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AR Home Care Demonstrator for Safety and Mobility

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Abstract

After being hospitalized, a growing number of patients and their families prepare for healthcare and long-term treatment at home. Therefore, customizing their home to suit patients' long-term care is crucial. However, adapting their home to fit the patient's needs comes with challenges and there are only limited facilitative elements to address this challenge. To deal with this issue, guidelines for placing furniture and tailored room setup depending on their mobility limitation have been developed in this project, along with an Augmented Reality (AR) App that provides an experience of rearranging their room. Additionally, this app aims to run on devices that people already own. (Mobile phone and Virtual Reality (VR) goggles). The app's core functionalities include AR furniture rearrangement mockups and interactive guidance provision. The app's system customizes the guidance based on the user's input about physical challenges, allowing users to organize their homes appropriately. According to evaluation from experts and patient groups, the results indicate that the prototype provides users with effective insights for rearranging their rooms. Moreover, there is a significant positive correlation between the app's guidance and the efficiency of the home rearrangement. Specifically, it was evaluated that using the prototype would greatly influence the patients or their families to gain insights into a safe and accessible home layout for patients with mild-level mobility limitations. Furthermore, this research can contribute to providing optimized advice and experiences for their room arrangement that can be applicable in any room.

Acknowledgment

Deepest appreciation to my supervisors, Daniel Saakes and Jodi Sturge for all the support and guidance during the graduation project. Also, A great appreciation to Wim Leppink and the TechMed Team for the provision of information and explanations about various medical facilities and equipment. Lastly, I had the pleasure of collaborating with my co-researcher, Seokho Jeong.

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1. Introduction

1.1 Context

With advancing age, many people develop functional impairments and need support to keep up with personal and instrumental activities of daily living to be able to remain in their own homes.[1] This trend has led to an increase in the Home HealthCare (HC) industry, as presented by the following statistics from IBIS World, the market size of the HC industry in the US has grown by 3.3% per year on average between 2016 and 2021. Moreover, the global HC market size is expected to grow at a compound annual growth rate of 7.88% from 2021 to 2028.[2] Therefore, technological development is necessary to follow the growing demand for HC. To ensure proper HC, patients require a Tailored Room Setup (TRS) that provides a suitable environment for necessary treatment and living after they return home after discharge from the hospital.

1.2 Problem Statement

The Space for Health project approved by The Administration for Social Welfare in Stockholm, indicates a significant correlation between environmental changes in the living space and the satisfaction of patients and their relatives.[3] Among these environmental changes, the result of a research about 'Exploring the Relationships Between Patient Room Layout and Patient Satisfaction' emphasizes the importance of clinical area design—and spatial layout in particular—on patient satisfaction outcomes.[4] For example, bed placement is one of the key elements in spatial layout. The provision of sufficient space for living areas is one of the most important aspects of the design of acute in-patient accommodation for allowing for key activities as well as reducing infection risks.[5]

The customized home rearrangement for patients needs to be carried out by considering these factors, however, there are only limited means to assist them for two reasons. Firstly, there is a lack of specialized experts providing customized interior design for patients. Secondly, people tend to decorate their houses on their own rather than hire interior design experts. There is a survey conducted in the U.S. regarding this point: Only 10.98% of participants stated they would recruit professional interior designers.[6] Therefore, it seems the Target Group (patients who will perform HC after discharge, their families, and caregivers) does not also commonly hire experts to customize their houses, and it seems that a new method that is differentiated from employing experts will be more effective. In addition, previous researches indicate that changes in the interior setting and spatial layout in the living space necessitate a systematic approach [3, 4] Therefore, a discussion based on literature reviews has been established to identify methods to design technological interventions to assist target group in TRS for systematic approaches.

1.3 Research Question

Research question:

How to design an AR-based Tailored Room Setup (TRS) application for being discharged from the hospital to the home environment?

Sub RQ1: What are the main considerations when customizing a room to suit a person's needs after being discharged from the hospital?

Sub RQ2: How can an AR app effectively deliver useful information and experience to potential users?

Sub RQ3: Which technical methods can be implemented within AR for furniture arrangement and guidance to create more suitable environments for safe and east-to-move home setup?

2. Background Research

In this chapter, the literature review on general information about HC and the implementation of an AR-based TRS app for it is conducted. Then, the state of the art is explored, and the discussion and conclusion based on the results are drawn.

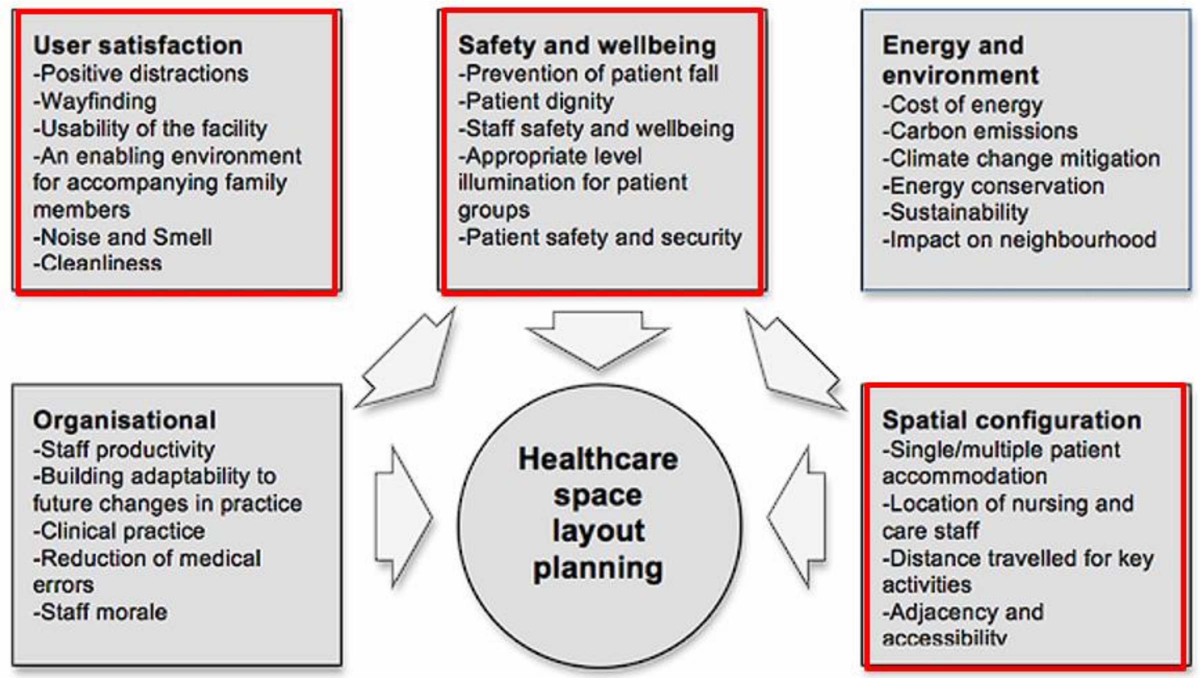
2.1 Literature Review

In this section, firstly the definition of HC and the broader context of how it manifests will be explored. The understanding of the overall context of what home healthcare is and its implications. One suitable disease for HC will be identified, followed by an exploration of TRS based on these diseases. The next step is exploring what HC entails for the identified disease and its corresponding TRS. Following that, a TRS principle model will be established for patients by considering the factors influenced by spatial layout in healthcare. Next, a literature review on the technical aspects will be conducted. The former part involves researching methodologies for delivering useful information to the target group, and the latter part involves researching technologies for implementing it within AR spaces.

2.1.1 Healthcare at Home

The World Health Organization (WHO) defines Home Care as an array of health and social support services provided to clients in their own residences.[7] For patients with incurable and advanced diseases, studies from England and the USA indicate that most of the patients with incurable and advanced diseases would prefer to be cared for and remain at home until their death [8]. In many cases, since medical equipment may be necessary to address certain diseases, it is required to bring medical devices into the home for HC. According to this matter, the advancements in technology and the universalization of medical devices are crucial. During the last few decades, home care has grown considerably in the USA in response to increased technological capacity to provide sophisticated medical treatment in the home.[9] Moreover, the market size of the Home Care industry has grown and is expected to grow in the future as mentioned in the introduction.[2] Therefore, the corresponding technological advancements have also been and need to be progressing. It appears that further technological foundation of HC has to be continuously improved due to the growing demand for HC.

2.1.2 TRS Principle Model



<Figure 1> Factors that influence space layout design in healthcare facilities.[10]

To provide appropriate TRS to patients and their families, it is necessary to understand the relationship between living spaces and healthcare. <*Figure 1*> illustrates the plan and criteria designed by Yisong Zhao et al.[10] for space layout design in healthcare settings, which are mostly applicable for delivering qualitative HC. Patient safety has been considered one of the most important aspects of the hospital design process and it relates to caregivers, patients, and visitors. For patients, a safe environment is essential for successful recovery for the caregiver's safety relates to the working environment and their wellbeing.[10] Therefore, five elements have been adopted as considerations to create a safe environment for patients and caregivers as follows: Organisational, User Satisfaction, Safety & Wellbeing, Energy & Environment, and Spatial Configuration. These elements are also applicable not only in the hospital but also in the home healthcare setup. The differences between them is that there are no professional medical staff and other patients at home. Therefore, the project focused on the layout of the patient's home, using User Satisfaction, Safety & Wellbeing, and Spatial Configuration as criteria for providing TRS for the patient.

2.1.3 Identification of Diseases Requiring TRS Guidance

TRS involves setting up a room Tailored to the patient's needs, and it significantly depends on the type of illness the patient has. When patients have physical disabilities, guidance is needed to help them adapt to their living environment effectively.[11] Additionally, since the Target Group of this project consists of patients with long-term scheduled HC, the illnesses to be targeted in the project are also aimed at long-term illnesses involving physical discomforts. Regarding this point, the chosen disease for the background research is stroke. Despite medical advances and a focus on prevention, physical discomfort and mobility limitations related to stroke continue to be a global health burden.[12] Stroke can cause various physical disabilities depending on which part of the brain is affected, and symptoms of a stroke manifest in the body parts controlled by the damaged areas of the brain.[13] Consequently, three scenarios have been set up based on the physical impairments that stroke patients may experience: wheelchair use, assistance walker use, and limited walking scenarios. These scenarios are primarily designed for stroke patients, but other patients with other physical disability requiring wheelchair & walker use or having difficulty with mobility can also receive guidance for TRS in the same manner. Therefore, stroke serves as an example scenario for the implementation of the technology in this project rather than being the sole target illness.

2.1.4 TRS Considerations for Patients Scheduled for Discharge

In cases where patients will perform HC, a precise home arrangement is necessary. Patients who have physical discomfort especially require more needs of TRS due to the limitation of movement. For instance, patients who require wheelchairs due to diseases such as stroke or paralysis may need appropriate modifications in their homes, such as low-angled slopes instead of stairs and ensured paths for wheelchairs The guidance provided by the American Stroke Association for modifying home mentions TRS for stroke patients using wheelchairs. These modifications involve the proper shape of doorways, the use of a "wet area" instead of a typical shower, and enough space next to the bed for comfortable lying.[14] Additionally, medical equipment such as blood pressure monitors or IV drips may need to be placed in the home as essential items depending on the type of patient's disease. Therefore, the physical layout elements to consider for TRS in this project are identified as standard furniture and medical equipment for patients' treatment. Since both medical equipment and common furniture are treated as the same type of objects in AR, the medical equipment can be also considered as furniture. Thus, the following section will consist of literature reviews on AR furniture placement methods.

2.1.5 Methodology for Delivering Useful Information on Home Setup

Since the first goal of the project is the rearrangement guidance, the most crucial aspect of TRS in AR is delivering information to users for home rearrangement. Thus, the literature review for searching methods for delivering information has been conducted. Chuhan et al suggest that providing explanations in the text for advised furniture arrangement strategies through AR is effective. Additionally, it also cites that detailed explanations for scenarios can be provided using speech bubbles.[15] This insight suggests that the Target Groups could be provided with several home arrangement strategies in the text within AR. Since the needed information depends on the type of disease, detailed explanations seem efficient when they are delivered in text. Furthermore, one useful strategy for TRS is providing various furniture placement scenarios. Since offering several sample furniture placement scenarios within the AR app allows users to compare scenarios and select the best one, the strategic approach is effective.[16] Next, the addressed methodology is related to the User Interface (UI). In the AR Interior Designer model in Jeff et al, the UI provides a tool tab for furniture selection and detailed information on the furniture(scale, texture, etc.)[17] Since accurate measurements are necessary for placing furniture and medical equipment, this methodology was judged useful for TRS guidance. Therefore, having information about the size of furniture that the user can place via the UI would contribute to placing furniture in the right position.

2.1.6 Implementation Techniques in AR

In this paragraph, a literature review on how to implement the overall AR environment based on similar precedents will be conducted. Firstly, it will address how to scan and measure the scale and distance between each object in the actual room. According to research by Jeff et al, it was mentioned that by fixing the Microsoft KINECT sensor and using the Random Sample Consensus algorithm, more accurate distance measurements between objects can be achieved. Additionally, it enables precise distance measurements without the need for VR goggles.[17] Therefore, this could be considered a potential further implementation for this project. Next, the focus will be on UI. Since the main goal of this project is to provide users with a rearrangement experience, the function to allow them to place virtual furniture mock-ups in an AR environment is crucial. Previous techniques have implemented this by inserting a tool tab in the UI for the selection of furniture.[15, 17] Additionally, a method of delivering information through text as mentioned above could be implemented by placing interactive description bubbles that allow toggling on/off to show measurement information for each placement scenario and explain strategies.[15] Lastly, the research has been conducted to find adequate theories to be used in the production of scenarios that will be presented to the user. In the AR model of Chuhan et al, the theory of Feng Shui is utilized to find the most suitable emotional connection between residents and their living spaces and provide furniture arrangement guidance accordingly.[15] Furthermore, Lap-Fai's AR model creates an optimized furniture arrangement environment through spatial recognition by optimization based on human ergonomics.[16] In this technique, Furniture Relationship Extraction is based on the real scale of each object, expressed as the x and y axis in a 2D plane, and the composition of furniture is formulated by the Boltzmann function.[16]

2.2 State of the Art

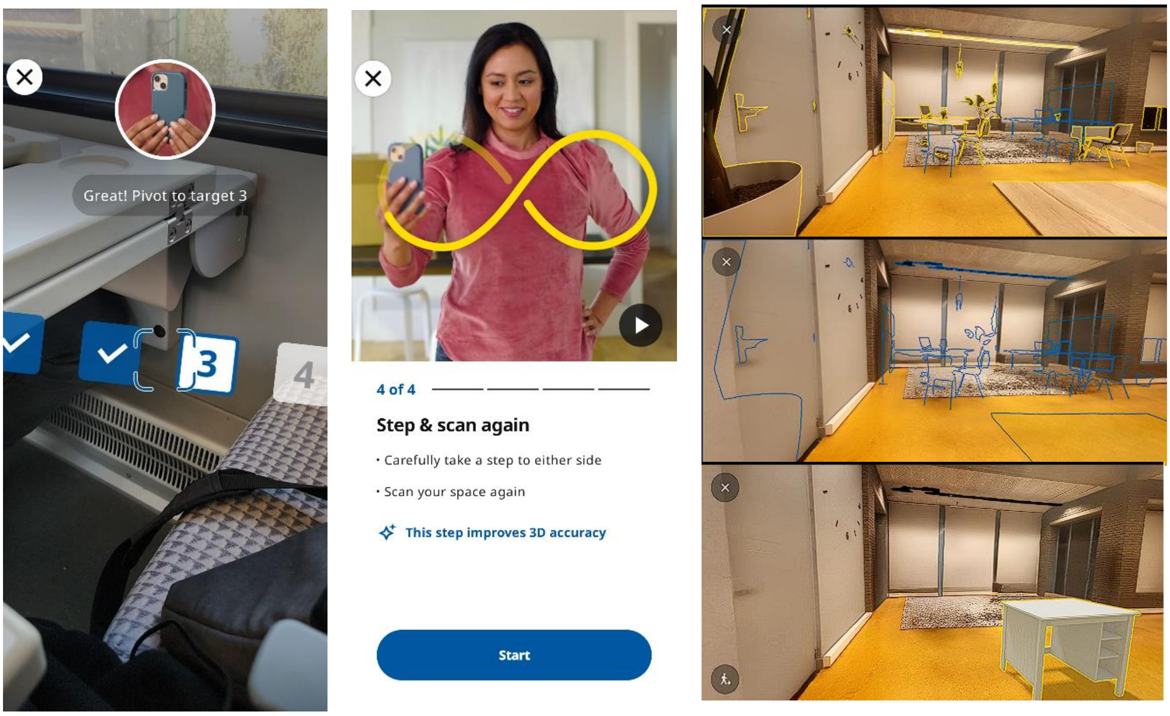
State of the art research is conducted to get extensive insight from the existing products to improve TRS via AR technology. Four examples are explored.

2.2.1 Ikea Place

<Figure2> IKEA Place [35]

In the 'IKEA Place' App launched in 2017, the AR application supports customers' decision-making by allowing them to explore virtual furniture items fit and look in a physical environment [18], and provides a real-time AR-based virtual furniture placement feature. This app makes it easier to make buying decisions in the user's own place to get inspired and try many different products, styles, and colors in real-life settings with a swipe by the user's finger within their mobile phone. Moreover, this app allows people to capture the settings in the app and share them as images or videos with friends.

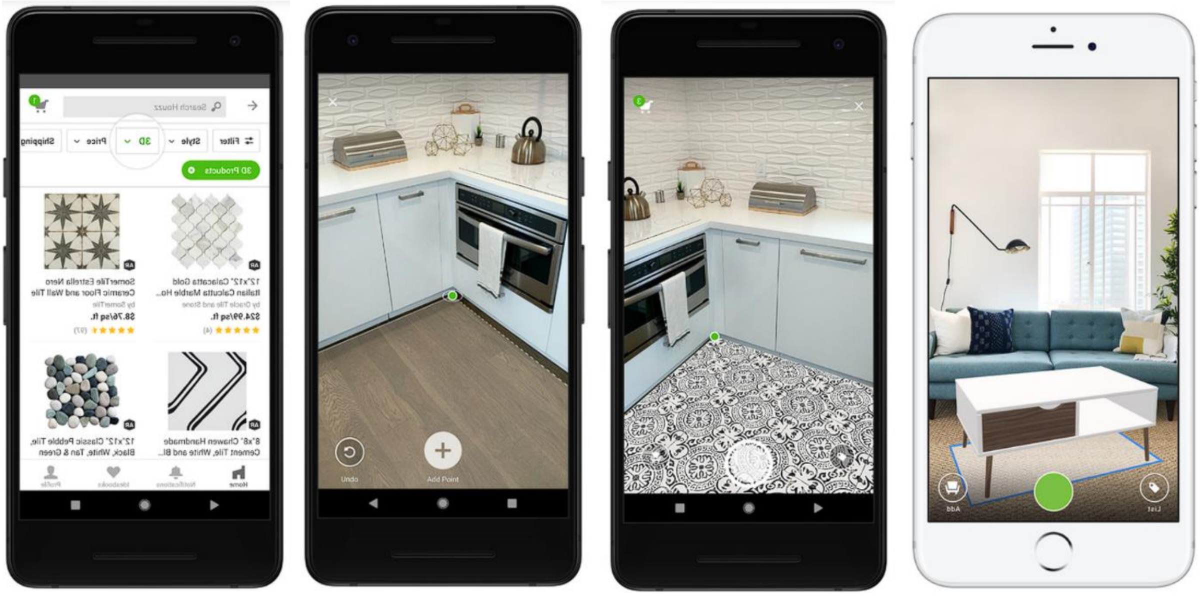
2.2.2 Ikea Kreativ



<Figure 3> Screenshots of IKEA Kreativ App use [36]

Ikea Kreativ is another version of Ikea's app released in 2023, following Ikea Place. It offers a function where users can scan a room multiple times and then place furniture in a fixed AR view using a single static 3D image. Since IKEA Kreativ uses static 3D images, this is different from Ikea Place, which provides real-time AR streaming. Users scan the same space from different perspectives on five points and then move step by step to scan multiple times for accurate spatial recognition. And then finally, it conducts approximately 10 minutes of AI processing to integrate all images into a 3D space. Ultimately, a single fixed 3D image is created as depicted in <*Figure 3*>, and all home rearrangement mock-ups taken within this view. There are two advantages when it comes to comparing with the real-time AR placement app. First, this approach is apart from the drawback of the shaking caused by hand movement during the app use. Next, it's possible to smoothly remove existing objects based on the AI processing system. Since the workspace consists of a fixed image as shown in <*Figure 3*>, AI photo completion automatically fills the space with something else that blends with the background after deleting the actual object.

2.2.3 Houzz



<Figure 4> AR View in My Room feature of the Houzz app [37]

The 'AR View in My Room' feature of the Houzz app provides mock-ups of the house interior through AR. The differentiated element from other apps is the feature to specify the ranged area of the floor to implement tiles or wallpapers as shown in *<Figure 4>*. This has provided insights into various interactions, for users in the project such as setting up places to park wheelchairs. Since the TRS of the project involves handling not only furniture placement but also all interior elements of the house, it seems that this function like mock tile and wallpaper application can be appropriately incorporated.

2.2.4 Autodesk Homestyler Interior Design

<Figure 5> Visual Studio feature of Homestyler [38]

<Figure 6> Homestyler AI Designer [38]

Autodesk Homestyler is a complimentary online home design software, where users can create and share their dream home designs in 2D and 3D. This program is distinguished from other apps by not only providing interior mock-ups through AR but also allowing users to simulate everything. As shown in <*Figure 5*>, it provides designing and building interiors in an empty virtual room. From the project's aspect, a major challenge in remodeling the homes of patients' families is the disposition of the existing furniture layout. Therefore, apps like Autodesk Homestyler offer the advantage of starting fresh with furniture placement by leaving only the skeleton of the house using virtual interior design programs. However, this approach is limited as it needs the accurate measurement of the house's whole framework. Moreover, Homestyler also provides AI design features as shown in <*Figure 6*>. The left image is a real photograph, while the right image is a transformed image by the AI Designer. Since this function offers augmented adjustments to real images, it seems it also has similarities with the AR project in this paper.

2.3 Discussion and Conclusion

The goal of this literature review was to get an overview of designing an AR-based furniture placement app for discharged patients. The gained insights were about considerations for various equipment that the patients need and the possible scenarios for TRS of patients scheduled for discharge. Additionally, insights were gained into various methodologies for delivering information to patients and the final form of the AR app of the project.

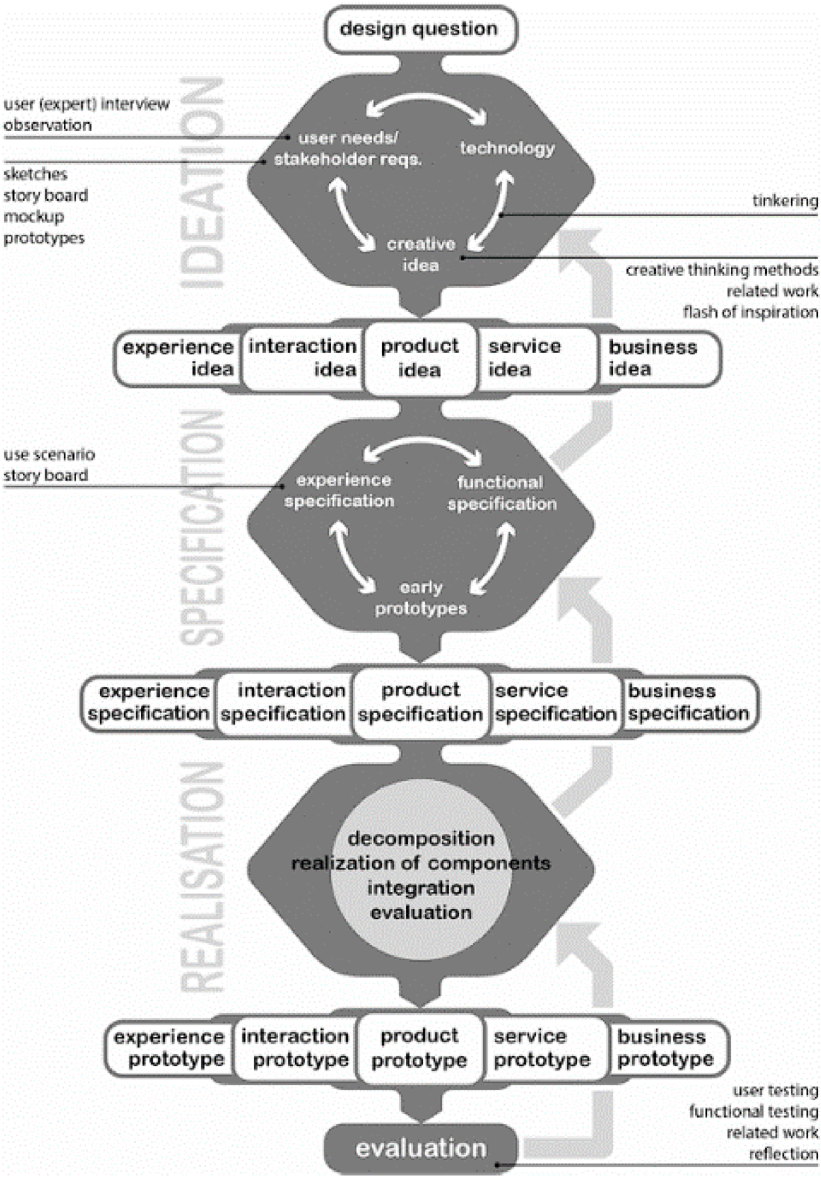
An interesting future research direction is the development of an automated AR app for TRS for every disease and room type, rather than a limited number of them. One precedent for this is the AR model of Jeff et al, which calculates standardized Euclidean distances based on the Microsoft KINECT sensor to provide automatically customized furniture arrangements.[17] The functionality of such models has already been proven and could be used to provide effective guidance to users.

Various state-of-the-art technologies assisting in AR home rearrangement were explored. Interestingly, every app has a common type of function. Primarily, each product includes functionalities enabling users to move, scale, and rotate furniture for appropriate placement. Additionally, they also integrated AI technologies in the app such as object removal or AI designers. Insights gained for the development of the target app in this project are as follows. Firstly, the drawbacks of real-time AR apps and how to address them are reminded. Secondly, insight into the provision of guidance through various interactions like recognizing floor and wall to attach something, beyond simple move/scale/rotate furniture placement was realized. While most products may appear similar at first glance as they provide furniture placement via AR, each app possesses distinctive edges. In the same context, the target AR app in this paper also stands out by providing TRS guidance for CH patients, setting it apart from others.

3. Method and Techniques

This chapter describes the methods and techniques utilized in the research and implementation of the app. The primary design approach is the Creative Technology Design Method. This method has been adopted as the goal formation of a prototype is designed to provide users with an effective experience.

3.1 Design Method



<Figure 7> Creative Technology Design Process [19]

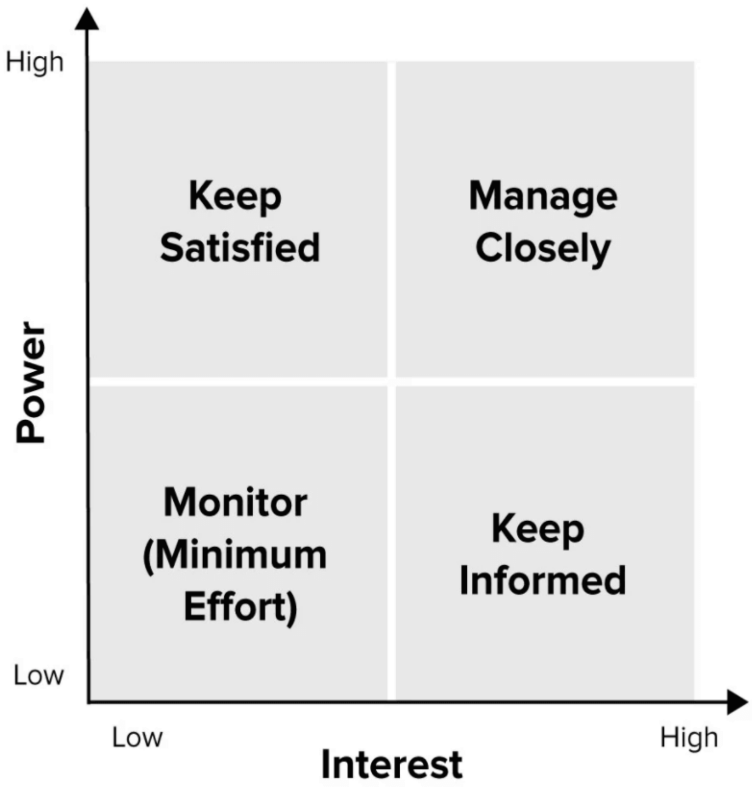
The design method utilized is the Creative Technology Design Process by Mader et al, which is primarily used in technology development projects within the Creative Technology Bachelor Course. [19] This method consists of four stages: Ideation, Specification, Realization, and Evaluation. The Ideation phase begins with fundamental starting questions, i.e. Design Questions, which are used to set the direction for the design. Ideas are generated through a series of iterative cycles as shown in <*Figure 7*>. These cycles consist of user needs, stakeholder requests, technology, and creative ideas. The ideated components are repeated based on these elements, and it leads to constructive final ideation. The Specification phase focuses on formalizing the generated ideas. This stage also consists of an iteration cycle of experience/functional specifications and an early prototype. It allows for detailed elaboration of each element when these phases finish. The third stage is Realization, and it involves bringing all elements developed in the previous stages to create the final prototype. The final stage is the Evaluation phase. This phase involves assessing all stages and conducting user tests and reflections for an elaborated final prototype. Since the core value of using this cycle-type method lies more on a linear process with possibilities for backtracking [19], all phases are possible to revisit previous stages for modification and improvement.

3.2 Techniques

3.2.1 Ideation Phase

The ideation phase begins with the identification of user needs and stakeholder requirements. The sub-chapters below perform analysis on stakeholder identification and their requirements. Following this, the identified aspects are used as the basis for brainstorming creative ideas. Finally, the ideation process concludes with the definition of the final concept and the determination of the technical goals.

3.2.1.1 Stakeholder Ideation and Analyzation



<Figure 8> Power/Interest Grid [20]

The Power/Interest matrix is used for analyzing stakeholders. The stakeholder map includes stakeholders, divided into proponents and opponents, problems identified by the stakeholders, and their suggested solutions to the problems.[20] The horizontal axis represents the extent of interest stakeholders have, and the vertical axis represents the impact they have. As shown in <*Figure 8*>, stakeholders are classified based on the balance of their power and interest into four areas: Keep Satisfied, Manage Closely, Monitor, and Keep Informed.

3.2.1.2 Stakeholder Requirement Identification

The MoSCoW prioritization method is utilized to identify stakeholder requirements.[21] This method is divided into the following stages: Must-Have, Should-Have, Could-Have, and Won't-Have. Must-Have is the non-negotiable element that is mandatory for the stakeholders. Should-Have is an important initiative that is not vital but adds significant value. Could-Have is a nice element to have initiatives that will have a small impact if left out. Lastly, Won't-Have is an initiative that is not a priority for a specific time frame.[21] Stakeholder's necessary elements are identified by using these four perspectives, and a final conclusion will be drawn.

3.2.2 Specification Phase

The specification phase begins with specifying the user experiences of the project and the functional reviews. Firstly, an early prototype is developed in the refined form by the processes and for specifying the direction of the targeted prototype. Next, A formalized system architecture model will be produced based on these specifications.

3.2.2.1 Early Prototype

The early prototype will be conducted as formation as a low-fidelity (lo-fi) prototype. Lo-fi prototype gives designers and programmers an idea of where images, text, buttons, and interactive elements might be placed[22]. Since the prototype aims for AR implementation, the assessment of the feasibility and basic AR functionalities are also included. On the other hand, another perspective to consider is keeping the principles related to prototype development to ensure the completeness of the prototype. The Principle of Scientifically Founded Judgment mentions that Engineers should endeavor to base their engineering decisions on scientific principles and mathematical analysis and seek to avoid the influence of extraneous factors.[25] The prototype developer has to assess the feasibility of the app by implementing the core functionalities that need to be included in the app. Based on the created early prototype, a review of the process is conducted to identify technical challenges. This review also provides an assessment of whether the app can be completed within the whole project period.

3.2.2.2 Experience and Functional Specification.

Experience and functional specification will be described by identifying personas and designing storyboards with scenarios. Personas are defined as hypothetical archetypes of actual users and usually result from a user analysis.[23] A persona describes a fictional person who represents a typical group of end-users and includes personal details, roles, tasks, goals, and skills. [23] Scenarios are designed based on the identified personas. Since personas are included as actors in scenarios in many cases, scenarios and personas are considered complementary artifacts. Finally, the flowchart is considered a visual representation of scenarios, and it is used to communicate ideas about a future system to stakeholders.

3.2.2.3 System Architecture

The system architecture is derived based on the storyboard established above. The system architecture process strives for an optimal result, by creating and maintaining the key issues, such as a balanced and consistent design, selection of the least complex solution, and satisfaction of the stakeholders.[24] The final design is presented as a diagram with nodes interacting with each other.

3.2.3 Realization Phase

In the realization phase, the ideas and strategies developed through the previously mentioned methods will be implemented into the final prototype. The prototype aims to fulfill the functional elements meeting stakeholder requirements and other additional elements. For elaborated realization, firstly, an explanation of the hardware and software used in the prototype and the reasons for their selection is provided. Following this, a review is conducted to determine whether the prototype meets the initially targeted functional requirements.

3.2.4 Evaluation Phase

Once the prototype creation is completed, user testing and expert evaluation will be conducted for evaluation. The sample user groups are divided into two groups. One sample group consists of experts and patients with medical knowledge related to the diseases of the target group such as physical therapists or professional caregivers. Next, since the potential app users are the common people who will live with patients together such as their families, the second sample group for the user test is determined as the normal people. One of the additional reasons is that since most target patients have physical discomforts, the co-residents are more likely to use this app. The feedback from these two groups will be integrated into the final prototype by evaluating and refining the performance of the app.

4. Ideation

4.1 Stakeholder

4.1.1 Stakeholder Identification

<*Table 1*> below shows the identified stakeholders.

Stakeholder	Role	Contact
Client	Decision-make	Daniel Saakes
Supervisor	Decision-make, Guide	Daniel Saakes & Jodi Sturge
Patients	User, Recipient of benefits by app use	-
Families & Caregivers	User	-
Designer/Developer	Design&Develop app	Junhyun Noh

<Table 1> Stakeholders

The main aspects of the categorized stakeholders are Patients, Families & Caregivers. While Patients could potentially be the main users, Families & Caregivers are likely to become the actual app users as the patients may have difficulty handling VR goggles or mobile devices due to their physical discomfort.

4.1.2 Stakeholder Analysis

<Figure 8-1> Analyzed Power-Interest Grid

4.1.2.1 Client

Daniel Saakes, an associate professor at the University of Twente's Engineering Technology faculty, is a client of this project. He is the main decision-maker and the starter who has commissioned and conceived this project. His power has the most influence on the project as he has conceived it. Since he has much experience in AR implementation, he has keen insights into the prototype. Therefore, he can provide detailed feedback on the technical aspects of the app, as well as on an aspect of the client. On the other hand, given his extensive knowledge in this field, he is likely expecting a high level of technical development. Thus, extensive communication with him is essential to receive feedback and fulfill his requirements.

4.1.2.2 Supervisors

Alongside the client Daniel Saakes, Jodi Sturge also serves as the supervisor for this project. She is an assistant professor with the Interaction Design (IxD) group in the Department of Design, Production, and Management in the Faculty of Engineering Technology. As the supervisors of this project, Daniel Saakes and Jodi Sturge are the decision-makers and guide the students in carrying out the project. While they hold significant power over the project as they lead the project and supervise designers, they have less interest in the project compared to a client. Additionally, Jodi Sturge who is a health geographer and design researcher can offer extensive guidelines regarding the project's target group, given her background in researching human health and well-being enhancement. Additionally, as a collaborator on the international research project 'Built Environments to Support Rehabilitation for People with Stroke,'[26] she can provide an expert review drawing on her extensive knowledge of stroke patients, who are the target group of the project. Furthermore, since the project's outcome will ultimately take the form of research, they can provide useful feedback on research and reports.

4.1.2.3 Patients

Patients are the core target group of this project. With the title of the project ‘AR Demonstrator for Care at Home’, it is crucial to provide TRS to patients scheduled for HC. Therefore, the conduction of behavior analysis and investigation of their requirements are necessary to produce a sophisticated prototype. The patients are the users and recipients of benefits through the app as this app is designed for the patients. However, the targeted patients in this project have physical discomfort, potentially limiting their direct use of the app, such as handling mobile phones and wearing VR goggles. Despite their physical limitations, they have the highest interest among stakeholders as they are direct beneficiaries of the app. However, since they do not directly intervene in the project, their power is the lowest.

4.1.2.4 Families & Caregivers

Families & Caregivers are the indirect target group of this project. As mentioned above, patients may not be able to use the app directly or rearrange their homes due to physical discomfort. Therefore, stakeholders who are likely to directly accept the TRS and rearrange the home are the Families & Caregivers. Adjusting the home to customize to patients with the necessary devices for their healthcare may be a challenge for them. Since the app provides guidance for TRS, it is expected that their interest will be high. In this project, experts including physical therapists and professional caregivers will be directly interviewed, and their reviews on app usage will be considered during the evaluation phase. Therefore, their power in the project is measured higher than patients. However, since they are only communicated as interviewees, and do not provide direct decision-making in the project, they hold less power compared to supervisors and designers.

4.1.2.5 Designer

The designers leading this project are Junhyun Noh (the paper's author) and Seokho Jeong (co-designer). They design the app based on necessary background research, communicate with stakeholders, and develop it. The designers conduct literature reviews, gather advice from the client and supervisors, conduct qualitative research such as interviews, and develop the AR app using Unity software. All hardware and software resources required for this process are provided by the university. The co-designer Seokho Jeong takes on different scenarios for his individual development but also shares knowledge in research and software development. Therefore, the designers hold both high power and interest in the project as direct developers of the app, but they have lower power compared to the client. On the other hand, they have a similar level of power as they collaborate with supervisors as they discuss and set the direction of the project.

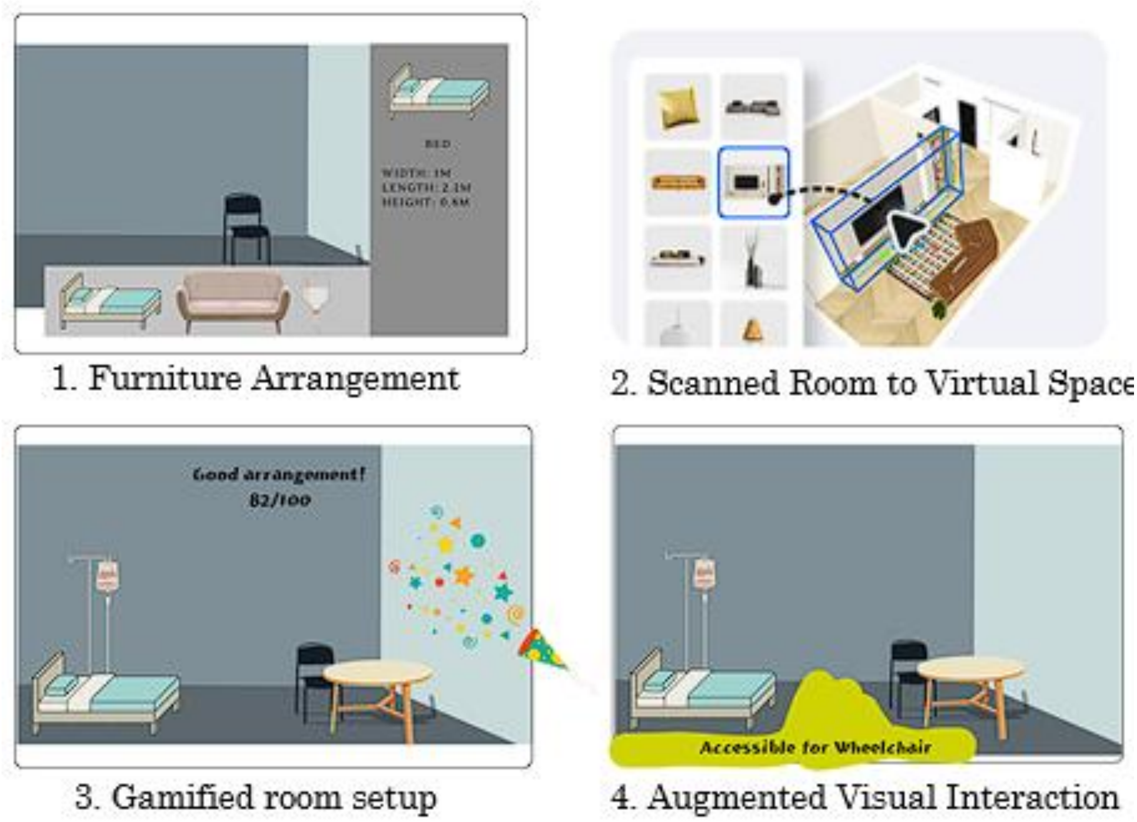
4.1.3 Stakeholders Requirements

Category	Requirements	Explanation
Must	App Development within the AR environment	Since the ultimate goal of this project is the implementation of an AR app, the basic setup of the AR environment is essential.
	App implementation of providing useful TRS guidance	The main objective of the project is to provide useful guidance on TRS to the target group. Therefore, the app should provide guidance differentiated from existing simple furniture arrangement apps.
	Implementation of an object rearrangement mock-up	Since every household has its own room arrangement and requires different items, the app should incorporate basic furniture arrangement functions as similar to the existing apps for arrangement mock-ups.
	Production of the usable app for the target groups	The app should be available on devices commonly owned by the general public, such as Android and iOS devices.
Should	Implementation of an easy-to-use, simple, and clear UI	For UI elements, that are always in the user's sight during app usage, they should be optimized to be easy-to-use, simple, and clear.
	Explanation via text bubbles in the app	Using text bubbles as a method to convey information to the user can provide more intuitive communication.
	Generation of at least one type of VR device	To achieve accurate scanning of real homes and furniture placement, the app should be developed to work on specialized AR devices such as Oculus Quest.
Could	Development of a multi-adaptable app for various devices	The prototype operates only in the Android and Meta Quest 3. It can be modified to run on IOS or other VR devices as well.
	Explanation via voice narration in the app	The text displayed on the screen can be intrusive. This can be replaced with voice narration to make the visuals cleaner. However, repeated voice narration might be somewhat noisy.
Won't	Infringement of human rights by app usage	For app usage, users need to download and run. No element during download or app execution should violate the user's rights. If there are any concerns, the app must inform of those aspects and be consented before executing the app.
	Infringement of privacy by app usage	Since AR necessitates the use of the camera, the user's camera information needs to be collected. All captured data must be stored solely within the individual's device, with no potential for misuse.
	Difficult to control within the app	The app should be accessible to the general public without significant difficulty. Therefore, visuals won't be overly complex, and they won't require skilled controls.

<Table 2> Stakeholder Requirements

4.2 Concept

Based on identified user needs/stakeholder requirements, four ideas are derived. As this project fundamentally revolves around AR technology, exploration of various methods in the AR environment is conducted.



<Figure 9> 4 Initial Ideas

4.2.1 Furniture and Medical Equipment Placement

The selection and placement function for furniture and medical equipment drew inspiration from existing furniture arrangement apps mentioned in the State of the Art (**Chapter 2.2**). Providing users with furniture placement mock-ups is the most insightful way for home rearrangement. Users run the AR app on their own devices, such as mobile phones or VR goggles. Through the app, users can perform real-time mock placement on the AR screen by selecting furniture or essential medical equipment from the UI menu and then using move/remove/scale/rotate them. When using specialized VR devices or sensors like the Microsoft KINECT sensor, more accurate measurements of the house size are possible[16]. Accurate size measurement enables precise furniture arrangement.

4.2.2 Implementation from Scanned Room to Virtual Space

'The implementation of a scanned room in a virtual space' is an idea inspired by IKEA Kreativ and Autodesk Homestyler mentioned in the State of the Art (**Chapter 2.2**). The real-time AR placement can be challenging due to factors such as hands trembling when running the app on a mobile phone. Additionally, since real-time space scanning only recognizes where the camera is pointing and updates the scan frame by frame, the method to implement into virtual space can make it more accurate. Therefore, the room can be implemented in the virtual environment at the same scale as existing models after scanning the entire house for precise placement. Another advantage of this approach is that users do not need to physically walk around the room. While users can navigate in the virtual space using controllers, real-time rearrangement in the actual space requires physically walking around the room. However, the implementation of a scanned room into virtual reality consumes a long process time and requires accurate measurement capabilities from cameras or sensors, and it demands more advanced technology development.

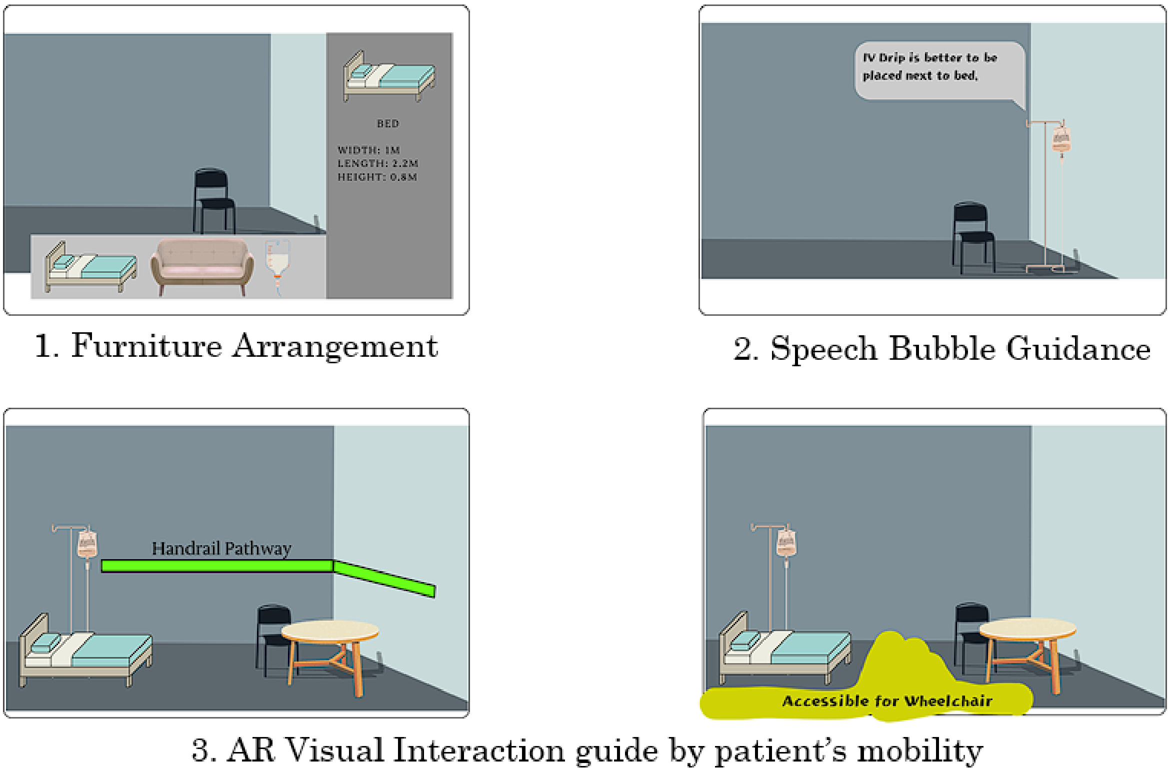
4.2.3 Gamified Home Arrangement

One of the easiest ways to make the app enjoyable and attractive is by adding gamified elements to the app. By assigning scores to the aesthetics and practicality of the furniture placement, users can be encouraged to actively use the app. However, it's crucial to establish meaningful criteria for this scoring feature. For instance, utilizing the principles of Feng Shui can be quantified to become the criteria.[13] Additionally, ergonomic principles derived from the Boltzmann formulation can be employed for assessment.[14] However, implementing these approaches requires extensive development, which means it can lower the feasibility of the prototype implementation. Another gamification method could involve praising users when they fit furniture placements in empty spaces almost perfectly. For example, users could receive praise for placing a table that perfectly fits between a sofa and a wall, as shown in the third image of <*Figure 9*>. Nonetheless, since the main purpose of the app is to provide guidance, excessive gamification can spoil the essence of the app's functionality.

4.2.4 Guidance through Visual Interaction

The biggest advantage of AR is the ability to scan real-world objects and synthesize virtual interactions over them, allowing for intuitive and useful guidance on TRS. The identified disease to focus on is stroke, and scenarios derived from stroke include wheelchair & walker use and walking assistance. The wheelchair & walker usage scenario provides guidance on accessible paths for wheelchairs and walkers, as shown in the second image of <Figure 9>, indicating visible colors for pathways that wheelchairs can pass away. Additionally, during the function usage of placement(**Chapter 4.2.1**), certain furniture or objects requiring specific guidance can receive placement advice through speech bubbles attached to the object when the users try placing it. Furthermore, other various methods of providing visual interaction can be explored further.

4.3 Final Concept



<Figure 10> Final Ideas

The final concept is derived from the integration of the three initial ideas mentioned above: furniture placement, speech bubble guidance, and AR visual interaction. *<Figure 10>* illustrates the scenes users see through the screen during app usage, demonstrating the final concept step by step. First, users can select objects from the UI's object menu and place them where they want using the Select/Move/Rotate/Remove function. The UI provides information on the actual length/height/width of the selected object (i.e. furniture and medical equipment) for precise placement. Moreover, the scale of the placeable 3D objects will be created based on the actual size of existing models. Second, objects requiring guidance are displayed in speech bubbles when selected from the UI menu as depicted in the image for advice on factors to consider during placement. Lastly, visual interaction is augmented in reality. As shown in the left figure, one of the visual interactions recommends pathways for placing handrails that patients can use as assistance while walking. Another considerable visual interaction involves displaying accessible paths of wheelchairs & walkers on the floor via the AR screen, guiding safe mobility.

5. Specification

In this section, the goal is to specify the final concept. First, an early prototype (Lo-Fi Prototype) will be developed and evaluated to determine whether developers can meet the functional requirements for the targeted app development and to set the direction for development. Next, potential user types of the app will be identified by creating virtual personas, and corresponding interaction scenarios will be produced. Finally, based on the evaluation of this Lo-Fi prototype and interaction scenarios, the final requirements identified in the project and the system architecture will be introduced.

5.1 Lo-fi Prototype

As mentioned in Early Prototype(**Chapter 3.2.2.3**), the first generation of the prototype will be developed as a Lo-Fi Prototype. The purpose of creating this prototype is to measure the direction and feasibility of the app development, and it will be tested with 3 participants by briefly implementing the project's two key features. To investigate how experience with AR/VR and electronic devices affects app usage, lo-fi prototype testers were recruited from users with little experience to those with extensive experience. Two key features are AR furniture Placement mockup (ARP) and AR tailored Guidance (ARG). <*Table 3*> is a table that brings together the essential features mentioned as "Must" in the MoSCoW table <*Table 3*>.

Category	Requirements	Explanation
Must	App Development within the AR environment	Since the ultimate goal of this project is the implementation of an AR app, the basic setup of the AR environment is essential.
	App implementation of providing useful TRS guidance	The main objective of the project is to provide useful guidance on TRS to the target group. Therefore, the app should provide guidance differentiated from existing simple furniture arrangement apps.
	Implementation of an object rearrangement mock-up	Since every household has its own room arrangement and requires different items, the app should incorporate basic furniture arrangement functions similar to the existing apps for arrangement mock-ups.

<Table 3> Requirements for Lo-Fi Prototype

According to the Principle of Scientifically Founded Judgment, engineers must develop within their capabilities.[24] Thus, this prototype provides insight into whether the developer can implement the key features. Additionally, this prototype will provide which platform is most advantageous for development such as Android, IOS, or VR Kits. Moreover, plans for Hi-Fi development on the selected platform are made accordingly.

5.1.1 Requirements for Lo-Fi Prototype

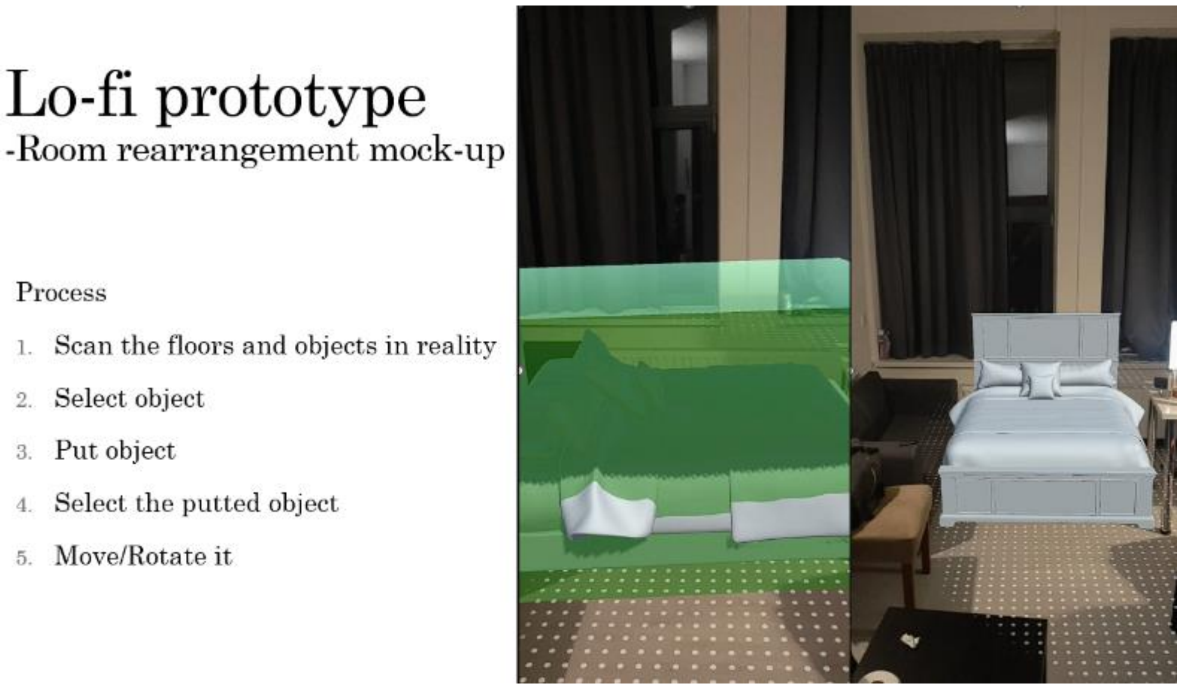
<*Table 4*> provides details on how to implement the 'Must' elements and their requirements mentioned in <*Table 3*> at the Lo-Fi prototype level. The primary goal is to meet all the checklists.

Requirements	Implementation Check Lists	O/X
App Development within the AR environment	Was it successfully built on the Android device?	
	Did the internal camera recognize the space?	
App implementation of providing useful TRS guidance	Does the handrail pathway appear on the wall?	
Implementation of an object rearrangement mock-up	Did the desired furniture appear in the AR space?	
	Can the user select/move/rotate the object?	
Opening Scene	Has an opening scene been created where the user can enter the patient's physical challenge details?	

<Table 4> Lo-Fi Prototype Check List

5.1.1.1 Lo-Fi Furniture Placement Mockup

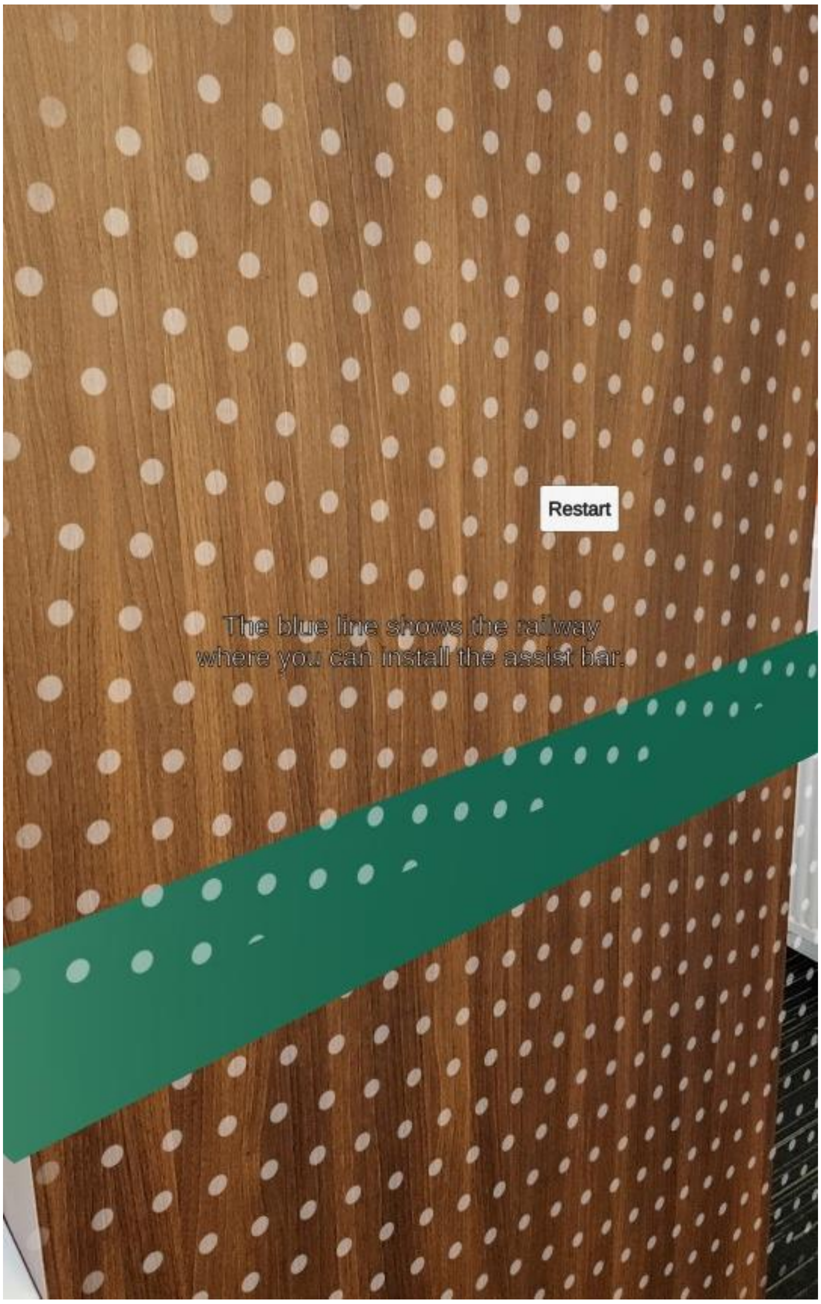
For the AR furniture Placement (ARP) feature, the development of the Lo-Fi prototype involved attempting to build a basic AR environment using a mobile device, providing insights into how it would be applied and interact with users. As shown in the right image of <*Figure 11*>, the floor was recognized using the Android device's internal camera, and the core functions of object placement, movement, and rotation were implemented through Unity.



<Figure 11> Screenshot of ARP in AR space

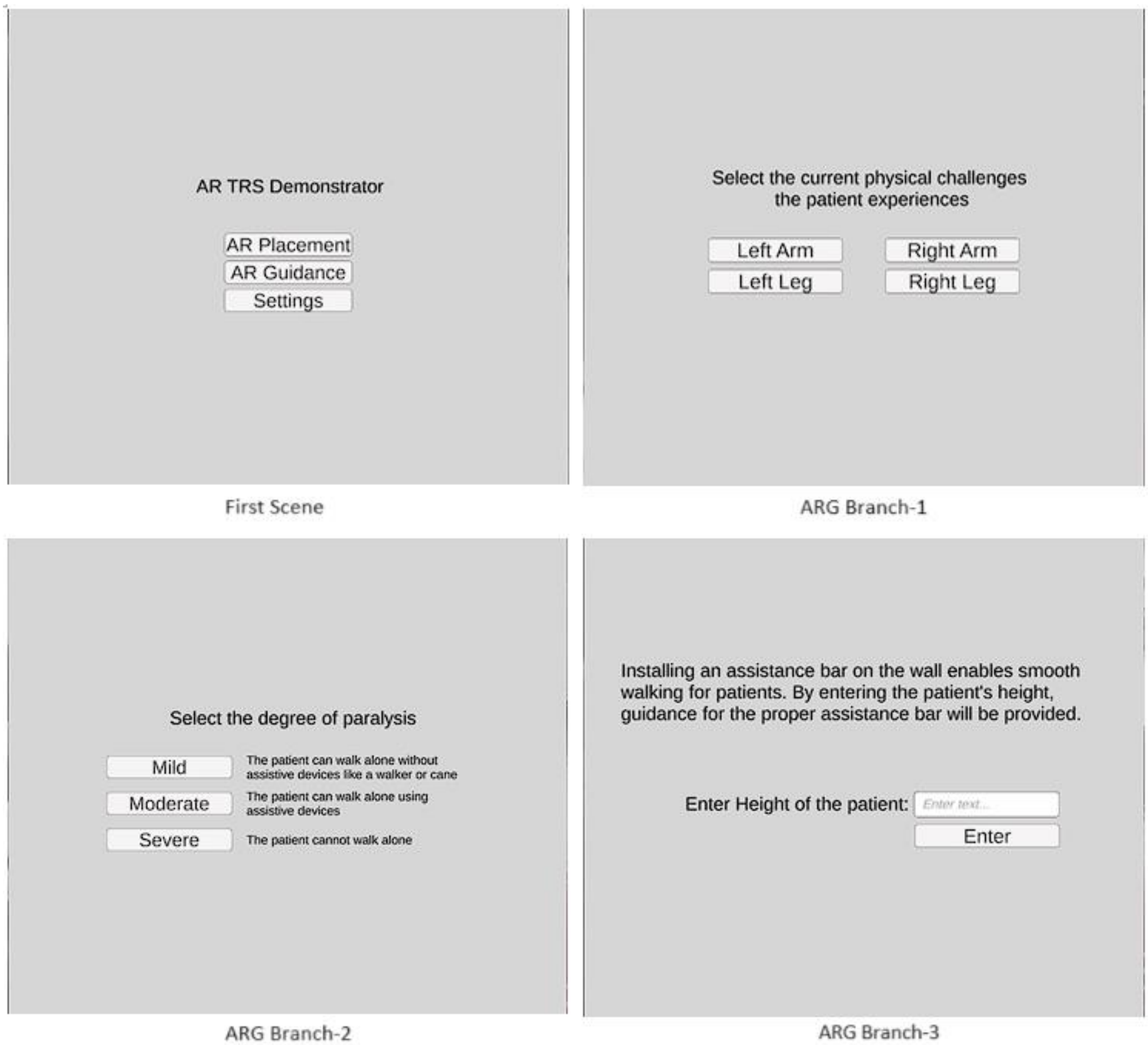
5.1.1.2 Lo-Fi Tailored Guidance to Patient

The development of the Lo-Fi prototype for AR-tailored Guidance (ARG) involves displaying recommended handrail installation pathways on walls, as mentioned for the third feature in Final Concept (**Chapter 4.3**). *<Figure 12>* shows a screenshot of the Lo-Fi prototype version of AR tailored guidance feature. In this structure, the user employs a method to recognize a vertical plane as a wall for 30 seconds, after which a railway pathway appears in the center of the recognized vertical plane.



<Figure 12> Screenshot of ARG in Lo-Fi VR space

5.1.1.3 Opening Scene



<Figure 13> Screenshot of Opening Scene and User Inputs

The first scene at <*Figure 13*> shows the opening that appears when the app is once launched. The patient information input fields required for executing the ARG (AR Guidance in the screenshot) function are also created as shown in ARG Branch-1/2/3 in the figure. Users choose which function to use, either ARP (AR Placement in the screenshot) or ARG, by selecting one of the three initial buttons. The ARP function allows users to place furniture and medical equipment freely on the floor by pressing the 'AR Placement' button, leading them directly to the placement scene. For the ARG function, users can enter detailed information about the patient's physical challenges, as shown as ARG Branch-1/2/3 in the figure. After completing this input, the screen transitions to the ARG scene depicted in the figure.

5.1.2 Lo-Fi Test Setup and Questions

5.1.2.1 Test Setup

This prototype is built on the developer's Android device. Given that participants might use different versions of Android software or might not use an Android device, the test was conducted using a Samsung Galaxy S22 running Android Software Version 14. The AR environment will be set up in the same room where the development took place. Thus, all test participants will be invited to the same room to conduct the test using the same Android device. After the tests were completed in the set-up environment, the participants answered the test questions through an interview.

5.1.2.2 Test Questions

The interview questions for evaluating the Lo-Fi prototype are divided into Before App Test and After App Test sections as follows:

Before App Test

Q1. Have you ever used AR or VR features?

Q1.1 If yes, what type of app was it?

Q2. Do you or any of your family members currently experience mobility issues or have had mobility issues in the past?

Q2.1 If yes, could you describe the type of physical challenge you or they experienced?

After App Test

Q3. What was your initial impression when you first launched the app?

Q4. Did the AR functionalities work as expected?

Q5. Was the overall flow and interface easy to understand during the app running?

Q5.1. If it wasn’t, what was that?

Q6. How did you feel about the 20-second room scanning process?

Q7. Do you think an app of this kind would be helpful for patients (or yourself) with physical challenges when starting home healthcare? Would you like to use this app?

5.1.2.3 Test Plan

The procedure of the Lo-Fi test was derived as follows:

1) Introduction: Provide participants with background information about the project and the Lo-Fi prototype.
2) Consent Form: Explain the potential scenarios that may occur during the test and obtain consent from the participants.
3) Pre-Test Questions: Ask the "Questions Before App Test".
4) Setup: Arrange the test environment and device according to the test requirements.
5) Conduct Test: Perform the test.
6) Post-Test Questions: Ask the "Questions After App Test".

- Observation: Observe and record participants' facial expressions and any comments they make during the app usage.

5.1.3 Result

Result of Requirements

The requirement checklists for the 1st generation prototype, as shown in <*Table 5*>*,* have all been completed. By implementing the main functionalities, we confirmed that the developers have the capability to realize this app and gained insights into the future direction of app development.

Requirements	Implementation Check Lists	O/X
App Development within the AR environment	Was it successfully built on the Android device?	O
	Did the internal camera recognize the space?	O
App implementation of providing useful TRS guidance	Does the handrail pathway appear on the wall?	O
Implementation of an object rearrangement mock-up	Did the desired furniture appear in the AR space?	O
	Can the user select/move/rotate the object?	O
Opening Scene	Has an opening scene been created where the user can enter the patient's physical challenge details?	O

<Table 5> Result of Requirement Checklists

Result of Lo-Fi Test

Test	Question	Participant 1	Participant 2	Participant 3
Before App Test	Q1. AR/VR experience	No experience with AR, but have been playing VR games.	Yes, used to play AR/VR games.	Yes, but just one or two times of short experience at an

				exhibition.
	Q2. Mobility Challenges near you	No, almost all people near me are healthy.	Yes, my grandfather got sick and used an assistant walker.	I'm struggling with Achilles tendon rupture for 1.5 years
After App Test	Q3. Initial impression	The concept and app were respectful and amazing.	This app would be the starting point of a revolution. That's amateurish at some points, but it's just a lo-fi prototype	Liked the simplest UI. In my aspect as a patient, this app could be improved to be helpful for patients.
	Q4. Functionality expectation	Expected more accurate object placements and more fancy, but that was not well-made.	The flow between scenes (ARP, ARG) needs more natural and more instructions.	The recognition of the plane didn't work as I expected. The settings and specifications of the camera could be a matter.
	Q5. Overall understanding	The flow was natural but I didn't know how to scan the room at first. Need to clarify the explanation more.	That was understandable with the interviewer's preliminary explanation, but I guess people can't understand the app itself.	Only the floor detection was quite unnatural. Also the furniture selection buttons were not clear.
	Q6. Scanning time	I think 20 sec is too short to scan the whole room for beginners.	I think it is enough	The 20 sec is enough, or maybe some more
	Q7. Are you willing to use	If I hire a room setup worker or someone, I would like to use this app and show them the screen to show what I made via your app.	If the Hi-Fi version app gives more helpful advice, I would like to use this app. But for the Lo-Fi version, not really.	As a patient, I think I am willing to use it. It is because I struggled to set up my room for the first time after discharging. I really needed any advice at that time.
	Q8. Any Ideas	Need to improve the accuracy of the plane scan. Since the room setup is for a patient, not their family, the patients probably dislike the setup without their opinion.	Not at all. I think it's a good start to the prototype. You can enhance it by taking this flow.	For enhancing the mobility of patients, it would be better to have a function like recommending the pathway or showing the rails for wheelchair users or something.
During App Test	Observation of Participants	The participant was struggling to scan the room. The floor	The participant was good at controlling and scanning the	The participant had a good sense of the app usage, so he

		scan was not done well because of his mal-scanning. So the satisfaction of app usage was likely to be underestimated.	phone. So the ARP and ARG worked well.	noticed the principle of scanning the room in a short seconds, so the flow was easygoing.

<Table 6> Result of Lo-Fi Test

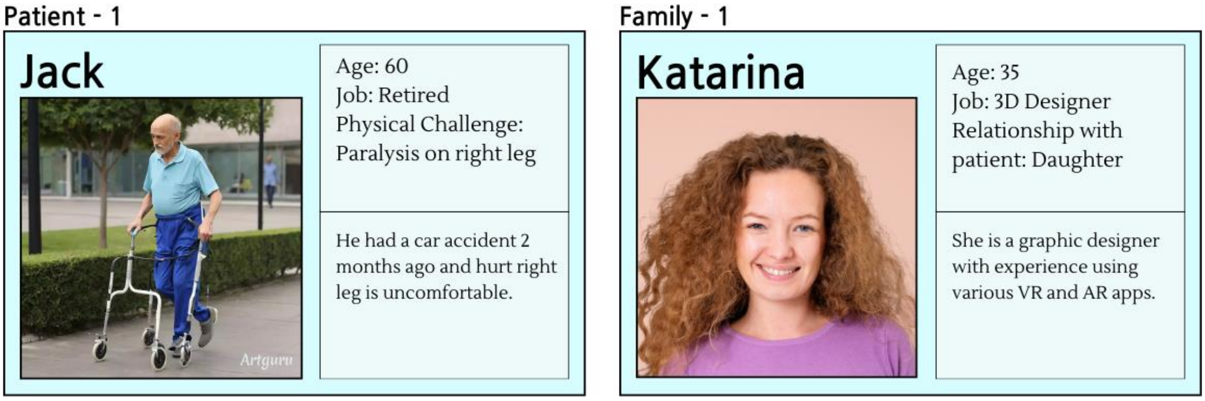
5.1.4 Evaluation

In this section, the core functionalities were implemented as the Lo-Fi Prototype. Through this process, it was confirmed that the developer possesses the necessary capabilities to create the app, and valuable insights were gained for the direction of app development. Firstly, during the ARP feature development, it became apparent that floor recognition using Android devices was less accurate than anticipated. This inaccurate spatial recognition could lead to incorrect furniture placements and scale adaption of 3D objects based on actual scales, which is a critical issue to address in the next prototype. Secondly, while implementing the ARG feature in a 3D space, insights were gained into how to effectively display the handrail pathways to users. Since these pathways recommend where to install handrails, they need to be toggleable and clearly visible from the wall. Thirdly, it was determined that separate inputs for left/right and arm/leg physical challenges in the ARG feature were unnecessary. For instance, if a user installs a handrail on the left wall from entering, that same wall becomes the right wall when exiting. Lastly, participants unfamiliar with AR or tech-savvies faced challenges in scanning the floor and placing objects using a mobile phone. Therefore, providing more detailed instructions will be crucial for improving user experience in the next prototype. In addition, it seems necessary to adjust the font and size of the text, as well as its positioning for better text readability.

5.2 Personas

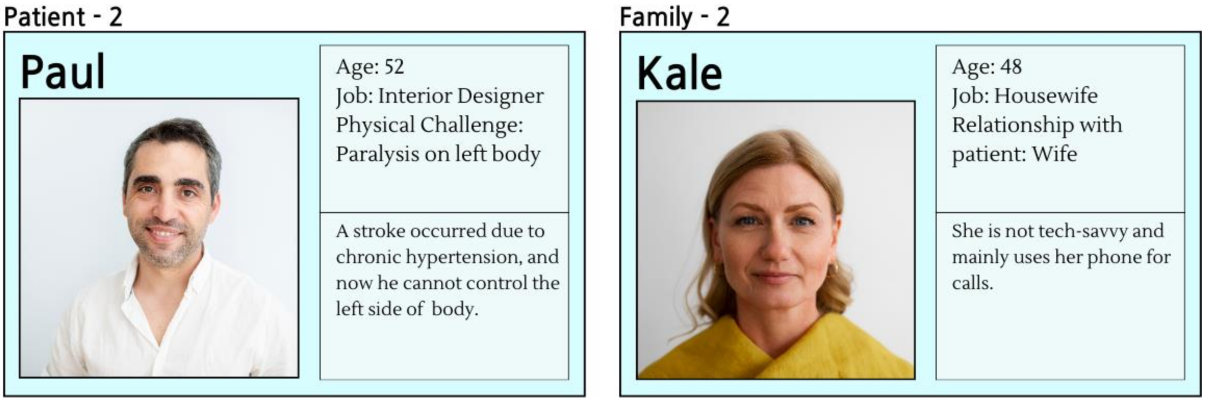
Based on the evaluation of the Lo-Fi prototype, two pairs of patient and family personas and one patient (user at the same time) persona were developed to create interaction scenarios. These personas represent the diverse needs and capabilities of the target users, including patients with physical challenges and their family members (and users who are also patients). Differences among the personas include familiarity with electronic devices and the specific types of assistance required by the patient. These personas serve to guide the development of the app, ensuring that it meets the varied needs of its users and enhances usability across different user scenarios.

5.2.1 Pair 1: Jack and Katarina



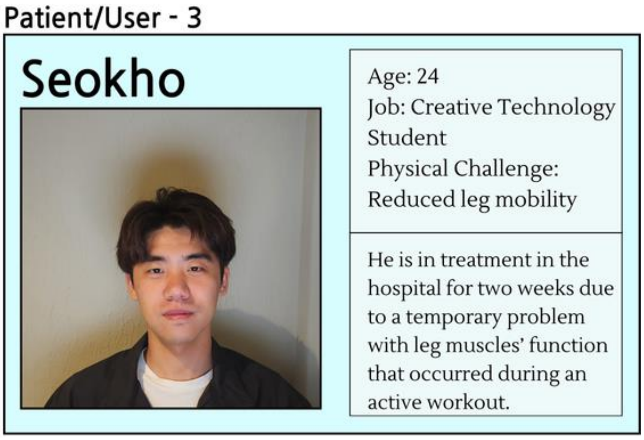
<Figure 14> Personas Pair 1

5.2.2 Pair 2: Paul and Kale



<Figure 15> Personas Pair 2

5.2.3 Patient & User: Seokho



<Figure 16> Personas 3

5.3 Interaction Scenario

5.3.1 AR-familiar User with Mild Mobility Limitation Patient

Background

Two months ago, Jack was involved in a car accident. As a result, he suffered an ischemic stroke (lacunar infarction), which caused right lower limb paralysis. For the past two weeks, he has been receiving medication treatment, including anticoagulants and antiplatelet agents, and plans to be discharged to his home environment next week. His doctor has recommended continuous outpatient treatment and rehabilitation after discharge. To prepare his home environment to support his rehabilitation, his daughter Katarina downloads and opens an AR furniture placement app on her phone to create a home environment suitable for Jack's rehabilitation. First, a message appears on the screen: "Scan the area by walking around the room." She walks around every corner of the room.

Furniture and Medical Equipment Placement

After completing the room scan, various menus appear on the UI. Katarina clicks on the main menu, "Rearrange Furniture and Equipment." Tool tabs for a selection of general furniture, medical equipment, rehabilitation equipment, office furniture, and hobby furniture appear on the UI. She selects necessary furniture from the general and office furniture tool tabs and places them around the room. She checks the width/length/height dimensions of actual furniture displayed in the UI's tool tab, then selects the proper size of the bed and other items that fit the room. Since the furniture available for this AR app uses actual-sized models, she can place them through the app's screen and see if the real furniture will fit into the empty space in the room. Additionally, remembering that Jack has been prescribed to receive anticoagulants via IV drip for two weeks, she selects an IV drip from the medical equipment tool tab and places it next to the sofa. A speech bubble appears above the IV drip: "It is best to place the IV drip next to the bed for many cases." She adjusts the placement next to the bed's head side. Finally, recalling the doctor’s suggestion to use equipment and resistance bands for strength training and stretching exercises, she selects a yoga mat, resistance bands, and dumbbells from the exercise equipment tool tab and places them on the floor.

Solutions Tailored to the Patient's Physical Disability

After completing the simulated furniture placement, Katarina explores other menus. She clicks on the "Guidance for Physical Disabilities" menu. A screen appears: "Select the current physical challenges the patient experiences," along with selectable buttons. She selects "Right legs." Then, she chooses the degree of paralysis: Mild, Moderate, Severe, and selects Moderate. The description for Moderate paralysis reads: "Significant reduction in sensation and muscle strength, making independent movement difficult, but limited mobility is possible with assistive devices or help from others. Example: 'In moderate paralysis, the patient can walk using assistive devices like a walker or handrail.'" Since this example matches Jack's condition, she selects it. Another prompt asks for the patient's height, which she enters. The following screen shows the AR view of the room with long lines appearing on the walls at waist height *<Figure 12>*. These lines indicate the ideal placement for parallel support bars to help Jack walk. These are determined to be at the appropriate height for Jack. She then decides to place these support bars in the living room, bathroom, and near the front door.

Sharing with the Patient

Having completed the simulated placement of furniture, medical equipment, exercise equipment, and parallel support bars, Katarina shares the results with Jack to get his feedback. She uses the app's "Record and Share Home Layout Simulation" menu to take a quick tour of the simulated home layout and sends the video to Jack. Lying in his hospital bed, Jack watches the video and provides feedback, suggesting adjustments like moving the desk slightly to the side.

5.3.2 AR-Unfamiliar User with Severe Mobility Limitation Patient

Background

Paul, 52 years old, suffered a stroke due to chronic hypertension, and it resulted in overall paralysis of his whole left body. Consequently, he cannot move without a wheelchair and is planning long-term rehabilitation at home after completing hospital treatment in 2 weeks. His wife, Kale intends to rearrange their home appropriately before his discharge. Upon hearing about an AR-based TRS app recommended by Paul’s doctor, she downloaded it. However, being unfamiliar with electronic devices, she struggles with using the app. Since Paul had experience as an interior designer, she relied on his guidance via screen sharing.

ARG Function Usage

Kale selects the AR Guidance menu in the opening scene and inputs information about Paul's physical mobility limitations. Subsequently, she receives guidance tailored to wheelchair users, including securing pathways and placing handrails based on TRS recommendations from the app. Following the app's instructions and Paul's guidance, Kale plans to install handrails near the toilet and inside the shower booth, guided by the examples provided by the app.

5.3.3 AR-middle-familiar User with Moderate Mobility Limitation Patient

Background

Seokho recently experienced temporary muscle issues in both legs due to overworkout. After two weeks of hospital treatment, he has returned home and cannot walk without an assistance walker. Since this is his first experience with mobility limitations, he is unsure where to start in setting up his home. Discovering an AR TRS app on the Google Play store, he downloads it for assistance.

ARG Function Usage

Seokho selects the AR Guidance in the opening scene. Comparing his situation with the app's descriptions, he presses the 'Moderate' mobility limitation button and receives guidance on securing pathways for his walker and installing handrails. He asks a friend to help secure the pathways for the walker as instructed by the app and installs a shower chair inside the shower room.

5.4 System Requirements

The system requirements are identified through the MoSCoW table. These requirements are categorized into functional and non-functional requirements to facilitate efficient development and easier testing.

5.4.1 Functional Requirements

<*Table 7*> presents the functional requirements of the system. This requirement list is based on the MoSCoW method.

Category	Requirement
Must	The internal camera of the user's device must scan elements within a room to recognize the space.
	Walls and floors in the AR space must be distinguishable and scannable.
	Users must be able to switch between scenes (Opening/ARP/ARG) via the UI.
	ARP) Users must be able to choose desired 3D objects (furniture and medical equipment) from a tool tab and place them on recognized planes in the AR space.
	ARP) Users must be able to select/remove/move/rotate 3D objects placed in the AR space.
	ARP) Specific 3D objects must include tooltips that provide guidance for proper placement.
	ARG) Users must be able to place handrails on scanned wall surfaces in the AR space.
	ARG) Handrail pathways tailored to the user's height must be displayed in distinguishable colors.
Should	Completed home rearrangements should be captureable and shareable via photo and video for collaboration with the patient.
	ARG) The system should provide users with short animations for insights based on the entered areas of paralysis for the patient.
	ARG) The system should offer customized guidance for various types of paralysis patients.

<Table 7> Functional Requirements Table

5.4.2 Non-Functional Requirements

<*Table 8*> presents the non-functional requirements of the system. This requirement list is also based on the MoSCoW method.

Category	Requirement
Must	Users should interact with the system easily.
	The UI should be designed to be user-friendly and clear.

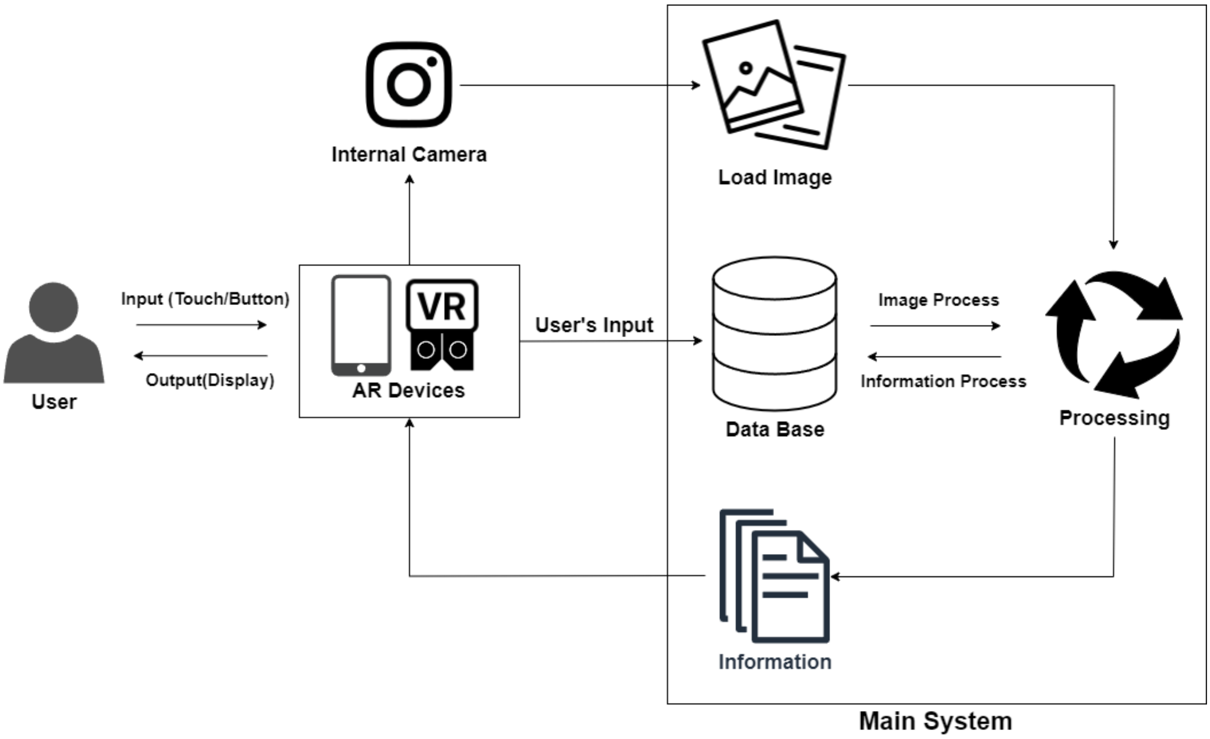
	The system should function regardless of the type of room in which the user runs the app.
	All elements provided by the system should benefit the user.
	All processes of the system must occur within the app itself, and third parties should not access personal data.
Should	The system should be engaging to use.
	The UI should be aesthetically pleasing.

<Table 8> Non-Functional Requirements Table

5.5 System Architecture

Since the product developed in this project is an AR app, this section provides a detailed analysis and diagram of the system architecture in terms of AR system. First, the general architecture of the overall interactions is presented, with a sequence flowchart of the app's operation. Next, specific system architectures are provided including the branch processing architectures of the ARP and ARG algorithms based on user inputs.

5.5.1 General System Architecture

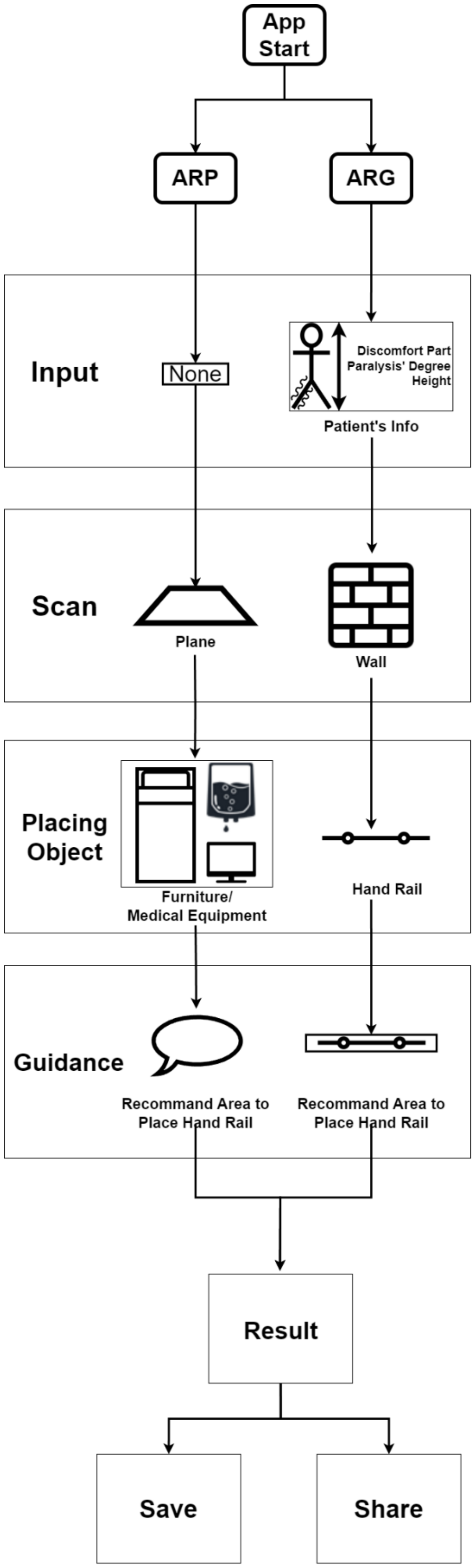


<Figure 17> General System Architecture

As shown in *<Figure 17>,* the general diagram of this app comprises three main components: User, AR Devices, and Main System. Once the app is launched on the user's AR device, these three components interact according to this system architecture. Users input commands by pressing buttons or scanning via the internal camera on their AR devices, and they receive immediate outputs from the system. The AR devices available for this project include Android devices and Oculus VR Kits, which transmit scanned image queries to the main system via their internal cameras. These loaded images start processing within the system, facilitating the exchange of data and information, and then the feedback is transmitted to the AR devices. Additionally, user inputs such as custom settings can be directly sent to the database via the AR devices.

5.5.1.1Sequence Flowchart

<*Figure 18*> below illustrates the flowchart when a user launches the app. The user clicks one of the buttons to transit among the main functionality scenes of the app ARP and ARG. The ARP immediately conducts to scan of the real space, while the ARG requires an initial step of entering patient information, which is detailed further in ARG Branch Processing Architecture (**Chapter 5.5.2.2**). Next, the internal camera of the AR device scans vertical and horizontal planes for the ARP and ARG functionalities, respectively. Since the user places objects based on the recognized planes, this scanning process is essential for detecting floors and walls. Once the system recognizes these surfaces, users can place objects at desired locations through screen touches or controller button clicks. In ARP, users can choose various furniture and medical equipment and place them as they want, while the ARG only allows them to install assistive handrails. Users can freely select, remove, move, or rotate these objects after placement. Additionally, during object placement, the system provides guidance for better placement through tooltips, animations, or visual interactions. Once the placement is complete, users can save the results as a video on their device or share it with others.

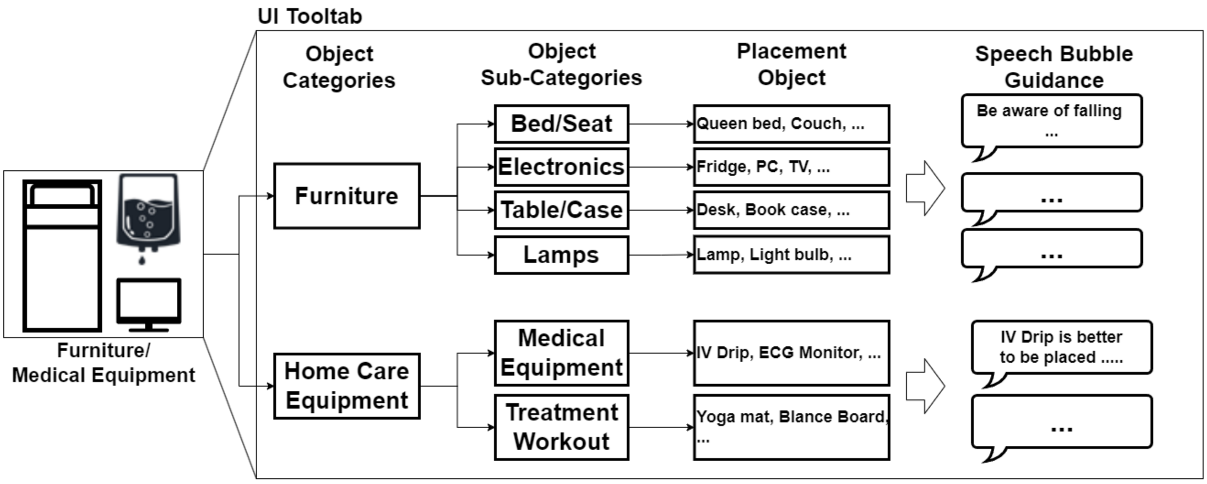


<Figure 18> Sequence Flowchart for App Launch

5.5.2 Specific System Architecture

This section describes the app's flow and how user inputs function within the system in detail. The flowcharts and architectures are derived.

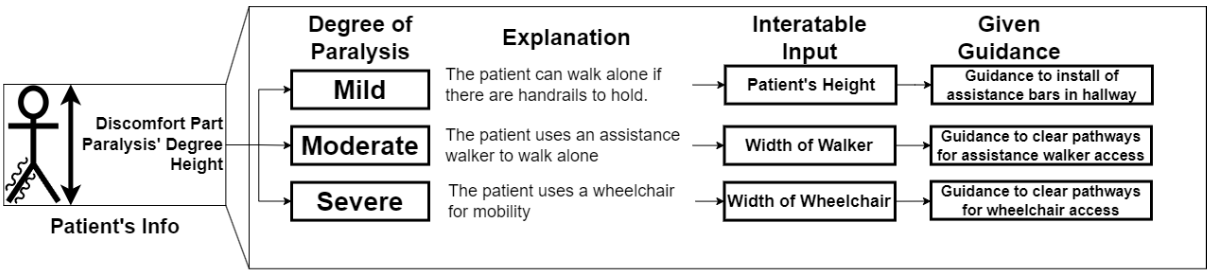
5.5.2.1 ARP Branch Processing Architecture



<Figure 19> ARP Branch Processing Architecture

Within the ARP scene, firstly users encounter an object selection tool tab implemented in the UI. This tool tab functions based on the branch processing architecture shown in *<Figure 19>*. Users first select the object categories they want to place in the AR space, then choose and place specific objects. Some of these objects include speech bubble guidance for the patient's Tailored Room Setup (TRS).

5.5.2.2 ARG Branch Processing Architecture

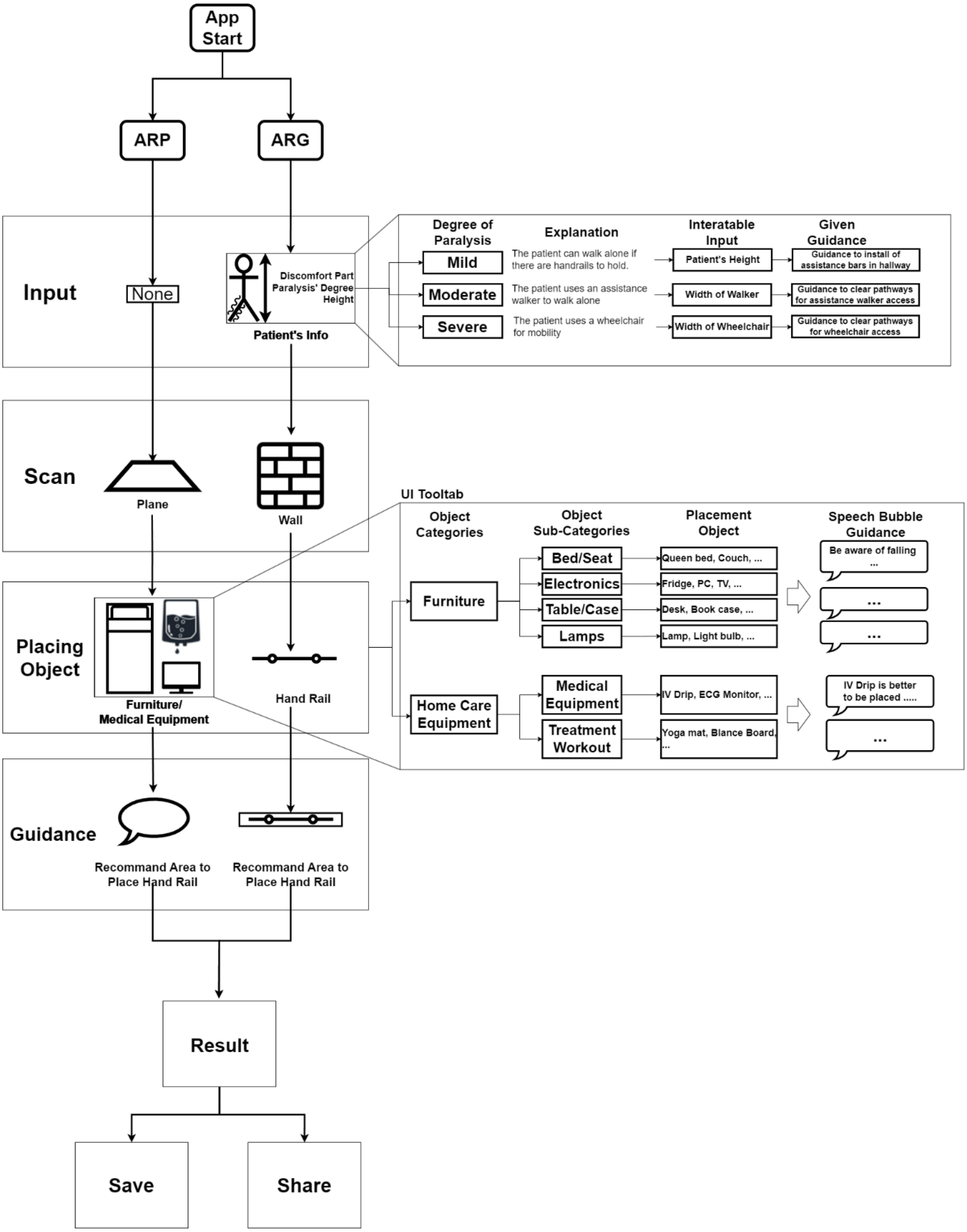


<Figure 20> ARG Branch Processing Architecture

Before starting the ARG scene, users input the physical challenges faced by the patient. These inputs follow the flow shown in <*Figure 20*>*.* Additionally, the interactable inputs vary the guidance based on the entered details. For instance, if the patient's height is 190 cm, the recommended height for the assistance bar installation would be around 90-110 cm.

5.5.3 Overall System Architecture

By merging the system architectures and flowcharts created in the previous sections, the overall system architecture in every single sequence is presented in <*Figure 21*> below. The branch processing architectures for ARP and ARG illustrate how users interact with the system UI, input data, and how the system processes these inputs to display different outcomes. All these steps are involved within a single stage of the app launch flowchart.



<Figure 21> Overall System Architecture

6. Realization

In this chapter, the whole realized implementation of the project is explained. As identified in the Flowchart for App Launch **(Chapter 5.5.2),** this app fulfills the following four functionalities: user input, scan, ARP, and ARG. Although this app is based on software development, all functionalities involve a combination of hardware and software.

6.1 Hardware

Hardware is essential for running the app. To realize all the necessary functionalities, a high-specification Android device or an Oculus VR kit is required.

6.1.1 Android Device

<Figure 22> Used Android Devices (Samsung Galaxy S22) [39]

The app development primarily utilized Android devices. Android platform-based devices hold the highest market share globally. Moreover, Android's broad hardware diversity across various manufacturers allows it to cater to a wider range of budgets and needs than other devices, thus, the adapted device was determined in Android’s platform. [27, 28]

6.1.1.1 Camera

<Figure 23> Internal Camera of Android Device (Samsung Galaxy S22) [39]

The Android device used for the prototype uses the Rear-Wide Angle lens, the middle lens among the three internal camera lenses in *<Figure 23>.* This lens supports a resolution of 50MP, providing the highest image quality among the three lenses. Additionally, it supports Dual Pixel Auto Focus (AF), where each pixel performs both imaging and phase-detection autofocus simultaneously, enabling faster and more accurate focus for room scanning during app usage.[29]

6.1.1.2 Touchscreen

<Figure 24> Touchscreen of Android Device (Samsung Galaxy S22) [39]

The 6.1-inch touchscreen of an Android device allows the user to change input values placed in the app's UI and provides immediate feedback through the display. It also enables object selection, removal, movement, and rotation in ARP and ARG functionalities through touch and drag input of the prototype.

6.1.2 Oculus VR Kit

For running AR programs, it is advisable to use a specialized kit tailored for AR. The market for VR devices is rapidly expanding, with global shipments of AR and VR devices expected to reach 18.81 million units by the end of 2023. [30] This statistic indicates that while there is significant potential for rapid adoption in the future, only a small number of households currently own these devices. Since the Oculus VR Kit is a commonly used model among households who are interested in VR apps and games, the development of the latest device in the Oculus series, the Meta Quest 3, was considered.

6.1.2.1 VR Goggles

<Figure 25> Meta Quest 3 Goggles [31]

Android or other common mobile devices using a single lens for AR spatial recognition have limitations in accuracy and speed of spatial detection. In contrast, VR goggles significantly enhance spatial recognition accuracy by using multiple lenses from various angles simultaneously. Meta Quest 3, released in November 2023 (this paper is expected to be released in July 2024), features four front-facing and two side-facing lenses for spatial recognition. These cameras enhance mixed reality experiences by enabling high-fidelity, full-color passthrough, and environmental understanding, allowing the device to seamlessly blend virtual elements with the physical world.[31] Additionally, it provides a 360-degree immersive view, offering users a vivid experience.

6.1.2.2 Controllers

<Figure 26> Meta Quest 3 Controller [31]

To control inputs like button presses within the AR space via VR goggles, a controller like the one shown in <*Figure 26*> makes it easier to use. Similar to how a mouse pointer on a PC indicates a location, the head of the controller points to the buttons and other inputs in the app, and the users can click it by pressing the button at the controller. However, first-time users can struggle to use the controller as they intend.

6.1.3 Comparison of Each Hardware

Comparison Category	Android Device	Oculus VR Kit
Accuracy of scan and placement	Lower	Higher
Realistic Experience	Lower	Higher
Universality of devices	Higher	Lower
Ease of Operation	Easy for everyone	Easy for users with VR experience
Development Compatibility	Less Complex	More Complex

<*Table 9*> *Comparison Table of Each Hardware*

As shown in <*Table 9*>, each hardware was compared based on five categories. The Oculus VR Kit is equipped with 4 to 6 lenses for spatial recognition, and it provides better specification in both scan time and accuracy for room scanning and object placement.

Additionally, the Oculus VR Kit offers a more realistic and vivid experience. Users are placed in an augmented reality environment with a 360-degree immersive view, filling their entire field of vision with the AR app, unlike viewing through a single smaller screen on a common mobile device. Next, the universality of each device was compared, and the ownership rate of Android devices was higher than that of VR kits. Also, because VR kits are not as common, first-time users might find them challenging but experienced users with VR experience are expected to use the app more efficiently than on Android. Finally, development compatibility was compared. While Android development mainly involves touch and camera movement inputs and builds 3d space on a 2D screen, the Oculus VR Kit requires more complex development with controller inputs and 360-degree mode application. In conclusion, the recommendation to users is as follows: If the patient's household has an Oculus VR kit at home or one available for rent, it is advised to use the Oculus VR Kit for higher accuracy and vivid experience. However, using an Android device still provides sufficient assistance.

6.2 Software

6.2.1 Unity

<Figure 27> Unity [40]

All interactions and processes of the app were developed using Unity. The used Editor Engine was 2022.3.17f1, with the additional module Android Build Support. The packages used for app implementation include AR Foundation, Google ARCore XR Plugin, Oculus XR Plugin, and XR Interaction Toolkit. Package AR Foundation was used to establish the basic AR environment. XR Plugins were used for custom settings for Android and Oculus VR Kit, and the XR Interaction Toolkit was used for object placement and select/move/rotate functionalities. Additionally, the Android Build Support is used for supporting to building of the developed app into Android devices as an Android Application Package (APK) file. All visual interactions and animations based on user input were built on mobile devices using Unity and the Build Support module.

6.2.2 Visual Studio

<Figure 28> *Visual Studio [41]*

Visual Studio 2022 was used to create scripts interactable with Unity. The system language used is C#, the default language of the Unity Engine.

6.2.3 Autodesk Maya and V-Ray

<Figure 29> *Autodesk Maya and V-Ray [42, 43]*

Autodesk Maya was used for creating object assets and animations in this project. Furniture, medical equipment, and handrails were created using Maya, and animations at 15fps were produced. Vray was used as the renderer for the animations.

6.3 Final Prototype (Hi-Fi)

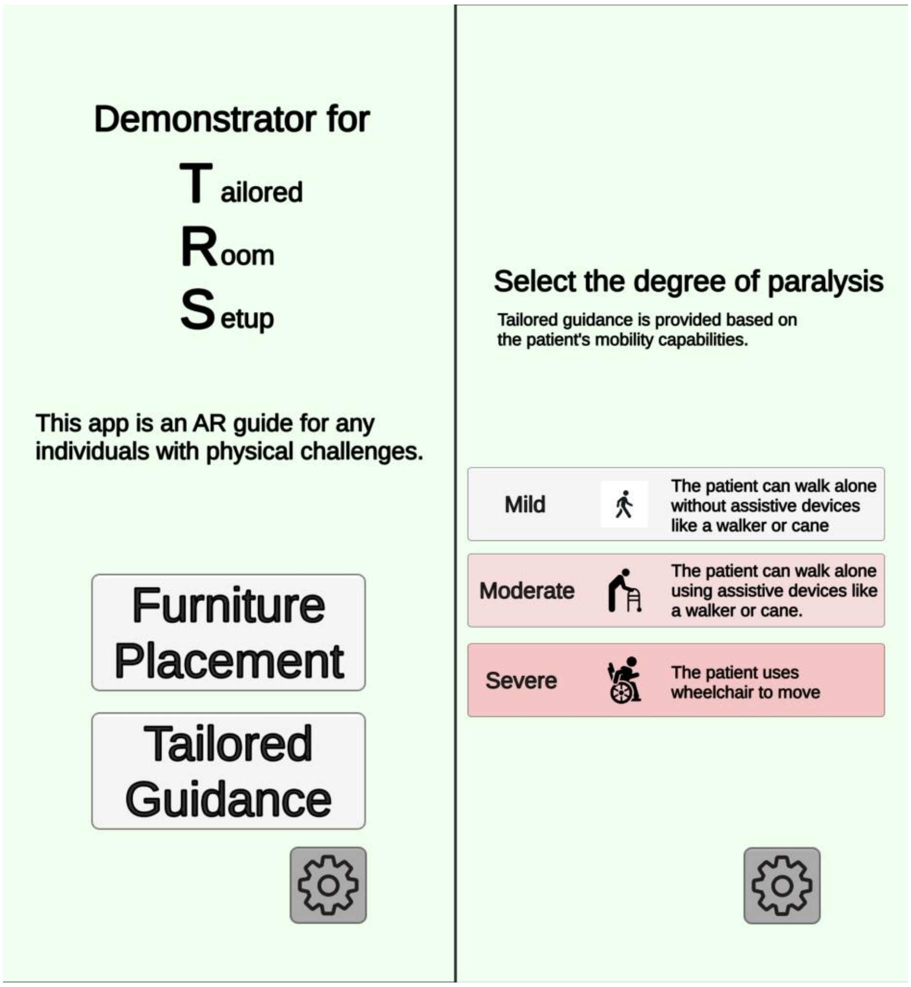
App Icon

<Figure 30> *App Icon*

6.3.1 Opening Scene

The opening scene has two main roles. First, it welcomes users when they start the app and provides information necessary for using the app. Second, it prompts users to input patient information for tailored guidance. Users input information through a branched sequence of multiple buttons and input fields as mentioned in ARG Branch Processing Architecture (**Chapter 5.5.2.2**).

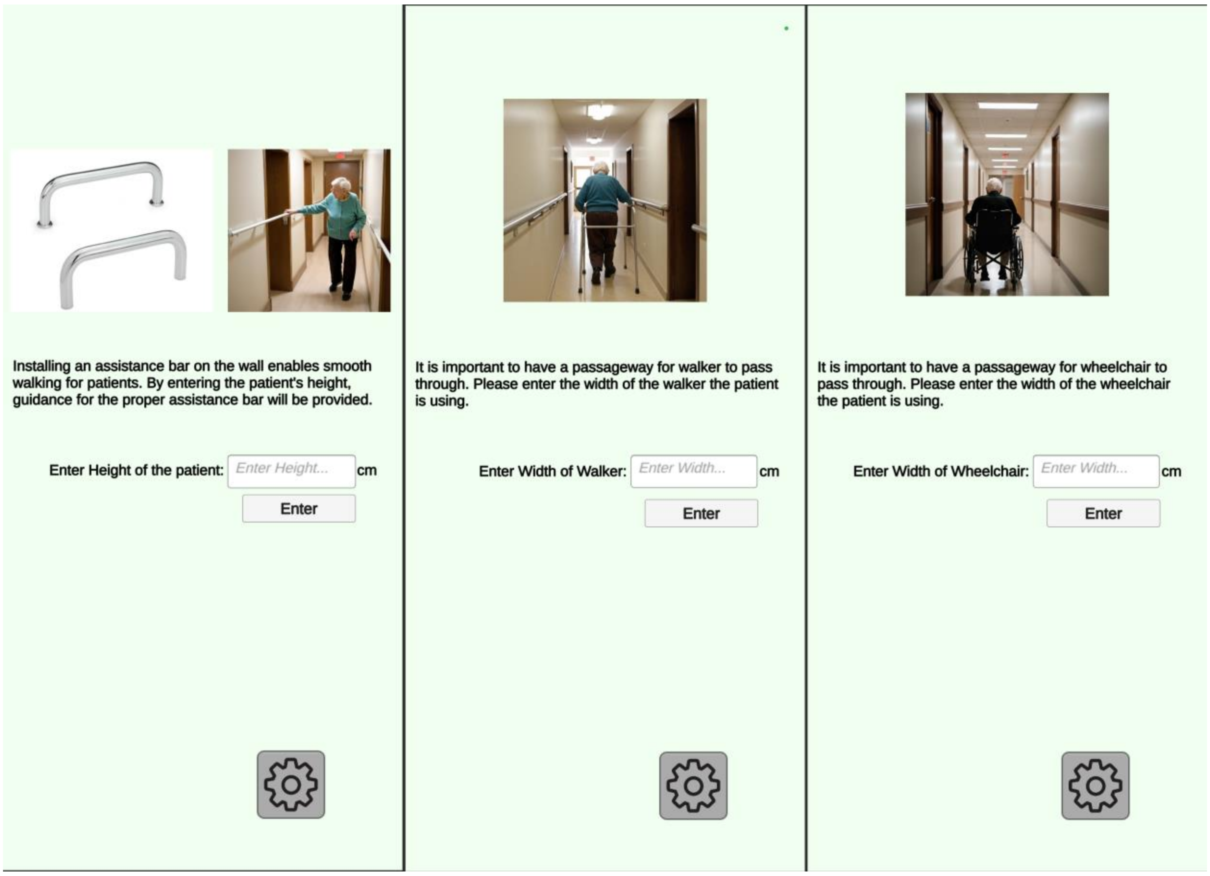
6.3.1.1 Starting Scene



<Figure 31> Starting Scenes

The starting scene, as shown in *<Figure 31>,* provides a brief explanation of what TRS means and the role of the app. The left image features the 'Furniture Placement' button for accessing the ARP function, the 'Tailored Guidance' button for the ARG function, and a gear icon button for settings of the app. Pressing the Furniture Placement button takes the user directly to the ARP Scene (**Chapter 6.3.2**, below). Pressing the Tailored Guidance button takes the user to the right image of *<Figure 31>,* where users can select the patient's degree of mobility limitation. To make it easy for users to recognize, the Mild/Moderate/Severe buttons are designed to show gradually red as the level of limitation increases.

6.3.1.2 ARG Input Scene



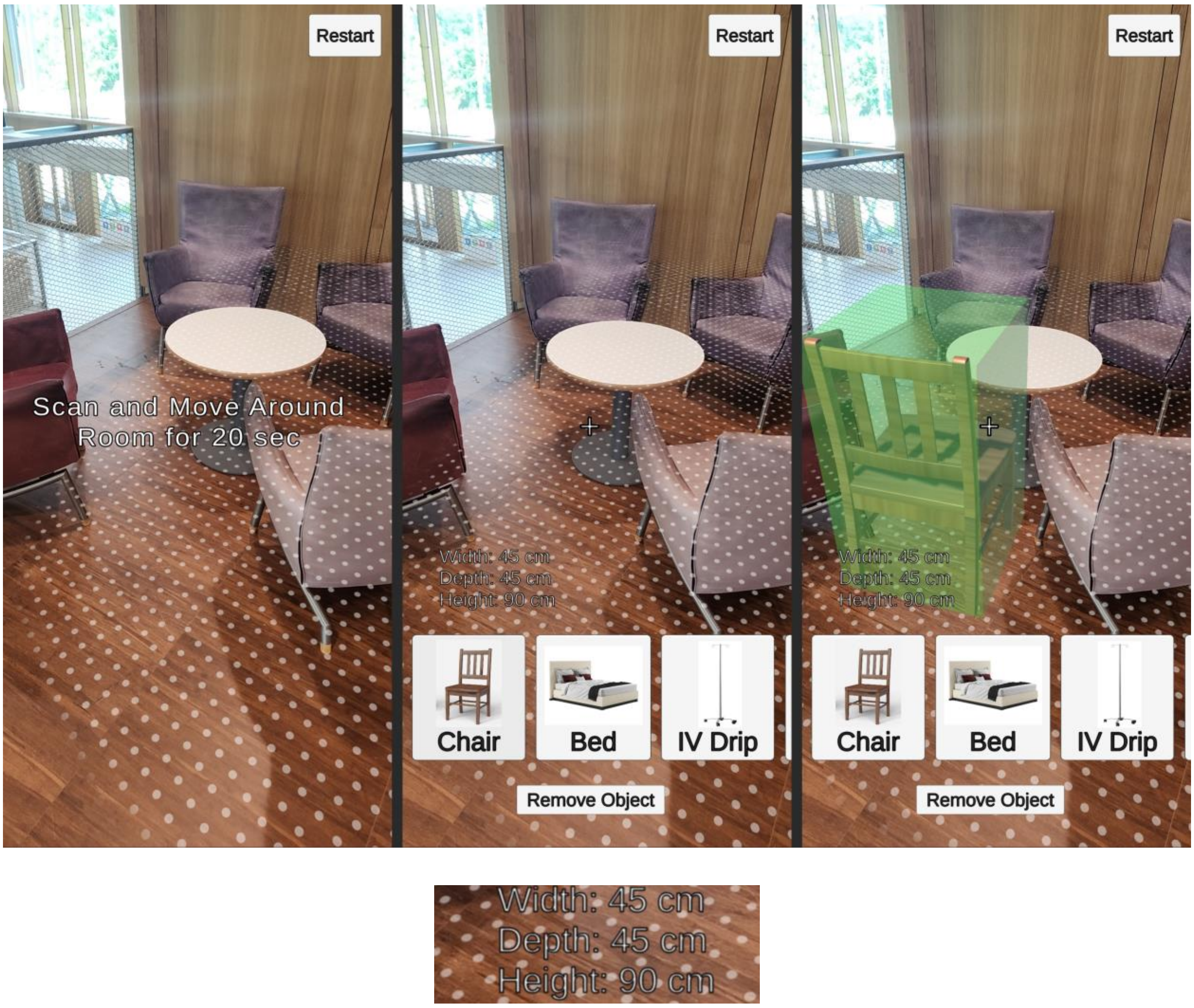
<Figure 32> ARG Input Scenes

<Figure 32> shows the screens that appear when each of the three buttons is pressed in the right image of *<Figure 31>.* From left to right, the Mild, Moderate, and Severe scenes are provided. Users can input information such as the Height of the patient, the width of the walker, and the width of the wheelchair in the input fields, with units in 'cm'. In the Hi-Fi prototype, only the input height of the patient affects the handrail position recommendation generated in the ARG scene. The functionality to calculate and assist with navigation using the inputted walker and wheelchair widths could not be implemented due to a six-month time constraint of the project. Instead of the AR function, animations are provided as alternatives (**Chapter 6.3.4.3**, below).

6.3.2 ARP Scene

The ARP scene provides users with a function to simulate the placement of furniture and medical equipment. The functionalities are divided into object placement, object control, speech bubble guidance, and object removal.

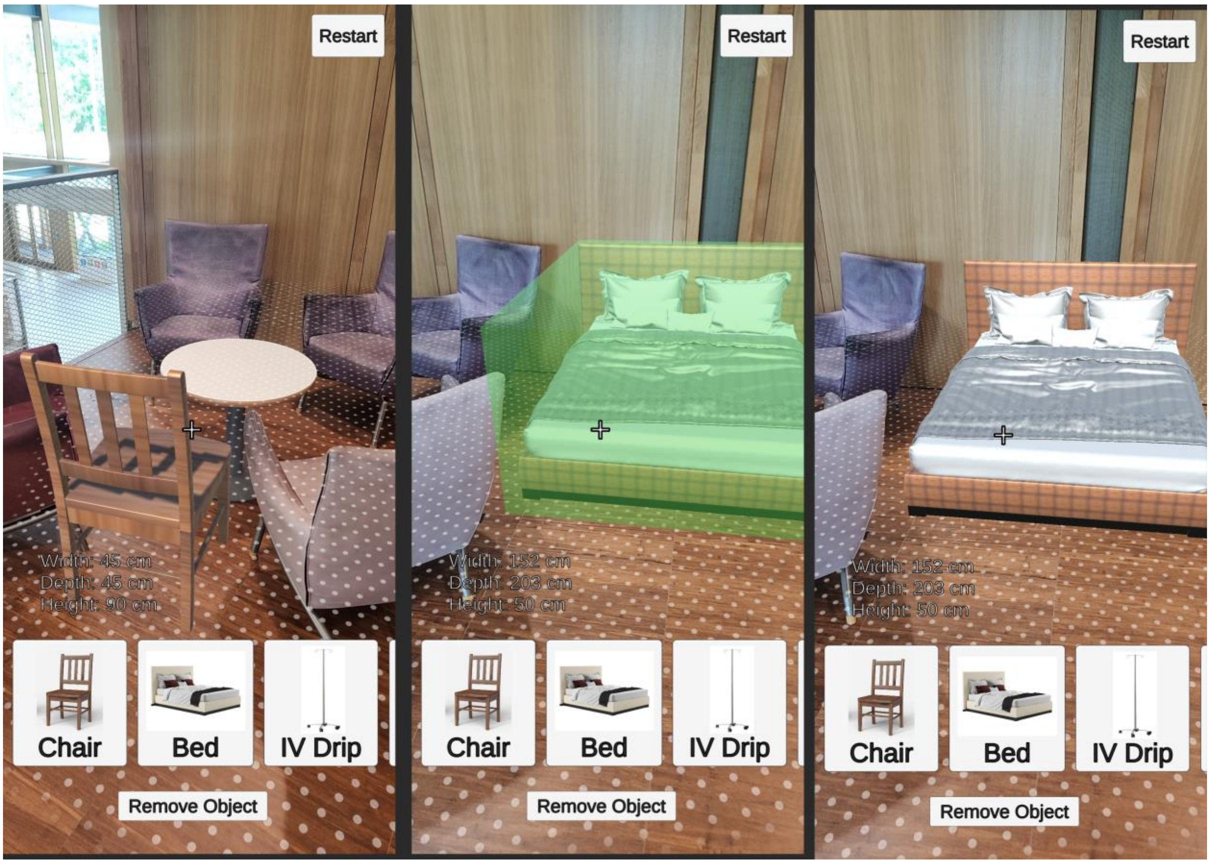
6.3.2.1 Object Placement



<Figure 33> Object Placement Screenshots

As shown in the left image of *<Figure 33>,* users are first instructed to spend 20 seconds exploring the room in the ARP scene. After 20 seconds, a tool tab UI appears as shown in the center image, allowing users to select and place objects. This scrollable object selection UI enables users to choose the objects they wish to place. Once an object is selected, its actual width/depth/height scales are displayed, as seen in the bottom image. Additionally, the sizes of objects placed on the screen are implemented to match the dimensions of existing models.

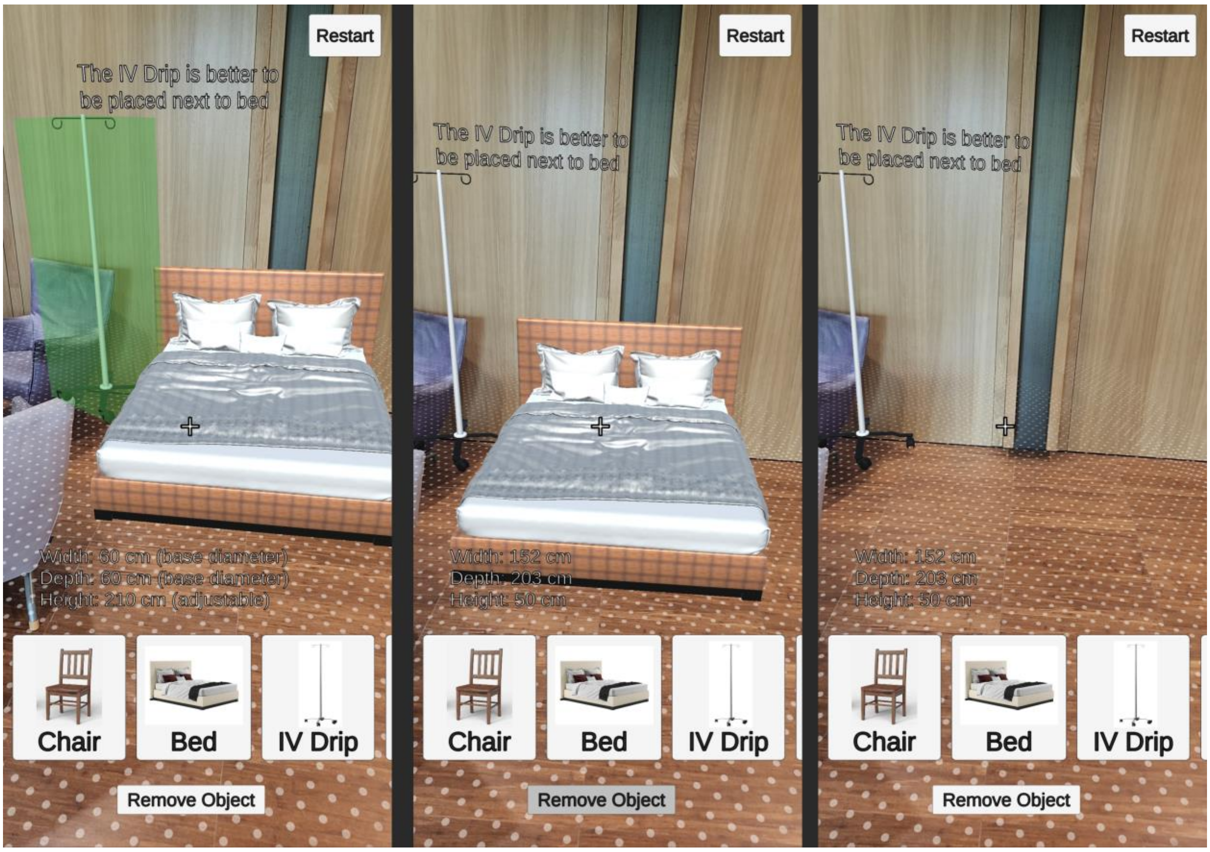
6.3.2.2 Object Control



<Figure 34> Object Control Screenshots

<Figure 34> demonstrates the functions of selecting, moving, and rotating placed objects. Virtual 3D objects can be selected and repositioned at any time. Moreover, since the objects are implemented at actual model sizes, the scaling feature is not possible to use. Users can experiment with placing various pieces of furniture, gaining insights into how well they aesthetically match the existing furniture in their room and whether they fit adequately in the available spaces.

6.3.2.3 Speech Bubble Guidance and Object Removal



<Figure 35> Speech Bubble Guidance and Object Removal

<Figure 35> shows the speech bubble attached to single objects when objects require guidance for placement, such as an IV (Intravenous therapy) drip. In this figure, guidance "The IV Drip is better to be placed next to bed" is provided as a speech bubble. Additional guidance includes suggestions like "Consider there is enough space for a wheelchair placement next to the table" when placing a kitchen table. On the other hand, users may want to remove objects. The center and right images in *<Figure 35>* demonstrate the object removal function. Users can aim the cross(+) in the center of the screen at the object they want to remove and press the "Remove Object" button at the bottom of the screen to make the object disappear.

6.3.3 ARG Scene

The ARG function implemented in the Hi-Fi prototype is provided only when users select Mild Mobility Limitation, as mentioned in the ARG Input Scene (**Chapter 6.3.1.2**). This function is divided into handrail position recommendations and the installation/length adjustment of the handrail.

6.3.3.1 Handrail Position Recommendations

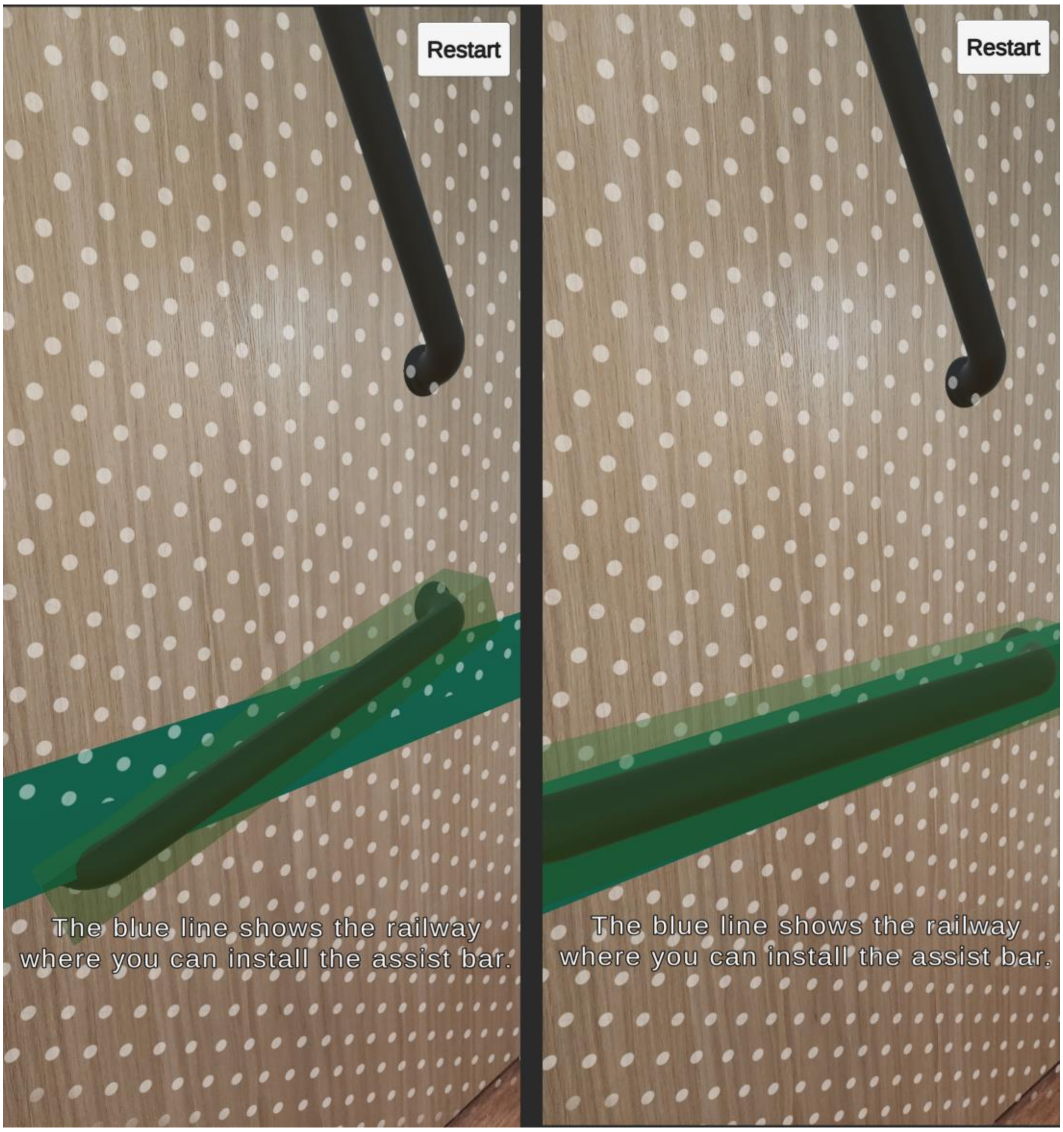
<Figure 36> Handrail Position Recommendations Screenshots

<*Figure 36*> shows the starting scene of the ARG Mild Mobility Limitation scene. First, after scanning the wall for 30 seconds, a recommended handrail installation path is provided as a blue line as shown in the figure. The blue line appears under the calculation depending on the patient's height input. <*Equation 1*> shows the logic for the blue line that appears based on the user's input. Users can gauge with their hands whether this position is appropriate.

$$Height\ of\ handrail\ install = \frac{Patient's\ Height}{2} - 10 \quad (cm)$$

<Equation 1> Handrail Recommendation Calculation

6.3.3.2 Handrail Placement



<Figure 37> Handrail Placement Screenshots

<Figure 37> shows the installation of a handrail on the wall. The handrail can be selected, moved, rotated, and scaled. Since increasing the thickness of the handrail is unnecessary, the scaling function only allows to adjust the horizontal length of the handrail. Users can place this handrail on the provided blue line, and check the best position by placing their hands on it to ensure it is appropriate through the screen.

6.3.4 Animation Guidance Scene

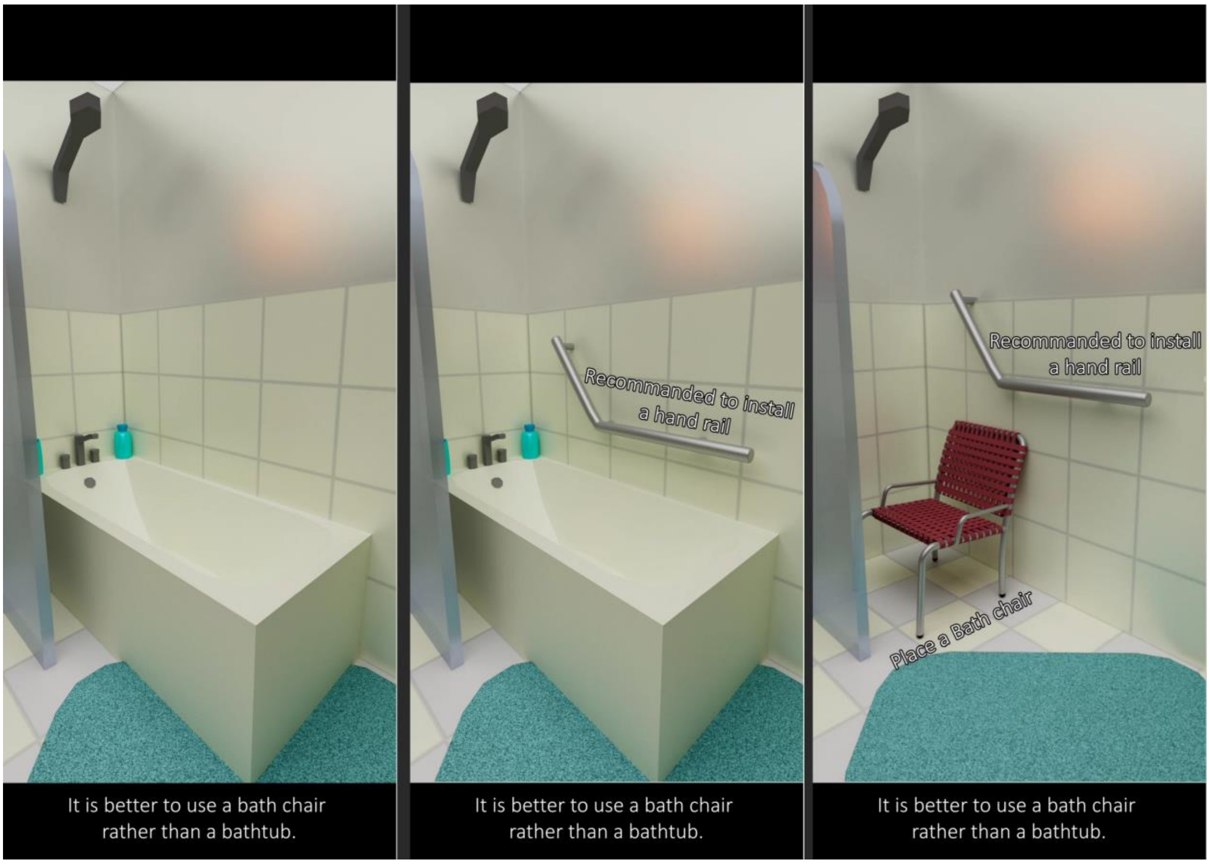
Animations were created for two purposes. The first purpose is to encourage patients to install a special setup in their bathroom, the most risky space where most home falling accidents occur. The second purpose is to provide an alternative video for the ARG function for Moderate and Severe inputs. As mentioned earlier in the ARG Input Scene (**Chapter 6.3.1.2**), the alternative animation videos are played in the virtual space.

6.3.4.1 Guidance in Toilet

<Figure 38> Animation Guidance in Toilet

This animation explains the recommendation that installing handrails parallel to the toilet prevents patients with mobility limitations from falling when sitting down and getting up from the toilet.

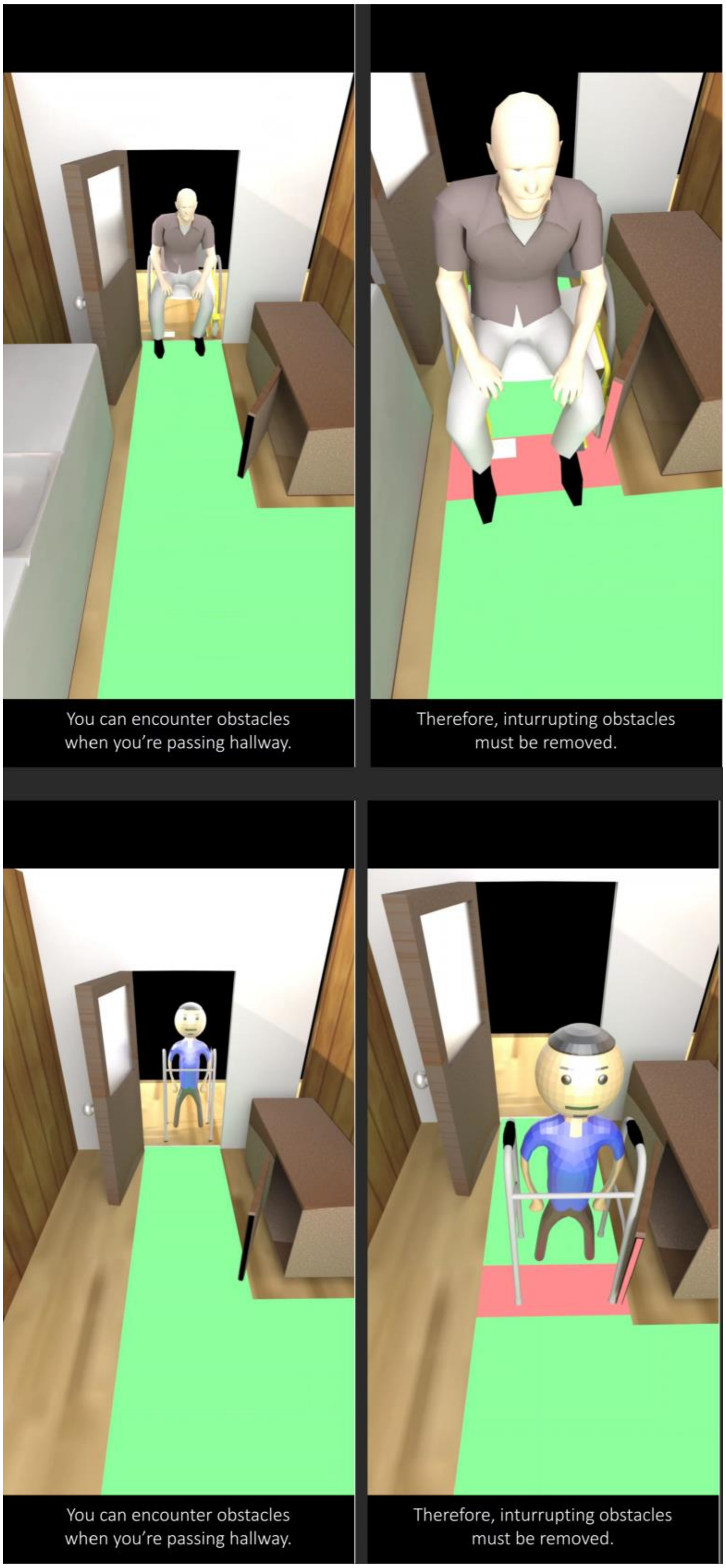
6.3.4.2 Guidance in Shower Booth



<Figure 39> Animation Guidance in Shower Booth

In the shower booth scene, it is recommended to install a handrail above the bathtub for patients with Mild Mobility Limitation, as shown in the center figure. However, for patients with Moderate and Severe levels, the system recommends replacing the bathtub with a bath chair.

6.3.4.3 Guidance for Mobility



<Figure 40> Animation Guidance for Mobility

<*Figure 40*> shows the screens that appear when users select Moderate and Severe Mobility Limitations. The top wheelchair scenario is for Severe, and the bottom walker scenario shows animation example scenarios. The video guides to removal of obstacles from the path. The width of the green path displayed in <*Figure 40*> is demonstrated by the user's width input entered in the opening scene, and if there are obstacles in the path, a red warning signal appears. When obstacles are removed from the path, the path turns green again. Ultimately, the goal of those functions is to ensure the main routes for the patient between all rooms in the house.

6.3.5 Development via Oculus VR Kit

<Figure 41> Photo during Playtest via Oculus VR Kit

The prototype was also developed using the Oculus VR Kit mentioned in Hardware (**Chapter 6.1.2**). However, the Oculus VR device requires separate spatial recognition functionality and UI which is different from the Android device, so it needed additional development. Due to the 6-month limitation of the project, full development was not achieved, and only the opening scene menu and user input function. Nevertheless, this provided a positive perspective on the direction of future app development and the feasibility of implementation with the VR Kit.

6.4 Functional Requirement Review

Category	Requirement	O/X
Must	The internal camera of the user's device must scan elements within a room to recognize the space.	O
	Walls and floors in the AR space must be distinguishable and scannable.	O
	Users must be able to switch between scenes (Opening/ARP/ARG) via the UI.	O
	ARP) Users must be able to choose desired 3D objects (furniture and medical equipment) from a tool tab and place them on recognized planes in the AR space.	O
	ARP) Users must be able to select/remove/move/rotate 3D objects placed in the AR space.	O
	ARP) Specific 3D objects must include tooltips that provide guidance for proper placement.	O
	ARG) Users must be able to place handrails on scanned wall surfaces in the AR space.	O
	ARG) Handrail pathways tailored to the user's height must be displayed in distinguishable colors.	O
Should	Completed home rearrangements should be captureable and shareable via photo and video for collaboration with the patient.	△
	ARG) The system should provide users with short animations for insights based on the entered areas of paralysis for the patient.	O
	ARG) The system should offer customized guidance for various types of paralysis patients.	O

<Table 10> Functional Requirement Checklists

As per the original objectives which was identified in Functional Requirements (**Chapter 5.4.1**), most of the requirements have been met. However, the functionality to capture and record screens for sharing with patients was not integrated into the app. Since users can adequately use other software to capture and share the results of their home layouts, this feature was marked as moderately complete (△).

7. Evaluation

This chapter provides a detailed analysis of the project's evaluation phase. The goal of the evaluation is to determine how the final prototype helps patients and their families rearrange their homes, which is the objective of this project.

7.1 Overview of Evaluation Methods

To evaluate the overall project and the final prototype app, two different tests were planned and conducted. The first is the user test, which involves general participants. The user test is designed to assess the usability and user experience (UX) of the prototype through interviews and 1-5 Likert scale questionnaires. The interview consists of a total of 10 questions: 3 pre-test questions, 7 post-test questions alongside 10 Likert scale questions. The second evaluation is the Expert Evaluation. This evaluation targets professionals with medical knowledge or patients who are having mobility limitations for at least one year. The main information collection method used here is the interview. Moreover, due to the mobility limitations of the patient participants, the app is not directly used by them. Instead, a video of the app's use is shown, and their answers are gathered.

7.2 Evaluation Questions

User Test

EQ1: ***Does the app perform its functions effectively?***

EQ2: ***Is the app's flow and design intuitive and well-structured?***

EQ3: ***Can individuals unfamiliar with AR technology or electronic devices easily understand, access, and use the app as intended?***

Three evaluation questions were created for the user test. First, **EQ1** was created to determine whether the app functions correctly from start to finish according to the developer's intentions. Since the ultimate technical goal of this project is app development, evaluating functionality is crucial. Next, **EQ2** was generated to assess the overall flow and design of the app, which connects its main features. **EQ3** addresses the concern raised in the Interaction Scenario (**Chapter 5.3**) about whether users unfamiliar with electronic devices can easily use the app. Moreover, the **EQ3** was also created to determine if the app is intuitive and accessible enough for widespread use.

Expert Evaluation

EQ4: ***Can the app provide practical assistance to patients and their families?***

EQ5: ***How is TRS currently provided to patients in the medical field, and what aspects can be integrated into this app?***

EQ6: ***What are the best methods for integrating the app into existing medical and support systems?***

The evaluation questions for the Expert Evaluation are designed to gain insights based on experts' medical knowledge and experience through interviews. Since the developed app aims to assist patients, **EQ4** was created to gather opinions from healthcare professionals and patients by showing them the app and assessing its practicality. **EQ5** seeks to obtain insights into how TRS is currently handled in the medical industry and how these practices can be implemented in the app. Finally, **EQ6** was created to gather opinions on how to integrate the app into medical and support systems once it is fully developed.

7.3 User Test

The user test involves having testers use the hi-fi prototype app to evaluate its usability, functionality, design, and overall UX.

7.3.1 Participant Demographics

All general participants are considered to have either experienced mobility limitations themselves or have family members who have, or who may potentially experience them in the future. Ensuring sampling diversity enhances the reliability and generalizability of data.[32] Including participants from diverse backgrounds allows for broader applicability of research findings.[33] Therefore, a total of four participants were recruited, ensuring sampling diversity by including various ages (20s to 50s) and genders. Additionally, to recruit participants both familiar and unfamiliar with electronic devices, participants from various occupations were selected. Participants were recruited by verbally requesting individuals of various ages at the university.

7.3.2 Setup

The Hi-Fi prototype was primarily developed to be compatible with Android device software version 14, so the only necessary hardware setup for testing was an Android mobile device. For participants who used Android devices, their consent was obtained to build the app on their personal Android phones for testing. Since two out of 4 participants were using Android devices, the two tests were conducted on their personal phones. The other two participants were provided with Android devices by the test supervisor for the tests. In terms of the spatial setup, tests were conducted in the participants' homes to determine if the app could be applied in all rooms (refer to the non-functional requirement table). One participant preferred not to test in their own room, so the test was conducted in a separate living space in a student housing building.

7.3.3 Testing Procedure

All user test participants follow these steps:

1. General Explanation of the Project
    - An explanation of the project's title, the interviewer's affiliated school and department, and the purpose of app development is provided.
2. Consent Form Reading and Signing
    - Participants receive a consent form, as shown in Appendix 1.
    - Consent for providing demographic information and using VR goggles or mobile phones is obtained.
3. Conduct the Pre-App Test Interview.
4. Run and Play the App
    - During this time, if participants request help due to manipulation difficulties, assistance will be provided.
5. Complete the 1-5 Likert Scale UX Questionnaire.
6. Conduct the Post-App Test Interview.

7.3.4 Interview and Questionnaire Questions

Pre-App Test (Interview, 3 questions)

Q1) Have you ever used AR (or VR) features?

Q1-1) If you have, what features were they?

Q2) What do you expect when you hear the general explanation of the app?

Q3) Have you or anyone in your family ever had mobility limitations?

Q3-1) If yes, what level of limitation was it? How long did it last?

Scale Questionnaire (Used 1-5 Likert Scales, 10 questions)

- User Interface (UI)

Q4) Was the UI design intuitive and easy to understand?

Q5) Were the positions and sizes of buttons and input fields appropriate?

Q6) Was the readability of the text provided in subtitles and speech bubbles good?

Q7) Was the UI aesthetically pleasing?

- Functionality and Usability

Q8) Was the scanning time appropriate? (20/30 seconds for ARP/ARG

Q8-1) If not, how many seconds would be appropriate?

Q9) For ARG: Was the handrail pathway shown in blue lines on the wall at an appropriate position to support the body?

Q9-1) If not, how many cm up or down would be better?

Q10) Did the functions for selecting/removing/moving/rotating/scaling work properly when placing furniture and handrails?

Q11) Do you think the width/length/height display feature of ARP would be useful for actual placement?

- Animation

Q12) Was the animation easy to understand?

Q13) Was the position of the subtitles in the animation appropriate?

Post-App Test (Interview, 7 questions)

Q14) After using the app, what was your overall impression?

Q15) Did you experience any errors or bugs during use?

Q15-1) What errors or bugs did you experience?

Q16) Do you think the handrail pathway feature in ARG would be useful?

Q17) Was the overall flow of the app natural?

Q17-1) If there were any unnatural parts, please describe them.

Q18) Are there any additional features you would like to see or improvements you think are needed?

Q19) If you or someone you know has mobility limitations, would you be willing to use and recommend this app?

Q20) If you have any other comments, please share them.

EQ1 evaluates the app's functionality. To address this, questions Q15, Q16, and the scale questionnaire from the Functionality category were created. For **EQ2**, which assesses the app's flow and design, Q17 and the scale questionnaires for UI and Animation were developed. To answer **EQ3**, Q1 and the Likert scale scores from the UI, Functionality, and Usability categories are used. Q1 determines whether the user is familiar with electronic devices and AR, and the Likert scales are compared among participants. Ultimately, if the scores of participants unfamiliar with electronic devices are similar to those who are familiar and close to 5, it indicates a low usability barrier. Additionally, questions Q2 and Q14 were derived to gain insights into the app's comprehensibility and accessibility.

7.3.5 Data Collection Methods

Interviews

All responses from interviewees are recorded and transcribed after the interview. Additionally, simple note-taking by the interviewer during the interview is used to organize keywords. Taking notes during interviews can enhance data accuracy and provide valuable context that audio recordings alone may not capture.[34] Additionally, the interview content was recorded with prior consent alongside note-taking, and it was transcribed into text and stored in a spreadsheet file.

Likert Scale Questionnaires

All responses to the 10 questionnaires are automatically stored in the interviewer's PC database. Data was exported to a spreadsheet for analysis.

Observations

The testers' interactions with the app are recorded on video. This observational data is collected for analysis after the tests to capture natural user interactions with the app.

7.3.6 Results

7.3.6.1 Interview

Questions	Participant 1	Participant 2	Participant 3	Participant 4
Before App Test (Interview, 3 questions)				
Q1) Have you ever experienced using AR (or VR) features?	Has experience with both AR and VR games.	Tried placing objects using AR. Also played Pokemon Go and tried it at exhibitions.	Tried AR furniture placement briefly.	No, I haven't tried it before.
Q2) What did you expect when you heard the general explanation of the app?	Expect someone holding a camera to scan the room and set it up in a hospital while the patient is lying down.	I imagined entering their height and seeing handles automatically appear on the wall in the room.	Thinks users will follow instructions from the app to rearrange their homes.	Has never tried AR before, so they feel they need to run the app to understand it.
Q3) Have you or your family ever experienced mobility limitations?	Grandmother used a walker for 3 months after back surgery.	Grandmother used a wheelchair for a long time. Used a neck brace for 3 months.	Did not encounter any issues.	Used crutches for two months after a leg injury.
After App Test (Interview, 7 questions)				
Q14) What was your overall impression after using the app?	Found the experience very enjoyable and highly practical.	Considered the perspectives of three handicapped persons.	Seems suitable for use by patients' families.	Found the first AR experience fascinating.
Q15) Did you experience any errors or bugs while using it?	Noted that single-color walls were not recognized.	Had difficulty moving when placing handles.	Had difficulty with placement due to unfamiliarity.	Did not experience placement difficulties due to lack of experience.
Q16) (ARG) Do you find the handrail pathway feature useful?	Found it convenient to install handles with guidelines.	Expected the handrail to appear directly instead of the blue line initially.	Lines appeared correctly and placement was easy.	Understood the purpose of the blue line quickly thanks to clear subtitles.
Q17) Did the overall flow of the app feel natural to you?	Did not encounter any issues with the flow	Felt natural, but suggested that instead of subtitles indicating the visibility of the blue line, it would be better to have an option to turn it on and off	Felt natural and not awkward.	Felt natural.
Q18) Are there any additional features you would like to see or improvements you would suggest?	Mentioned, "It would have been nice if they introduced whether to scan the floor or the wall."	Found it inconvenient when the input field was covered when the typewriter came up.	No, I think it's enough. I would say you can just improve your prototype as you have done so far.	Would like the ability to place scanned rooms in a 3D virtual space.
Q19) If you or someone you	Expressed willingness to use	Yes, especially for people living alone.	Yes, as far as I know, there is no	Certainly, even when injured,

know experiences mobility limitations, would you be willing to use and recommend this app?	the app again.		app or any infrastructure for guidance for this TRS stuff.	struggled due to the lack of a manual.
Q20) Do you have any other comments or opinions to share?	-	The ARG handrail function needs to provide images or instructions on what the blue line signifies before scanning.	I hope it gets developed and launched.	The intention of your prototype is so revolutionary. It has a large potential.
Test Supervisor's Observation	Participant 1 struggled with scanning the space but managed object placement quite well without assistance.	Participant 2, who has extensive AR experience, was able to use all the app's features independently without additional help.	Participant 3, who is not familiar with electronic devices, had difficulty placing objects throughout the test.	Although Participant 4 initially needed the administrator's help due to inexperience with the app, they soon began to control it well.

<Table 11> User Test Interview Results

7.3.6.2 Likert-Scale Questionnaire

Questions	Participants				
User Interface	#1	#2	#3	#4	Avg.
Was the UI design intuitive and easy to understand?	4	5	4	5	4.5
Were the location and scale of buttons and input fields appropriate?	5	4	4	4	4.25
How was the readability of text and messages?	3	4	4	3	3.5
What about the aesthetic elements?	3	3	4	3	3.25
Functionality/Usability					
Are the walls and floor well-scanned?	3	4	2	3	3
(ARG) Did the handrail pathway's location seem conducive to supporting the body?	4	5	4	3	4
(ARP) Did the furniture arrangement selection/removal/ movement/rotation functions work properly?	5	5	3	4	4.25
Are ARP's width/height/length provision features useful?	5	4	4	4	4.25
Animation					
Was the animation easy to understand?	5	4	4	5	4.5
Was the subtitle position appropriate?	5	4	4	4	4.25

<Table 12> User Test Likert Scale Questionnaire Results

7.4 Expert Evaluation

The expert evaluation was designed to assess the usability of the hi-fi prototype in the medical industry for actual patients and their families. This evaluation involved showing app usage videos to 4 experts and conducting interviews to determine if the app could be effectively used in real-world scenarios. Given that 2 participants in the patient group currently experience mobility limitations, it was deemed impractical to have them use the app directly due to the extensive setup and playtime required.

7.4.1 Participant Demographics

Participants in the expert evaluation interviews include medical experts and patients. Medical experts are selected based on their specialization in the medical field or experience treating patients with mobility limitations. Patient interviewees have experienced mobility limitations for over a year and continue at the moment of the interview. To derive a more practical evaluation, patients currently experiencing mobility limitations were recruited, as they possess firsthand knowledge of challenges, discomforts, and solutions related to their condition, thus qualifying them as experts.

7.4.2 Interview Procedure

Participants in the expert evaluation follow these steps:

1) General Explanation of the Project
    a. Explanation of the project's title, the interviewer's affiliated school and department, and the purpose of app development is provided.
2) Consent Form Reading and Signing
    a. Participants receive a consent form, similar to Appendix 1
    b. Consent is obtained for providing demographic information and agreeing to the interview recording.
3) Watch a 3-minute App Usage Video
    a. Participants watch a video of app usage for 3 minutes.
    b. They can ask questions immediately if there are any points they do not understand.
4) Conduct Expert Interview

7.4.3 Interview Questions

10 interview questions were derived for expert evaluation as below:

Demographics

Q1) Could you share your experience in the medical field or any mobility limitations you have encountered?

Key Features of the App

Q2) How do you think the main features of the app (such as furniture arrangement simulation and special AR guide) could help in the patient's daily life or treatment process?

Q3) Do you think the feature for guiding the installation location of parallel bars will be useful in reality? Why do you think so?

Q4) Do you think the furniture arrangement feature could make the patient's living space safer and more convenient?

Q5) Do you think patients or their families will be able to easily access and use this app?

Expert Opinions

Q6) Do you actually provide guidance for setting up the home when patients are discharged? If so, how do you provide it?

Q7) How can this app be integrated into the current medical or support systems?

Improvements and Additional Features

Q8) Are there any features you think should be added to the app or areas that need improvement?

Q9) What aspects of the app did you particularly like, and what aspects do you think need improvement?

Q10-1) Expert: Would you be willing to recommend this app to your patients?

Q10-2) Patient: Would you be willing to use this app yourself? Or if you had known about this app when you were about to be discharged, do you think you would have used it?

To answer **EQ4** (Can the app provide practical assistance to patients and their families?), questions Q2 to Q6 were created. For **EQ5**, questions Q6 and Q8 were developed, and for **EQ6**, question Q7 was derived.

7.4.4 Data Collection Methods

Interviews

All responses during the interviews are recorded and transcribed after the interview. Additionally, the interview content was recorded with prior consent alongside note-taking, and it was transcribed into text and stored in a spreadsheet file.

Observations

Participants' interactions with the app during the video viewing are observed. This observational data is collected after the tests to capture data on how users naturally interact with the app during video viewing.

7.4.5 Results

7.4.5.1 Interview Results

Question	Medical Expert 1	Medical Expert 2	Patient 1	Patient 2
Experience in the medical field				
Q1) Could you share your experience in the medical field or any mobility limitations you have encountered?	I have been working as a caregiver for 15 years. I take care of patients in their 80s and 90s at a nursing home, most of whom have mobility limitations due to a lack of leg strength.	Graduated with a bachelor's degree in Physiotherapy. Worked as a therapist assistant for 2 years. Many of the patients had mobility limitations.	A year ago, I ruptured my Achilles tendon, used a wheelchair for six months, and then used crutches for three months. Even now, I have difficulty walking and find it hard to climb stairs alone.	24 years ago, I fractured my cervical vertebra C5 in a car accident, resulting in paralysis of my legs and inability to control my fingers. I can control my shoulders and elbows.
Key Features of the App				
Q2) How do you think the main features of the app (such as furniture arrangement simulation and special AR guide) could help in the patient's daily life or treatment process?	Installing handrails to prevent falls will be very helpful in preventing slips.	This app could play a role in recommending the installation of handrails for patients who are at high risk of falling.	After a sudden accident, I ended up using a wheelchair. When I returned home to start rehabilitation, I felt very lost. Therefore, animations emphasizing wheelchair path securing would have been helpful.	I cannot move, so my wife takes care of me, and she struggles with rearranging the house. Therefore, using an app like this to simulate furniture placement in advance would provide valuable insights.
Q3) Do you think the feature for guiding the installation	I definitely think it's useful. When their legs are uncomfortable, people tend to hold on to things. From my	It seems useful, but usually, a good position to support the body is about 15 cm lower than half the	Since people's arm and leg lengths can vary, the handrail pathway recommendation	-

location of parallel bars will be useful in reality? Why do you think so?	experience, patients I have cared for often grabbed onto corners of walls so much that they became discolored. Having proper handrails that are easy to grab would be much better.	height of the person. Therefore, it would be better to recommend a slightly lower position.	function might be better if it is provided only as a 'recommendation.' The main purpose should be to install handrails that consider the patient's arm and leg lengths.	
Q4) Do you think the furniture arrangement feature could make the patient's living space safer and more convenient?	Not only patients but all users can gain insights when changing their home layout through this feature. The IV drip guide also seems like a good idea, but AR guides are more useful.	There are already established apps for furniture arrangement, like the one from Ikea, so there might not be a need to use this app specifically. The unique feature in this prototype was the 'speech bubble guidance,' which, if further incorporated, could make the app much more helpful for patients.	When I was living in the hospital, there were wide passages and no doorsteps for wheelchair users, but it was hard to adapt at home initially. This seems like it would make things more convenient.	Yes. All the functions are designed to provide guidance on elements that could cause injury or discomfort to patients, so I view it positively.
Q5) Do you think patients or their families will be able to easily access and use this app?	If one is familiar with electronic devices, it shouldn't be too difficult to use.	Unless a doctor recommends the app, it might be challenging for patients to find and use it on their own, but using the app itself doesn't seem difficult.	When I was discharged, I didn't even think about finding this in an app. If someone had promoted it, I probably would have tried it. Promotion is important.	Unless the government or a medical association provides this as a manual, I think people might not know about it and therefore not use it.
Expert Opinions				
Q6) Do you actually provide guidance for setting up the home when patients are discharged? If so, how do you provide it?	When patients with mobility issues are discharged, we provide advance warnings. We inform both patients and caregivers about safety precautions, like not staying too close to windows. We have observation records and special notes for each patient, where we mention any specific changes needed at their home.	Although we do not provide separate booklets, we do educate caregivers and patients on fall prevention at home.	I wasn't provided with anything specific."	There is no such guide, but the government supports the costs of home modifications due to mobility limitations.
Q7) How can this app be integrated into the current medical or support systems?	Grab bars in bathrooms are already recommended to patients in the industry. However, there's no separate guidance on installing handrails. From the medical staff's perspective, ARP functions also provide insights on how to place patients in a	Collaboration with hospitals is important. In the hospital where I worked, we held regular online meetings with patients and caregivers to explain the overall protocols for home care. Through such online sessions, the app	I don't know.	The government supports home modification costs, but since they do not provide specific guidance, they could develop this app publicly and distribute it to patients and caregivers.

	bright atmosphere and how to secure more space.	could be recommended.		
Improvements and Additional Features				
Q8) Are there any features you think should be added to the app or areas that need improvement?	It would be nice to include beds that can elevate the patient, like hospital beds.	I often guide my patients to lay carpets to prevent slips. While installing handrails is good, it would also be beneficial to add simple fall prevention guides like laying carpets, which do not require installation resources.	In addition to handrail recommendations, it would be nice to have augmented reality features that consider various types of patients.	In a home with a wheelchair user, there should be no thresholds or stairs. Adding this to the guidance would be beneficial.
Q9) What aspects of the app did you particularly like, and what aspects do you think need improvement?	I liked that handrails could be freely controlled. I appreciated the intention behind developing technology for people with disabilities. It made me feel that our society is still warm. I would like to see more comprehensive instructions on how to use the app.	There hasn't been an app of this kind before. Even without the AR function, I haven't seen an app that provides such guidance. So I think the intention is excellent, and I hope it gets commercialized through high-quality development. I think it's an app worth recommending. However, it would be better to conduct more research on the challenges faced by patients to provide more comprehensive guides.	When I was discharged, I received no guidance on rearranging my home, and I thought it would be nice to have such a tool. Adding more disease-specific guidance for various patients would make the app even better.	When doing an actual viewing, professional caregivers or acquaintances measure the width for wheelchair access, so being able to do this remotely through the app would be very useful.
Q10) Expert: Would you be willing to recommend this app to your patients? Patient: if you had known about this app when you were about to be discharged, do you think you would have used it?	Yes, I would recommend this app to others. Especially, patients who have a Mild level of mobility limitation can use it effectively.	Yes, I would recommend it.	If I went back to when I was discharged, I would have used this app.	I am inclined to use it. If I had known about the app, I would have tried it once. Now I'm in the phase of mild mobility limitations, so I will use it when I move housings.
Test Supervisor's Observation	Medical expert 1, who is not familiar with electronic devices, watched the app usage video with a lot of curiosity and seemed very amazed.	Medical expert 2 frequently expressed admiration while watching the app usage video and muttered to himself, "This is a feature I thought would be useful."	Patient 1 quietly watched the video without much reaction, which is presumed to be due to his personality.	Patient 2 continuously expressed amazement while watching the video.

<Table 13> Expert Interview Results

7.5 Discussion of Evaluation Results

In this section, user tests and expert evaluations were conducted for a structured assessment. Firstly, based on these evaluations, the Non-Functional Requirement Review was assessed. Next, conclusions for the six EQs were discussed.

7.5.1 Non-Functional Requirement Review

Category	Requirement	O/X
Must	Users should interact with the system easily.	O
	The UI should be designed to be user-friendly and clear.	△
	The system should function regardless of the type of room in which the user runs the app.	O
	All elements provided by the system should benefit the user.	O
	All processes of the system must occur within the app itself, and third parties should not access personal data.	O
Should	The system should be engaging to use.	△
	The UI should be aesthetically pleasing.	△

<Table 14> Non-Fuuctional Requirement Table

The app's non-functional requirements identified in the Specification phase (**Chapter 5**) were evaluated through user testing. Most of the Must-Have requirements were adequately met. However, based on the assessment of the UI category in the Likert-Scale Questionnaire (**Chapter 7.3.6.2**), the scores for UI message readability and aesthetic elements were in the 3-point range, indicating that these requirements were not fully met. Additionally, the two Should-Have requirements were not sufficiently fulfilled.

7.5.2 Evaluation Questions Review

All EQs are evaluated based on the scores from the Likert-scale questionnaire and interview responses.

User Test

EQ1: Does the app perform its functions effectively? Except for the floor and wall scanning functionality, all other responses for the functionality/usability category in the test questionnaire showed mostly high scores in the range of 4. Additionally, interview questions regarding other functions revealed no dissatisfied participants. Therefore, the app's functionality is considered to function as the developer’s intention.

EQ2: Is the app’s flow and design intuitive and well-structured? While the readability of UI messages and aesthetics scored in the 3-point range which indicates some inadequacies, the animation categories received high scores, all in the 4-point range. Questions about the app’s flow were mostly answered positively, indicating a natural flow. Therefore, while the UI design needs to be improved to be clear and better in aesthetics, the app is well-made in terms of animation and user flow.

EQ3: Can individuals unfamiliar with AR technology or electronic devices easily understand, access, and use the app as intended? To answer this question, the functionality/usability scores based on participants' familiarity with electronic devices (as answered in Q1) were compared. Participants 1 and 2 (familiar with electronic devices and experienced with AR) averaged 4.5 in functionality/usability scores. In contrast, participants 3 and 4 (who were less familiar) scored an average of 3.625, nearly 1 point lower. Additionally, according to the test supervisor’s observations, participants 1 and 2 adapted to the app's functions more quickly and handled floor and wall scanning and object placement more easily than participants 3 and 4. Therefore, it can be concluded that users who are familiar with electronic devices or have AR experience are more likely to use the app as intended by the developers, indicating the need to make the app easier to use.

Expert Evaluation

EQ4: Can the app provide practical assistance to patients and their families? Based on responses to Q2-Q5, both experts and patient groups agreed the app could be useful in a real home environment for patients. However, as the hi-fi prototype does not include various functions, it is recommended to develop the app further to provide clearer and more useful guidance depending on the patient's level of mobility limitation.

EQ5: How is TRS currently provided to patients in the medical field, and what aspects can be integrated into this app? Responses to Q6 and Q8 indicate that there is currently no clear manual for providing TRS in the medical field. Experts dealing with patients' diseases provide guidance or education to help patients adjust at home after discharge, but it appears insufficient. This suggests the need for manual development such as a guidance app and highlights the app's potential. The areas for improvement in the hi-fi prototype mostly involved adding more useful guidance. This requires individual research on the type of patient’s illness and suggests future development towards providing a wider range of personalized home care guides based on that research.

EQ6: What are the best methods for integrating the app into existing medical and support systems? To integrate this app into existing medical and support systems, it is recommended to promote the app through collaboration with government or medical institutions and encourage its use along with usage education through online training sessions.

8. Discussion

8.1 Final Prototype Performance

The clients of this project, Daniel Saakes, and Jodi Sturge, expect the development of an AR app that helps patients scheduled for home healthcare after discharge and their families set up their homes according to the patients' homecare needs. Their initial development requirement was to develop an AR app that assists in rearranging users’ homes when patients are discharged. For this matter, the designer implemented a prototype app that provides tailored room setup (TRS) guidance based on three degrees of mobility limitation and supports an AR furniture placement mockup (ARP) feature. The clients were satisfied with the results. The evaluation phase showed that the prototype could influence patients to set up their homes usefully by providing TRS guidance tailored to their mobility limitations. The TRS Demonstrator app prototype provided users with insights and a vivid experience in rearranging their rooms using their personal Android mobile devices. Additionally, the three levels of mobility limitation inputs (Mild, Moderate, and Severe) provided different interactable AR guidance and animation guidance successfully. Interviews with medical professionals and patients regarding the developed prototype indicated that this guidance could reduce the difficulties experienced when setting up the home before the patient returns after discharge. Furthermore, the handrail installation mockup and placement recommendation feature were evaluated to have particularly positive effects for patients with mild mobility limitations through user tests and interviews with experts and patients.

8.2 Limitations and Recommendations

Background Research Limitation

The first limitation of the research is that the guidance scenarios to be provided to patients can be changed within a big range depending on the type of illness they have. Since the graduation project is a temporal project within 6 months, the technical implementation was undertaken only in scenarios regarding mobility limitations. The second limitation is the lack of existing suitable tools for the assistance of patients' TRS. As a result, rather than finding literature on similar AR placements for the target group, the project concluded as follows: existing AR furniture placement technologies could be used in the same manner they have, by adding customized equipment or scenarios for the patients on the existing technologies. Furthermore, as proper technological developments for our Target Group are not implemented enough, the successful development of this app in the future can become a valuable guidance tool for many patients undergoing CH.

Hardware Platform Limitation

All scores from the user test's Likert scale questionnaire were above 3. Among the results, the floor and wall scanning functionality and text readability received the lowest scores of 3 and 3.25, respectively. The app prototype was developed on a 6.1-inch Android mobile device, and since typical mobile devices use only a single camera for AR spatial recognition, the accuracy of AR spatial recognition was limited. Additionally, small English texts displayed on a 6.1-inch screen may have been difficult to read for users who have low vision or who are not familiar with English. Two recommendations were identified to address these issues. Firstly, following the prototype development via Oculus VR Kit (**Chapter 6.3.5**), the AR environment of the app has potentials to be developed. The high-end Meta Quest 3 model, mentioned in Hardware (**Chapter 6.1.2**), supports faster and more accurate spatial recognition using six spatial recognition lenses. This development would allow users to place objects with higher accuracy and provide a more vivid experience through a 360-degree immersive view. Secondly, using devices with larger touchscreens (such as tablets instead of a 6.1-inch mobile phone device) could be beneficial. Larger screens would allow for more precise object manipulation and improved text readability due to larger text size.

Limited Types of TRS Guidance

The prototype's AR TRS Guidance by the patient's Mobility Limitation (ARG) feature is divided into three stages: Mild, Moderate, and Severe. Due to the project's six-month time constraint, only the handrail placement and recommendation feature for the Mild stage was implemented. For the ARG for Moderate and Severe stages, they were provided only as alternative animations. General users, experts, and patients recruited for the evaluation all expressed a desire for the specified ARG features demonstrated in the alternative animations to be implemented in the actual AR environment. This suggests that the navigation function, which ensures the removal of obstacles in the patient's movement path considering the width of wheelchairs and walkers as shown in the animations as shown in <*Figure 40*> (**Chapter 6.3.4.3**), could be included to improve the system.

8.3 Future Work

The first future work for the project includes adding more TRS guidance, making the app functional on more platforms (such as iOS and Oculus VR Kit), and conducting further research to improve spatial recognition and object placement accuracy through AR. Additionally, the use of the Microsoft KINECT sensor to enhance spatial recognition accuracy and provide automated placement could be considered [16]. Secondly, user test results (**Chapter 7.3.6**) indicated that users who were unfamiliar with electronic devices took longer to understand and control the app and reported lower satisfaction. This could be addressed by making the app more user-friendly for them or developing an educational program for app usage. Thirdly, according to the overall insight of evaluation results from the general public and medical experts from Evaluation (**Chapter 7**), the app should incorporate a feature that provides guidance tailored to various patient conditions. TRS for home healthcare can vary depending on the type of disease, and it should offer not only considerations for mobility limitations but also guidance to assist with treatment or condition monitoring. For instance, it could provide instructions on necessary precautions when installing devices like blood pressure monitors in a patient's room. Finally, once the app's ultimate prototype is completed in the future, research on how to make it accessible to patients and their families is necessary. According to expert opinions derived from Expert Evaluation Results (**Chapter 7.4.5**), the app could be integrated into the healthcare systems by collaborating with government and medical institutions to promote and guide its usage through online educational sessions for patients and caregivers.

9. Conclusion

This project proposes the development of augmented reality (AR) technology to guide patients and their families in setting up a Tailored Room Setup (TRS) upon returning home after discharge. The potential users of this technology are patients and their families who struggle with arranging their homes to accommodate patients with mobility limitations and require assistance. The research objective of this project is to design an AR-based TRS app to address this challenge.

One of the most challenging scenarios for patients returning home after discharge is when they have mobility limitations. Unlike the customized hospital environment, typical homes are not designed for patients' mobility. Therefore, an AR-based TRS app has been developed to provide guidance to them. Using AR technology, the app offers furniture placement mockups and guidance tailored to the patient's mobility limitations. Families can run the app on their Android mobile devices to receive guidance and simulate home rearrangement. First, users can utilize the furniture placement mockup to place desired furniture based on speech bubble guidance in AR space. Subsequently, users select one of three levels of mobility limitations (Mild, Moderate, Severe) and input the patient's information, receiving different guidance accordingly. The final prototype focuses on features for patients with Mild mobility limitations, including the virtual installation of handrails on walls by referring to the recommended handrail position adjusted to the patient's height.

Participants including medical experts and patients were recruited for prototype evaluation. The evaluation results indicated a positive correlation between the use of this app and providing TRS for patients and their families. Additionally, the potential for integrating a more advanced version of the app into medical or support systems was suggested.

Currently, there has been a lack of clear manuals or tools for home healthcare setting up for patients, causing difficulties for patients and their families. The prototype shows positive potential as a solution to these challenges. This project can be the first step of a big dream in ensuring sustainable and safe home healthcare for those facing such difficulties.

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Appendix 1

Informed consent form

You shall be given a copy of this informed consent form

The goal of the study is to gain insights into the app implementation and background research conducted for the Creative Technology Bachelor graduation project, "AR Demonstrator for Care at Home." This study shall take approximately 20-30 minutes and includes both a testing situation as well as an interview with the researcher.

Read before filling in this consent form, the study information sheet about what the study entails.

Please tick the appropriate boxes	**Yes**	**No**
I have read and understood the study information sheet, or it has been read to me. I have been able to ask any questions about the study have been answered to my satisfaction.	○	○
I consent voluntarily to participate in this study and understand that I can refuse to answer questions. I can withdraw from the study at any time, without providing a reason.	○	○
I understand that the information I provide shall be used to determine the effectiveness of the visualization as well as for the improvement of the prototype.	○	○
I understand that personal information collected about me that can identify me, such as [e.g. my name or job], shall not be shared beyond the study team.	○	○
I understand that I can use an Android phone or wear VR goggles to conduct the test. (If you experience any nausea or dizziness while wearing the VR goggles, you can always take them off at any time without prior notice.)	○	○

Signatures

______________________	______________________	________
Name Participant	Signature	Date

I have accurately read out the information sheet to the participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

______________________	______________________	________
Researcher name	Signature	Date

Study contact details for more information: Junhyun Noh, j.noh@student.utwente.nl

Contact information for questions about your rights as a participant

If you have questions about your rights as a research participant or wish to obtain information, ask questions or discuss any concerns with this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee of the EEMCS at the University of Twente by ethics-comm-eemcs@utwente.nl

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