LiveNature: Ambient Display and Social Robot-Facilitated Multi-Sensory Engagement for People with Dementia

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ABSTRACT
The wellbeing of people with dementia in long-term care facilities is hindered, as they spend most of their time alone with little engagement in meaningful activities and an absence of pleasant sensory stimulation. We designed an interactive system called *LiveNature* that adopts a novel combined approach involving an ambient display unit and an interactive robotic sheep, to offer long-term access and to engage people with dementia in long-term care facilities in rewarding experiences. *LiveNature* aims to provide holistic multi-sensory engagement to provoke positive emotions, increase social bonding, and restore attentiveness and communication. The design was implemented within a Dutch nursing home. An evaluation of the user experience and the effectiveness of the design was conducted in a real-life setting with nine participants, five family members, two caregivers and four volunteers, using observational rating scales and semi-structured interviews. The results of the rating scales and the findings from qualitative data showed evidence of enhanced positive engagement.

Author Keywords
People with dementia; long-term care; multi-sensory stimulation; ambient displays; social robots.

CSS Concepts
• Human-centered computing~ Contextual design

INTRODUCTION
The number of people with dementia (PWD) is on the rise as the worldwide population is aging. Dementia is a progressive disease that erodes PWD's ability to perform daily tasks, as they gradually experience reduced cognitive ability, loss of memory, learning skills, and impaired affect regulation [1]. Alongside this loss of ability, many challenging behaviors begin to emerge, which are mostly coping strategies that

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Figure 1. Design of *LiveNature*, as implemented in Vitalis, a Dutch nursing home: (a) overview of the *LiveNature* design including the ambient display unit; (b) an interactive robotic sheep developed based on a Pleo robot; (c) user evaluation in Vitalis with a participating resident.

PWD use to deal with complex settings. Psychiatrists refer to these challenging behaviors as the Behavioral and Psychological Symptoms of Dementia (BPSD), such as an inability to maintain focused attention, agitation, apathy or depression [22]. The need for professional and intensive care services means that most PWD are eventually admitted to Long-Term Care (LTC) facilities where they can receive quality care. However, starting a new life under difficult psychological and social circumstances presents a significant challenge [6]. Residents with dementia in LTC are often reported to spend most of their time with limited sensory stimulation or conversation and little engagement in meaningful activities, which can further lead to disruptive BPSD, sensory deprivation or social isolation [34]. Therefore, without a cure in sight, developing and evaluating meaningful activities that foster and sustain engagement is critical for the quality of life of this group.

Various approaches have contributed to improvements in dementia care. Multi-Sensory Stimulation (MSS) can provide stimulation of the senses without the need for high cognitive load, and is suitable for people at any stage of dementia. MSS has been widely studied and proven to improve functional performance and reduce the frequency of BPSD [3]. The ambient displays provide ongoing displayed information that naturally blends into the environment [4], and therefore enables continued access to users. This is ideal for use in public/shared spaces. Moreover, social robots are designed to provide companionship and to promote therapeutic interaction by encouraging people to engage and interact in activity similar to pet therapy [41]. However, the use of a single approach often has limitations such as a lack of active engagement, an inability to provide holistic sensory stimulations, or being challenging to put into practice [27, 47]. There are a few design researches or practices that combine the benefits of these approaches, therefore, we aim to integrate approaches so that they can offer synergy and holistic experience through multiple interaction possibilities.

In this paper, we propose an interactive system design called *LiveNature* that combines an ambient display unit with an interactive robotic sheep (IRS) to engage PWD living in LTC facilities in a holistic "living in nature" experience. The design was implemented in a Dutch nursing home (Vitalis, Eindhoven, the Netherlands) through a large display-based installation (see Figure 1a) and a Pleo robot-based IRS (see Figure 1b). *LiveNature* aims to provide multi-sensory engagement to provoke positive emotions, increase social bonding, and restore attentiveness and communication. An iterative design process towards the final design of *LiveNatur*e was adopted, with co-creation involving all stakeholders. An evaluation study of the user experience and design effectiveness was conducted with nine participants, five family members, two caregivers and four volunteers, using observational rating scales (Observational Measurement of Engagement (OME) and the Observed Emotion Rating Scale (OERS)) and semi-structured interviews. The main contributions of this work are as follows: (1) a novel combined approach (an ambient display and a social robot) that offers long-term access and an effective design solution for engaging and stimulating residents with dementia in LTC; (2) a use context through *LiveNature* for facilitation of the social robot use, and (3) a working system implemented in a real-life setting with a user study and evaluation.

RELATED WORK

In order to provide suitable stimulation and to engage PWD in meaningful activities, the following approaches were used to guide the design to suit individual abilities in the context of LTC.

Multi-sensory Stimulation for People with Dementia

Deterioration in the senses is expected as part of the aging process. The risk of sensory deprivation for seniors with dementia is even higher, due to the neuronal losses caused by the disease. The shift towards an unstimulated or wrongly stimulated LTC environment makes the situation even worse, resulting in normal stimuli becoming confusing and consequently leading to BPSD [6]. To address this, the MSS (or Snoezelen) method was proposed, and this has become increasingly popular in dementia care. It aims to help stimulate the remaining functions and maintain cognitive abilities by stimulating multiple senses. MSS offers an alternative approach than cognitive-oriented activities to cope with a diminished learning ability. As this approach does not need complex reasoning, it allows a broader range of users to benefit from these stimulating activities. The typical application of MSS is the Multi-Sensory Environment (MSE) [19], in which visual projections, soundscapes, light or tactile materials are commonly available for self-exploration by users. Empirical evidence from research has confirmed that MSE can enhance feelings of comfort, support communication, and maximize a person's potential to focus [3]. However, despite all of these advantages, MSE treats PWD as recipients, and passively engages them with little involvement from social or communication aspects. It has been reported that many existing MSE seems to fail to address the specific user needs due to inadequate design and poor facilitation resulting in such spaces being underused [19]. Researchers and designers therefore need a proactive strategy to actively engage PWD in MSS sessions using properly designed artifacts and facilities.

Ambient Displays for People with Dementia

Ambient displays as a subset of peripheral displays provide continuing displayed information that can be monitored by users without requiring their focused attention [4]. We encounter many cases of peripheral monitoring of information in daily life, such as checking clocks and windows. These displays sit at the periphery of attention and provide relevant information such as the time or weather. Ambient displays as enhanced computational artifacts can easily blend into the environment, offering a natural method of interaction [30]. They provide continued access to users, are available to a broad audience, and have the ambitious goal of presenting information without distracting or burdening the user. In an application for PWD, such ambient displays are usually in the form of a calendar, a digital family portrait, a window or ambient lighting [11, 16]. They function as a way of presenting useful information to support daily living, reminiscence activity or calm technology. There are still several challenges related to developing ambient displays for PWD, such as: (1) what kind of information should be displayed using peripheral attention; and (2) how to effectively convey this information in order to draw awareness and eventually to change behaviors.

Researchers in HCI have also constructed tools and techniques for tangible, sensing-based ambient displays, as a way of combining the peripheral monitoring of information with embodied interactions [12, 23]. This has partially addressed the difficulties described above. It also reinforces the benefits of using peripheral attention for acquiring information via the "creation, manipulation, and sharing of meaning through engaged interaction with physical artifacts" [32]. One example is VENSTER, which is translated into English as "window" [29]. VENSTER is an interactive art installation using a display in the form of a window, offering the experience of looking out, and is designed for PWD in LTC. The installation can show pre-recorded calming content such as a park, activating content such as a person outside the window, or interactive content such as snowing, which is enabled via a touchscreen. A string for a window blind is attached to the window frame to allow switching between scenes. An evaluation suggests that activating content can be used as a meaningful activity for PWD, and that interactive content can potentially be used as an activating therapy or exercise. The other successful project referred to as AAT (Ambient Activity Technology) unit, is a wall-mounted interactive tool for PWD [53]. The design is reminiscent of an old-style radio/TV unit and provides personalized reminiscence activities (favorite music or a slideshow of family photos). It recognizes users through an identity badge. The system also allows simple interaction by turning the wheel and knobs. Both VENSTER and AAT provide users with free access to the installation and help facilitate communication. They succeed in supporting PWD over a wider range of stages, and create the possibility of social interaction. These tangible, sensing-based ambient displays could be reinforced with tactile interaction for a holistic sensory experience, since PWD with visual or auditory impairments can also engage in such activities through tactile stimulations.

Social Robots for People with Dementia

Social activities for PWD are often challenging, and residents with dementia living in LTC are commonly reported as being socially isolated. Social robots differ from rehabilitation robots (which enable rehabilitation training) and service robots (which support care or assist in daily living) in that they function to optimize emotional and social wellbeing [33]. For PWD, initial evidence has confirmed the therapeutic effects of social robots and has demonstrated that they can enrich social interactions, improve affect, and provide companionship and motivation [7, 18, 31]. The pressing need for innovative technology that can enhance quality of care, decrease caregiver burden and reduce care cost has motivated related research. Most of the studies in this area focus on PARO, a commercially available baby seal robot, which has been widely researched around the world to demonstrate its role as a social mediator for facilitating social interaction [21, 42, 50]. The therapeutic sessions were successful for all stages of dementia, since the interaction process is familiar (stroking an animal), they can use pre-existing knowledge of how the animal reacts as a reference for shaping the interaction when encountering a robot. Other cases of social robots used in dementia-related research include AIBO, a robotic dog [24], NeCoRo, a robotic cat [28], and Pleo, a robotic dinosaur [40]. Each of these robots is designed to evoke emotions, to interact in sophisticated multi-sensory ways and to increase activity levels both from a physical and a social perspective. Recent studies of these robots as interventions emphasize not only an understanding of revoked emotions and behaviors, but also their impact on prognosis and their influence on social contexts [36, 41, 43]. However, in order to maximize its positive effects, the context of use and proper facilitation of these social robots need to be guided. Reports show that it is both challenging and labor intensive for caregivers to provide a use context for these social robots [33]. Researchers now see how to exploit to utilize the social robots in dementia care more fully.

OBJECTIVES

The preceding discussion shows that these approaches have great potential in resolving the problem of the under-stimulated and unengaged situation of PWD living in LTC. As an explorative study, this paper therefore introduces an interactive system design called *LiveNature* that combines an ambient display unit and a social robot. In this system, the ambient display focuses on conveying information from an ambient level using peripheral attention, while the social robot emphasizes the promotion of social connection through emotional interaction via focused attention. We believe that through this combination, *LiveNature* can (1) offer users long-term access to the installation design; (2) help foster and maintain interest through active interactive multi-sensory engagement; and (3) create a use context for the social robot, which can be challenging in terms of facilitating an initial interactive session with a social robot for PWD, as caregivers typically need to create a use scenario and to explain the reason why they are bringing this "animal" to the residents [15]. In addition, (4) through this combination, we believe that users are more likely to experience positive emotional reactions and to achieve the expected therapeutic effects than with a singular sensory stimulated experience or an interaction session with a social robot.

The overall purpose of the combined approach is not only to make the design solution more accessible to and effective for residents with dementia living in LTC, but also from a user-centered perspective, since many psychosocial interventions or designs in the field of dementia care are behavior-oriented, meaning that they are developed from a perspective of helping to manage BPSD [20]. These approaches can assist with challenging behaviors and reduce the care burden within the context of LTC. However, the symptoms and behaviors of individuals with dementia are not solely a manifestation of the underlying disease process, but also reflect the social and environmental context, as well as their perceptions and reactions [37]. We believe that in order to improve their quality of life, it is essential to engage PWD in meaningful activities by altering their living environment, promoting social bonding, and eliciting positive emotional reactions, and then potentially to change their behaviors, rather than the other way around.

DESIGN

The following describes three key design considerations and the iterative design process that ultimately led to the development of *LiveNature*, and gives details of the implementation.

Design Considerations

Within the context of LTC, the design should take into consideration the following aspects: (1) the whole story of system design should fit the institutionalized context; (2) the design affordance should encourage intuitive interaction without complex reasoning, in order to fit the diminished abilities of users; and (3) as LTC facilities speak to all stakeholders including residents, caregivers and families visitors. Design should allow the use of a broader conditions and able to involve all stakeholders. It is our challenge to maximize the positive impact under the context of existing deficits from both individual and facility levels.

Sensory Enjoyment through a Relaxing Experience of Nature

Nature is well acknowledged for its therapeutic effects on human health [17, 2]. A recent study on technology-based nature-assisted therapy for PWD proved that digital content of nature also holds effectiveness in reducing undesirable behaviors and improving engagement [13, 8]. The viewing of natural settings is suitable for any variation of the stages and conditions of PWD, without the risk of increased agitation due to excessive or inappropriate stimulation. It is also an excellent fit for LTC usage, as it connects residents living indoors with an outside environment. An animal figure (digital or physical) as a sub-element of nature appears to be a reasonable choice, and means that the use of social robots naturally blends into the use scenarios. Informed by existing psychosocial interventions in dementia care, we adopted nature-assisted and animal-assisted therapy with the aim of providing sensory enjoyment for PWD through a relaxing nature/animal experience [39].

The complete interactive system design is two-fold: the ambient display unit and a social robot. The former describes a system unit containing an 87-inch ultra-high definition display, a computer control system including sensors and actuators, and the tangible extension of the display that enables simple interactions. It blends naturally into the LTC environment and simulates a window outlook experience accompanied by nature soundscapes [54]. Its aim is to emulate the soothing effects of nature-assisted therapy and the feeling of being in an outdoor environment. The social robot simultaneously works as a distributed agent of the ambient display unit with physical spatial proximity of users by nature. This aims to evoke human emotions, provide tactile sensory input and reduce the risks of anxiety, depression and social isolation. The system strives to create an immersive multi-sensory environment that is reinforced with rich interaction possibilities for engaging PWD in meaningful activities.

Encourage Intuitive Interaction through Reminiscent Objects

The living situation and context for PWD in LTC facilities are often complex. The residents generally have a range of different etiologies and are at different stages of the disease. In addition, they are undergoing a progressive decline in multiple fundamental aspects, including not only cognitive and mobility factors but also psychological difficulties such as passivity or apathy. This presents inevitable challenges to achieving engagement, as PWD in their later stages often have a lack of inner motivation, short attention spans and a reduced sense of self. Reminiscence therapy aims to assist in creating interpersonal connections using remote memories and familiar objects [26], thus enabling intuitive interaction using pre-existing knowledge.

Unlike most designs that employ reminiscence therapy in HCI, in which forms of display media such as touchscreens are used, we use tangible/tactile interactions as an extension of the digital content and avoid the use of abstract shapes or forms [26, 53]. Our work places emphasis on encouraging PWD to initiate proactive use and can therefore help them regain a sense of autonomy, instead of letting caregivers or others take the lead. Since this work was undertaken in collaboration with a Dutch care home, we addressed three aspects of design that are familiar to a generation of elderly Dutch people in order to trigger reminiscence. Since almost all residents had either grown up on a farm or had significant experience of farming, we used a farm setting for the nature scenes. We used video footage of typical farm scenery, with farm animals as the main content of the display. We also mounted an actual old-fashioned water pump right beside the display, on top of a wooden frame that served as a trough. This created an augmented simulation involving providing the animals with water. We also brought in an IRS with a size and weight similar to a lamb, in order to engage users to hold, hug and pet it. The IRS was equipped with sound and haptic feedback.

Peripheral/Proximal Interaction to Cover the Spectrum of Users

Peripheral interaction describes a scene in which users can interact with the designed interactive system at the periphery of their attention. This interaction may also shift to the center of their attention when relevant [4]. Inspired by this idea, we aimed to create a user scenario in which peripheral attention was applied to allow PWD to enjoy a multi-sensory experience from the ambient nature soundscape and natural scene on a screen, whilst their center attention was on interacting with the therapeutic robotic sheep. When a response is triggered from petting the robotic sheep (in which the sheep shown on the display become active and start to walk around and bleat), attracting the user's attention to the surroundings, the user can shift their focus back to the display. The interaction between the robotic sheep and the user is mediated by touch, which by nature requires the user to be close to the social agent. This physical spatial proximity and touch will naturally influence the social bonding and behaviors of PWD [35]. Through a combination of peripheral interaction and proximal interaction, the system can help maintain users' attentiveness, as users can continuously shift their attention between different agents to remain in flow. According to Wada et al. [51, 53], an interaction can enlarge the number of functions, as the "interpretive flexibility" can enable its application and success in diverse contexts. The adoption of both peripheral and proximal interaction allows the system to offer more interaction possibilities through self-exploration and interpretation [42]. Therefore, covers a great spectrum of stages users, as the system allows multiple ways of engagement when interacting or even no interaction with the system.

Iterative Design Process towards *LiveNature*

The iterative design process involves co-creation by all key stakeholders to allow essential knowledge and insights to be gathered in order to design for PWD. This design research is an extension of the former work of authors called *Closer to Nature* [14], which was implemented as a permanent fixture in Vitalis (see Figure 2a). *Closer to Nature* started with the aim of connecting residents to the outdoors through an indoor interactive experience, due to their limited contact with real nature. The system consists of a display that resembles a life-like window overlooking a farm's animal shed. In front of the display, there is a wooden frame with a self-built circulatory system utilizing an electric water pump, a water filter, and pipe connection; an old-fashioned water pump is mounted on top of a wooden frame which has an infrared sensor inside, and can pump water into the physical half of the animals' water trough. The *Closer to Nature* installation was successful in creating a positive experience and facilitating communication for many of the residents. Some key design recommendations and reflections from the preliminary user study were used to guide further designs, since (1) a proactive strategy is needed for better initiation of engagement; (2) more holistic sensory stimuli (enhancement of tactile interaction) could be beneficial in increasing the positive effects; and (3) since some residents with mobility constraints use wheelchairs, interactions that require a lower threshold of motor effort are required to meet their needs. The following design iterations were made on the basis of the design of the *Closer to Nature* installation. This iterative design process towards the final interactive system design *LiveNature* is described in this paper and explains the unitization of the social robots.

First Design Iteration

The first design iteration addresses the issue of how to initiate user engagement. We learned from the preliminary user study of *Closer to Nature* that although residents very much enjoyed the surprising experiences when the animals appeared, they tended to forget what triggered this appearance and sometimes even the existence of the installation itself. We therefore placed some figures of farm animals, such as decorations and plush toys, within their living environment to remind residents of the installation (see Figure 2b and 2c). We also added a video to the installation which appeared every 25 mins when no interaction was detected, with footage of a sheep that tries and fails to drink water and then leaves, to motivate interaction. The feedback from caregivers suggests that the influence of these animal figures was too subtle and was seldom noticed by PWD. However, the added footage of the activating scene worked well, as expected, as it captured residents' attention and provoked interaction.

Figure 2. The iterative design process towards *LiveNature*: (a) the *Closer to Nature* installation; (b) and (c) examples of the distributed decorations of farm animals in the first design iteration; (d) the second design iteration, in which an interactive goat covered with conductive sensor patches was developed.

Second Design Iteration

We noticed from the observations of interactions that many PWD tended to reach out towards the animals on the screen as if they could pet them. This generated the second design iteration in which a physical model of a goat was employed to extend the virtual animal therapy into the physical world, thus contributing to the completeness of the created multi-sensory environment through tactile stimuli (see Figure 2d). A goat prototype covered with a furry textile and woven patches of conductive sensors was developed as a mediator for the connection between the visual farm scene and the physical context of the residents. In addition, videos equipped with nature soundscape replaced the original background noise. The nature soundscape, including birds singing, wind and animal sounds, blended into the indoor acoustic environment and was expected to be pleasant, calming and relaxing for residents [54]. We also set a timer in the processing program and dimmed the brightness of the video at night. Hence, the installation could also operate as a reminder to distinguish between day and night routines for residents. The feedback on this iteration suggested that the interactive goat prototype offered modest promise in terms of its usefulness; however, it did not achieve the expected bonding effects, as it was too statue-like and was perceived by the users to be "dead". The other two changes (the additional sounds and the tactile exterior of the goat) were useful in practice and were successful in creating an immersive sensory experience.

Third Design Iteration

This paper focuses on the third design iteration. The aforementioned work led to the design of *LiveNature*, which employed the IRS. The system design of *LiveNature* responds to interactions with both the old-fashioned water pump and the IRS. The IRS extends the idea of a physical animal figure and provides tactile interaction with a lower threshold of motor effort (petting and holding), thus addressing the needs of users in wheelchairs. A model of a sheep was chosen over a goat, as it has a denser and fuller textile quality. The zoomorphic design of the IRS (mimicking a lamb) invites users to cuddle and hug it. It responds to interactions by giving audio and haptic feedback when a touch input is sensed. Pleo was used for realization, and we used the default embedded motions which indicate happiness and aim to evoke pleasure responses. The ambient display unit shows interactive videos with footage of a farm shed and flocks of sheep accompanied by a nature soundscape; this links the IRS to the system. The interactive visual content of the natural setting has both static and activating scenes: when no interaction is detected by the IRS, the display shows a static scene of a flock of sheep lying on the ground, standing or eating grass; when user interaction with the IRS is detected, the sheep stand up, move around and gather in front of the display.

System Design and Implementations

The final system design described in this paper aims to provide multiple avenues for engagement experiences through self-exploring enabled interaction possibilities:

- *The immersive multi-sensory experience.* In the best use scenario, the system provides an immersive multi-sensory experience that maintains the user's flow of attention, shifting between watching the display and interacting with the robotic sheep. The acoustic environment, interactive video content and tactile interaction contribute to the completeness of the multi-sensory engagement.
- *Social robot interaction experience.* In the case where the user concentrates only on the interaction with the IRS, reflecting the later stages of dementia in which some tend to live in their own world, the system performs as a common social robot for the enjoyment of an "animal petting" experience.
- *Animal watering experience.* In cases where the user ignores or refuses to interact with the IRS, s/he is still offered the animal watering experience using the old-fashioned water pump.
- *"Outlook on nature" experience.* When no interaction occurs, the system will continue to provide a relaxing "outlook on nature" experience, and encourages "in the moment" enjoyment, whereby users are able to watch an ambient relaxing video of a farm with a flock of sheep or listen to a nature soundscape of birds singing and the wind blowing.
- *Social bonding experience.* The system also performs as a bridge to increase social bonding. It encourages the involvement of other key stakeholders (caregivers, volunteers, family and visitors) into the interaction.

Implementation of the Ambient Display Unit

The controlling hardware is hidden behind the wall of the ambient display unit, which consists of an ultra-high resolution display (BenQ, 87') and a computer (MSI Nightblade MI B089). The computer is connected to a custom-made Arduino enclosure (Arduino Uno with an extension board) that reads an infrared sensor (Sharp, 2D120XF95) and controls a power supply for an electrical water pump (Easy Tpy 513-0214). In the closed water loop, a water filter (Philips InstantTrust Marine) was installed to maintain the quality of the water at a drinkable level to avoid safety concerns. We used Processing as the programming environment to ensure the stable and long-term running of the system, and set up an alarm to monitor the running state using a watchdog via a web server. The computer connects to the Wi-Fi provided by Vitalis for remote control or to update software. Locally, the interaction triggers were logged.

Implementation of the Interactive Robotic Sheep

The IRS is a prototype developed by re-programming the Pleo robot using the Pleorb Development Kit (PrbDK). We disguised the appearance of the Pleo to a lamb, and equipped it with a furry textile and with a soft stuffing material underneath, so it felt soft upon hugging and touching. After this transformation, the dimensions of the IRS were length ±50 cm, height 27 cm (full size with legs out stretched), width 17 cm, and weight approximately 4 kg, similar to a real lamb. We chose the Pleo robot as it already has well-developed and categorized emotional behaviors (happy, sad, tired, angry, hungry and miscellaneous) that can provoke human emotions, and is equipped with multiple embedded touch sensors, motors and a microphone for the possibility of programming again. We used five touch sensors: two on the back, two on the rear, one on the head, and one on the chin. When touch input is detected, we invoke different pre-existing motions of Pleo via the programming of the IRS. We also changed the media sounds to recordings of three different lambs bleating, of different duration, so that in practice it works naturally, smoothly and realistically. IRS moves its legs, neck, head, and tail when it senses touch input and makes happy sounds to evoke human emotions. IRS connects to the computer of the ambient display unit through Bluetooth.

EVALUATION

We conducted an explorative user evaluation to research: (1) how PWD respond to the interactive system design of *LiveNature* in general; (2) the effectiveness of *LiveNature* in terms of engagement, affection and restoring attentiveness, connectedness, and communication; and (3) the user experience and reflections from the perspectives of staff and family members.

Participants and Settings

The explorative user evaluation was conducted in a real-life setting in Vitalis. Twenty participants were recruited, including nine residents of Vitalis, five family members (two spouses, two daughters and a son), two caregivers (one male and one female) and four volunteers (all female). The inclusion criteria for residents with dementia were as follows: a documented formal diagnosis of dementia; an age of 65 and above; a Mini-Mental State Examination (MMSE) score lower than 24; and a physical ability to sit, hold and interact with the IRS. The exclusion criteria included residents with acute visual or auditory impairment reported by staff. The nine residents were within the age range 78 to 92, and were at various stages of mild, moderate and severe dementia according to staff reports. The mean MMSE score was 11 (SD = 8, RANGE = 0–23), matching the staff reports of the stages of dementia. The demographics of the participating residents are shown in Table 1.

Participant	Gender	Age	Stage of dementia	Type	MMSE Score	Restraints
P1	M	90	Moderate	VD	12	None
P2	F	92	Moderate	MD	12	None
P3	F	89	Mild	AD	21	None
P4	F	81	Severe	MD	0	L/E
P5	F	80	Severe	AD	0	L/E
P6	F	78	Severe	VD	7	L
P7	F	80	Moderate	MD	18	None
P8	F	81	Severe	MD	9	None
P9	M	86	Mild	AD	23	None

Table 1. Demographics of participating residents, where 'Type' is an abbreviation for the type of diagnosis of dementia (AD: Alzheimer's dementia; VD: vascular dementia; MD: mixed dementia); 'Restraints' is an abbreviation for restraints reported by staff (L/E: disorder in language and emotional expression; L: disorder in language expression).

The installation was situated in the hallway, a common space within Vitalis that connects to the individual living spaces. This common space has large windows to the outside, receives lots of sunlight, and has a relatively quiet environment, and is therefore ideal for the user study. Two seats were positioned in front of the display to create a comfortable sitting environment.

Study Design

The evaluation study followed a repeated measurement design with two study settings: an ambient display unit-based interaction (setting 1) and a combination of an ambient display unit and a social robot-based interaction (setting 2). Setting 1 resembles the original setting of the *Closer to Nature* installation, while setting 2 was the installation design of *LiveNature*. Setting 1 was used as a baseline for a comparison study of the effectiveness in terms of engagement and affection. These conditions were repeated twice, in alternate order. Participants were invited to participate once a week for a total of four weeks, and were randomly allocated into two groups with an alternating order of participation to eliminate confounding effects. The study took place during non-planned activity days and times, between 10:00 to 12:30 a.m. and 14:00 to 17:00 p.m., to accommodate morning care and meal times. Individual sessions were designed up to 20 minutes, which was long enough to detect behavioral changes over time but still short enough to avoid interrupting nursing care.

Ethical Considerations

This study was approved by the Vitalis care facility. Written informed consent was received from the participants, and their legal guardians gave consent when the participants were no longer capable of giving informed consent. Two months prior to this, all residents, their legal guardians, and care staff were informed in a formal meeting about the upcoming study and their rights to refuse or quit at any time.

Measures

Before the evaluation study, a MMSE was carried out with each participant by the facilitator. The facilitator is a trained researcher who had experience with dementia care. A lower score in MMSE represents a higher level of cognition impairment. After each individual session, the facilitator and an observer were asked to fill out observational rating scales including OME and OERS. Engagement was measured using OME [9]. We utilized a short version containing three main subcategories that reflected the user engagement in terms of duration, attention and attitude. The duration of engagement refers to the time in seconds for which participants engaged with the stimulus. Attention to the stimulus during engagement was scored using a four-point scale ranging from 'not attentive' to 'very attentive'. Attitude to the stimulus during engagement involved a wide perspective including positive and negative facial expressions to verbal content and physical movements towards the stimulus. This subcategory was scored using a seven-point scale ranging from 'very negative' to 'very positive'. The inter-rater reliabilities for these subscales were 0.78 for attention and 0.70 for attitude. User affective states were measured using OERS, an observation-based five-point Likert scale with descriptive indicators for five affective states: pleasure, anger, anxiety/fear, sadness and general alertness [25]. These items can be scored using a fixed time duration or intensity. We used intensity in this study. A higher score indicates a greater display of a particular effect. Data for anger, anxiety/fear and sadness were not used, as few data were captured for these effects. Inter-rater reliability was 0.74 for pleasure and 0.68 for general alertness.

DATA ANALYSIS AND RESULTS

Data analysis of the observational rating scales of OME and ORES was completed using IBM SPSS Statistics Version 24, and qualitative data were transcribed, translated and analyzed in NVivo using thematic analysis [5]. The results of both quantitative and qualitative analysis are presented in the following.

Assessing Engagement Using OME

We performed a non-parametric statistical analysis due to the use of categorical ordinal variables in the rating scales. A Wilcoxon signed rank test was performed to check the differences between the two settings. The results of this analysis show significant differences between the two settings in terms of the duration ($Z=2.77$, $p=0.006$) and attention ($Z=2.49$, $p=0.013$) of the engagement (see Table 2). The attitude was not significant, according to the test results. A longer time duration and higher attention score of engagement was discovered in the *LiveNature* setting, indicating that the use of the IRS can help maintain user interest and restore attentiveness during the interaction.

Assessing Affective States Using OERS

As the subcategory of attitude towards stimulus in OME has a general scope that includes behavior and verbal and facial expressions, we also adopt OERS to measure positive affective states (pleasure and general alertness). A Wilcoxon signed rank test was again performed to check the differences between the two settings in terms of pleasure and general alertness. The results show that *LiveNature* produced significantly higher general alertness (Z=2.97, p=0.003) than *Closer to Nature*. *LiveNature* also produced more pleasure (see Figure 3), although this result was not significant. The outcomes of the Wilcoxon signed rank tests for OME and OERS are presented in Table 2.

Rating items	*CtN* M (SD)	*LN* M (SD)	Z value	Sig. (2-tailed)
Engagement (OME)				
Duration	498.00 (234.17)	678.39 (244.99)	−2.77	.006
Attention	4.89 (1.28)	5.67 (0.84)	−2.49	.013
Attitude	5.17 (0.78)	5.39 (1.20)	−1.07	.285
Affect (OERS)				
Pleasure	2.17 (0.62)	2.50 (0.86)	−1.90	.058
General Alertness	3.72 (0.96)	4.39 (0.92)	−2.97	.003

Table 2. Results of Wilcoxon signed rank tests of the OME and OERS rating scales.

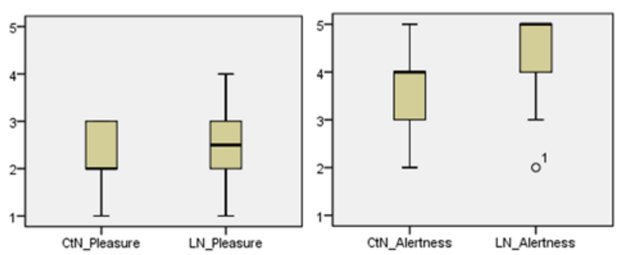

Figure 3. Differences in pleasure and general alertness for two settings (CtN: Closer to Nature, LN: LiveNature).

Findings from Observation and Semi-structured Interviews

Qualitative data, including audio recordings of interview sessions and notes taken by an observer, were collected through semi-structured interviews and direct observations. Semi-structured interviews were conducted with the participating residents of Vitalis, family members, caregivers and volunteers to evaluate the overall experience of *LiveNature*. The findings below are described using example quotations with the coded representations of participation (for instance, P1= Participant 1).

Feedback from Participating Residents

Common feedback from the evaluation study of both settings included expressed enjoyment, recollected memories, and facilitated verbal communication. Communicated positive experiences and enjoyment were recorded for the majority of participants (6 out of 9, as 3 participants were limited by language expression disorder) in both study settings. Participants commented on how much they liked the beautiful scenery in the display, how they appreciated the installation and how they enjoyed talking with the facilitator. Phrases such as “this is nice”, “this is beautiful”, “I like sitting here with you”, and “I can do this all day long” often arose during study sessions. The qualitative results also showed that both settings could help recollect memories and perform as tools for facilitating communication. Many participants shared their prior experiences on a farm as well as stories about their occupation, hobbies, residence and pets. The designed settings succeeded in encouraging conversations with an unfamiliar person (the facilitator) about their personal experiences, which rarely happens during regularly scheduled activities or daily social interactions.

The results from the qualitative data also indicate differences between the two study settings in terms of restoring communication. The setting of *LiveNature* generated a broader spectrum of topics than *Closer to Nature*. Participants talked mainly about themselves in *Closer to Nature*, while several participants (P1, P2, P7, P8) extended the topic of conversation to their children or grandchildren in the *LiveNature* setting. P7 said the sheep reminded her of children; she used to be a baby-sitter and would bring them to a farm to feed the animals. P1 spoke about his children as if they were still young, and expressed his feelings towards the IRS in a polite way, saying “…the children would love it, you know. The involvement of the IRS in the *LiveNature* setting provoked different emotional reactions toward the interaction. Most participants (except P1 and P4) displayed pleasure towards the IRS, appraising it as looking cute, adorable and soft, and even naming it. P2 said, “It is nice even just holding it. It feels soft—oh, it is moving towards me.” Some were surprised when they realized that IRS was a robot and could respond to their touch behaviors. P3 discussed with the facilitator about how to enable the sensors and expressed pride after finally figuring out where to touch to trigger sound and movements. P8 was confused by the realistic movement and sound effects of the robotic sheep, and thought it was a real sheep. When it was suggested that she return the IRS, she said, “I can’t give this to you; it costs money, you know.” Some participants (P5, P6, and P7) were also surprised by the feedback through the screen display when interacting with the IRS, as the ambient display unit increased the animal sounds in the soundscape and shifted to the activating content in the display. P5 turned the IRS towards the display when sensing the feedback and said, “Look, you need to look.” (P5 suffered from language expression disorder and did not normally speak.) There were other findings from participants; for instance, the IRS was considered to be rather large and heavy. Participants P3, P7, and P9 appreciated the role of the facilitator in the social interaction and the opportunity to join the sessions, as they had someone to talk to who would listen to their stories. It was also discovered from P4 that the bird sounds in the soundscape were distracting, as she started to look for the birds at one point.

Perception of Use by Family Members

It was generally agreed by all family members that the installations were well designed and that the sensory experience was valuable for their family members. Some highlighted the difficult fact that they no longer knew what to talk about when visiting. During the interview, a daughter of P6 said, "It is hard to let her go into a nursing home and to see her condition getting worse every day. The disease developed quite rapidly and severely"; "I used to come here and read newspapers with her—now all I do is push her out for a walk". When she observed P6 in the *LiveNature* setting with the IRS on her lap, she felt that her mother "woke up" when seeing the animals and started responding to her, for which she felt very grateful. P1 was visited by his daughter and two grandsons, and they were therefore invited to participate in the study together. His grandchildren used to arrive, say 'hello' and then leave, but now they come to *LiveNature* and play together. The daughter of P1 said, "It works really well as a starting point for a conversation." The attitudes towards the IRS of the spouses were less positive than those of the children; they were emotional, and did not accept that their husbands were happy playing with a toy-like robot. However, they confirmed the benefits of companionship; as one interviewed spouse said, "He would really enjoy the company of a dog. As you can see, there are not many animals around here, for safety reasons, I guess. It would be nice to have a companion for the elderly here."

Feedback and Suggestions from Caregivers and Volunteers

The feedback from caregivers and volunteers also acknowledged the benefits of the sensory experience, its attractive visual appearance, the tangible interactive components and its potential positive influence in their everyday lives. They commented that both settings made the environment calming and enjoyable for inhabitants. Two caregivers mentioned the challenges involved in constantly fulfilling the patients' attention-seeking needs and dealing with their impaired language expression abilities. They commented that both *Closer to Nature* and *LiveNature* made it easier to make a connection with the residents. The activation scene in the display worked very well, as it generated curiosity and the interactive experience was beneficial in exercising motor skills. The user study of *LiveNature* also addressed feedback on the IRS. One caregiver explained that they used to have a PARO for robot interaction sessions, and compared the use of the IRS with the PARO from the perspective of facilitation. One caregiver stated that the overall experience of *LiveNature* created a natural introduction for the involvement of the IRS. *LiveNature* provides access to a user scenario that makes facilitation much easier in practive. There were also suggestions for the design of *LiveNature*, for instance greater movement of the IRS and a louder soundscape from the display to compensate for hearing-impaired users.

IMPLICATIONS AND FUTURE WORK

The implications arising from the findings and design research process are discussed here to highlight directions for future work and knowledge sharing with related personnel working in this field.

Design for holistic sensory enrichment. Although engaging PWD in activities can be challenging, sensory stimulation that speaks to their remaining abilities becomes extremely important. MSS can be used as a way to compensate for sensory deterioration, to stimulate remaining functions, or to access memories. The overall sensory experience could be beneficial for PWD with certain sensory (hearing and/or visual) impairments, mobility constraints, or expression constraints, and it therefore plays a crucial role in the success of the design to a border spectrum of PWD. The time span for exposure to sensory stimulation is also important. Ambient displays are an effective approach for providing continued sensory experience, and therefore have great potential to contribute to the overall benefits and a longer exposure to sensory enrichment for PWD.

Design strategies for active engagement. Design for PWD aims to actively involve and engage this group of people in meaningful activities. Through the iterative design process, we developed four strategies for designing interactive systems towards active engagement: (1) enable intuitive interaction through design affordance; (2) capture user interest by using activating scenes/content; (3) maintain user attentiveness through combined peripheral and proximal interaction; (4) expand possibilities for interaction through the increased interactivity of the system design. The first of these focuses on how to initiate interaction through quality aesthetic design, while the second emphasizes the fostering of engagement through stimulating content. The third aspect addresses system design through a spatial environment, and the last aims to create an adaptive system to meet the needs of a range of users and offer social inclusion.

Reminiscence objects for a new experience. Design for dementia often attempts to access remote memories through reminiscence for therapeutic effect. We aim not only to allow user to remember the past and to live in those happy memories, but also to open up broader opportunities for different experiences that are stimulating and new. The adoption of reminiscence objects provides tools to facilitate communication in order to enable new experiences of sharing and social bonding with others. This helps us to understand how to design and offer new types of interactive system for promoting wellbeing in dementia.

User-centered vs. family perceived. It is important to reflect on who are we designing for within design research for PWD.

This process is user-centered meanwhile all stakeholders are involved. It is unrealistic to fulfill only the needs of users without considering caregivers, or to ignore practical institutional constraints. However, it is essential for the wellbeing of PWD themselves. Moreover, should design also consider the perceived impression when people observe the use? During the evaluation, we found that one resident immensely enjoyed the companionship and interaction with the IRS, while his wife was not excited to see her loved one with a toy-like artifact. This raises our reflection on the question of whether design for dementia should also consider the perceived impression when users are no longer able to think for themselves [38].

Empirical field study and co-creation with stakeholders. The implementation in a real-life setting holds great value in terms of the co-creation and involvement of stakeholders [10]. Those who are familiar with PWD can easily make connections and interpret behaviors on a deeper personal level. This provides the possibility of an iterative design process and long-term effectiveness studies. An empirical field study in a real-life setting is also more straightforward in practice than on paper.

Further study of the following aspects would be valuable. Although the findings suggest that the IRS succeeded in provoking user emotions and facilitating social interactions, the design and implementation of the IRS still require further work to improve the weight, size, movement and auditory feedback. In addition, the IRS is designed to give feedback only when it senses touch input, and future work on the provocative behavior of IRS is needed to help initiate user interaction and maintain user attention. Moreover, a long-term effectiveness study is needed to explore the influence on possible cognitive and behavior changes. The experimental setting and design of this evaluation study only addressed the comparison between *LiveNature* and *Closer to Nature*, and the social robot session was not included for practical reasons related to the controlled conditions. And considered compensated through the qualitative interviews with caregivers on PARO using experiences. However, a further exploration could be conducted to confirm the benefits of collaboration on the design approaches (the ambient display unit and the social robot). Given the fact that residents in LTC often have different levels of dementia, the participants could be grouped into different stages to develop detailed design strategies. Finally, since data collected using observational rating scales can only provide a general impression of user engagement, further observational behavior analysis through coding schemes may be beneficial for a more comprehensive understanding of engagement [40].

SOCIETAL IMPACT AND ETHICAL REFLECTIONS

The design of *LiveNature* described in this paper is currently available to a small group of residents (around 30) in Vitalis, and is implemented in a real-life setting to offer a positive experience in their daily lives. It aims to engage PWD in an interactive multi-sensory environment to address the problem of the under stimulated and unengaged situation in which they are living. However, it has more significant potential long-term effects in terms of triggering behavioral changes, and possibly even a radical change in the development of the disease. *LiveNature* allows for the stimulation of multiple senses to help maintain cognitive and sensational function. It also emphasizes social interaction and experiences in which technology simply serves as a medium for facilitating human interaction. It has been proven to help PWD living in Vitalis to enact embodied behaviors through multiple possibilities for interaction, to perceive and express emotions in a tailored context, and to establish relationships by encouraging communication. The implemented design is already changing their lives.

There are also ethical implications of this research and user studies, since this vulnerable user group are in most cases unable to make logical decisions, to express agreement or disagreement. (1) This empirical field of research with PWD should consider the protection of the users' autonomy, privacy, and dignity [43, 52]. We therefore set up clear protocols for obtaining signed, informed consent and for data collection, storage and access. (2) The nature of care is still human care [49]. Concerns over the employment of robots in dementia care are often raised, as this tends to replace human relationships with technology [44, 45, 46, 48]. The interactive system design of *LiveNature* and its design iterations do not serve as a replacement for human care but form a bridge connecting PWD with caregivers or families. We seek to ensure that a facilitator (or caregiver) is present when *LiveNature* is used, in order to ensure qualified, reflective and ethical implementation and use of the interactive system design.

CONCLUSION

Starting a new life in a nursing home is a difficult choice for people with dementia and their loved ones. Residents of LTC facilities face challenges arising from environmental and psychosocial factors which make their condition even worse. We aim to make positive changes in their situation through an interactive system design called *LiveNature* implemented in a real-world living environment. The system offers a holistic multi-sensory experience through a nature display and soundscape from an ambient display unit, and tactile interaction provided by an IRS. The results of evaluation confirm that the proposed system design can evoke positive emotions, increase social bonding, and help restore attentiveness and communication; the system can therefore contribute to an enhanced quality of care and an improved quality of life in general.

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