CLEI Electronic Journal, Volume 28, Issue 2, paper 12, April 2025

Digital Ecosystem Model to Produce Mixed Reality Environments to assist Neurocognitive Disorder

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Abstract

In the realm of digital ecosystems, integrating Lean UX principles into virtual environments for older adults presents a promising avenue for enhancing cognitive health and addressing neurocognitive disorders. This research builds on the foundation that virtual reality (VR) and augmented reality (AR) technologies can significantly improve the quality of life for the elderly, fostering social interaction and cognitive stimulation. Despite the proven efficacy of VR and AR in engaging older adults, there remains a gap in applying Lean UX methodologies to optimize these digital experiences. This study investigates the incorporation of Lean UX into digital ecosystems for older adults, tailoring virtual environments to their unique needs and preferences, thereby aiding in the treatment and management of neurocognitive disorders such as Alzheimer's disease. Employing a user-centered design approach, iterative prototyping, and multidisciplinary collaboration, the research analyzes variables such as user engagement, adaptability, cognitive load, accessibility metrics, and user satisfaction. Findings reveal that Lean UX leads to more intuitive, accessible, and personalized VR interfaces, increasing user satisfaction and potentially mitigating neurocognitive decline effects. The implications underscore empathetic design in creating inclusive digital solutions that support older adults' well-being and independence. Future work involves fieldwork to validate and refine the digital ecosystem model in real-world settings.

Keywords: Mixed Reality, Internet of Things, Neurocognitive Disorder, LeanUX, Digital Ecosystem.

1 Introduction

The integration of technology into the lives of older adults is an ever-evolving field of study. Hwangbo et al. [1] highlighted the importance of adapting smartphone interfaces to enhance the experience of older users, while Saracchini et al. [2] explored how mobile augmented reality can serve as assistive technology for this demographic. Virtual and augmented reality, in particular, have shown promise in supporting physical therapy in retirement homes[3].

Quality of life and dignity in aging are crucial issues [4], and technology can play a vital role in this regard. Ro et al. [5] presented a projection-based augmented reality for older adults with dementia, suggesting that technological solutions can be adapted to meet specific needs.

Physiological changes associated with aging [6] also pose unique challenges for the design of assistive technologies. User experience with smart voice assistants shows how technology can be personalized to improve accessibility and usability for older adults [7].

The effectiveness of virtual environments, such as the virtual forest for people with dementia [8], and personalized human-computer interaction for psychiatric and neurological illnesses [9] highlight the potential of these technologies to improve cognition and emotional well-being. Persky and McBride [10] argue that immersive virtual environment technology is a promising tool for research and practice in social and behavioral genomics.

The discussion by Garcia et al. [11] on the use of virtual reality in dementia and the systematic review by Clay et al. [12] on the use of immersive virtual reality in the assessment and treatment of Alzheimer's disease underscore the clinical relevance of these technologies. Tsao et al. [13] and Boletsis and McCallum [14] explore how augmented reality and cognitive games can be used to support cognitive therapy and gamification.

Internet of Things (IoT) technology, as seen in HalleyAssist [15], can assist the elderly in their daily lives, while Cardona Reyes and Muñoz Arteaga [16] highlight the multidisciplinary production of interactive environments to support occupational therapies. The perception of hazards in elderly drivers enhanced by augmented reality cues shows how AR can improve safety and independence [17].

The design of concurrent, distributed, and real-time applications with UML [18], and system and simulation modeling using SYSML [19] are fundamental for the development of these assistive technologies. Dillon and Watson [20] provide historical lessons on user analysis in HCI, which are relevant for user-centered design.

Smartphone-based fall detection for the elderly [21], and the understanding of Alzheimer's disease by Bucciarelli [22], are examples of how technology can be adapted to address specific aging-related issues.

To this foundation are added the findings of Park et al. [23], who investigated the impact of virtual reality-based cognitive-motor rehabilitation on motivation and cognitive function in older adults with MCI, finding significant improvements compared to conventional methods. Bevilacqua et al. [24] conducted a systematic review on the efficacy and effectiveness of non-immersive virtual reality in the rehabilitation of older people, highlighting its acceptance and potential benefits.

Mikhailova et al. [25] explored the requirements of older adults for an augmented reality communication system, emphasizing the need to consider the preferences and emotional needs of this group to encourage the adoption of immersive technologies. Tian et al. [26] provided experimental evidence on the impact of virtual reality-based products on older subjects with MCI, using multiple sources of data to analyze brain activity and behavioral conditions.

These studies underscore the importance of designing technological interventions that are not only effective from a clinical standpoint but also motivating and appealing to end-users. The integration of these technologies into care plans can offer new avenues for improving the quality of life and independence of older adults, while addressing the challenges associated with aging and cognitive decline.

This work has been formed in seven sections: Second section, named Background, contains basic definitions of the technologies related, Third section contains some work with VR devices for treating neurocognitive disorder patients, Fourth section contains the problem outline, with other works using the integrated technologies of this approach, Fifth section describes a Digital Ecosystem Model for the development of Mixed Reality Environments, showing a general architecture for possible scenarios and organizing the model by interaction layers in order to assist the patients with neurocognitive disorders; A case study is presented in section six, applying several technologies in a real scenario. Finally, the conclusions are described in section seven.

2 Background

Virtual Reality (VR), also referred to as virtual environments, creates an immersive atmosphere by surrounding an individual with sound and visuals, simulating the sensation of physical presence within that virtual space [8]. The versatility of modern game engines has made the development of virtual environments significantly more accessible and efficient compared to previous generations of game engines. This advancement has transformed VR into a reliable tool to enhance user experience (UX) and integrate seamlessly into daily routines [3], [8], [9]. The application of virtual environments in social interaction holds great potential for advancing education, decision-making simulations, training, healthcare, and clinical practices [10], enabling innovative methods to convey ideas.

Augmented Reality (AR) encompasses a set of technologies that allow users to view their real-world environment through a device that overlays additional graphical information onto real objects, effectively adding virtual layers to the real-world view. AR can simplify various daily activities by highlighting objects with colors or displaying notifications.

Mixed Reality (MR), as illustrated in Figure 1, combines real objects with interactions involving virtual ones, allowing users to engage with physical objects enhanced by 3D virtual objects rendered on an MR headset [27]. The use of physical peripherals can be more suitable for elder users, providing them with haptic feedback that makes them feel more comfortable and engaged.

Fig. 1. Simplified representation of Mixed reality by Milgram and Kishino (1994) [28].

Recent advancements in electronic miniaturization have resulted in the development of reliable and powerful mobile microcomputers such as the Raspberry Pi. These devices are perfectly suited to act as the central hub in custom and open-source home automation systems [29]. They are capable of controlling a range of electronic devices, including sensors, electric motors, and actuators, with Arduino serving as the low-level hardware interface.

Lean UX is a design methodology that focuses on rapid iteration, collaboration, and user feedback to create user-centered products efficiently. Rooted in the principles of Lean Startup, Lean UX emphasizes minimizing waste and maximizing learning by developing only what is necessary to test hypotheses and gather insights. This approach fosters a culture of experimentation and flexibility, allowing design teams to adapt quickly to changing user needs and market conditions [30]. Unlike conventional UX practices, which regularly depend on massive documentation and long task cycles, Lean UX prioritizes lightweight, shareable artifacts and pass-useful teamwork to boost up the layout method. By integrating continuous feedback loops and real-time user checking out, Lean UX helps make sure that the very last product aligns closely with user expectancies and promises maximum price [31]. This methodology has proven particularly effective in environments where speed and adaptability are crucial, such as startups and agile development teams.

The concept of a Digital Ecosystem involves loosely connected networks of interacting organizations that are digitally linked and facilitated by modularity. These ecosystems mutually influence each other's offerings [32]. In this context, a digital ecosystem can be established through interactions among various components, including the Internet of Things (IoT), virtual environments, AR/VR headsets, and wearable devices. Moreover, smartphones, tablets, and smart assistants act as intermediaries, connecting these technologies with elderly patients.

Digital Ecosystems:

- Connectivity and Modularity: Leverage the connectivity and modularity of digital ecosystems to integrate various technologies such as IoT, virtual environments, and portable devices.
- Interaction with Emerging Technologies: Incorporate AR and MR to enrich the user experience, allowing for a more natural and comfortable interaction with the virtual environment.
- Personalization and Scalability: Use mobile microcomputers like Raspberry Pi to customize and scale home automation solutions that integrate with the virtual environment and improve the quality of life for older adults.

- Data Analysis and Feedback: Collect and analyze data on user behavior and preferences to continuously adapt the virtual environment to their needs.

3 Related Work

The application of AR/VR to neurocognitive disorders is a relatively new area in the treatment of mental diseases. With the reduction in costs of virtual reality headsets and the increase in power of mobile devices, VR applications have become more accessible than ever before.

The development of virtual environments has experienced exponential growth, leveraging modern engines like Unity [3], [5], [9] (which are free for non-commercial applications) and mobile phones with AR/VR accessories such as cardboard headsets. These tools enable users who are unfamiliar with virtual environments to experience mixed reality technology and allow developers to create experimental AR/VR apps at relatively low costs.

Since 2012, there has been a noticeable growth in VR apps designed for various neurocognitive disorders [11]. Without needing to take patients out of nursing homes, these apps allow the exploration of diverse scenarios and the study of elders' reactions to virtual nature environments like forests [8]. An adaptive VR environment proposal uses real-time feedback from users to modify the virtual environment based on what the user sees and interacts with, while monitoring brain activity [9].

The combination of virtual environments and physical exercise allows the elderly to avoid routine and "visit" (virtually) other places outside their living environments [3]. This approach has received positive feedback from users, who express a desire to exercise for longer periods. One such project focuses on a virtual environment using Unity and includes hardware design for an arm and leg exerciser machine.

Diseases as Alzheimer’s have promising results when combined with virtual reality [12], [26]. Studies have demonstrated the benefits of integrating VR and MR with theoretical models [13], such as using reminiscence therapy.

Research directly addressing mild cognitive impairment (MCI) through virtual environments shows that VR can assist in identifying, intervening, and treating this condition by analyzing brain activity and behavioral conditions using near-infrared functional spectroscopy and behavioral recording devices, supported by the Microsoft Kinect device [26].

Ji-Su Park et. al [26] explored the impact of virtual reality-based cognitive–motor rehabilitation (VRCMR) on motivation and cognitive function in older adults with mild cognitive impairment (MCI). Forty participants were divided into a VRCMR group, which used a computer recognition program called MOTOcog, and a conventional cognitive rehabilitation (CCR) group, engaging in traditional activities like puzzles and card games. Both groups underwent 30 minutes of daily rehabilitation for six weeks. The VRCMR group showed significant improvements in cognitive assessments, including the Montreal Cognitive Assessment (MoCA) and Trail Making Tests (TMT-A/B), and reported higher interest and motivation levels compared to the CCR group.

The use of non-immersive virtual reality (VR) in rehabilitation, is well-received by older adults due to minimal cybersickness. A systematic review of the last decade’s literature from databases like Cochrane and PubMed was conducted, focusing on randomized controlled trials [24]. The studies showed clinical heterogeneity and varied in quality based on the Physiotherapy Evidence Database (PEDro) scale. VR was found to enhance cognitive and motor abilities, positively affecting patients’ emotional states and compliance. It has been effective in treating symptoms of various neurological disorders.

The study ”Like a Virtual Family Reunión” [25] explores the attitudes and requirements of older adults regarding augmented reality (AR) communication systems. Through interviews with 30 participants from Germany, the research identified key technological, emotional, social, and administrative requirements for AR systems. The study emphasizes the importance of addressing the emotional needs of older adults, particularly the perceived intimacy of AR-based communication, to encourage the adoption of immersive technologies.

Project CogARC [14] integrates real objects with AR add-ons and visual detection software installed on a tablet, enabling elderly patients to engage in small games. Although the project yielded positive results, there was negative feedback concerning certain interactive aspects of the games.

HalleyAssist [15] utilizes a sophisticated ecosystem to prevent various health-related issues in elderly patients by combining sensor sets to more accurately detect anomalies in movement patterns stored in a knowledge base. However, this work also highlights the importance of software and user interface design to make these devices and applications more accessible and user-friendly for older adults [2], [3], [5].

The DCPAR project [2] employs a combination of a pico-projector worn around the neck and a tablet app for the user. While the tablet app design received positive feedback from elderly users, the weight and bulkiness of the pico-projector around the neck presented challenges.

The Eldergames Project created a mixed reality environment with tabletop games to train cognitive functions [27]. This project explores the emotional aspects of player interactions, demonstrating positive results and proving that a well-designed UX for elderly patients is achievable.

Most current design practices either fail to specifically address the needs of aging individuals or view these needs negatively as problems to be solved [33]. Given the growing aging population worldwide, it is crucial to design better for older adults by considering their wants, needs, desires, and expectations as foundational elements. This necessitates modifying existing design practices and methodologies to be more effective for aging user populations. The workshop aims to gather researchers, designers, and developers interested in designing, developing, evaluating, and deploying digital products, technologies, tools, and services for older adults. It will serve as a platform for sharing experiences from various perspectives through presentations, discussions, and a hands-on design activity, generating innovative ideas for future directions in designing for aging people.

Cardozo et al. [34] proposes improving older adults experience with social networks on tablets using Lean UX. The study proposed 23 design recommendations aimed at enhancing the user experience for older adults on social networks, focusing on simplicity, intuitive design, and addressing vision and motor skill challenges. An iterative and incremental prototyping cycle based on Lean UX methodology was applied, which was guided by the design recommendations and centered on the needs of older adults. The alternative social network design for tablets resulted in a significant reduction in the difficulties experienced by older adults when using the social network Facebook. There was an increase in the number of tasks and actions successfully executed by older adults using the prototype. Due to the improvements in usability and task success, there was an increase in the degree of satisfaction among older adults, contributing to a better overall user experience. These findings suggest that a user-centered approach, combined with Lean UX principles, can lead to significant improvements in how older adults interact with and benefit from social networks on mobile devices, particularly tablets. The study lays the groundwork for further customization and application of these methods to other products aimed at the older adult population.

These references provide a solid foundation for understanding how technology, particularly virtual and augmented reality, can be used to improve the quality of life of older adults, addressing both their cognitive and emotional needs. With the integration of Lean UX and digital ecosystems, a robust framework is offered for the development of virtual environments that can prevent or mitigate the effects of neurocognitive disorder in older adults, improving their quality of life and autonomy.

4 Problem Outline

Implementing Lean UX and digital ecosystems for older adults presents several challenges that need to be addressed to ensure successful adoption and usage:

- Digital Literacy: Many older adults may not have the digital skills required to navigate new technologies. This can lead to difficulties in understanding and using digital solutions effectively [35].
- User-Friendly Design: Complex interfaces, lack of intuitive design, or an overload of features can overwhelm older users. It’s crucial to design user-friendly solutions with clear instructions to help seniors overcome initial hurdles[36].
- Accessibility: Physical limitations such as reduced vision, hearing, or motor skills can make it challenging for older adults to interact with digital devices. Solutions must be designed with these considerations in mind [37].
- Personalization: Older adults have diverse needs and preferences. Personalization is key to ensuring that digital solutions cater to individual requirements [38].
- Trust and Privacy: Concerns about data privacy and security can make older adults hesitant to use digital solutions. Building trust through transparent practices is essential [39].
- Affordability: Cost can be a barrier. Ensuring that digital solutions are affordable and offer value for money is important for wider acceptance [40].
- Technical Support: Providing ongoing support and assistance is necessary to help older adults troubleshoot issues and feel confident in using the technology [41].
- Integration with Existing Systems: Digital solutions must be able to integrate seamlessly with existing healthcare and support systems to provide a holistic experience [42].
- Cultural Sensitivity: Solutions must be culturally sensitive and considerate of the diverse backgrounds and values of older adults [43].

- Continuous Feedback and Improvement: Implementing a system for continuous feedback and iterative improvement is crucial to adapt to the changing needs of older adults [44].

Addressing these challenges requires a multidisciplinary approach that combines expertise in technology, design, healthcare, and gerontology. By focusing on these areas, developers and designers can create digital ecosystems that are not only technologically advanced but also deeply attuned to the needs of older adults.

Despite VR devices have the potential to allow non-experienced users the ease of use for Virtual Environments, there are things to consider with elderly users like the cybersickness [24] and physical risks like falls [21] we can find ways to monitor the elderly combining the use of cameras and/or sensors, using non-immersive peripherals or lower immersion experiences like AR environments .

It is essential for the elderly to understand the importance of the feedback they can provide in the use of the ecosystem, as knowing their well-being at any given time will allow for the adjustment of parameters on the fly with the help of the LeanUX agile methodology to adapt the user experience in a simple and direct manner.

This work aims to encourage elderly individuals to engage in consistent physical activity to maintain brain health through the use of virtual environments and lightweight devices that promote user engagement.

Systems Design for occupational therapy [16] has demonstrated positive outcomes in motor rehabilitation using virtual environments and peripherals. This approach strikes a balance between ergonomics, intuitive interfaces, and pleasant environments to enhance elderly user engagement, making therapy sessions enjoyable.

Many research articles related to AR for the elderly focus on practical applications, device functionality, and experiment design based on specific scenarios [5], [17], [27], often neglecting the software design aspect.

Integrating Lean UX and digital ecosystems in the creation of virtual environments for the prevention of neurocognitive disorder in older adults could be approached in the following way:

Lean UX:

- Rapid and Continuous Iteration: Adopt an iterative and agile approach that allows for short development cycles and constant user feedback. This facilitates the quick incorporation of comments to improve the design of virtual environments.
- User-Centered Development: Maintain a constant focus on the needs and preferences of older adults with neurocognitive disorders. Conduct research to understand specific challenges and adapt the design of virtual environments accordingly.
- Early Testing and Validation: Use low-fidelity prototypes to quickly test different ideas and concepts with users. Conduct usability tests frequently to proactively identify and resolve issues.
- Waste Elimination: Prioritize features and functionalities of the virtual environment that add real value for older adults with neurocognitive disorder. Remove complicated elements that may hinder the user experience or increase cognitive load.
- Multidisciplinary Collaboration: Encourage collaboration among designers, developers, healthcare professionals, and older adults with neurocognitive disorder to ensure an inclusive, accessible, and effective virtual environment.
- Flexibility and Adaptability: Maintain flexibility to adjust the design of the virtual environment based on user feedback and evolving needs over time. Be prepared to make changes at any stage of the development process to continually improve the user experience.
- Focus on Simplicity and Clarity: Design a virtual environment that is intuitive and easy to use for older adults with neurocognitive disorder. Prioritize simplicity, consistency, and clarity in the user interface and interactions.

The combination of Lean UX and digital ecosystems provides a robust framework for the development of virtual environments that can prevent or mitigate the effects of neurocognitive disorder in older adults, improving their quality of life and autonomy.

5 Digital Ecosystem Model

Defining a digital ecosystem architecture is essential due to the presence of various technologies interacting through multiple communication protocols, which can cause confusion among the interconnected devices [32]. Different patient scenarios will require the use of multiple distinct environments. This work proposes a digital ecosystem architecture that combines AR, VR, MR, and software design tools such as the Unified Modeling Language (UML) [18] and System Modeling Language (SysML) [19]. It leverages the Human-Computer Interface [20] to adapt User Interfaces (UI) and User Experience (UX).

We are looking for a way to easily adapt to the most possible kinds of mental diseases starting from a generic architecture and following the evolution of the participants' conditions. Our focus lies on Alzheimer's disease [22]. Alzheimer's disease is a progressive neurodegenerative disorder characterized by memory loss, cognitive decline, and personality changes [45]. It is the most common cause of dementia in the elderly, affecting over 24 million people worldwide. The disease poses significant challenges for both patients and caregivers, as it leads to a gradual loss of independence and increased care needs.

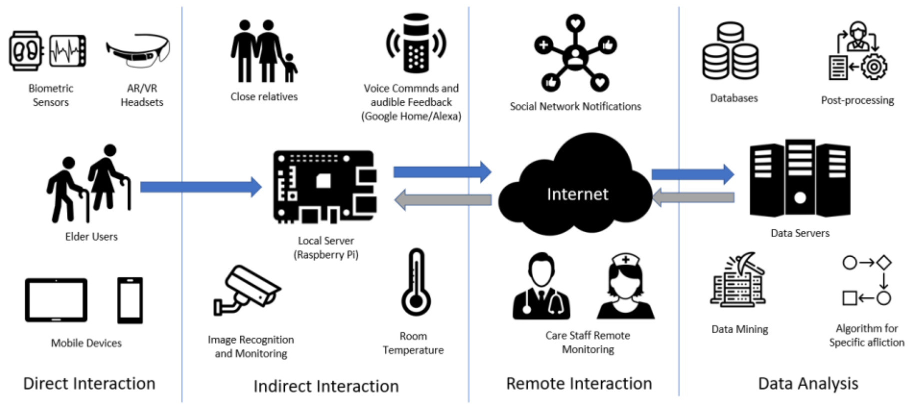

Fig. 2. **Digital Ecosystem Model for the Production of Mixed Reality Environments to Assist Neurocognitive Disorder Patients**

The descriptive model proposal is shown in Figure 2 divided by Interaction Layers involving the different kinds of devices and the relation with various actors. A description of each layer is provided below:

5.1 Direct Interaction

We define Direct Interaction as the engagement between patients and physical devices, including tablets, smartphones, AR/VR headsets, and body-attached wearable devices. These devices serve as conduits for various interactions, including monitoring biometric data such as heart rate and step count. For instance, smartphones can assist in fall detection [21].

However, certain neurocognitive disorders may cause patients to forget that they are wearing a VR headset or other wearable devices. To ensure a comfortable experience for the elderly, it is essential to provide non-intrusive gadgets.

Tablets and smartphones play a crucial role in keeping elderly users informed about their medical condition. They also serve as a medium for receiving calls and notifications from relatives and care staff, maintaining constant interpersonal contact. Additionally, the sensor suite within smartphones can detect accidental falls, movement patterns, and daily activities for further analysis.

AR/VR headsets, when used in virtual environments, offer a diverse range of therapies for physical workouts. By alternating virtual scenarios, we aim to make the experience less monotonous for patients.

5.2 Indirect Interaction

The Indirect Interaction layer encompasses devices that patients can engage with, connected to a local network server for localized data processing. Typically, wearables possess limited processing power, battery life, and storage capacity. Therefore, a more robust device is necessary to aggregate all local information.

Microcomputers, such as the Raspberry Pi [29], have demonstrated powerful processors suitable for collecting data from wearables and other locally networked devices. These include:

- **Cameras**: Used for pattern recognition and live remote monitoring.
- **Smart Assistants**: Devices like Google Home or Alexa [7], which provide direct user feedback and respond to voice commands.
- **Room Ambiance Monitoring**: These systems record data and inform decisions regarding simple actions, such as adjusting air cooling systems and ceiling fans, or notifying users based on changing temperature conditions. Adjustments may also extend to related devices, such as room lights.

Once the basic patient situation is processed, the Raspberry Pi connects to the internet, providing real-time information to care staff and deploying alerts during anomalous situations.

In this interaction layer, patients can trigger straightforward commands via the voice assistant to modify lighting or adjust room temperature. If these parameters are not patient-dependent, nearby relatives can make the necessary room control adjustments.

5.3 Remote Interaction

Remote interaction is facilitated through an internet connection, serving as the primary channel for care staff and distant relatives to stay connected with elderly patients. This connectivity enables:

- Care staff to monitor the patient's condition using audio and video communication.
- Relatives remain informed and engaged through social network notifications.

Such remote interactions allow all parties to be apprised of the patient's physical status and to initiate direct communication using smart assistant speakers or mobile devices.

Additionally, medical staff are alerted to any anomalies detected in the patient's condition. They can promptly respond by making audio calls directly to the patient's mobile phone, tablet, or smart assistant speaker. This immediate feedback loop enables swift action to be taken in response to the patient's needs.

5.4 Data Analysis

To safeguard the data collected from patients, an encrypted connection is essential when storing information on application servers. This is the stage where big data processing occurs, enabling the identification of behavioral anomalies by analyzing variations in movement and voice patterns. Such analysis facilitates the early detection of diseases commonly associated with aging.

A robust server infrastructure is necessary to accommodate an increasing number of users from diverse locations, such as hospitals, nursing homes, or private residences. This infrastructure will categorize users based on their specific diseases and conditions, enhancing the ability to identify anomalous patterns and early symptoms among patients with similar ailments.

The data analysis process involves several steps [46]:

- Data Collection: Using wearables and smart devices, continuous data collection on biometric signals (e.g., heart rate, step count), environmental conditions (e.g., room temperature, lighting), and interaction patterns (e.g., usage of AR/VR applications) will be conducted.
- Data Preprocessing: This step involves cleaning and transforming raw data to ensure quality and consistency. Noise reduction techniques will be applied, and missing values will be addressed through imputation methods.

- Feature Extraction: Key features relevant to neurocognitive health will be extracted from the data. This includes metrics like activity levels, sleep patterns, and cognitive performance indicators gathered from VR interactions.
- Anomaly Detection: Machine learning algorithms, such as anomaly detection models, will be employed to identify deviations from normal behavior. This facilitates the early identification of potential health problems.
- Pattern Recognition: Advanced pattern recognition techniques will analyze trends and patterns in the data, identifying common factors associated with cognitive decline or improvement.
- Statistical Analysis: Statistical tests will be conducted to validate the significance of the findings. Comparative analyses, such as pre- and post-intervention assessments, will help determine the efficacy of the interventions.
- Visualization: Data visualization tools will be used to present the analysis results in an understandable format for healthcare professionals and caregivers. Interactive dashboards will allow for real-time monitoring and decision-making.
- Feedback Loop: A continuous feedback loop will be established where insights from the data analysis inform iterative improvements in the digital ecosystem. User feedback will be incorporated to refine and enhance the system.
- Evaluation Instruments: Instruments, semi-structured interviews, and cognitive assessment tools will be utilized to evaluate user engagement, satisfaction, and cognitive performance.

To comprehensively understand the state and progression of Alzheimer's patients, it is crucial to utilize well-established assessment tools that evaluate various cognitive, functional, and behavioral domains [47]. These instruments provide valuable insights into the severity and impact of the disease, allowing for effective monitoring and tailored interventions. Below are four key tools commonly used for this purpose:

- Mini-Mental State Examination (MMSE): The Mini-Mental State Examination (MMSE) is a brief test that evaluates various cognitive functions, including memory, attention, language, and visuospatial skills. It is commonly used to detect cognitive impairment and follow the progression of neurocognitive disorders such as Alzheimer's disease. The test includes simple questions and tasks that help assess temporal and spatial orientation, word registration and recall, calculation, and language.
- Neuropsychiatric Inventory (NPI): The Neuropsychiatric Inventory (NPI) measures neuropsychiatric symptoms in patients with dementia, including changes in behavior and mood. This inventory covers areas such as agitation, depression, anxiety, apathy, and hallucinations. It is useful for assessing the frequency and severity of these symptoms, as well as the impact they have on the caregiver.
- Informant Questionnaire on Cognitive Decline in the Elderly (IQCODE): The IQCODE (Informant Questionnaire on Cognitive Decline in the Elderly) is a questionnaire that allows caregivers to evaluate the cognitive decline of patients over time. It is based on the caregiver's observation of changes in the patient's cognitive abilities compared to their previous level of functioning. It is useful for detecting cognitive decline without requiring the patient to directly perform a test.
- Relevant Outcomes Scale for Alzheimer's Disease (ROSA): The Relevant Outcomes Scale for Alzheimer's Disease (ROSA) is a brief, multidimensional instrument that evaluates cognitive, functional, and behavioral manifestations in patients with Alzheimer's disease. ROSA is used for periodic evaluations and monitoring the patient's progress over time. Like Lean UX, ROSA follows an iterative approach, providing constant feedback that allows for continuous adjustments to interventions, thereby improving the patient's quality of life.

By integrating these instruments into the data analysis, we can obtain a comprehensive understanding of the state and progress of patients with Alzheimer's disease.

For the measurement of users interaction with applications, User Experience (UX) evaluation questionnaires are quantitative tools used to collect data on user satisfaction, ease of use, and design preferences [48]. These questionnaires allow researchers to get an overall picture of how users perceive a product or system, helping to identify areas for improvement and validate whether the design meets the users' expectations and needs. They are a quick and cost-effective way to detect patterns and gain valuable insights into the user experience. Some known tools for UX evaluation are:

- AttrakDiff: Measures user perception in terms of attractiveness and usability, covering both pragmatic and hedonic aspects [49].

- UEQ (User Experience Questionnaire): Evaluates user experience across various dimensions, including usability, aesthetics, and emotion [50].

- meCUE (Modular Questionnaire for Measuring User Experience): A modular questionnaire that includes separate modules to assess instrumental and non-instrumental product perceptions, user emotions, consequences of use, and general attractiveness judgment [51].

Utilizing these UX evaluation instruments can provide valuable insights into user satisfaction, usability, and emotional responses.

6 Case Study

The primary audience for our study comprises elderly patients residing in public nursing homes under the auspices of the "Integral Development for the Family" institute (DIF) in Aguascalientes, Mexico. This study presents a theoretical case, designed to explore and propose a digital ecosystem model tailored to the needs of elderly patients. Conducting interviews with the care staff is crucial to gain insights into the elders' exercise routines, recreational activities, sleep patterns, main interests, and other aging-related ailments that are not directly linked to neurocognitive disorders [52] It's also important to understand their general preferences, as well as their willingness to adopt technological gadgets and wearable devices.

Figure 3 presents the mixed reality infrastructure scenario, offering a detailed view of the information management process. It illustrates the various methods through which care staff can receive updates and monitor the patients effectively.

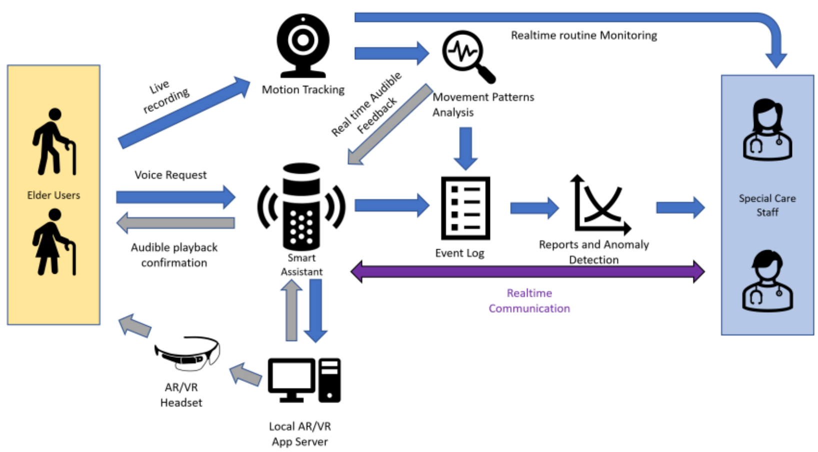

Fig. 3. Digital Ecosystem for the Assistant of Patient with neurocognitive disorders from DIF Institute.

We aim to adapt virtual environments using therapeutic techniques to track the progress of patients participating in the project. In cases where patients have physical or mental limitations, device adaptations will be necessary. However, the overarching goal is to have devices prepared for a wide range of scenarios.

6.1 Direct Interaction

The Xiaomi Mi Band (Figure 4) is a particularly valuable wearable device for monitoring daily step count and heart rate in patients. It offers a cost-effective solution with prices ranging from 15 to 40 USD, delivering satisfactory quality readings. The device's battery life is impressive, lasting between one to three weeks, varying by the generation of the wearable and the active features.

Each Mi Band requires a smartphone to store the data collected from patients through a Bluetooth connection. The device can gather data for one to two weeks before the battery is fully drained.

The data retrieved provides insights into the patient's daily activity levels, enabling adjustments to their exercise routines as needed. Additionally, the Mi Band includes a straightforward heart rate monitor, which can facilitate more frequent heart rate checks by care staff without the need for in-person visits.

Fig. 4. Elder user wearing the Xiaomi Mi Band 3, a great wearable with simple and compact design.

In the initial stage of the project, we have chosen the Oculus Rift (Figure 5) as the VR headset to serve as the interface between patients and the virtual environment. As we progress to subsequent stages, our objective is to utilize the Cardboard headset paired with a smartphone. The Cardboard headset offers a cost-effective VR solution and is easily replicable, making it convenient for maintenance and spare parts replacement.

Fig. 5. Elder user with the first retail version of Oculus Rift, that will be used in the first stage of the project.

6.2 Indirect Interaction

Amazon Alexa and Google Home (Figure 6) are voice-controlled Smart Assistants that use cloud voice processing algorithms [7] to respond quickly to natural language commands. This device can provide the patient with weather, time, or therapy schedule information; also, this device can offer the patients a virtual interaction with the Smart assistant that includes asking for any information, hearing jokes, playing voice games and solving riddles to make their routine more fun.

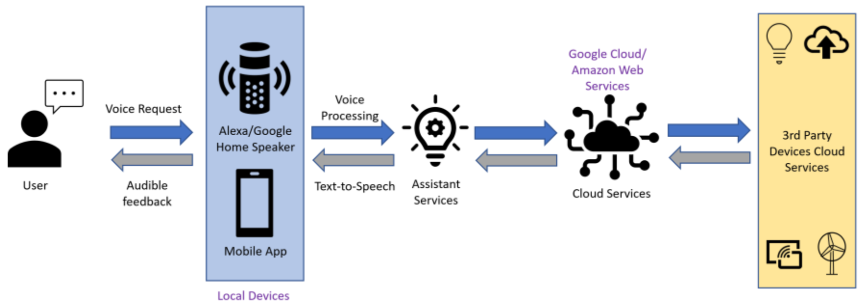

Fig. 6. General Smart Assistant Architecture view, showing how Alexa and Google Home work with their respective online services.

6.3 Remote Interaction

APIs from popular social networks such as Facebook, Instagram, and X (formerly known as Twitter), as well as instant messaging applications like Telegram, can be utilized to keep relatives and friends informed about the patient's condition. Additionally, medical staff will receive special notifications containing biometric data, rather than social network interactions, to monitor the patient's status in a more timely manner.

6.4 Data Analysis

The initial step for data analysis involves creating a knowledge base with all the data gathered from devices near the patient. The data obtained from the patients' routines will be used for data mining to identify patterns using statistical and heuristic methods. In a later stage, this will enable the detection of anomalies in movement and early signs of ailments, providing medical staff with the opportunity to treat conditions promptly.

Given the need for a comprehensive evaluation of the user experience (UX) tailored to older adults, the User Experience Questionnaire (UEQ) was selected as the primary instrument for measuring UX. The UEQ was chosen due to its versatility, ability to measure a wide range of UX dimensions, and its efficiency in gathering user feedback. Its broad applicability and ease of interpretation make it a valuable tool for iterating and refining digital ecosystems to better suit the needs and preferences of elderly users.

The iterative use of ROSA allows for continuous and personalized adjustments, similar to how Lean UX adapts user experiences based on feedback and collected data, in comparison we can find:

- Continuous Iteration and Evaluation: Both methods are based on iterative cycles and periodic evaluations to continuously improve.
- User/Patient Focus: Lean UX and ROSA prioritize the needs and experiences of the user/patient.
- Multidisciplinary Collaboration: Both methods encourage collaboration across different disciplines to gain a comprehensive view.
- Validation and Adjustments: Lean UX and ROSA use feedback and collected data to make adjustments and improvements.

This combined approach ensures that both the medical and user experience aspects are thoroughly assessed, enhancing the overall effectiveness and personalization of interventions.

7 Conclusion

Mixed reality enables elder users to interact with virtual environments and enhance their daily social interactions from home, breaking boredom and making their daily therapy sessions more manageable. The AR component can assist elders in perceiving their home environment better when they are alone.

Integrating Lean UX principles into the design of digital ecosystems can significantly improve the rehabilitation and daily life of older patients in nursing homes by breaking their routine. Virtual environments with AR/VR headsets are excellent tools to engage users with the ecosystem. Introducing the elder population to the technologies they have missed for many years can improve their daily activities at a low cost while preserving their autonomy as much as possible.

To connect devices and interact with involved actors, it is necessary to model the digital ecosystem. Each device's role is crucial to maintaining a steady connection between layers. Understanding each user's specific case will help address the needs of different neurocognitive disorders in the elderly.

Integrating Lean UX into digital ecosystems with a VR interface for older adults offers several benefits. Lean UX focuses on creating intuitive and user-friendly products, crucial for older adults who may not be as familiar with digital interfaces. The iterative nature of Lean UX, combined with the use of the User Experience Questionnaire (UEQ), allows for quick prototyping and testing, ensuring that VR interfaces can be adapted based on real feedback from older users. This approach helps reduce the cognitive load on older adults by prioritizing simplicity and clarity, making digital ecosystems more accessible to them.

The principles of Lean UX, reflected in the continuous assessment and personalization provided by the ROSA method, ensure that the design accommodates various limitations that may come with aging, such as reduced vision or motor skills. This alignment between Lean UX and ROSA methodologies enhances the comfort and satisfaction of older adults, leading to products that truly meet their needs and preferences.

A critical area of research will be the analysis of variables that influence the successful implementation of Lean UX in virtual environments tailored for older adults. This involves:

- User Engagement: Measuring the engagement and interaction levels of older adults with virtual environments using ROSA and UEQ.
- Adaptability: Assessing how well older adults adapt to changes in the virtual environment resulting from iterative design processes.
- Cognitive Load: Evaluating the cognitive demands placed on older adults by the virtual environment to ensure that Lean UX principles effectively minimize complexity.
- Accessibility Metrics: Establishing quantitative measures for accessibility to ensure that virtual environments are usable by older adults with varying degrees of physical and cognitive abilities.
- User Satisfaction: Utilizing ROSA, UEQ, AttrakDiff, and meCUE to gauge the satisfaction of older adults with the virtual environment, providing insights into areas for improvement.
- Learning Curves: Analyzing the time and effort required for older adults to become proficient in using the virtual environment, aiming to streamline the learning process.
- Technology Acceptance: Understanding the factors that affect the acceptance of new technologies by older adults to enhance the adoption rates of virtual environments.
- Personalization Effectiveness: Measuring the impact of personalized features on user experience and how they contribute to the overall usability of the virtual environment.

By focusing on these variables, we can refine Lean UX methodologies to create virtual environments that are not only technologically advanced but also deeply attuned to the needs and preferences of older adults. This ensures that the solutions developed are not only functional but also enjoyable and empowering for this demographic. The goal is to foster an inclusive digital ecosystem that supports the well-being and independence of older adults through thoughtful design and continuous innovation.

Future Work: As part of our ongoing efforts, we plan to conduct fieldwork to validate and refine our digital ecosystem model. This future work will involve the implementation and testing of the selected instruments (UEQ for Lean UX and ROSA for Alzheimer's) in real-world settings, collaborating with public nursing homes and other care facilities. Gathering real-world data and feedback from elderly users and care staff will further enhance the effectiveness and usability of digital ecosystems tailored for older adults.

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