Indoor Navigation: Augmented Reality as Case Studio for Cognitive Inclusion

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Abstract: - Longer life spans due to developments in medicine and technology have led to an increasing number of people aging in health conditions that require assistance and treatment. Older adults who are not self-sufficient need medical, welfare, rehabilitative, and social services assistance. Long-term care has a significant impact on the national social and health system and involves a growing number of caregivers who are challenging to find. With the use of digital technology and artificial intelligence (AI), it is possible to implement home care systems by avoiding the use of public health care and improving the living conditions of older adults. In the field of innovative technologies, augmented reality (AR) represents valuable support for older people, not only to improve their confidence and independence but also to enrich their social life and cognitive well-being. The present study addresses the problem that afflicts older people in terms of loss of orientation and walking from their usual environment. This situation requires the assistance of a dedicated person who accompanies the subject to predefined destinations and prevents them from running into danger. Our proposed solution is a navigation system that allows older patients to move without resorting to their caregivers. The study aimed to verify the possibility of applying the technology generally used for video games to develop an indoor navigation system. A smartphone APK application for augmented reality was developed using the Unity-Vuforia framework. The method differs from traditional approaches in that it indicates the target destination without the use of arrows and instead employs labels. In the lab, staff members assessed the solution. The destinations were successfully reached, with an error of 2%.

Key Words: - augmented reality, caregivers, assistive technology, internet of things, near field communication, iBeacon, Matterport, Unity, Vuforia.

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1 Introduction

Life has been extended thanks to advances in the medical field and the evolution of technological solutions to support medicine. However, there is an increase in the number of people who experience critical health conditions as they age, with negative consequences for the performance of their daily activities, their independence, quality of life, and sustainability of health and care systems. A common symptom of old age is cognitive impairment. However, the impact of cognitive impairment is relative to everyone; therefore, it is difficult to categorize the needs of older people and their ability to care for themselves according to age. Activities of daily living (ADLs) are the activities that an adult individual performs independently and without needing assistance to survive and care for themselves. It refers to activities closely related to basic needs, for which they may encounter difficulties such as reduced mobility, memory, sensory and mental health problems, medication management, and personal care. Activities such as showering, dressing, eating, and moving around without running into dangerous situations can become challenging without assistance. Rating scales of the ADL (Katz Scale) and IADL (Instrumental Activities of Daily Living) are used to assess the level of autonomy of older people. The smaller the final score on a range of values from lowest to maximum, the more the subject's autonomy has been impaired. Therefore, providing adequate support to help older people maintain their independence and improve their quality of life has become necessary. A suitable solution to ensure a better quality of life and maintain their domestic habits is represented by Ambient Assisted Living (AAL), [1]. It is an area that uses IoT technology governed by artificial intelligence to provide support for the assistance of those in need of help. These systems monitor various activities and situations via intelligent sensors. Depending on the level of severity found, they can monitor lifestyle, alert assistants, start events on connected home appliances, or notify support services, [2].

Patients who take a more active role in managing their health can experience a better quality of life. Their involvement is crucial, as it can influence their self-management and independence. Factors such as the severity of the disease, the coexistence of different pathologies, and the age of the patient can also play a role. However, other decisive factors are the psychological aspects and the support of family members, caregivers, general medical staff, and the social context. To break down the psychological barriers that hinder the acceptance of technology as a support to their daily activities and reduced use of caregivers, a design approach that considers the specific needs of the elderly, and that is intuitive and easy to use, [3]. Experiences conducted in recent years have shown that the involvement of patients and caregivers in the design of innovative technological health systems improves performance and makes the proposed technological solution acceptable, [4]. Action is needed to raise awareness among the elderly about the benefits that assistive technology can bring to their daily lives.

In addition, it is crucial that there is ongoing support for education and assistance in the use of these technologies.

In the field of innovative technologies, augmented reality (AR) represents a valuable support for the older people, offering benefits such as:

- Navigation Assistance: AR can provide visual directions and simplified routes within buildings.
- Rehabilitation and Physiotherapy: Through AR, older adults can follow rehabilitation programs with visualizations that guide the exercises.
- Socialization: AR is not just a technological tool but a bridge that can help seniors overcome the physical barriers to socialization. By allowing them to attend virtual events or communicate with friends and family, it can bring back the joy of human connection, even in the face of physical distance. Reminders and Cognitive Support: AR applications can provide visual reminders for appointments, medication to be taken, or daily activities, supporting memory and time management.
- Entertainment and Mental Stimulation: AR can offer immersive experiences and games that stimulate the mind, helping to keep cognitive functions active.
- Home Safety: AR is not just about entertainment or socialization, but also about safety. By highlighting potential hazards in the home, such as tripping objects or steps, it can significantly reduce the risk of falls, providing a sense of security and peace of mind for both seniors and their caregivers.
- Exercise: RA can encourage physical activity through games and activities that promote movement, contributing to overall physical well-being.
- Cognitive impairment symptoms are disorientation and the inability to orient oneself in familiar and unfamiliar indoor environments. Seniors who find it difficult to move independently within the home due to their inability to connect landmarks and paths with places in the environment will wander without knowing their destination and why they are walking. An indoor navigation system helps cover spatial and temporal orientation, preventing them from running into dangerous situations. In this article, we illustrate a pilot study developed for the creation of an easy-to-use navigation system based on augmented reality and a medium-high-range smartphone.

The article is structured as follows: Section 2, "Navigation," discusses the characteristic aspects of a Navigation system and the available technologies; Section 3, contains some interesting related works; Section 4, "Materials and Methods," after a brief introduction on the AR describes the technology platforms used; Section 5, "Methodology" illustrates the application modules; Section 6, "Results" reports the results of the pilot case; Section 7, "Discussion" examines the results in the context of the existing literature and finally section "Conclusions”.

2 Navigation

Continuous care to ensure that older people with mild cognitive impairments can move around without running into dangerous situations or avoid unconsciously leaving home is a heavy workload for the caregiver and an expensive commitment. Assisted inland navigation can help relieve the stress of those who care for them and improve the quality of life of older adults.

An indoor navigation system consists of three components, which are the home position, the wayfinding, and the guide route. Knowing the subject's position helps to identify the path to follow or an alternative path that must be found in the presence of obstacles. Wayfinding focuses on finding the route to provide for the specific destination. Route planning can be done on the shortest or safest route. The route guide provides directions for navigating to the destination. However, indoor navigation presents problems compared to outdoor navigation due to obstacles that produce signal distortions. It is impossible to use GPS, which is one of the standards for outdoor navigation, so it is necessary to use other systems to overcome these problems. With the development of smartphones and the possibility of connecting them to the Internet, it has been possible to create indoor navigation applications. Indoor navigation systems provide users with spatial context of a location and directions, such as directional arrows to move around premises or labels to locate the desired destination.

An indoor navigation system strategically places Wi-Fi wireless access points within the facility and digital maps of environments where rooms, stairs, and general room layouts are visible. The user can select or search for any point of interest on a 3D digital map and receive all the directions to reach the chosen destination.

Many types of positioning, localization, and navigation systems are based on different technologies, [5]. Commonly used are microelectromechanical systems (MEMS), WIFI, Bluetooth, RFID, NFC, VLC, artificial intelligence (AI), and GPS systems, [6].

Micro-electro-mechanical systems (MEMS) are based on highly accurate and compact motion and orientation sensors. These systems include accelerometers, gyroscopes, and magnetometers that, combined, can track the movement and direction of a subject within a building. Combining these sensors with other indoor location technologies allows for the creation of precise indoor navigation systems, improving accuracy, [7].

WIFI-based technology uses access points (APs) located at various points in the building that emit signals that are detected by mobile devices. Using signal strength from multiple APs, the system calculates the user's position through the trilateration process. WIFI signals are not attenuated due to the reflection or diffraction of obstacles, [8].

An alternative technology is Bluetooth, [9]. Beacons are used that cannot receive signals but can only transmit unique signals to mobile devices. In this case, the position can be determined with the trilateration technique. However, this solution is expensive and requires additional hardware to be installed.

Radio Frequency Identification (RFID) is an automatic identification technology that uses electromagnetic fields to detect and track labels attached to objects. This technology is based on three main components: RFID tags, RFID readers, and antennas. Tags can be passive, active, or semi-passive, with substantial differences in terms of power, reading range, and cost. Passive tags, without an internal power source, are activated by the electromagnetic field generated by the reader, which is responsible for sending and receiving signals. On the contrary, active tags are equipped with an internal battery that extends their range but also increases their cost and complexity. Antennas play a significant role in determining the performance and range of an RFID system. This sort of technology operates on a variety of frequency ranges, including ultra-high (UHF) to low (LF), depending on which is suitable for a certain application. RFID is used in a wide range of businesses, including corporate asset management, electronic payments, logistics and storage administration, access control, and animal tracking. RFID provides several benefits, including continuous monitoring and procedure automation, but it also has certain downsides, such as system costs and potential environmental interference. Nonetheless, this technology is gaining popularity among enterprises due to its versatility and efficacy in information management. RFID systems use worn-on RFID tags, [10], [11]. The information is compiled by readers and sent to a server for analysis. The server uses the data to determine the locations of the individuals moving about the buildings. The system calculates the location of RFID tags based on their proximity to readers.

Another applicable technology is VLC (Visible Light Communication), which uses an enabled smartphone camera to detect the light emitted by a fluorescent lamp or LED. LED light is modulated at high speeds, invisible to the human eye, to transmit information. For every emission source, the light that is released has a distinct ID attached to it. Through the ID, the smartphone determines the location of the source on a stored map, acquiring the user's position.

NFC (Near-Field Communication)- based systems use NFC tags, small chips that can be placed at points within a building, [12]. With an NFC-enabled smartphone or tablet, users can get close to the tags to receive location information and navigate to a destination.

Another applicable technology is augmented reality (AR), [13], [14], [15]. It can help the user reach their chosen destination by assisting them visually. AR in indoor navigation is an innovative solution that combines real-time positioning with virtual data overlay to enhance the navigation experience. AR works through a process articulated in the following:

- Indoor positioning (localization) – determination of the user's current coordinates.
- Navigation – plotting a route from the starting point to the destination point.
- Rendering – superimposition of virtual objects on top of the real environment.

In practice, Augmented Reality adds details to the user's perceived field of view (Figure 1). In other words, this augmentation takes place in real-time, perfectly combining virtual aspects with the user's actual surroundings. For example, when utilizing AR on a smartphone or tablet, the device's camera records the real-world scene, and the AR software evaluates this input and overlays appropriate pictures, animations, or information on the display. This might range from virtual furnishings in a living room to informative labels floating over actual items.

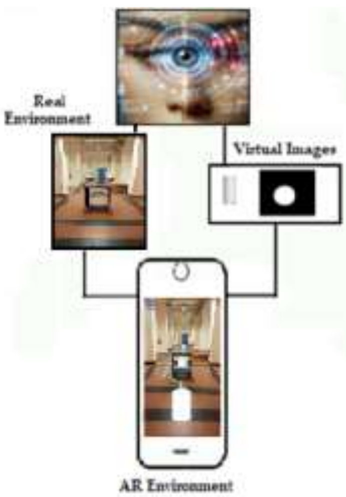

Fig. 1: Augmented Reality

Furthermore, the defined region in front of the user's eyes, known as the "AR canvas," provides for the selective presentation of data, guaranteeing the augmentation does not conflict with or subtract from the surroundings. Because AR systems may highlight the correct path or propose points of interest without subtracting from the surroundings, this targeted augmentation can be quite useful in navigation.

The ability of augmented reality (AR) to add many layers of sensitive-to-context data has important ramifications for many industries.

3 Background

Below are some interesting testimonials about assisted indoor navigation systems that use different technology platforms to achieve a satisfactory level of accuracy.

For example, [16] designed an application that allows older people with neurogenerative diseases to move autonomously within hospitals where they have been admitted, avoiding interrupting the activities of the medical staff to whom they should have turned for guidance. The app has been developed on an Internet of Things (IoT) system that uses a smartphone with a Wi-Fi interface to guide seniors in indoor navigation and Bluetooth beacon technology for contact tracing. When the patient connects with the hospital network, the designed app displays the digital map of the hospital using augmented reality technology. It overlays the current location and the chosen destination. All movements are sent to the Cloud so that they can be viewed by medical staff.

[17], designed a system that aims to improve the well-being of older adults and help them become more independent by introducing an internal navigation system that uses PHS (Personal Handy-phone System) technology combined with Bluetooth technology, specially designed for their abilities. The application has been developed for older residents in a residential care facility in Oslo, with a needs-friendly approach, an intuitive interface, and customized features. The structure consists of ninety-one smart-home apartments controlled by a central computer system and smart-home systems to control air conditioning systems and domestic services. Apart from the main computer system, every unit has a tablet that may be utilized for standard internet surfing. The design was developed based on results acquired from questionnaires, direct observations on the behavior of older people on the use of digital technology, interviews, tests, and in consideration of the results of related work. By using this system, seniors will be able to move unsupervised in unfamiliar buildings and feel safe and independent.

Again, [18], designed the ALMA system aimed at older people and, more specifically, people with cognitive and motor disabilities to support indoor navigation. The system supports users in moving safely indoors, starting from their current location to other places of interest, considering their needs and limitations, and considering the state of the environment (e.g., the presence of obstacles). The system consists of five modules:

- An RF-based Indoor Location Module to provide room-level localization of people and objects. It typically operates by measuring the strength of the RF signals (such as RSSI—Received Signal Strength Indicator) emitted by a mobile device or a tag. Multiple receivers (access points, beacons, or base stations) are strategically placed throughout the indoor environment. The technology can determine the device or object's position by assessing signal levels received from various sites. Advanced systems may additionally include techniques such as Time of Flight (ToF) or Angle of Arrival (AoA) for more accurate localization.
- A networked intelligent camera system for monitoring the indoor and outdoor environment.
- An Intelligent Module for online planning and scheduling of user routes and activities, adapting the specific needs of users to the state of the environment.
- Personal Navigation Assistant is a mobile application that provides a user-friendly interface with all the features of ALMA. It is a standard wireless device (a smartphone or tablet) with a software application. It provides users with information on the directions to their destinations and can be helpful if they need help. In addition to navigation, the program offers real-time information about nearby points of interest, rescue services, and other modes of public transportation. The assistant may also be integrated with other services, such as traffic updates and weather forecasts, so that users are always informed and capable of operating a vehicle in a safe and efficient manner.
- The Personal Mobility Kit, which is connected to a commercial electric wheelchair, allows users to navigate automatically or assist and interact with their surroundings.

To support the different modules, a Mapping Server service collects and stores a set of maps of the environment, providing information on physical obstacles, possible destinations, and available services.

Extensive experience has been developed by [19] in the design of NavMarkAR, an augmented reality (AR)-based navigation system that uses landmarks to provide route directions. It is designed to improve the spatial learning and navigational skills of older adults, who often face challenges navigating indoor environments due to declining cognitive and navigational skills. The system was developed using HoloLens 2 smart glasses [20] and the Unity3D graphics engine version 2020.3.48f1, [21]. The user interface has been implemented with support for the Microsoft Mixed Reality Toolkit (MRTK) version 2.7.3, [22]. Scene Understanding SDK [23] was also used for spatial mapping, generating a structured representation of the real environment, with essential features such as walls, floors, and ceilings, correlating it with the virtual representation, ensuring that virtual content is positioned realistically and consciously in the context. Spatial data and built-in HoloLens sensors were used to achieve precise localization of the user's locations in real time scanning the environment through integrated cameras, depth sensors, and spatial mapping. A three-dimensional mesh of the surroundings is created, and the augmented reality app uses it to accurately put digital elements into the user’s field of view. This step allows to mix virtual objects with the real surroundings and to remain in position even if the user moves.

The AR application uses the HoloLens' spatial data to determine the user's position and orientation in relation to their surroundings. Because data is updated on a regular basis, the software may dynamically rearrange digital information to ensure accurate alignment with its physical surroundings. Using this spatial data, the augmented reality system may place labels, indicators, and other virtual things in contextually suitable locations, increasing user experience and simplifying navigation. The system has been set up to the navigation paradigm based on reference points as opposed to the most commonly used turn-by-turn instructions or directional indicators. By connecting with landmarks based on their interpretations, the authors facilitated the acquisition of spatial knowledge.

To engage users and prevent cognitive overload, the authors hypothesized virtual keys that can be activated in the AR field of view. This feature allows users to use navigation aids as needed and to adapt the guidance to their preferences and memory retention capabilities. An initial usability test with six participants led to the refinement of the prototype, followed by a more in-depth study with thirty-two participants in a university setting. The results indicate that the use of NavMarkAR has improved navigation efficiency and the accuracy of cognitive maps, and future developments will explore the long-term retention of cognitive abilities with the use of such navigation aids.

The research by [24] focuses on using AR for indoor navigation, where QR codes are installed at various locations within a building. It is an innovative approach that enhances the user's experience by providing interactive and immersive guidance within buildings. Users scan a QR code to select their destination, and the system uses Google AR Core to update the user's location in real-time. The shortest path to the destination is calculated using the A* search algorithm, and directions are displayed on the user's camera screen as augmented reality animations. Using Simultaneous Localization and Mapping (SLAM), the user can build or update a map of a simulated environment with the track of the position of a subject within it in real-time.

Innovative is the project of [25], who developed an advanced indoor navigation system in augmented reality (AR) that uses computer vision and machine learning for precise positioning and obstacle detection. The system was developed for Android devices using Unity. From a methodological point of view, the authors used the Android SDK platform, ARCore, and ARFoundation. The system uses markers or points of interest positioned within the rooms (QR) to detect the user's position. The detection and recognition of markers unique to each position is done with ARFoundation through computer vision techniques. The user's current position is thus detected and simultaneously mapped in the 3D environment using the Simultaneous Localization and Mapping (SLAM) technique. The shortest path is determined with the A* algorithm and is displayed in AR with directional arrows. In addition, the system has other features designed specifically for patients with cognitive disorders such as Alzheimer's: path retracing allows the patient to retrace the path they have already crossed using the AR overlay; reminders to help them complete daily tasks and finally, in emergencies where there is poor visibility, the system provides guidance to reach the nearest exit using AR-generated walls and overlays.

4 Materials and Methods

With the generation of new smartphones, augmented reality (AR) can be particularly beneficial as an indoor navigation system for older people, offering visual and interactive support that can improve their autonomy and safety. The augmented reality system has features that make it preferable to other computer systems used in indoor navigation. The features that differentiate it are:

- Integration with the Real Environment: Unlike other systems, AR superimposes digital information on the physical environment, enriching the user's accurate perception without replacing it.
- Improved User Experience: AR can significantly improve the navigation experience by providing intuitive visual cues that guide the user through complex paths.
- Accessibility and Usability: AR is more accessible and user-friendly than other computer systems, as it does not require advanced technical knowledge to be used effectively.
- Personalization: AR allows for advanced personalization of the information displayed, adapting to each user's specific preferences and needs.

There are two indoor navigation technologies based on AR: markers and markers less. Those with markers use target images to indicate things in a specific space. These indicators determine where the AR application places digital 3D content [26], [27] within the user's field of view to activate augmented reality. The accurate placement of digital 3D data inside an AR setting is contingent upon certain markers or cues that instruct the AR system on how to arrange virtual objects within the real world. These markers can be physical markers (such as QR codes or pre-made visuals) or virtual markers formed by fusing sensor input with geographic data. Where and how the 3D data is deployed is determined by the AR application based on the position, orientation, and size of the detected indication, whether it is virtual or real. For example, if the device recognizes it via plane detection, the system can arrange it such that it seems to be resting on a level surface. The accuracy of this placement is important for maintaining the illusion that the virtual content is part of the real world.

Conversely, the marker-less method uses a real-world object as a marker. Tracking combines the object's natural characteristics with the target object's texture.

Currently, there are two indoor navigation application development toolkits available in environment AR: ARKit [28] and ARCore SDK [29].

Software development kits (SDKs) called ARKit and ARCore were originally made available by Apple for use with iPhone and iPad apps beginning with iOS11, and then by Google. Both allow the creation of augmented reality apps for smartphones. They interact with the camera and motion sensors to deliver the device's motion data in space, using Visual Inertial Odometry (VIO) technology and insert virtual objects into the real scene. A comparison of the two kits shows that developers prefer ARKit because the development platform is unique and is only applicable to proprietary HW products. Google, on the other hand, cannot secure its platform given the multiplicity of Android smartphones.

Our studio is based on a solution that does not require the installation of technological infrastructures. We experimented with a platform that is usually used for video games. It makes use of a smartphone to download an Android Application Package (APK) created on the Unity Vuforia platform. The system directs the user to the chosen destination through an annotated environment map without requiring cognitive effort. This solution provides on-screen directions superimposed on natural environments, as seen through the camera of a mobile device, such as a smartphone or tablet. In this way, the user can easily navigate the environments without consulting a map or references. Although it is based on the interaction of the natural environment with virtual objects, the proposed solution differs from others that use the same technology in that the model does not use arrow keys, QR, or labels to identify the desired destination. Users do not need to interact with a 3D map to select their destination and get answers. This requires cognitive effort on the part of the user. The route is not plotted based on points of interest or visual indicators. The usual routes are already predefined and placed in a choice menu.

For the realization of the system, different technological environments have been used, such as:

- Matterport,
- Unity,
- Vuforia

Matterport Capture software is the module that allows the generation and customization of an immersive digital twin environment of the designated location without resorting to expensive equipment such as laser scanners or lidar sensors. The artificial intelligence engine, called Cortex, a deep learning neural network, accurately predicts the geometry of 3D buildings using only the smartphone's camera. Its functional features are high resolution, accuracy, quality, and acquisition speed. It also has several features to improve the quality of the scanned model.

Unity 3D is the 3D graphics engine of choice for rendering and representing the digital twin created with Matterport. The engine offers a primary scripting API in C# and is used to develop virtual reality, augmented reality, and simulation models.

Vuforia Engine is a platform for developing augmented reality applications for mobile devices. It applies computer vision technology to recognize and track 3D objects and planar imagery in real-time. When viewed through a mobile device's camera, it is capable of positioning and orienting virtual objects with real-world objects.

The smartphone used was Xiaomi's Redmi Note 11 Pro 5G model. The characteristics are that the smartphone has a large 6.7-inch screen with Super AMOLED technology, a 2400 x 2080 pixels resolution, and a refresh rate of 120Hz. It features a Qualcomm Snapdragon 665G system chip, an Adreno 619 GPU, and 6GB of RAM. The internal memory is 64GB, expandable via microSDXC up to 1024 GB. The device uses the Android 11 operating system. It has three rear cameras: the primary 108 MP, a second 8 MP ultra-wide camera, and a third 2 MP macro camera.

4.1 Software Development Environment

This subsection outlines the necessary steps taken to establish the development environment required for constructing the application. We deemed it suitable to depict every stage of its formation to facilitate its reproduction. These three technologies, as previously explained, necessitate a series of activities for their integration, as depicted in Figure 2. Several technologies and techniques were used in the development of the AR navigation system.

The main technology used to create the AR experience was Unity 3D Engine, used for the design of behaviors, 3D contents, and the integration of several input modalities, such as gesture or touch controls. Vuforia Engine, designed to monitor and identify 3D pictures and objects in the real world, is the next in line. The superimposition of digital material over real-world objects—whether viewed through a smartphone or HoloLens—is made possible by Vuforia's interface with Unity.

On the other hand, Microsoft Mixed Reality Toolkit (MRTK) offers support for developing augmented reality apps for HoloLens. MRTK facilitates users' development of mixed reality applications by providing pre-built systems and components for common tasks including input management, geographic mapping, and user interface design.

Ultimately, the area was mapped and structured using the Scene Understanding SDK, enabling the creation of a virtual model that accurately reflects the real world.

5 Methodology

The methodological approach to the design of the Indoor navigation system involves the following phases:

- Capture the real-world environment.
- Creation of the database of the digital environment.
- App development.
- Download to smartphone.

In the proposed system, we have developed a Unity application that assists seniors who need help navigating the internal structure. Using Augmented Reality, we show the path the user can view through his phone.

Figure 2 shows the design flow and interaction between the modules.

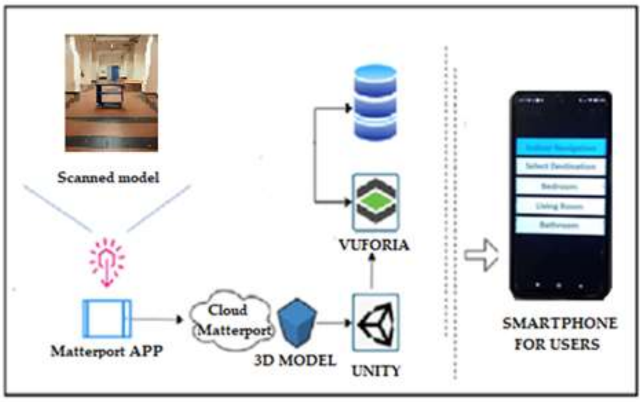

Fig. 2: Flow Chart of design phases

The Matterport Capture app plays a pivotal role in our process. It allows us to scan the physical environment, a crucial step that conditions the entire development of the navigation system. The quality of the 3D digital model of a natural environment is key. As the system is interactive and cyclical, we repeat the process several times until we obtain a qualitatively valid version. The 3D scan of the physical environment is then transferred to the Matterport Cloud service. This service, powered by CortexAI, a built-in artificial intelligence, processes the acquired model and generates a 3D digital twin with precise dimensions that mirror the physical one.

Area Target Generation (ATG) captures and generates the 3D-scanned model in the database. The scan can be edited before generating a target area. The ATG generates assets and data structures with an accurate representation of space for occlusion and collision simulation, thus creating a suitable model for implementing augmented reality.

The Target Area database, generated through the Area Target Generation (ATG) process, is then imported into the Unity Game Engine. This engine is a tool and a platform for creating immersive and interactive experiences, making it a crucial part of our development process.

Through the NavMesh function, Unity generates a mesh to approximate the walkable areas and obstacles of the environment, which is created for pathfinding and AI-controlled navigation. The creation of this navigation app enables the Unity navigation system to detect and define the walkable surface and then proceed to navigation between the user and the points of interest (POIs). Setting up navigation requires that the floor plan of the prefabricated created with Vuforia be aligned with the Unity target area. This verification is conducted with the Navigation function in Windows-AI-Navigation; when a blue overlay appears on the model plane, we will confirm the walkable surface as a connected surface. The locations in the scenario where the agent may pause and move are indicated by the walkable areas. The walkable area is automatically constructed from the scene geometry by assessing the position in which the agent can stand.

The algorithm used for pathfinding is the NavMesh, an alternative to the A* one used in iOS applications, in which the graph for the path is represented by polygons connected to the vertices (mesh). To activate it, we need to create a Game Object in Unity to which the agent, which represents a human subject moving in the scene, must be associated with the defined path, and which can be defined as a cylinder of assigned size and through a script the target which is represented as a sphere. The parameters related to the set path must also be defined in terms of speed, angular velocity, acceleration, stopping distance, and automatic braking.

The last phase of development is route visualization, in which we use an API (Application Program Interface) to set the starting and ending points of the path. The app simulates the animated path according to the chosen destination. The application created with the Android Build Support module on Unity Editor was exported and installed on the smartphone as an APK. These files are just ZIP files named with a .apk extension instead of the traditional.zip.PK. From a functional point of view, the app is activated through the menu in which the planned routes are reported (Figure 3).

Fig. 3: Application Menu

5.1 Digital Environment Scanning

Matterport Capture is a mobile application that works on Android and iOS smartphones. It allows users to generate a digital representation of any actual environment and include more information. Additionally, users have the capability to observe the space in virtual reality using the Matterport VR app.

The overall navigation procedure is directly influenced by the quality of the 3D digital model of a natural environment. We utilized the Matterport Capture application to perform a comprehensive scan of the tangible surroundings. The system operates in an interactive and cyclic manner, continuing until a qualitatively valid model is achieved (Figure 4). After the image is scanned, it is sent to the Matterport Cloud. Using Artificial Intelligence technology called Cortex AI, the cloud interprets the image and creates a 3D digital replica that accurately represents the physical object.

The scanning program enhances the quality level of the model by employing a range of functionalities.

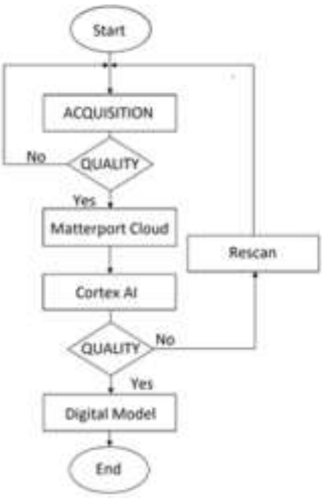

Fig. 4: illustrates the process of creating the digital model

The scanning program enhances the quality of the model by implementing a sequence of functions (model in Figure 5).

Fig. 5: The three-dimensional model obtained through scanning

5.2 Generation of Database Area Target

Area Target Generation is a tool within Vuforia Engine that captures a model that has been scanned in 3D and creates a database. Prior to producing a target area, the scan can be modified. The ATG produces assets and data structures that provide a precise depiction of space for occlusion and collision simulation. The Area Target Generator (ATG) allows for the generation, display, and modification of the area target. By using the smartphone camera, the space is captured and transformed into a Vuforia—3dt Space file, which is a locally optimized representation of the full scan. Vuforia provides functionalities that allow the space to be divided into the desired sections (Figure 6).

Fig. 6: Targeted area

Within the Space Viewer, there is a toolset called Navigate Space that allows users to examine the model in many ways. This includes transitioning between 3D representation of the model, structured mesh or point cloud visualization, and panoramic image visualization. Within Navigate Space, users have the option to temporarily conceal the ceiling (Ceiling cutoff) during the display, if the slider obstructs the view. The concealed sections persist as components of the produced Area Target. Furthermore, utilizing the Overview feature enables the user to magnify the perspective of the entire area, whereas the Dive function allows the user to zoom in on the environment from a first-person viewpoint.

The Generate function subsequently constructs the database for the Target Area, which encompasses a collection of files responsible for generating navigation and occlusion.

The generated dataset files are:

- New_ model.target.dat
- New_model_target. Unity package
- New_model_target.xml
- New_model_target_authoring.3dt
- New_model_target_navmesh.glb
- New_model_target_occlusion

5.3 Path Making

Unity utilizes the NavMesh [30], [31], function to construct a mesh that approximates the places where characters can walk and the obstacles in the environment. This mesh is then used for pathfinding and navigation of AI-controlled entities.

The produced Target Area was imported into the Unity engine for the purpose of creating the navigation app.

This application makes it easier for the Unity navigation system to locate and define areas that are appropriate for walking. Travel between the user and the points of interest (POIs) is subsequently made possible. Before creating navigation, there are a few preliminary procedures that must be finished to ensure that the pre-built structure's layout, created using Vuforia, is correctly aligned with the assigned Unity Target Area. When the Navigation function in Windows-AI-Navigation is enabled, the connected walkable surface will be shown as a blue overlay on the model plan (Figure 7). The areas inside the scenario where the agent can stand and move about are designated as walkable sections. By analyzing the scene's shape and identifying the precise spots where the agent can go, the walkable area is created.

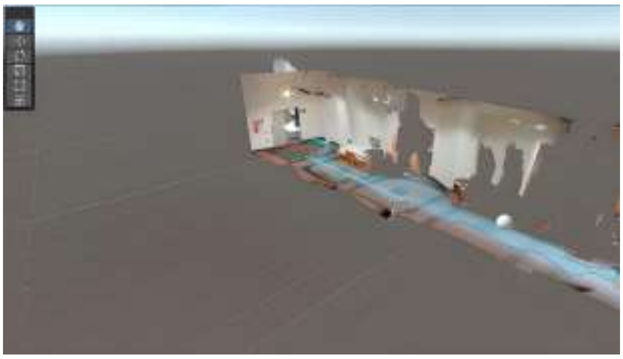

Fig. 7: Display of the NavMesh

The pathfinding algorithm utilized is NavMesh, which serves as an alternative to the A* algorithm commonly employed in iOS applications. In this approach, the path's graph is represented by polygons connected to the vertices, forming a mesh. To activate it, the following steps must be performed:

- In Unity, instantiate a Game Object named "NavMesh" that will automatically produce a navigation mesh for this object. To utilize the NavMesh Surface, it is necessary to include it in the mesh. Additionally, it is important to specify the walkable areas and the characters that will traverse this mesh. The debug function allows the user to identify and address any issues that may arise during the production of NavMesh. These issues include problems with the voxelization of the input scene, region division, and the display of mesh poles.
- The agent in NavMesh is the entity that can navigate along the specified route. The prototype agent, which emulates a human's movement in the scene, manages both the determined path and the control of its motion. The agent is constructed using a cylinder, which requires the specification of parameters such as radius, height, max slope, and step height. The radius determines the proximity at which the agent can approach a wall or ledge, while the height sets the limit for the agent's movement. The max slope indicates the maximum incline of a ramp that the agent can navigate, and the step height determines the maximum height of an obstacle that the agent can overcome.
- Movement parameters encompass various aspects of an agent's motion. These include speed, which denotes the maximum velocity the agent can attain, angular velocity, representing the maximum rotation the agent can perform, maximum acceleration, which sets a limit on how quickly the agent can change its velocity, stopping distance, which determines the distance at which the agent will come to a halt when approaching its target position, and automatic braking, which, if activated, will decelerate the agent as it reaches its destination. To facilitate the movement of the character to the intended location, it is imperative to create a script that includes the specification of the target destination. In our scenario, it is symbolized by a spherical shape, [32], [33].

5.4 Visualization of the Route

In the latter phase of development, the path's beginning and final coordinates are determined using an API (Application Program Interface). Depending on the destination that is chosen, the program duplicates the animated trajectory. Android Build Support is used to export the application to the smartphone. Visual depictions of the simulated path, both with and without obstacles, are shown in the Results section, [34], [35].

6 Results

NavMesh uses the algorithm of [36] and Artificial Intelligence to determine the optimal path and avoid obstacles. The algorithm applies the graph of connected nodes, starting from the node closest to the starting point and following the connecting nodes to reach the destination through the shortest path. The user selects the desired destination through the menu with a simple and intuitive user interface. We designed it following the indications provided by a previous study by [37], who suggested that displays should be used to avoid confusion and frustration in which there are no color contrasts and overlapping images. The app assists in secure navigation by returning, depending on the chosen destination, the animated route on the smartphone screen superimposed on the preloaded map. The user will do this in autonomous locomotion mode in the sense that he will be directed directly to the destination without acting on a controller. If the user wishes to change the choice, he can do so by requesting the change of destination, to which the system will propose the list of destinations again. The application does not allow an interactive choice of destination, [38], [39].

We hypothesized three preloaded paths in which, through scripts, the user and the chosen targets have been defined and represented respectively from a cylinder and by spheres in the simulated path.

Our study, guided by [40] findings, understands the unique challenges older adults with disorientation problems face in finding their essential destinations. We have dedicated our efforts to providing a simple orientation solution that focuses on these three destinations: room, bathroom, and dining room. This approach is designed to make the user feel understood and catered to, addressing their sleep, food, and socializing needs.

The system is equipped with a robust obstacle detection feature, ensuring the user's safety by checking for any obstacles in the navigation path. In case of an obstacle, the system provides an alternative route or one that bypasses the obstacle, giving the user a sense of security and confidence in their navigation.

When the application is accessed, destinations are displayed, and the user can choose their preferred destination. By selecting the destination from the menu, the system displays an animated simulation of the route he must take to reach the desired destination on the smartphone. The path's starting point is represented by a cylinder with which the user's figure is associated, while a sphere represents the point of arrival. The following Figure 8 shows a path where there is an obstacle.

Fig. 8: AR pathfinding with an obstacle

The path's starting point is the beginning of the corridor, where a cylinder representing the user appears. The point of arrival is the living room, selected from the menu, positioned at the end of the corridor, represented by a sphere. The agent's direction is deflected from the original direction to bypass the obstacle, represented by the cube, and then resumes normally.

To verify the correct functionality of the system, tests were conducted in the laboratories of the University of Reggio Calabria using seven staff members. The tests were repeated twenty times under the following conditions:

- verifying different selected routes.
- routes with obstacles.
- evaluating the degree of driving to the desired destination and the response time of the system to the choices made.
- measuring the time taken to reach the desired destination.

The destinations were successfully reached, with an error of 2%. The results obtained in terms of precision are comparable with previous experiences. The model's error in determining the final destination was of the order of about ten cm.

Feedback and evaluations on the use of the system were collected concerning:

- Functionality refers to the speed of use in model responses.
- Usability refers to the ease of use of the model.
- Utility refers to the model's ability to make the user independent.

An evaluation with a scale from 1 to 5 was requested for the above parameters, whose values take on the following meaning:

1. Unsatisfactory
2. Below average
3. Average
4. Above typical
5. Excellent

The results obtained are shown in Table 1.

Table 1. Evaluation Parameters

User	Functionality	Usability	Utility
1	5	5	4
2	4	4	4
3	5	5	5
4	4	4	5
5	5	4	5
6	5	5	5
7	5	4	4

Almost all parameters reached the expected maximum value, with the functionality being particularly appreciated (Figure 9).

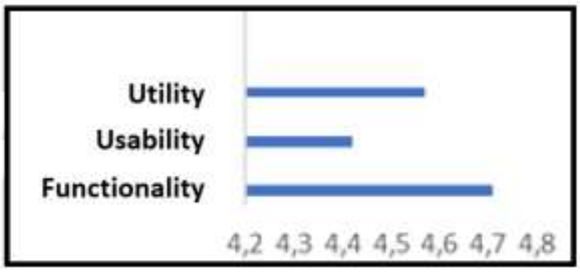

Fig. 9: Evaluation Parameter Diagram

The NavMesh algorithm utilizes the Dijkstra algorithm to calculate the route. It also incorporates Artificial Intelligence to determine the ideal path while avoiding obstacles. The algorithm operates on a graph consisting of interconnected nodes. It begins at the node that is closest to the starting point and traverses through the related nodes until it reaches the target. The navigation mesh is represented by a mesh of polygons. The algorithm is positioned on a vertex of a polygon that corresponds to the node's position and calculates the shortest path between the chosen nodes.

7 Discussion

The development of this case study aims to provide helpful support for seniors who lack autonomy in conducting their daily activities.

Activities of daily living (ADLs) are those essential activities that involve personal care and managing daily necessities. These activities are crucial for the well-being and autonomy of older people. The main ones are going to the bathroom, getting dressed, eating, and getting around. As we age, some of their functional abilities are reduced, so older adults need help that can be provided to them through the assistance of family members and professional caregivers or the use of so-called assistive technology. In particular, moving from one room to another in the house becomes difficult and, in some cases, even dangerous. Older adults with memory problems show enormous difficulties in spatial and temporal orientation, with obvious problems with movement even in familiar environments. The lack of spatial recognition results in the inability to connect landmarks and the paths to be taken within the environments. These difficulties manifest themselves in various behaviors, such as hesitation in choosing a route, why they need to reach a destination, and identifying landmarks. As a result, the patient moves in a wandering manner and can run into dangerous situations without awareness of the environmental conditions around him. Navigation in indoor environments requires specific motor or perceptual functions in addition to cognitive ones. Thus, a navigation system or other assistance devices can help seniors overcome obstacles associated with spatial and temporal orientation while simultaneously preserving and enhancing their sense of autonomy and dependency. Nevertheless, interior navigation presents different obstacles than outside navigation because of impediments or the overlapping of many levels or barriers that distort the signals. For example, GPS, a reliable system for outdoor navigation, is unsuitable for indoor environments, so it is necessary to use other systems to overcome these problems and ensure high accuracy and reliability. Smartphones equipped with motion and position sensors and the possibility of connecting to the Internet to acquire information on the user's location at any time and place have made indoor navigation applications possible.

The methodological approach followed was to study a digital solution that could allow older adults to move in complete autonomy within closed environments with characteristics that ensure:

- Improved quality of life.
- Simple directions on the path to take, such as to reduce stress and confusion.
- Reduction of the need to use navigation aids people.
- Provide customized itineraries based on the patient's needs.
- Reduction of public assistance costs.

We arrived at the proposed solution after a careful analysis of the state of the art of the indoor navigation system. We have analyzed the characteristics that a navigation system for seniors must have and what technologies can be used. The review found many systems with different functional features, technologies, and infrastructure. Each solution has its advantages and limitations. The analyzed applications showed no standard solution for outdoor navigation, such as GPS, and each researcher used their development methodology.

Some researchers have used sensor-based technologies to detect the user's location and movement.

In contrast, others have resorted to computer vision or physical references such as QR codes to detect location. Other applications involve indoor navigation solutions but are integrated into larger home care systems. They are characterized by application and operational complexities and require specific hardware. These elements increase costs.

Considering older people's desire for a peaceful and safe life at home and their potential resistance to digital technological solutions, our focus has been on the unique capabilities of augmented reality (AR). AR is best suited to the needs of cognitively impaired seniors among the available technologies. It uses an overlay approach to provide information about the environment on mobile devices, making it an easy-to-use and effective solution for indoor navigation.

We chose the smartphone as the central element of the solution due to its technical capabilities and the older people's trust in this device. For this pilot study, we explored the potential of video game design tools to simulate paths within the premises of augmented reality. This approach does not require additional hardware or wearable sensors, which would incur extra installation and maintenance costs.

It makes use of a smartphone to download an Android Application Package (APK) created on the Unity Vuforia platform. This differs from AR applications on smartphones that usually use ARKit or ARCore SDKs (Software Development Kit).

The choice of a smartphone further enhances the acceptance of the technological tool among older people, making it a practical and accessible solution.

The proposed application differs from traditional techniques, as it is based exclusively on interacting with the real environment and virtual objects. The older people do not have to interact with a 3D map on which to select the destination and receive directions on the path to follow. This requires cognitive effort on the part of the user. The route is not plotted based on points of interest or visual indicators. It differs from others that use the same AR technology in that the model does not use arrow keys, QR, or labels to identify the desired destination.

The paths are already predefined and placed in a choice menu. The menu is simple and essential and is created to select one of the three options. Three preloaded paths have been hypothesized in which, through scripts, the chosen targets have been defined and represented by spheres in the simulated path. With the location of the point of arrival, the app simulates the animated route to be taken from the point of departure to the point of arrival. Depending on the choice, the user sees a display of the animated route he must take to reach the target destination, superimposed on the preloaded map. The interface is such that it does not require any cognitive effort. The application allows one to reach the chosen destination with an accuracy error of a few centimeters.

Ultimately, the application is distinguished by the following features:

- Precision. The application guides the user to their destinations within a reasonable error percentage.
- Cost. No infrastructure elements or additional hardware are needed.
- Pre-loaded indoor maps. There is no interaction with a 3D map on which to select the destination.
- Intuitive user interface (UI). The visualization of the actions that the user must perform facilitates the process, ensuring that patients learn as little as possible without increasing their cognitive load.

Considering the results, the template appeared effective, easy to use, and had a simple user interface. It has been used in academic settings and with healthy subjects. However, we believe that due to its characteristics, it can be easily used in real-world environments with cognitively impaired adults to attest to the model's validity, which is currently considered a potential tool.

8 Conclusions

This pilot study aimed to verify the potential of the tools usually used in video games to create an indoor navigation AR application to support older people with cognitive problems who have problems moving indoors. Among other things, no such experiences have been found in the literature. Following the results obtained in the scientific environment, we think, in the future, to extend the application in a residential home for older people, with a study protocol and with the full involvement of caregivers to verify the effectiveness of the navigation model and the degree of acceptance.

This activity has been postponed to a second phase as it requires a careful and methodical approach that involves a long time for the definition and articulation of different activities.

Based on feedback from patients and caregivers, the system can be improved based on the needs and capabilities analyzed by the patients. This test will be helpful to be able to extend its application in clinical settings. The proposed solution has been developed for limited navigation areas. In the future, it is planned to extend the system to an entire multi-story building. Based on the tests conducted, the pilot model can already be considered an effective assisted navigation tool for older people, capable of containing health expenditure and contributing to improving the quality of their lives.

In the future, the advances that can be achieved in augmented reality will contribute to the creation of increasingly advanced navigation systems with more precise results that older people appreciate.

Declaration of Generative AI and AI-assisted Technologies in the Writing Process

During the preparation of this work the authors used Copilot in order to improve the readability and language of the manuscript in the introduction section. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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The authors have no conflicts of interest to declare.

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