the scope of this paper but it is certainly important for further development of the Intelligent Environment prototype. Together with the people with dementia it has been determined that lights, projections, and sounds as system effectors can offer support to the user. However, whether this affects the behavior of people with dementia remains to be researched. Especially because during the dementia process cognitive and sensory changes take place. The effectors should not overrule people with dementia and/or affect the autonomy and dignity of the user. Especially by people with dementia, these sensory signals can be interpreted differently so validation is needed to make sure the signals do not have negative consequences. The usability and effectiveness of the prototype must therefore be further explored.

5 Conclusion

This paper showed how the needs of people with dementia can be integrated into the design of an Intelligent Environment that can support people with early dementia using different effectors embedded in the home environment, using the first three phases of the Empathic Design Method. Integrating user needs into the design of new intelligent environments could improve the implementation of such technologies into the lives of people with dementia. In the first phase need assessment, and problem definition was set up whereafter in the second phase a set of ten design requirements was presented. The requirements were elicited in co-creation with relevant stakeholder groups. Based on these requirements, a multidisciplinary design team (e.g., care professionals, researchers, designers, technical SMEs) developed a technically working prototype of the Intelligent Environment and implemented it in a demonstration home. This indicates that the requirements were realistic from a technical viewpoint. The prototype is an important tool for further developing intelligent environments with and for people with dementia. Testing the validity of the Intelligent Environment prototype in the demonstration home together with people with dementia and other stakeholders ensures that we can develop technologies that support people in maintaining their circadian rhythms. Such an Intelligent Environment enables people with early dementia to live longer independently at home.

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