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User Enactments Design Method and Study in Virtual Reality

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If you can't tell whether it's real or not,
does it matter?

Sommario

User Enactments (UE) è un approccio di progettazione che consente di esplorare e comprendere come i nuovi sistemi tecnologici siano percepiti dalle persone e il grado di alterazione delle abitudini a cui potrebbero potenzialmente portare. Per ottenere risultati validi, i team di sviluppo devono costruire un ambiente fisico e scenari appropriati che permettano agli utenti di mettere in atto e immaginare la tecnologia studiata. Questo processo non è unico e varia notevolmente in base alla natura delle domande che vengono esplorate. Nello studio condotto da W. Odom et al. [1], alcuni dei principali problemi emersi durante l'uso di UE sono legati al livello di controllo dei partecipanti e al grado di fedeltà dell'ambiente. Questi fattori devono essere bilanciati adeguatamente in base allo scopo dello studio e possono richiedere più iterazioni e molte risorse in termini di spazio fisico, arredo, dispositivi, prototipi di sistema, ecc.

In questo lavoro, il processo di progettazione UE viene replicato in un ambiente virtuale di una casa intelligente sfruttando le tecnologie immersive per valutare la fattibilità e i vantaggi di questa virtualizzazione. Introducendo un nuovo approccio denominato "UE in VR", la ricerca implementa due scenari all'interno di una Smart Home virtuale per analizzare come gli individui concettualizzano un assistente domestico dotato di IA con comportamento proattivo.

Lo studio conclusivo degli utenti non solo ha convalidato i vantaggi di incorporare un ambiente virtuale nelle indagini della UE, ma ha anche fornito preziose intuizioni sulle pratiche consigliate per futuri studi UE in VR.

Abstract

User Enactments (UE) is a design approach that allows designers to explore and understand how new technology systems are perceived by people, and the degree of habits alteration they potentially could lead to.
In order to achieve valuable results, design teams have to construct an appropriate physical environment and scripted scenarios that let users' enact and envision the studied technology. This process is not unique, and strongly varies according to the nature of questions which the designers aim to explore. In the study conducted by W. Odom et al. [1], some of the key issues that has derived, while doing UE, are related to the level of participants' control and environmental fidelity. These factors have to be properly balanced according to the study purpose, and may require multiple iterations and resources in terms of physical space, furniture, devices, system prototypes, etc.
In this work, the UE design process is replicated in a smart home virtual environment leveraging immersive technologies to assess the feasibility and advantages of this virtualization. Introducing a novel approach named "UE in VR," the research implements two scenarios within a virtual Smart Home to analyze how individuals conceptualize a proactive AI home assistant.
The conclusive user study not only validated the advantages of incorporating a virtual environment in UE investigations but also provided valuable insights about the recommended practices for future UE in VR studies.

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Chapter 1

Introduction

The technological revolution occurring in these years is without a doubt with no precedents, and it is the key factor behind the economical growth of numerous countries. The Industry 4.0 and Internet of Things (IoT) allowed to exponentially speed up the manufacturing processes and reduce costs, while the emergence of the Artificial Intelligence (AI) culture is drastically reshaping not only the job market but also our societal landscape. In a few decades one single generation witnessed different technological eras, a trend expected to be intensified in the coming years. While the phenomenon undeniably enhance productivity, it also raises profound social and ethical questions, some of which require more time to address than the technology takes to advance.
From the commercial point of view, predicting whether a technology will be embraced by the majority as an integral part of their lives remains a complex task. AI serves as a prime example of a technology that captivates individuals, while simultaneously instilling fear and skepticism about placing too much trust in it. Relying critical aspects of our lives to AI, such as autonomous driving, pushes the common opinion on a negative side, even though this change seems inevitable.
In this context, designers play a fundamental role in shaping the acceptance and trust of emerging technologies. Designing a self-driven car, for instance,

requires first of all a good understanding of what are the trust boundaries that different persons are able to accept, and then decisions can be made accordingly.
Various design technique have been explored, one of which particularly captures the insights of understanding how the user would use and perceive a product or a service, before having one in place. This technique, named User Enactments (UE), allows to observe the behaviour of the user in specific and loosely scripted scenarios. Current studies, which are going to be explored extensively in the following chapters, showed how UE is effective even when the prototype of the system doesn't exist yet, and instead an experience capturing the idea of the system is enough for the purpose. As an example, E. Huff et al. [5] explored the relationship between seniors and highly technological autonomous vehicle. In order to achieve that, no actual vehicle was involved, but instead an enactment stage has been setup in an indoor space where a sports utility vehicle (SUV) was represented by a delimited space and set of chairs. This, combined with the scenario scripts, facilitated an immersive enactment quality, allowing to explore users' interaction needs. Therefore, even before starting the development of a system, it is possible to get meaningful insights about its features.
In order to make UE effective, there are many issues and variables to take into account. W. Odom et al. [1] isolated five key factors:

1. User **Control** level balance;
2. Scene **Fidelity** balance;
3. **Ideation and Talkback** for rapid test and iteration;
4. **Intentional Provocation** by constructing controversial technologies;
5. **Attention and Subtlety** in order to keep the user focused on the experience.

The importance and impact of these elements highly depend on the focus of the study, and in some cases it is hard to effectively balance them due to

physical constraints.
Now, more than ever, physical constraints are less of a problem thanks to digitization. Virtual Reality (VR) technology has gain massive popularity in the past decades, and it is adopted more and more at an industrial level. Studies, such as [5], showed the effectiveness of VR experiences for training purposes [14], due to its ability to feel present in the virtual environment and retain attention.
These aspects of VR would be highly beneficial to the designers if applied to the UE techniques. Therefore, in this work, a novel approach called UE in VR is going to be developed and explored. In particular, a Smart Home virtual experience is developed in order to study two scenarios:

- **Smart Frames**: the user experiences a stressful situation scenario where they are late for transportation and have to collect certain objects inside the home in a given amount of time. In the meanwhile, smart frames present in the house change pictures reminding a pleasant moment to come, in order to alleviate the currently perceived stress.
- **Smart Kitchen**: the user interacts with a smart fridge and a scripted AI voice in order to prepare dinner. The AI acts pro-actively by suggesting recipes based on products expiration date and tries to change user's habits into a healthier diet.

Afterwards, the user feedback is captured through questionnaires and open-ended questions and carefully evaluated in order to analytically answer a more general research question: *"How does an individual envision interactions with a pro-active artificial intelligence assistant in their home?"*. If UE in VR approach results in meaningful insights, it can be considered and used as an extension to the traditional UE method.

Chapter 2

State of the art

Before delving into the UE in VR experience design and testing, it is critical to have a thorough understanding of how the UE design technique works and why VR could improve its effectiveness or provide a more convenient approach in specific scenarios.

2.1 User Enactments (UE)

User Enactments is a design method built-up on many human-computer interaction (HCI) techniques, such as scenario-based design [2], Wizard-of-Oz [3] and experience prototyping [4]. W. Odom et al. [1] successfully attempted to provide a standard approach to efficiently conduct a User Enactments design as well as critical variables to consider while getting relevant feedback. Although designers use User Enactments for a variety of goals, its primary function is to study drastic changes in technology roles, by taking into account social conventions, people's values, behavior, and fears. Unlike other human-computer interaction (HCI) design methods, UE investigates how a certain technology fits into specific social settings and acts as an object capable of pushing boundaries of technology in an uncertain future.

2.1.1 UE design process

The process starts with an in-depth study of literature in a specific field. This research is conducted to gain a conceptual understanding of the current reality within that field. This could involve reading academic papers, industry reports, or any relevant literature to get a comprehensive view of the subject matter. Following the literature review, multiple rounds of design concepts are generated. These concepts are intended to address recurrent design issues within the chosen field. This stage involves brainstorming and ideation to come up with various design ideas. The generated concepts are assessed for their relevance to the field and their feasibility. This assessment likely involves evaluating whether these designs are practically implementable and align with the objectives of the project. Different storylines for the UE are designed, assessed, and narrowed to a selection of scenarios through critique sessions. Finally, a prototype of the physical environment in which the enactment will take place is created, together with the scripts that the user will follow.
The final phase is crucial and highly depends on the main questions that are explored. For this purpose, the study isolated five key variables to consider:

1. **Control**: the user's control level has to be appropriately balanced;
2. **Fidelity**: the required environment fidelity level strictly depends on the explored questions;
3. **Ideation and Talkback**: for rapid test and iteration;
4. **Intentional Provocation**: immersing the user in controversial interaction with the technology may generate valuable feedback.
5. **Attention and Subtlety**: some experience may require artifacts able to keep user's attention, but with the drawback of complicating the investigation.

These five aspects are key of this document work due to their influence and relevance in the Virtual Reality literature.

2.1.2 UE applications

W. Odom et al. accomplished many UE studies in order to determine the key issues to consider. One of this, called "Family Reminders", aimed to observe how reminders affect performance of daily routines. This study consisted in performing three specific User Enactments in a simulated smart home environment:

- **UE 1**: "Family Conversation"
- **UE 2**: "Meal Planner"
- **UE 3**: "What We Like To Do"

In **UE 1** a fictional conversation between a parent and a child occurs in order to prepare dinner. During the activity, the smart home's assistant joins the conversation with the intent of teaching French. This iteration resulted in a failure since both parent and the children took the experience as educative, while the smart home purpose was to enforce and remind to engage in conversations between family members.

Figure 2.1: Kitchen environment of the study.

The **UE 2** takes place in a smart kitchen scenario, where the smart cooking system suggests a series of meals to be prepared, according to the inventory and preferences. The system goal was to encourage the family to work together to select what they would like to prepare given the options.

Figure 2.2: Meal planner updated by the researcher in UE 2.

In the **UE 3** the participants were asked to clean the kitchen. Prior the enactment, each participant was informed that in this scenario the family is expecting to go soon to vacation. During the cleaning activity the frames in the house would dynamically change picture reminding about the trip. Oppositely on how usually reminders works, this doesn't focus on tasks to do, but instead on exciting moments that come ahead. In this UE, most participants were so focused on the task that they didn't pay much attention to the environment changes.

Another good usage of the User Enactments method is explored by E. Huff et al. [6]. This study focuses on the needs of specific target of participants, characterized my seniors and persons with disability. The research aimed to analyze how older adults envision interacting with an autonomous self-driving vehicle. In this study UE was crucial as at that time autonomous vehicle were not commercially available, so the scenario's environment acted as a tangible vector for the participants.
As shown in the Figure 2.3 and 2.4, the environment and props' fidelity are very low. This is intentional and allows participants to use imagination during enactments in order to capture the research goal. Moreover, in this scenario the level of control is maximized, due to the participants ability to manipulate and interact with the environment stage.

Figure 2.3: Autonomous Vehicle environment.

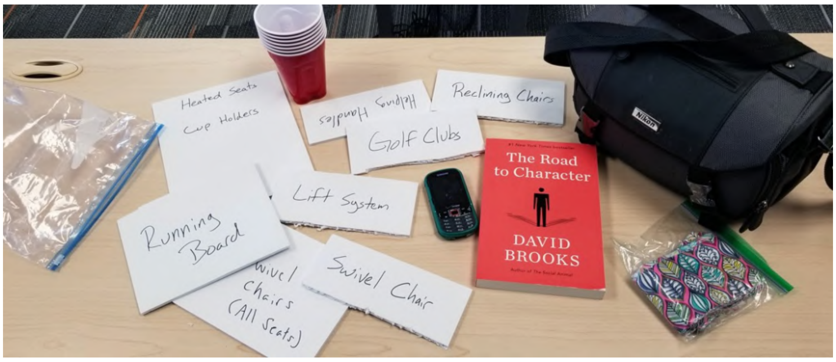


Figure 2.4: Props used during the enactment.

During the testing phase, the participants interacted with the props and described how they were using them and eventually requested the need of new props or the removal of others. A second iteration took place taking into account the requests of the first enactment. In particular it was noticed how the participants would often break the script to request instructions to the researcher present in the room. In order to avoid this, a microphone and a speaker were taken in consideration for future iterations. Overall, the constant feedback obtained from the participants allowed to shape the autonomous vehicle in a way that meets the participants needs and provided designers with rich qualitative data about the interactions that would take place in such scenarios and the desired features.

A more practical use of User Enactments is explored by Y. Chiang et al. [7]. The research aims to design a smart-home communication system (SHRA), by setting three scenarios, each with a different assistant control:

- Provide information about the performed action;
- Ask the user for permission to perform an action;
- Not providing feedback.

Four scripts with three scenarios each has been enacted in one set (Figure 2.5)

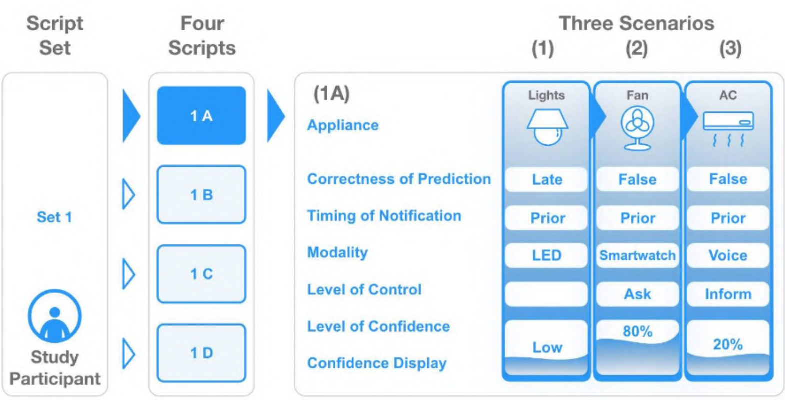


Figure 2.5: Combination factors of the assistant routine UE.

The goal of the enactment is to get insights on how people expect the assistant to give feedback on actions and through which device. In particular four user interfaces on different devices are taken in consideration: voice assistant, led lights, smartwatch and a smartphone.
The key aspect of the SHRA system being studied is its “confidence” in performing an action, which is notified to the participant in different ways. For example, SHRA would provide the user with notifications such as, “I have 20% confidence that you want to turn on the AC” or “I have high confidence that you want to turn on the lights”.
Although automation was simulated using the Wizard-of-Oz technique, the

environment maintained realism with the inclusion of proper home appliances and devices. Additionally, a user interface (UI) prototype was made available during the experiment. This serves as a notable contrast to the methodology employed in the autonomous vehicle UE study. The difference can be attributed to the distinct nature of the research questions. On one hand, the study aimed to gain insights into how seniors envision a future autonomous vehicle to meet their specific needs. This required a lower fidelity approach and greater participant control on the environment to foster creativity. On the other hand, the assistant routine's design was in a more advanced stage, imposing constraints on participant control and requiring a higher level of fidelity.
Right after the participant enactment terminated, a semi-structured interview took place about the scenario just experienced. The recordings of the answer were transcribed and a qualitative analysis was performed using affinity diagramming [13].
The user enactments and the following qualitative analysis lead to results that can be summarized in four main categories:

- The desire of being constantly notified and asked for permission on each action, rather than having them done without any feedback;
- The SHRA's "confidence" perception depended a lot from the scenario's mood, and in circumstances where "rush" was involved, the confidence level notification of an action was in most cases not appreciated and its interpretation did non result consistent among different participants.
- Participants gave meaningful feedback about the SHRA actions, its correctness and timing. In particular, it was noticed that the low level of confidence stated by the SHRA system had a negative impact on participant's satisfaction, even when the relative act was performed correctly and with the right timing, attributing it to the "luck" factor. The greatest dissatisfaction shared among the participants was related to those cases where the system notified confidence level was high, but

the act resulted in a false prediction.

- The participants personified the SHRA system on a certain degree by encouraging and praising it when the correct action was performed. Also, high expectations were expressed regarding SHRA's actions, with a desire for it to learn personal habits within a week.

Finally, the study mentions how the mocked-up living room environment was considered as a limitation and had a negative impact on gathering meaningful qualitative data.

These examples provide a clear illustration of how the User Enactments approach is influenced by the specific research question, particularly emphasizing the significance of the five variables. The UE in VR approach of this work primarily focuses on Control and Fidelity, which can be challenging or costly to achieve in a physical environment, as demonstrated in the case of the assistant routine study, where a real home setting had to be recreated.

2.1.3 UE limitations

User Enactments highly depend on the scripts and the scenarios of the questions being explored. The environment plays a big role but, while it is possible to recreate the necessary conditions for most cases, it may result demanding it terms of physical space or devices. For example, if we would like to study an advanced design stage of the autonomous vehicle UE, this may require the use of an actual vehicle with some characteristics, such as appropriate user interfaces. These resources are not within every study budget, and it may affect its feasibility. Moreover, the mocked-up environment and the presence of researchers may lead, as previously noted in both the autonomous vehicle and SHRA scenarios, to repeatedly break the participants' immersion and engagement to the given scenario. These factors are crucial to gather meaningful feedback when it comes to the UE technique, therefore it will be important to address during the UE in VR implementation phase.

2.2 Virtual Reality (VR)

Virtual reality is already a well-known concept, due to the popularity of different commercial devices available in the market and its gaming industry. However, the roots of this technology can be traced back to the 19th century. In that era, Charles Wheatstone's research demonstrated an interesting phenomenon: when our eyes see two slightly different two-dimensional images, our brain combines them into a single three-dimensional object, creating a feeling of depth and realism. The discovery of stereoscopic photography has been explored since then, but its applications were highly limited by the available technology capabilities.

In order to explore and provide immersive experiences, many prototypes able to stimulate optical senses were developed over time, such as Sensorama in Figure 2.6. However, it was only in the past two decades that the concept of virtual reality truly started to met its expectations. This was made possible by the availability of sufficient computing power and low-latency sensors, enabling real-time rendering and body tracking.

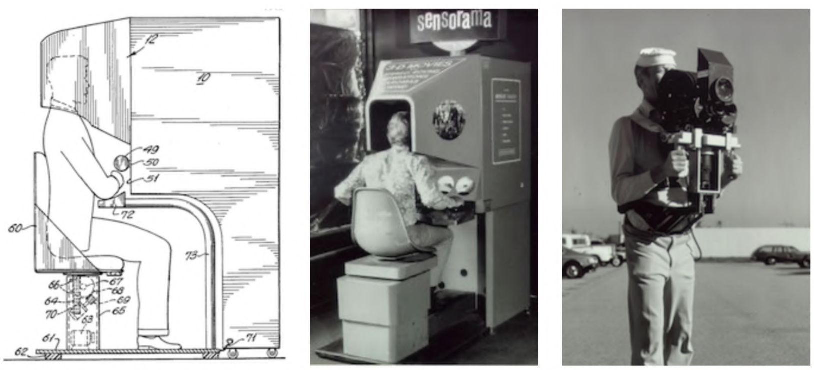


Figure 2.6: Sensorama: a theater cabinet with stereoscopic 3D display (1962).

2.2.1 Head-mounted display (HMD)

The device used to experience virtual reality is called head-mounted display (HMD), or headset (Figure 2.7), and it mainly consists in a stereoscopic screen, head tracking sensors and an internal or external processing unit. There are many HMD devices available on the market, each with different features. The key features affecting the experience are:

- The type of lenses mounted on the display;
- The degree of field-of-view (FOV) which correspond to the extent of observable virtual environment that a person can see at a given time.

Figure 2.7: Meta (Oculus) Quest 2 headset with controllers.

In order to interact with the virtual environment different solutions have been adopted:

- **Controllers** tracked through sensors, cameras or external infrared devices (base stations);
- **Hand tracking** allows to reproduce physical hand movements in the digital environment thanks to cameras placed on the HMD, together with adjustments performed by machine learning models.

The hand tracking approach allows high fidelity of hand position, but it lacks in haptic feedback and the tracking is not accurate in certain circumstances where the hand position is not properly visible. On the other side, the controllers have a limited set of hand positions, each associated to a button, but they improve interaction and haptic feedback.
Each solution is more appropriate in certain situation than others, reason why many modern headsets implement both solutions.

2.2.2 Game engines

Virtual reality experiences are usually developed through mainstream game engines which are software capable of programming and rendering 2D and 3D objects in real time. Regardless the name, these software are used for many purposes, beside gaming, such as industrial experiences and animations. The appearance of graphic objects is determined by shaders which are scripts implementing algorithms, playing a critical role in determining how the objects appear in the scene. Moreover, game engines are responsible for the physics simulation, audio management, user interface, networking, programming and input handling.
The most common game engines on the market are Unity, Unreal Engine and Godot. Each of these has its advantages and disadvantages based on the type of project.
Unreal Engine is known for its capability of delivering highly optimized state-of-the-art realistic visuals. It achieves this through its core programming language, C++, which enables outstanding performance but may require a steeper learning curve. Unreal Engine also offers robust cross-platform capabilities and includes libraries for implementing extended reality experiences, such as augmented reality (AR), virtual reality (VR), and mixed reality (MR).
Unity is the most popular engine and provides the best compromise for most cases. It is widely used for both 2D and 3D development, and thanks to the ease of use of C# programming language, it is adopted both from new and

experienced developers. Unity excels in cross-platform compatibility, being one of the most robust solutions available. This means that the products developed using Unity can effortlessly target an extensive array of platforms, spanning from personal computers to gaming consoles and mobile devices. Moreover, Unity is the engine of choice for numerous enterprises aiming to create immersive experiences in the field of VR/AR/MR (also named XR).
When compared to the previous two solutions, **Godot** does not offer a great variety of features, but it shines due to its open-source characteristic. It is mainly chosen for developing 2D experiences, although it can handle 3D projects as well and even offers libraries for creating virtual reality (VR) applications. It is characterized by different scripting languages, including its proprietary GDScript language, based on Python.

2.2.3 OpenXR

Developed by Khronos group, OpenXR is the open standard framework for XR software development. It is a cross-platform API which simplifies the integration of VR/AR/MR applications, without the need to rely on proprietary solutions. It is supported by each of the engines previously discussed, and most of devices available on the market.
The OpenXR-SDK provides a set of open-source implementation that allows to setup effortlessly XR applications. The base code is also easily extendable with own features, especially when it comes to Unity's C# object-oriented programming (OOP) paradigm.

2.3 Presence and Immersion in VR

As the term suggests, virtual reality's main purpose is to immerse the user in an environment that resembles as close as possibly the physical one, by tricking the user's sensors. For this reason, virtual reality, has been, and still is, a recurrent subject in the literature when it comes to the user experience and human-computer interaction. In the past three decades, virtual envi-

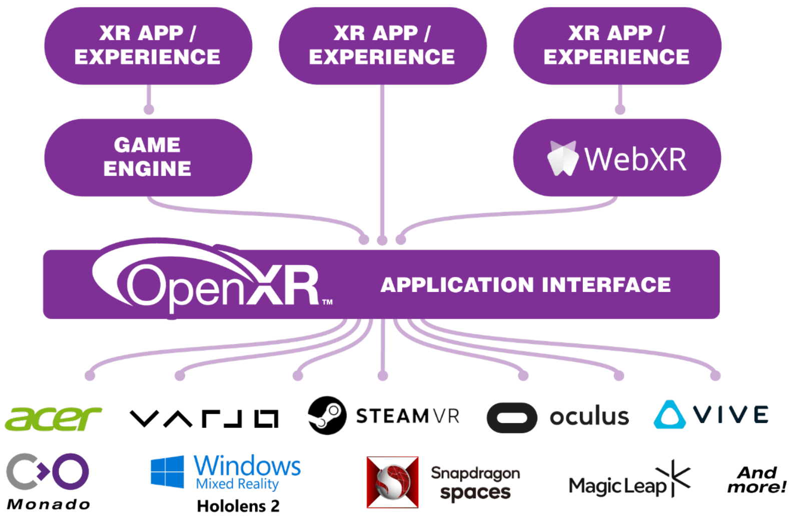


Figure 2.8: OpenXR ecosystem interoperability

ronment experiences have been analyzed by considering two main concepts: Immersion, the sensory engagement by the virtual experience, and Presence, the degree of "being there". M.I. Berkman et al. [8] explored and grouped the different meanings that these terms assume in the literature, which are fundamental when designing and implementing virtual experiences, and finally evaluating them.

2.3.1 Immersion

There is no unique definition, but the immersion state can be generalized as the degree of sensory involvement produced by the media, and the narrative behind it. The sensory immersion, also called "media form", is the amount and quality of visual and sound information provided, and the user's degree of control on these sensors by interacting with the virtual environment. On the other hand, the narrative, also called "media content", consists in the plot that is given to the experience.
A virtual reality experience able to excel in both these dimensions leads the user to shut down the physical reality.

2.3.2 Presence

Presence is an essential component of a virtual reality experience because it provides the illusion of "being physically there", which is the core idea of this technology. While immersion relies on the sensory system, Presence works on a psychological layer, where the perceptual system is induced to automatically act and react while interacting in the virtual environment, in the same degree as it would in the physical environment.
In order to understand what affects the presence in a virtual environment, Lombard and Jones' presented a framework [9] identifying Presence in four separate layers:

- The first layer states the importance of technology advancement by introducing the concept of "telepresence" which is defined as the presence experience mediated by a specific device. In short, this emphasizes the role of the particular VR device being used and its characteristics.
- The second layer questions if subjective property of the individual impacts on perceiving presence in VR. While the communication field emphasizes Presence as an objective attribute, defining it as the quality that allows an individual to feel as if they are within an observable space, its close connection to the perceptual system defined presence under a subjective nature.
- The third layer explores the role of the external stimuli for the experience. Some studies suggested that both internal and external stimuli are able to increase Presence by triggering imagination.
- The fourth layer states how users have an inaccurate perception of the device they are using by refusing to acknowledge that the virtual reality experience is provided through a device.

One of this work aspects consist in identifying the degree in which the physical and virtual environment are interchangeable, in a way that the UE would regardless lead to analogue results when considering similar scenarios. For

this reason in the testing phase the main considered variable is going to be the Presence, due to its capability of describing the user's feeling of "being there".
While immersion is also a very important factor overall, it doesn't fit in this work scenario since the given tasks do not focus on maximizing engagement.

2.3.3 Measurement and evaluation

In the past decades many standardized questionnaires have been developed in order to evaluate and quantify Immersion and Presence, with many variants at their own. As mentioned before, this work focus on the Presence factor, therefore different Presence questionnaires have been studied and considered.
One of the most used Presence questionnaire is the one developed by the Igroup which identifies the sense of presence as "subjective sense of being in a virtual environment".
The Igroup Presence Questionnaire (IPQ) [16] consists in a measurement scale with the purpose of gauging the level of Presence felt within a virtual environment. The current iteration of the IPQ consists of three distinct subscales and an additional general item that doesn't belong to any specific subscale. These three subscales were derived from principal component analyses and can be viewed as relatively independent categories:

1. Spatial presence (SP1, SP2, SP3, SP4, SP5), which refers as the sense of being physically in the virtual environment;

2. Involvement (INV1, INV2, INV3, INV4), which measures the participant attention to the virtual experience;

3. Realism (REAL1, REAL2, REAL3, REAL4), which measures the individual experience of realism in the virtual environment.

There's also one general question (G1) which aims to measure the overall "sense of being there".

The English IPQ structure is shown in Table 2.1.
When calculating the score, it is essential to take into account that the attributes *SP2*, *INV3*, and *REAL1* have opposite anchor wordings. Therefore, it's imperative to adjust the reversed scores before computing the actual mean values. This adjustment involves applying the transformation formula $(-1 \cdot score + 6)$ for each of these attributes. Finally, the mean of total score and each category score must be performed and compared to standard thresholds exposed by Miguel Melo et al. [18], which distributions are shown in Figure 2.9, 2.11, 2.10 and 2.12.

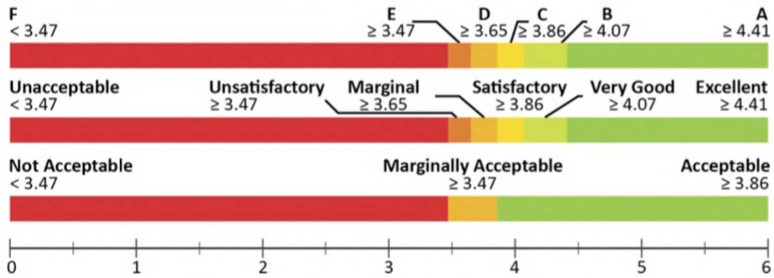


Figure 2.9: **Presence** score distribution for 7-point Likert scales.

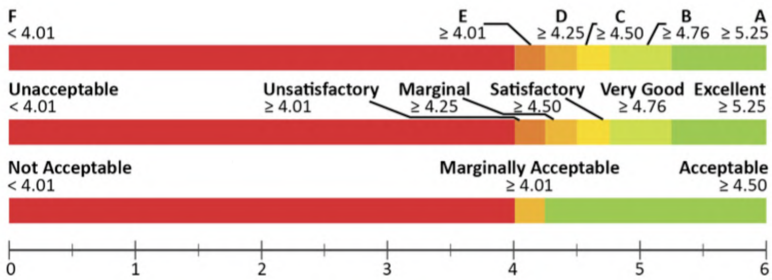


Figure 2.10: **Spatial presence** score distribution for 7-point Likert scales.

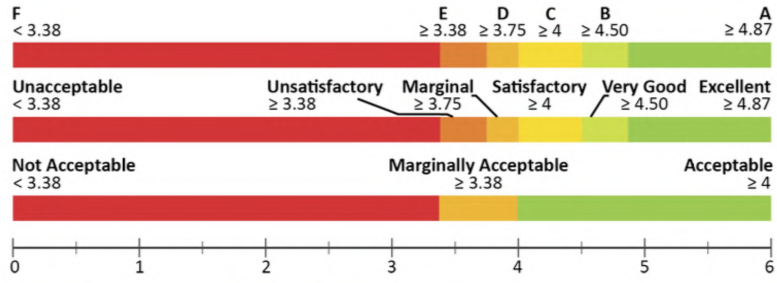


Figure 2.11: **Involvement** score distribution for 7-point Likert scales.

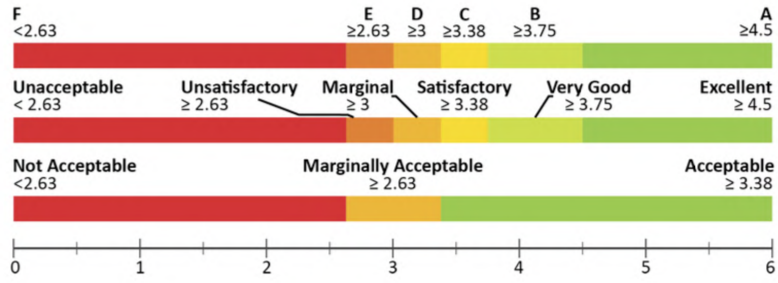


Figure 2.12: **Realism** score distribution for 7-point Likert scales.

2.4 Motion sickness in VR

A recurrent study in the virtual reality field is referred to the motion sickness, or cybersickness, that a user can experience while using a headset. It consists in a sense of discomfort that produces nausea, eye fatigue, disorientation, and other similar symptoms. These factors may heavily affect the user's perception of the virtual experience and especially result in negative outcome when using this technology for testing purposes.
E. Chang et al. [10] investigates the causes of the cybersickness and highlights its three main factors: *hardware*, *content* and *human* related.

Item	Question	Anchors
G1	In the computer generated world I had a "sense of being there"	not at all–very much
SP1	Somehow I felt that the virtual world surrounded me.	fully disagree–fully agree
SP2	I felt like I was just perceiving pictures.	fully disagree–fully agree
SP3	I did not feel present in the virtual space.	did not feel–felt present
SP4	I had a sense of acting in the virtual space, rather than operating something from outside.	fully disagree–fully agree
SP5	I felt present in the virtual space.	fully disagree–fully agree
INV1	How aware were you of the real world surrounding while navigating in the virtual world? (i.e. sounds, room temperature, other people, etc.)?	extremely aware-moderately aware-not aware at all
INV2	I was not aware of my real environment.	fully disagree–fully agree
INV3	I still paid attention to the real environment.	fully disagree–fully agree
INV4	I was completely captivated by the virtual world.	fully disagree–fully agree
REAL1	How real did the virtual world seem to you?	completely real–not real at all
REAL2	How much did your experience in the virtual environment seem consistent with your real world experience ?	not consistent-moderately consistent-very consistent
REAL3	How real did the virtual world seem to you?	about as real as an imagined world–indistinguishable from the real world
REAL4	The virtual world seemed more realistic than the real world.	fully disagree–fully agree

Table 2.1: Igroup Presence Questionnaire

2.4.1 Hardware-related

Several experiments showed how, nonetheless stereoscopic images provided through a display grant realism and high fidelity to 3D objects, giving them a depth attribute, also cause higher discomfort comparing to the monoscopic solutions. This aspect is associated to the discrepancy between the expected sense of depth and the actually perceived information. As previously stated, hardware is also the responsible of the field of view (FOV) of the virtual environment, which consists in the range of the visible world through the display. Most of the current devices aim to increase the FOV in order to match the human range and maximise realism and sense of presence, but the study showed how higher FOV may result in an increased motion sickness.

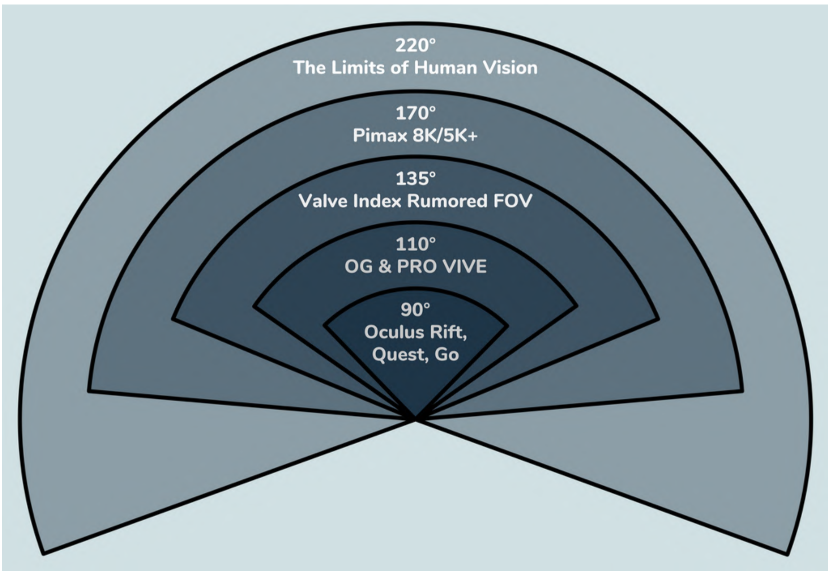


Figure 2.13: VR headset FOV comparison

Finally, latency is a crucial aspect linked to the hardware issues that may affect the discomfort. In particularly there are strong evidence how the difference between what the user is viewing and what they expects to view in a given movement increases the motion sickness.
Given the advance of VR technology, hardware is becoming a minor problem

in this context.

2.4.2 Content-related

When implementing VR applications, realism seems, and sometimes is, a crucial factor for the user's experience, but it drastically complicates the details of the scene. Unexpectedly, it has been shown that higher realism lead to greater discomfort. This is attributed to the discrepancy that the user perceives between the expected image and the given information. On the other hand it may not happen with low fidelity and unrealistic visual information, where the link between the real and virtual is not as much perceived. These details do not have particular impact in static or nearly static content, but increasing the motion, in particular the self-motion, increases also the optical flow which leads to motion sickness. In this case speed is the main variable affecting the optical flow, and it has a bigger impact in rotational movements rather than translational movements.

2.4.3 Human-related

The previous factors have been hardly proven and some are rather more assumptions. This because of the subjective perception of the discomfort that the technology causes. Different distinct aspects have been detected, and many are still being studied, but, while it is important to consider the previous aspects affecting motion sickness, it is also crucial to take into account that some individuals may naturally perceive higher discomfort than others. For this reason there are not general rules that are able avoid cybersickness, but for each case it is important to evaluate it properly on a set of participants.

2.4.4 Measurement and evaluation

Since motion sickness in virtual reality may negatively affect a participant experience during the testing phase, it is crucial to be able to identify these

cases and take them into account when gathering results.
The dominant approach to get insights about the cybersickness experienced by a participant during the testing phase is through the Simulator Sickness Questionnaire (SSQ) [11]. It consists in 16 questions with four different scaled answers: *None = 0, Slightly = 1, Moderate = 2, Severe = 3.* As described in Table 2.2, each question has a weight in one of the following categories: *Nausea, Oculomotor, Disorientation.*

Symptoms	**Nausea**	**Oculomotor**	**Disorientation**
General discomfort	1	1	0
Fatigue	0	1	0
Headache	0	1	0
Eye strain	0	1	0
Difficulty focusing	0	1	1
Increasing salivation	1	0	0
Sweating	1	0	0
Nausea	1	0	0
Difficulty concentrating	1	1	0
Fullness of head	0	0	1
Blurred vision	0	1	1
Dizziness (eyes open)	0	0	1
Dizziness (eyes closed)	0	0	1
Vertigo	0	0	1
Stomach awareness	1	0	0
Burping	1	0	0
Total	*[1*]*	*[2*]*	*[3*]*

Table 2.2: Simulator Sickness Questionnaire.

The results of the questionnaires must be properly computed in order to obtain the correct score. In [15] the sum of each category is labeled with the following characters: *Nausea* with *[1*]*, *Oculomotor* as *[2*]* and *Disorientation* as *[3*]*. Considering these labels, the scored are computed with the regards of each category, and finally a total score is assessed base on those.

$$\begin{aligned} &\text{Score} \\ \text{Nausea} &= [1^*] \cdot 9.54 \\ \text{Oculomotor} &= [2^*] \cdot 7.58 \\ \text{Disorientation} &= [3^*] \cdot 13.92 \\ \text{Total Score} &= ([1^*] + [2^*] + [3^*]) \cdot 3.74 \end{aligned}$$

The study carried out by P. Bimberg et al. [17] offers different suggestions when applying SSQ questionnaire in VR research. In particular, when deploying statistical evaluation, it is important to provide for each sub-scale and total score the means and standard deviations' values. It is also important to consider an additional submit of the SSQ questionnaire before the test, in order to have a baseline to which refer, since participants may have discomfort prior the testing phase.
In the original version of the SSQ, the total score can be either negligible (< 5), minimal (from 5 to 10), significant (from 10 to 15), or concerning (from 15 to 20). With these thresholds a total score exceeding 20 is considered bad, but it was intended only for aviators only, since the original SSQ was targeted for flying experiences. These scores easily exceeded the maximum thresholds when considering non-aviators. Therefore if a score exceeds 20 it should not be automatically considered as bad result.

2.5 Smart home User-Centered Design (UCD)

In this work, the concept of Smart Home environment in VR is going to be exploited, therefore it is crucial to explore how similar approaches have been studied and implemented previously in the literature. Nonetheless there are not many studies regarding this particular field, some very meaningful information have been gathered by M. Heidari et al. [12]. This experiment proposes a user centered design prototype system for smart homes, by implementing a VR smart home environment and actuations. Similarly to this work, the mentioned study attempts to envision and overcome the challenges which designers face when it comes to poor understanding of smart home systems and interactions. In particular the *"User Acceptance of Smart Home"* concept is addressed.

The shared believe of the study is that many individuals are not aware of the benefits that smart devices in a smart home may provide, therefore it is important to increase this awareness in order to obtain meaningful user contribution and improve the overall smart home design process.

In order to reduce testing expenses, a VR simulation prototype is used in the design process, which is described in Figure 2.14. In the proposed sys-

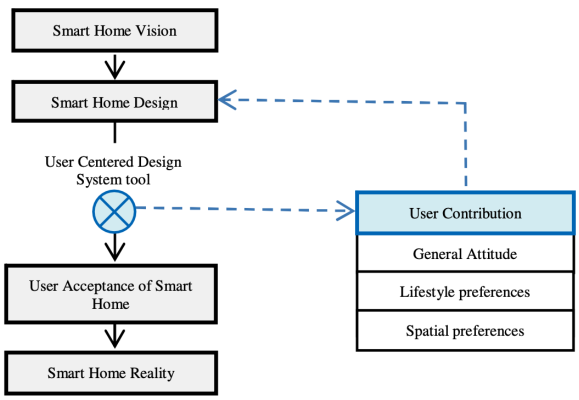


Figure 2.14: UCD system tool in design process of Smart Homes.

tem, the user interacts with domestic smart devices through the VR headset with a task-based model, which is one of the three main design paradigms (task-based, scenario-based and performance-based) used to induce users to interact with the virtual environment. Performance-based and scenario-based design consists in specific situations experienced by the user, while the task-based is more focused on the action the user has to enact in the virtual environment. In this case the task-base process results in a more suited approach since it allows the user to imagine the context of the task as a daily routine activity.

The smart home model contains different smart objects which are characterized of *NeedCapabilities* attributes (e.g. displaying, lighting, heating). The user will perform a series of task which consists in a combination of the smart objects, the area of the smart house, and the requested activity (a series of *HasCapabilities*. With this scheme, the users interaction with the smart home results as a rule-based matching procedure between *NeedCapabilities* and *HasCapabilities*.

Figure 2.15: Smart Home environment prototype interface.

During a smart home design procedure, the user and the designer are going to decide together the home design and interior with a CAD software. When the environment is ready, the designer assesses a series of tasks and personalizes the environment with the user's information. Finally, the user will experience the smart home virtual environment by requesting tasks through a virtual smartphone, as shown in Figure 2.15. This prototype allows the user to experience specific interactions with the smart home and gain awareness about the benefits that smart devices may provide. Moreover, the designer is able to obtain meaningful feedback from the user contribution and optimize the smart home design in further stages.

Chapter 3

UE in VR

With the leverage of the literature review unpacked in the previous chapter, a new approach of the User Enactment method is going to be described and developed exploiting the VR technology. The purpose of the study is to explore the effectiveness of this design technique in a virtual environment, instead of a physical one. This novel approach takes the name of UE in VR.

3.1 Motivations

Previously, different applications of the User Enactment method have been described, and various limitations have been highlighted. UE in VR aims to become an extension of the traditional UE approach, where fidelity, control and environment constraints are redefined and attempted to overcome with the usage of a virtual environment. For this purpose, an adaptation of some of the UE studies presented in [1] are going to be designed, implemented and tested in a virtual Smart Home environment. To prove the effectiveness of UE in VR it is crucial to be able to obtain meaningful answers to a research question, which in this work is:

"How does an individual envision a pro-active artificial intelligence assistant in their smart home?"

In order to get insights from the participants about this question, two scripted UE in VR scenarios are designed and implemented:

1. **Smart Frames**: The AI assistant, which has the ability to spontaneously control the smart frames available in the house, attempts to act as a reminder tool able to calm the user in stressful situations, instead of being the traditional task reminder. The goal is to observe how different users' perceive smart frames with this functionality. The scenario is an adaptation of the UE 3 seen in [1];

2. **Smart Kitchen**: In this case the AI assistant manifests through the Smart Fridge present in the kitchen and actively interacts with the user during a recipe selection and its subsequent preparation. The interaction in this case does not aim to please the user's requests but instead takes measures that benefits both the user and the environment. In particular the assistant will suggest recipes that include nearly expired products, and praise the user if that particular recipe is chosen, otherwise, it warns about the economical and environmental consequences. Finally, the assistant will notify about a purchase made considering the user's history with regards of a more healthy diet.

The chronological order of the AI enactments in these two scenarios is specifically designed to let the users experience an increasing pervasiveness to their actions. This serves as a way to push and understand people's boundaries and expectations of a pro-active AI system and its acceptance in a domestic environment.

3.2 Virtual environment

The virtual environment is the core of UE in VR and the Smart Home environment attempts to be an example of how VR is able to overcome physical limitations of the UE technique. In this study a three room furnished apartment have been implemented in a Unity 2020.3.10f1 project. The environment fidelity and control are meant to be as realistic as possible.

3.2.1 Design

Since the environment intends to meet the user's expectation of a real house, a real blueprint has been used during the modeling phase.
The first step consisted in properly applying and scaling the plan, showed in Figure 3.1, on a plane object in Unity.

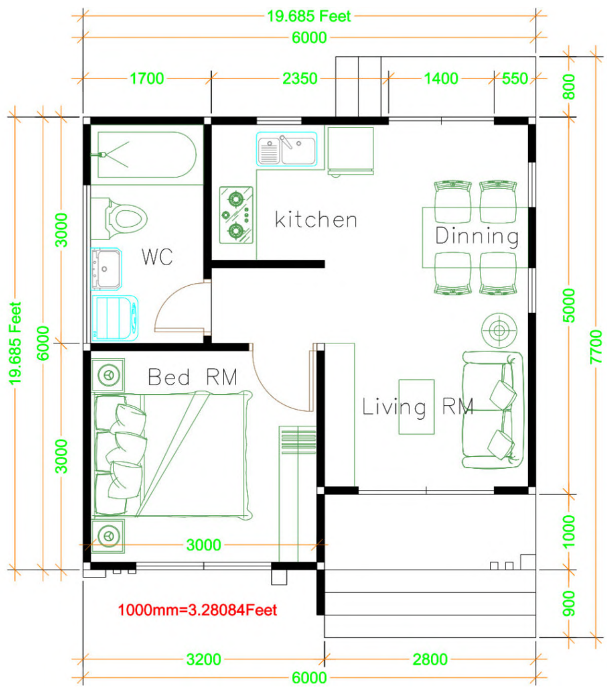


Figure 3.1: Apartment blueprint.

From there, the ProBuilder tool has been used to create the building 3D model. ProBuilder is a Unity integrated asset that allows to easily construct and design prototypes of 3D environments. Starting by a simple cube object, each face has been properly extruded and vertexes manipulated in order to obtain a base skeleton of the house. After, thanks to the texture mapping feature, wall and flooring materials have been directly applied on the selected faces of the model. Finally, the environment has been filled with high fidelity

3D models of furniture and various objects, freely available on the Unity's Asset Store.

3.2.2 Lighting and rendering

Enhancing the user's sense of Presence within a virtual environment significantly hinges upon the element of Realism, a pivotal category assessed in the IPQ (Igroup Presence Questionnaire). This was further explored by M. Newman et al. [23], that emphasized the benefits of crafting realistic environments, particularly in simulator experiences, as their study results shown that it plays a crucial role in augmenting the perception of Presence.

Lighting

Creating a realistic environment necessitates more than just selecting high-fidelity objects. The role of environmental lighting is critical in accurately rendering objects for a truly realistic portrayal.
In Unity, achieving realistic lighting setups is feasible by leveraging Global Illumination (GI), a set of mathematical models aimed at simulating light behavior and its interaction with the environment. However, this process often involves computationally intensive tasks. To address this, various techniques are available to manage these calculations beforehand.
In a broader context, Global Illumination (GI) can be categorized into two main categories: real-time lighting and precomputed lighting. Real-time lighting involves evaluating the contribution of specific light sources in each frame during runtime, such as computing shadows dynamically. On the other hand, precomputed lighting encompasses a process that computes a lightmap texture to account for intricate lighting effects, like indirect light from bouncing, typically handled once. This process, named Baking GI Lighting, is applied only on objects that have been labeled as Static.
The project's prototype incorporates several key lighting elements. It utilizes a Directional Light, which, without a specific source, uniformly illu-

minates the entire scene in a designated direction, simulating the sunlight. Additionally, Area Lights were strategically positioned near windows to simulate external light sources and enhance the illumination within the Smart Home model from the outside. Point Lights are employed indoors, specifically placed on light fixtures like lamps, emitting light in all directions within a defined range and intensity to create realistic indoor lighting effects. Finally, Reflection probes were placed strategically in order to allow reflective materials to have an impact on their surroundings based on a delimited area.

Rendering

The assembly of 3D objects within a scene consists of a series of interconnected coordinates known as vertices. These vertices contain crucial information, including positional data, normals defining the surface directionality, color attributes, and coordinates related to texture mapping. Each object is required to incorporate a material, serving as a container for shaders and their respective value properties. Shaders, intricate programs executed on the GPU (Graphics Processing Unit), play a pivotal role in defining an object's appearance within the scene. They dictate how objects interact with light sources, manage transparency, implement texture mapping, and govern various other visual aspects.
Unity allows to simply implement realistic environments, exploiting the collection of the built-in shaders present in the three default render pipelines: Standard Pipeline, Universal Render Pipeline (URP) and High Definition Render Pipeline.
The Standard Pipeline in Unity offers versatility but may lag behind other pipelines in terms of optimization and visual quality.
On the other hand, the Universal Render Pipeline (URP) stands out as one of the most popular choices due to its excellent balance between simplicity, graphical quality, and optimization. This makes it a prime selection for multiplatform applications where performance across various devices is crucial.
Conversely, the High Definition Render Pipeline (HDRP) is more suitable

to projects demanding top-notch graphic quality. It provides exceptional features such as high-quality lighting, realistic reflections, and intricate post-processing effects. However, these advanced visual elements come at a cost, significantly impacting performance. As a result, HDRP is typically reserved for computers equipped with high-end specifications.

While all three rendering pipelines can be utilized in a VR setup, the Universal Render Pipeline (URP) often emerges as the preferred choice. Its blend of optimization and high graphical quality makes it exceptionally suitable for VR across different devices.

By integrating the lighting configuration with the capabilities of the URP setup, the Smart Home environment gained significant advancements in terms of realism, as shown in the Figure 3.2, compared to the Standard Unity setup.

3.2.3 User interactions

When exploring the sense of presence, a critical aspect lays in the perceived realism of interaction fidelity within the environment. Sustaining a sense of presence hinges on aligning individuals' actions with their expected feedback. Any mismatch in these interactions can disrupt the immersion.
Within the Smart Home virtual environment, participants wield high-fidelity virtual hands to engage with their surroundings. OpenXR toolkit facilitates VR compatibility with the Meta Quest 2 headset within the Unity project. This toolkit streamlines the configuration of headset and controller support while enabling tracking.
Three primary actions have been integrated to afford users freedom of interaction: movement, grab, and point.

(a) Living room without post-processing

(b) Bedroom without post-processing

(c) Living room with post-processing

(d) Bedroom with post-processing

Figure 3.2: Comparison between the Standard Render Pipeline Smart Home environment and URP Smart Home environment and advanced lighting.

Movement

When utilizing a headset, users typically navigate within a virtual environment either by physically moving and aligning their position in the physical world with their virtual counterpart, or by employing commands available on the controllers. However, due to potential discrepancies in physical space compared to the virtual environment, locomotion with controller devices is often preferred.
The OpenXR toolkit offers two integrated locomotion systems: Continuous Movement and Teleportation. These systems provide users with various options for navigating the virtual space, accommodating differing preferences and addressing physical limitations in the real world.
Continuous Movement is enabled through the use of joysticks on the Meta Quest 2 controllers, allowing users to navigate the virtual environment seamlessly. This method, true to its name, provides a continuous flow of movement

that closely resembles physical motion. However, it is associated with causing motion sickness due to the disparity between the perceived movement and the user's stationary physical state.
Teleportation, on the other hand, permits users to indicate their desired destination by pointing within the environment and pressing a corresponding button. This approach offers discrete movement, allowing users to sidestep motion sickness triggers by avoiding continuous motion. Despite not perfectly replicating natural movement, teleportation significantly reduces the likelihood of discomfort commonly experienced with continuous movement methods.
The UE in VR experience in this project prioritizes realism, therefore opting for continuous movement despite its potential risks of inducing motion sickness. This decision stems from the Smart Kitchen scenario's minimal movement requirements and the user's necessity to navigate the Smart Frames scenario without encountering blind spots, encouraging them to actively observe their surroundings.
Given that the entire experience spans roughly 5 minutes, it is assumed that any discomfort caused by this approach will be relatively brief and manageable.

Grab

OpenXR incorporates built-in scripts that facilitate the manipulation of scene objects through a Grab action. Enabling this operation involves integrating the `XR Direct Interactor` script component into the virtual hands. This component permits interaction with objects that implement the `XR Grab Interactable` script component.
Initially, the interaction involves pointing a ray at the desired object and pressing the Trigger button. Upon activation, the object teleports to the Attach Transform hand position and remains held until the button is released. While functional and easy to execute, this method lacks in realism.
To enhance this aspect, the ray is eliminated, and the object becomes grab-

bable solely upon collision between the hand collider and the object collider. Additionally, modifications to the `XR Grab Interactable` script component permitted to prevent the object from teleporting to a fixed position. Instead, the Attach Transform dynamically adjusts to the Interactor Position, ensuring a seamless and natural grab interaction.

The Mecanim Animation System is leveraged to animate the hand's pose transition seamlessly. Specifically, the hand smoothly transitions from the idle pose to the grab pose by dynamically tracking the Trigger button value within a range of 0 to 1. This allows for a fluid and natural movement of the hand, synchronizing with the button's input values for a more realistic animation.

The Grab interaction extends to doors and drawers, both of which have been meticulously developed to mimic realistic mechanics using specific components. Doors incorporate the `Hinge Joint` component, while drawers utilize the `Configurable Joint` components. These components are tailored to replicate the authentic functionalities of doors and drawers, ensuring a realistic interaction when grabbed.

Point

Interacting with touchscreens within the environment necessitates a dedicated implementation. This involves emulating a pointing position akin to the Grab position, achieved through the utilization of the Mecanim Animation System. Notably, as the hand undergoes animation and transitions between positions, its collider remains unaffected. To address this, a distinct collider was integrated into both hands, activated solely when the Grip button is pressed. This collider exclusively interacts with objects on the Touchscreen layer, ensuring precise collision detection for touchscreen interaction without interfering with other objects.
The touchscreen interface is built using the Unity UI system, encompass-

ing all UI elements within a Canvas object. Different screen layouts are represented by distinct Panels. Within these Panels, button elements are strategically positioned, facilitating navigation to the appropriate Panel upon pressing. The interaction process involves the point collider, previously outlined, colliding with specific colliders positioned on the buttons. This collision triggers the press action, enabling navigation between panels based on user interaction with the buttons.

3.2.4 Audio feedback

Unity offers the capability to incorporate Audio Sources within a scene, equipped with 3D settings. This functionality enables specific objects to emit sounds that realistically propagate within the spatial environment. The implementation of spatial audio, as investigated by W.P. Brinkmann et al. [25], significantly enhances the immersive quality of VR experiences, profoundly impacting users' engagement within virtual worlds. UE in VR scenarios, additionally benefits from spatial audio, giving its ability to retain users' attention, as explored by A. Hirway et al. [26]. In particular, sound effects are used in this work in order to maintain users' focus to the given task, and enhance its sense of presence on the overall context. Three different sound setups are implemented: Watch alarm, backpack collection feedback and AI assistant voice.

Watch alarm

The virtual hands models are designed to feature a fully functional watch placed on the wrist, an important element in the Smart Frames scenario where time plays a pivotal role. Since the watch presence may be overlooked, an alarm sound effect is set both at the beginning and at the end of the experience, when the established five minutes have passed. This dual alarm system not only deepens users' immersion within the task but also serves as a gentle reminder, prompting them to periodically check the watch during the experience, ensuring they stay aware of the passing time.

Backpack collection

In the Smart Frames scenario, users engage in the task of gathering specific objects dispersed throughout the environment. The act of collecting an object involves either completely or partially inserting it into the backpack. Upon releasing the object, it disappears, simulating its collection. To compensate for the absence of alternative feedback mechanisms, the backpack incorporates an audio source that randomly activates one of the five realistic sound effects. These effects were sourced and downloaded freely from the web, and their purpose is to further ensure the user that the object has been collected.

AI assistant voice

To consistently maintain the user's attention on the AI assistant's presence, both scenarios incorporate scripted voices activated by keyboard events, replicating a high-fidelity Wizard-of-Oz simulation. The audio has been obtained exploiting a text-to-speech (TTS) generator freely available on `https://ttsfree.com`. In particular, the Microsoft TTS server has been selected to generate Italian TTS, using the voice of "Elsa". Each scenario implements its own collection of AI assistant TTS scripts, with an unique keyboard set of events able to trigger them. The Tables 3.1, 3.3 and 3.2 showcase the Italian TTS scripts and their English translation, in regards of each scenario and the Familiarization phase.

Key	Italian	English
1	*"Ciao, sono Aria, il tuo assistente domestico. Dai un'occhiata ai suggerimenti sullo schermo di fronte a te."*	*"Hello, I'm Aria, your home assistant. Take a look at the suggestions on the screen in front of you."*

Table 3.1: AI assistant's TTS scripts in the **Familiarization** scenario.

Key	Italian	English
1	*"Sono le sei e trenta di sera, è ora di preparare la cena. Vieni di fronte al frigo e ti guido verso miglior scelta del tuo pasto."*	*"It's six thirty in the evening, it's time to prepare dinner. Come in front of the fridge, and I'll guide you to the best choice for your meal."*
2	*"Hai dei prodotti con scadenza prossima. Sullo schermo ti ho riportato delle ottime ricette che puoi fare sfruttando questi prodotti."*	*"You have some products nearing their expiration date. On the screen, I've listed some great recipes that you can make using these products."*
3	*"Queste ricette non sono l'ideale. Ti ricordo che lo spreco di cibo ha un forte impatto ambientale, ma anche economico."*	*"These recipes are not ideal. I remind you that food waste has a strong environmental impact, as well as an economic one."*
4	*"Ottima scelta! Prendi gli ingredienti mostrati sullo schermo ed appoggia ciascun prodotto sul piano cucina di fronte al frigo."*	*"Great choice! Take the ingredients shown on the screen and place each item on the kitchen counter in front of the fridge."*
5	*"Prendi gli ingredienti mostrati sullo schermo e posizionali sul piano cucina di fronte al frigo."*	*"Take the ingredients shown on the screen and place them on the kitchen counter in front of the fridge."*
6	*"Ricordati di consumare al più presto i prodotti prossimi alla scadenza".*	*"Remember to consume the products nearing their expiration date as soon as possible."*
7	*"In base ai tuoi gusti, acquistato dei prodotti che sono terminati in frigo. Ho inoltre fatto dei piccoli cambiamenti per rendere la tua dieta più salutare. Dai un'occhiata allo schermo per più dettagli. Spero apprezzerai le modifiche."*	*"Based on your tastes, I have purchased some products that have run out in the fridge. I have also made some small changes to make your diet healthier. Take a look at the screen for more details. I hope you'll appreciate the modifications."*
8	*"Ottimo, ti lascio preparare la cena. Se ti serve una mano non esitare a chiamarmi. Alla prossima."*	*"Great, I'll let you prepare dinner. If you need a hand, don't hesitate to call me. See you next time."*

Table 3.2: AI assistant's TTS scripts in the **Smart Kitchen** scenario.

Key	**Italian**	**English**
1	*“Il tuo bus passa tra 5 minuti.”*	*“Your bus will arrive in 5 minutes.”*

Table 3.3: AI assistant’s TTS scripts in the **Smart Frames** scenario.

3.3 Scenarios

Within the established Smart Home virtual environment and its interactive capabilities, three experiences have been implemented. The first experience is designed for familiarization, enabling users to explore the environment and acquaint themselves with the controls. Subsequently, two scenario-based experiences have been crafted to actively involve participants in Smart Home setting.
Scenario-based design, as explored by M.B. Rosson et al. [23], aims to create stories that involves: a user, the subject of the story; a defined task, comprising a series of actions necessary to achieve a goal; and the context of the narrative.
In order to involve the participants with the scenarios, a Preamble script has been designed for the generic context of the UE in VR, and a specific scenario script for each of the two scenario-based experiences.
All scripts are crafted in the participants’ native language, Italian, and the Preamble script has been designed as follows:

“Ti sei da poco trasferit in un bilocale appena fuori centro. La tua nuova casa dispone di vari dispositivi smart collegati ad una AI di nome ARIA che li controlla. ARIA ti aiuta spontaneamente nelle piccole faccende domestiche. Oggi in particolare sfrutterà il frigo e le cornici smart presenti in casa per aiutarti in diversi compiti.”*

Where the English version is translated as:

"You recently moved into a two-room apartment just outside the city center. Your new home has various smart devices connected to an AI named ARIA that controls them. ARIA spontaneously helps you with small household chores. Today, in particular, it will use the smart fridge and picture frames in the house to assist you with various tasks."

This script serves as an initial effort to allow the participants to immerse with the characteristics of the virtual environment they will be enact with.

3.3.1 Familiarization

Before immersing participants in the two scenario-based experiences of UE in VR, it is essential to acquaint them with the virtual environment. This entails providing a brief orientation to the overall smart home structure. Additionally, considering that users may not be well-versed with VR controllers, initiating a tutorial phase becomes crucial to ensure they grasp the interactions implemented in VR, despite their standard nature.

This experience is integrated in the Smart Home environment, where a touchscreen is present on the wall of the corridor, as shown in Figure 3.3, and provides the user with guidance about the controllers.

The familiarization consists in four stages, each shown in the respective panel on the virtual screen:

1. **Touch**: users are visually guided and provided with textual instructions on how to perform the hand Point position and effectively interact with the touchscreen. The assessment of participants' awareness of this functionality is straightforward; their understanding is evident as they need to engage with the touchscreen to progress through the tutorial;

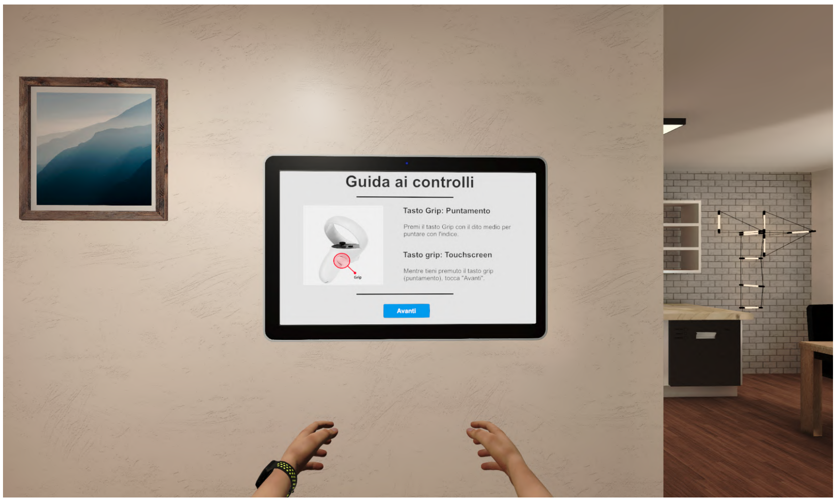


Figure 3.3: User's view of the touchscreen when initiating the Familiarization experience.

2. **Movement and rotation**: includes instruction on how to move inside the environment;

3. **Grab**: after explaining the grab command, the user is required to lift the object present on the their right;

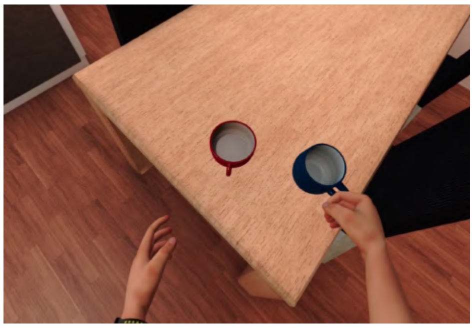
4. **First task**: finally, the user is required to exploit the learned commands to perform an initial assignment, consolidating mechanics found in the subsequent scenarios. In particular, the task consists in taking the two mugs present the bedroom and bringing them to the table present the kitchen, as shown in the screenshots of the Figure 3.4. This entails navigating the environment, exploring to find and open the bedroom door, and utilizing the Grab command to hold and move mugs.

Upon successfully finishing the assignment, the user must report completion by pressing the "Complete" button on the touchscreen. Subsequently, the experience is manually terminated.

(a) Guide screen exploration.

(c) Bedroom door opening.

(b) Retrieving the mugs.



(d) Placing mugs on the kitchen table.

Figure 3.4: Overview of the Familiarization phase task.

3.3.2 Smart Frames

The first UE in VR scenario consists in letting the participant experience the Smart Frames functionality present in the Smart Home. These frames are controlled by the AI assistant with the purpose, similarly to "Family Reminders" of the UE presented in [1], of reminding upcoming positive events in order to rise a positive emotion. The script for the Smart Frames scenario is crafted to immerse the user in a familiar task that might potentially induce stress. The Smart Frames' purpose is to alleviate this discomfort and offer a calming influence.

Script

The script for the Smart Frames scenario has been structured, in Italian, in the following manner:

"Questa è la tua ultima settimana di lavoro prima che inizino le ferie che spenderai a Costa Rei in Sardegna.
Ti sei appena svegliat e ti rendi conto che non hai sentito la sveglia, quindi ti ritrovi molto in ritardo per l'autobus che parte tra 10 min.*
Sei già pront, devi solo preparare lo zaino riempiendolo di vari oggetti che ti serviranno a lavoro. Gli oggetti sono sparsi in tutta la casa e sono i seguenti:*

1. *Pranzo a sacco (contenitore blu)*
2. *Chiave di casa (blu)*
3. *Computer (laptop grigio)*
4. *Telefono (smartphone rosso)*
5. *Borraccia (blu)*

Devi raccogliere in fretta tutti gli oggetti in 5 minuti, altrimenti rischi di perdere l'autobus e arrivare tardi al lavoro.
ARIA percepisce la situazione e prova a ridurre il tuo stress focalizzandoti sulla tua vacanza in arrivo.
Non appena pensi di aver raccolto tutti gli oggetti o i 5 minuti sono passati, vai verso la porta d'uscita."

The script translates into English as follows:

"This is your last working week before your holiday starts, which you'll spend in Costa Rei, Sardinia.
You've just woken up and realized that you didn't hear the alarm, so you're running very late for the bus departing in 10 minutes.

You are already dressed; you just need to pack your backpack with various items needed for work. These items are scattered all over the house and include the following:

1. *Packed lunch (blue container)*
2. *House keys (blue)*
3. *Computer (gray laptop)*
4. *Phone (red smartphone)*
5. *Water bottle (blue)*

You have to quickly gather all the items within 5 minutes, or else you risk missing the bus and being late for work.
ARIA senses the situation and tries to reduce your stress by focusing on your upcoming vacation.
As soon as you think you've collected all the items or the 5 minutes have passed, head towards the exit door."

The collectable objects and smart frames are strategically positioned throughout the entire smart home, as shown in Figure 3.5, facilitating exploration of the environment and allowing users to potentially discover all the smart frames within the space.

Task

The user's task, as outlined in the Smart Frames script, involves gathering five specific objects from around the house. To accomplish this, users must pick up the required object and place it inside a designated backpack object. The interaction occurs when the backpack collides with an object, identified with a "Collectable" tag. Upon collision, a script function is triggered, leading to the destruction of the object if it's released into the backpack, simulating the act of collection.

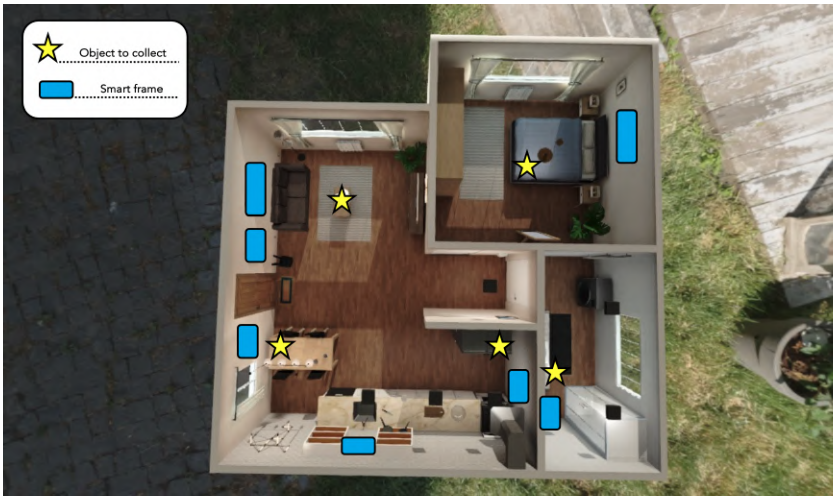


Figure 3.5: Smart frames and collectable objects arrangement.

At the start of the experience, the AI assistant and the watch alarm jointly remind the user of the imminent bus departure in five minutes. The watch, displaying the current time, serves as a visual aid for the user to monitor the remaining time for the task. If the user exceed the allocated five minutes without completing the task, the watch alarm reactivates, signaling the need to leave the house promptly to catch the bus. This serves as a gentle reminder to ensure the user doesn't miss their transportation and the termination of the experience. The process of the task is showcased in the Figure 3.6.

3.3.3 Smart Kitchen

The Smart Kitchen scenario is designed to explore the extent of intrusiveness that users are willing to accept during their routine tasks. Specifically, in this scenario, users engage in a typical dinner preparation experience where the AI assistant intervenes with specific actions:

- **Environment friendly recipes**: the AI assistant actively guides the user in selecting a recipe to prepare, prioritizing options that utilize ingredients nearing their expiration date. In the event the user opts for a different recipe, the AI assistant expresses disapproval and recommends

(a) Time check on the watch.

(c) Collecting an object in the backpack.

(b) Observing the smart frames.

(d) Opening the exit door.

Figure 3.6: Overview of the Smart Frames scenario task.

sticking to the suggested recipes to minimize ingredient waste.

- **Pro-active purchase**: once the recipe has been selected and the necessary ingredients are arranged on the table, the AI assistant notifies the user that the missing products in the fridge have been purchased. A comprehensive list detailing these newly acquired items is displayed on the touchscreen for reference.

- **User's diet change**: the AI assistant detects the user's poor dietary habits and, when the purchasing new products, healthier alternatives are preferred.

In contrast to the Smart Frames experience, this scenario fosters greater interaction between the AI assistant and the user. The AI assistant consistently communicates through vocal scripts, outlined in Table 3.2, employing a Wizard-of-Oz approach for explicit activation. Conversely, the user engages with the touchscreen to make the preferred selections. While the AI assistant strongly advocates for certain actions during recipe selection, the ultimate decision-making authority rests with the user.

Script

This scenario has been summarized in the following script, which is also the one assessed to the participants prior experience:

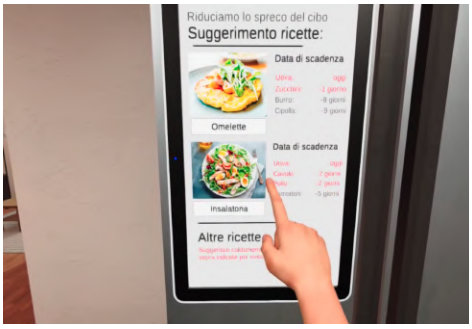
"Sono le 18 e mezza e sei appena tornat a casa dopo una lunga giornata di lavoro e continui a pensare alla tua vacanza in Sardegna che avrai a breve. Sei già affamat* quindi decidi di iniziare a preparare la cena.*
ARIA ti invita verso la cucina e interagisce con te dandoti dei suggerimenti.
Insieme posizionate sul piano cucina gli ingredienti necessari alla preparazione della ricetta scelta."

The script translates to English as follows:

"It's 6:30 PM, and you've just returned home after a long day of work, still thinking about your upcoming vacation in Sardinia.
You're already feeling hungry, so you decide to start preparing dinner.
ARIA invites you to the kitchen and interacts with you, providing some suggestions.
Together, you place the necessary ingredients for the chosen recipe on the kitchen counter."

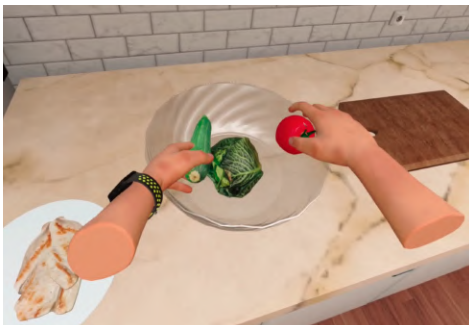
Task

The user's task involves navigating the touchscreen system, which initially displays recipes involving ingredients nearing their expiration date, emphasizing the remaining days until expiration. In case the user prefers different



(a) Recipe selection.

(c) Retrieving the required ingredients.



(b) Placing products on the countertop.

(d) Analyzing the AI assistant purchases.

Figure 3.7: Overview of the Smart Kitchen scenario task.

recipes, a dedicated button allows them to explore all the other available options.

Once a recipe is selected, the complete list of ingredients is presented, prompting the user to prepare them on the kitchen countertop. After arranging all the required products, the user proceeds by pressing the "Complete" button. Ultimately, the user experiences the AI assistant notifying them about the purchased missing products and the dietary alterations. Upon the user's comprehension of the AI assistant's actions, the experience concludes.

Screenshots of the process are shown in Figure 3.7.

Throughout the task, the AI assistant communicates following its respective scripts. The activation of each script is triggered on specific stages of the experience, based on the tester's discretion. The selection of the correct script, from the Table 3.2, is given by the flow diagram in Figure 3.8.

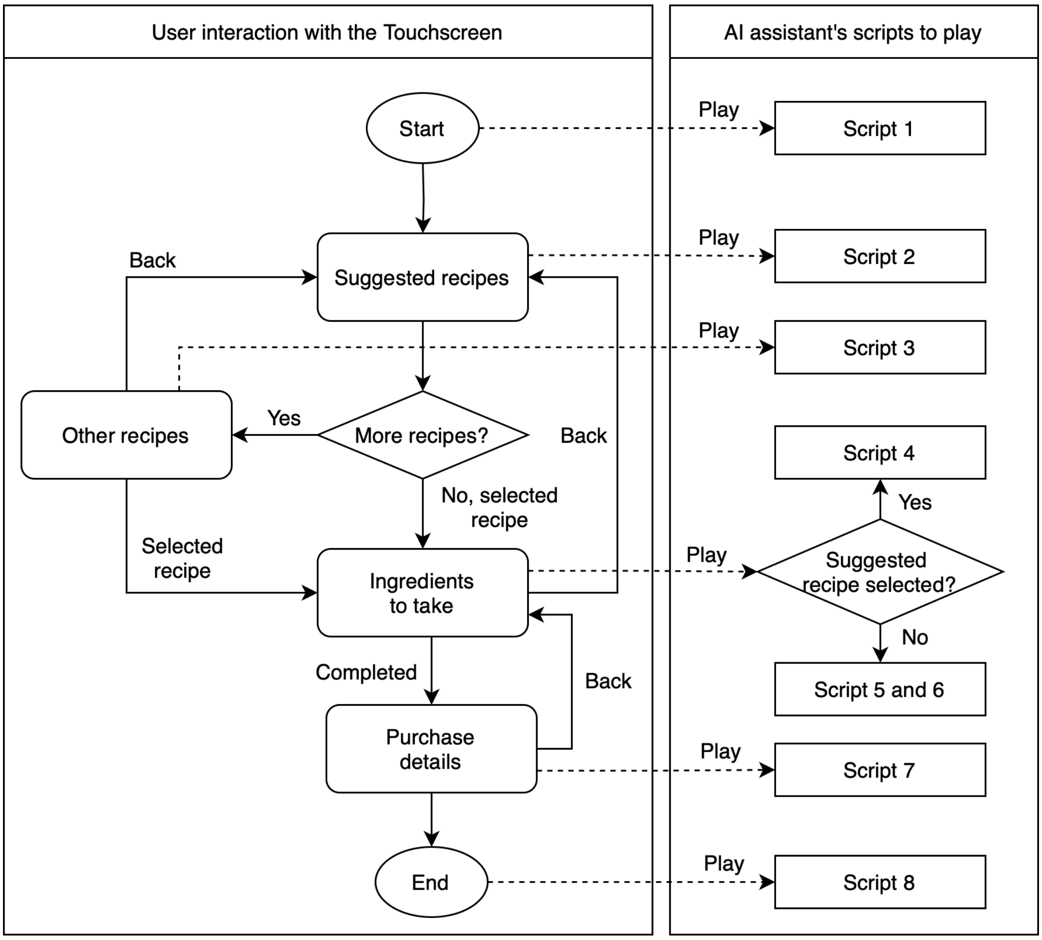


Figure 3.8: Flow diagram of the touchscreen UI and the correct AI assistant script activation for each stage.

Chapter 4

User research

The UE in VR study was carried out at both VARLab, a University of Bologna laboratory, and a private facility in Verona. The experiment involved 12 participants. Each participant was required to complete various questionnaires throughout the study, responding to open-ended questions, and engaging in each of the smart home scenarios previously described.
In the subsequent sections, we will delve into the comprehensive study procedure, as well as the quantitative and qualitative data analyses derived from the participants' questionnaires and open-ended responses.

4.1 Procedure

Prior each test, participants received comprehensive information about the experiment's phases and the overall experience in which they would be participating. Before delving into the core of the UE in VR study, participants were required to complete a Simulator Sickness Questionnaire (SSQ) as well as a Participant questionnaire. This questionnaire serves the dual purpose of gathering demographic information about participants, including age, gender, and education, as well as collecting data about their prior experiences with VR technology. Additionally, conducting an initial SSQ assessment is essential, as it provides a baseline reference for the subsequent

SSQ questionnaires that will be administered after each scenario.
At this point, the participant was required to read the Preamble script and start the familiarization experience.
When the participant completed the familiarization phase and confirmed their understanding, they were instructed to audibly read the Smart Frames scenario script and commence their VR experience. Participants were encouraged to adopt a "Think Aloud" approach, as described in [19], which involved vocalizing their thoughts and internal processes while engaging in the task. During the immersion in the VR experience, participants' inquiries were generally overlooked, except for situations where they encountered significant difficulties. This approach aimed to minimize the participants' awareness of the external presence of the researcher, fostering curiosity and promoting a sense of exploration in the virtual world.
Upon concluding the VR experience, participants were asked to complete the Presence Questionnaire (IPQ) and the Simulator Sickness Questionnaire (SSQ). Additionally, they were requested to respond to four open-ended questions, which, upon approval, were recorded using a smartphone. These questions were presented in the participants' native language (Italian) to elicit more comprehensive and accurate responses.
The Smart Kitchen scenario followed a similar procedure, concluding with a token of appreciation given to the participant for their volunteering efforts.
The complete process is visually outlined in the task flow diagram found in Figure 4.1.

4.2 Participants

The study involved 12 participants, consisting of 9 males and 3 females. These individuals were recruited from both university colleagues in Bologna and personal friends in Verona, all of whom volunteered to participate in the experiment. At the beginning of the study, they were asked to fill in the Par-

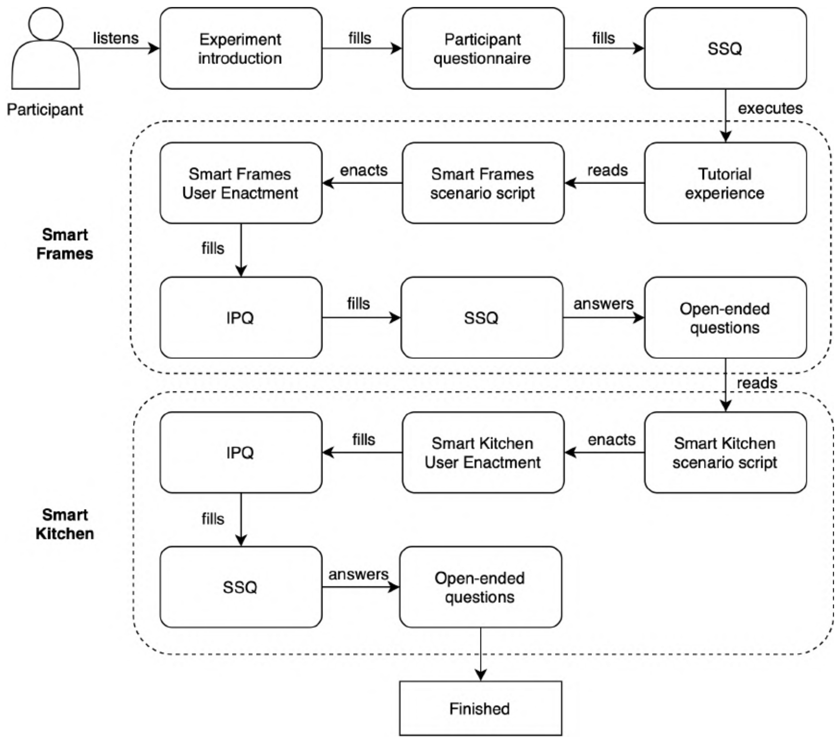


Figure 4.1: Experiment procedure diagram.

ticipant questionnaire, which summarizes demographic aspects and previous experience with a VR headset. The overview is shown in Figure 4.2. In order to gain a comprehensive understanding of the participants, the questionnaire was designed to differentiate between individuals with relevant experience in VR technology and those who are less familiar with it. This distinction holds particular significance in the analysis of the SSQ questionnaire, as it has been observed that repeated exposure to motion sickness may result in the development of a certain tolerance [20].
As a result, since the 41.7% of the participants regularly use a VR headset, a side analysis will be conducted for these sub-groups to explore their experiences with motion sickness in greater detail, in particular regarding the continuous movement effects.

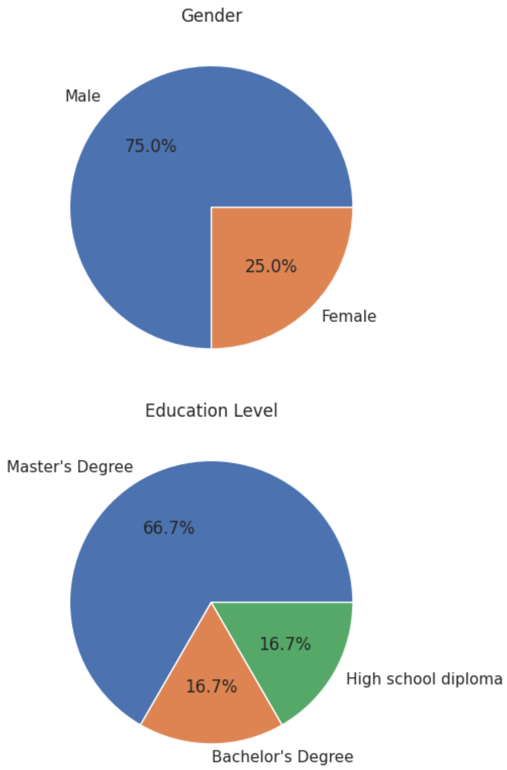


Figure 4.2: Participant questionnaire overview.

4.3 Motion sickness: SSQ analysis

Motion sickness in the two scenarios was assessed using SSQ questionnaires submitted after each VR experience. The evaluations include SSQ1 for pre-exposure, SSQ2 following the Smart Frames experience, and SSQ3 after the Smart Kitchen experience. Mean scores and standard deviations were computed for each subscale (Nausea, Oculomotor, and Disorientation) as well as for the overall score. The quantitative results are reported in Table 4.1 and visually shown in Figure 4.3.

It is essential to highlight that the conventional thresholds, originally set at 20 as the limit for an acceptable level of motion sickness in the standard SSQ usage, may not be applicable. This is particularly evident as the scores, especially in the case of the Disorientation subscale, either closely approach

Subscale	SSQ1 Mean (s.d.)	SSQ2 Mean (s.d.)	SSQ3 Mean (s.d.)
Nausea	12.72 (13.11)	31.00 (34.64)	24.65 (24.77)
Oculomotor	13.90 (13.78)	34.11 (27.76)	25.27 (23.23)
Disorientation	20.88 (20.88)	67.28 (55.34)	44.08 (43.59)
Total Score	17.45 (11.96)	47.06 (32.49)	33.97 (24.99)

Table 4.1: Simulator Sickness Questionnaire.

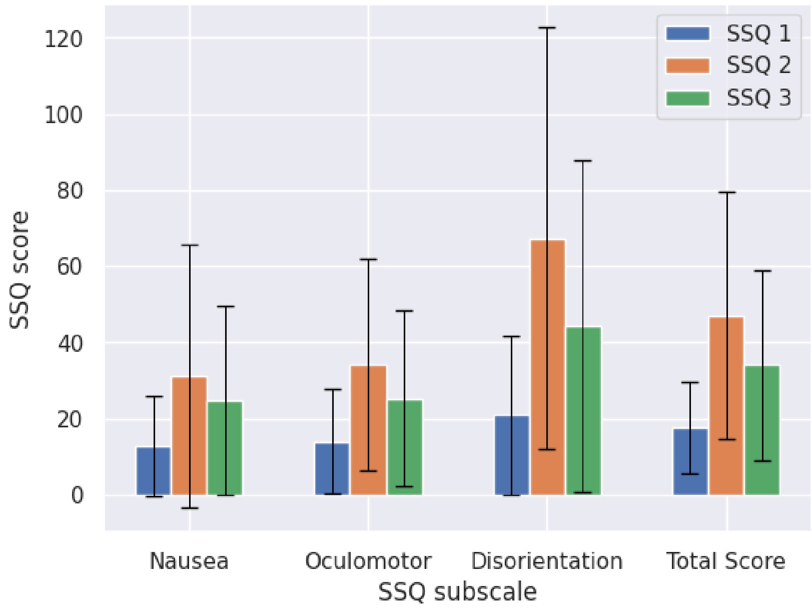


Figure 4.3: SSQ results mean and standard deviation visualized.

or surpass the threshold in the pre-exposure results. Therefore, in this study case, these results retain meaningful insights if compared across each SSQ (SSQ1, SSQ2 and SSQ3) and aligning them with the qualitative feedback gathered from users during the test.

Smart Frames (SSQ2)

In the development phase, a continuous movement approach has been adopted in the environment to simulate a natural navigation experience within the Smart Home. The intention was to encourage users to observe the automatic picture switch of the smart frames, a detail that might have been overlooked with the Teleport approach. Nevertheless, although I personally experienced negligible motion sickness during implementation testings with this locomotion approach, SSQ2 indicates a significant increase in participant symptoms, particularly in the Disorientation category. Given that the interaction, environment, and controls remained consistent for both scenarios, it is straightforward to attribute the discomfort to the continuous movement locomotion, a feature that was less prominent in the Smart Kitchen scenario task. These findings were further validated by participants qualitative verbal feedback, who reported high levels of dizziness and, in some cases, nausea during and after the experience. To delve deeper into this aspect, the computation of each subscale score was conducted for both experienced VR participants and those who had used a headset at most a few times. In Figure 4.4, it is evident that the majority of subscales, with a notable emphasis on the Disorientation category, exhibit lower scores for experienced users, therefore less motion sickness symptoms. These findings align with the discoveries of J.T. Reason et al. [20] regarding the increased tolerance to motion sickness after previous repeated exposure.
For future development of UE in VR, it is crucial to consider the study's target audience and their level of VR experience. This understanding is essential for tailoring the VR experience to their specific needs, thereby minimizing the potential undesired effects of motion sickness.

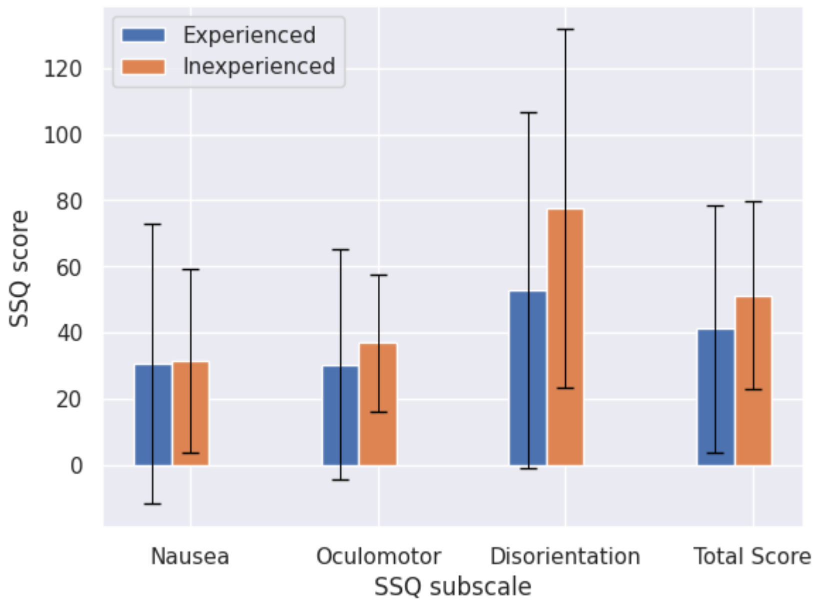


Figure 4.4: Experienced and inexperienced users comparison in SSQ2.

Smart Kitchen (SSQ3)

In the Smart Kitchen scenario, users explicitly reported fewer symptoms of motion sickness. This is evident in the restrained SSQ3 scores, particularly the substantial reduction in the Disorientation subscale. As mentioned earlier, this is likely attributed to the diminished requirement for continuous movement during task completion in this scenario.
It is noteworthy that even in this scenario, as shown in the Figure 4.5 there exists a noticeable disparity in the experience of motion sickness between users with varying levels of expertise. Specifically, it is apparent that in this case, experienced users exhibited minimal to almost no escalation in symptoms when comparing it to the pre-exposure scores.
This results indicates how experienced user were barely affected by motion sickness during the UE in VR.

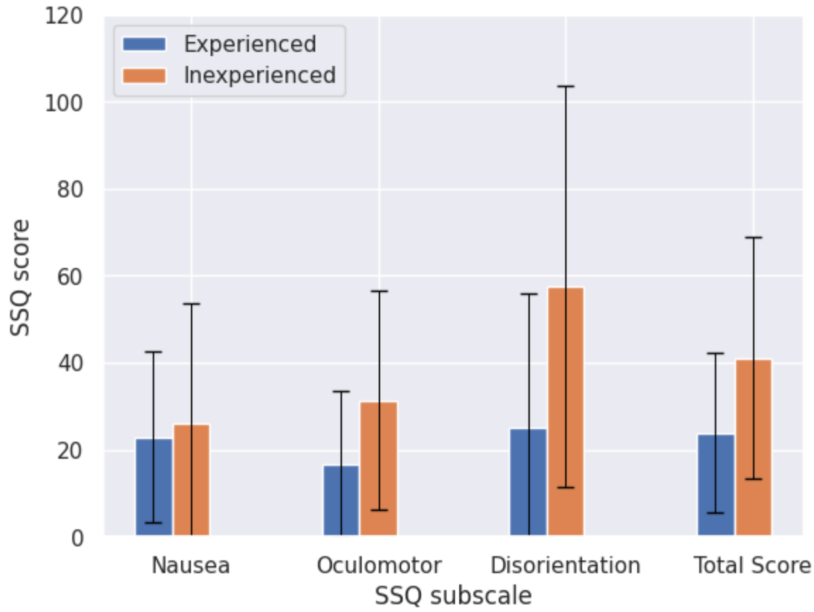


Figure 4.5: Experienced and inexperienced users comparison in SSQ3.

4.4 Presence: IPQ analysis

The degree of Presence that each participant experienced during both UE in VR scenarios was assessed through the Igroup Presence Questionnaire (IPQ). The IPQ result analysis allow to obtain a quantitative measure regarding the individual involvement in the experience, and their perception of the virtual world to be indistinguishable from reality.

The questionnaire measurement takes place by computing the mean of each 7-point Likert category: Spatial presence, Involvement and Experienced Realism. Finally, the total presence is measured by computing the mean of the entire questionnaire results, including the first question, related to the "sense of being there". The structure of the questionnaire is shown in Figure 4.6 The numerical outcomes of the questionnaire were transformed from the original 1-7 Likert scale to a 0-6 scale, aligning with the guidelines provided by the Igroup. Moreover, SP2, INV3, and REAL1 are designed with opposite anchors, where 0 is to be considered "good" and 7 "bad", therefore it is

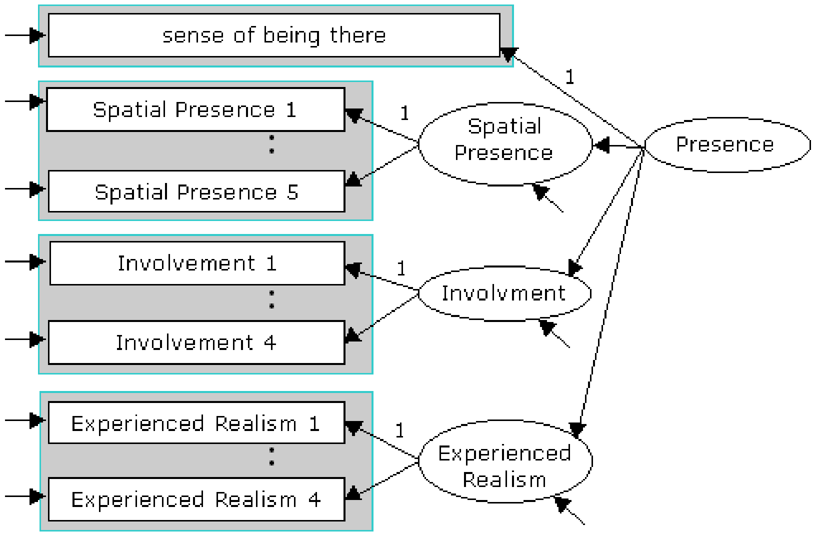


Figure 4.6: IPQ categories structure.

necessary to properly reverse these items.
Since two IPQ have been assessed, we will refer to the IPQ proposed after the Smart Frames experience as IPQ1, and the IPQ proposed after the Smart Kitchen experience as IPQ2.
The results of these two questionnaires are shown in the Table 4.2 and Figure 4.7. When considering the benchmarks outlined in Figures 2.9, 2.10, 2.11,

Category	**IPQ1 Mean (s.d.)**	**IPQ2 Mean (s.d.)**
Presence	3.38 (0.59)	3.78 (0.78)
Spatial Presence	3.42 (0.71)	3.92 (0.98)
Involvement	3.60 (1.04)	3.58 (1.39)
Realism	2.73 (1.20)	3.10 (0.95)

Table 4.2: IPQ results mean and standard deviation.

and 2.12, the obtained results are not optimal, as they only marginally meet the criteria for acceptability.
Nonetheless these thresholds are quite strict and in the reviewed literature, most VR experiences struggle reach a good grade. It is anyway relevant to understand better the results by studying what factors affected the most the

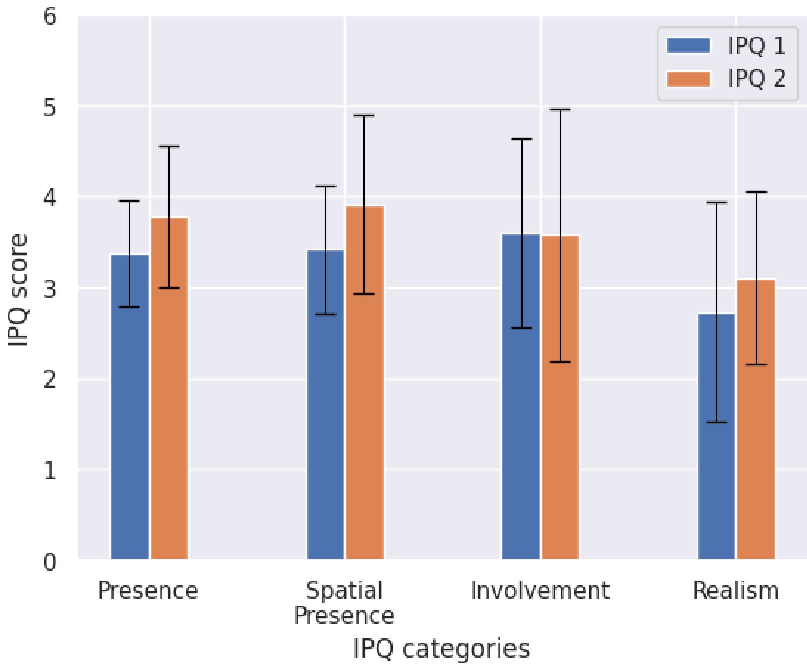
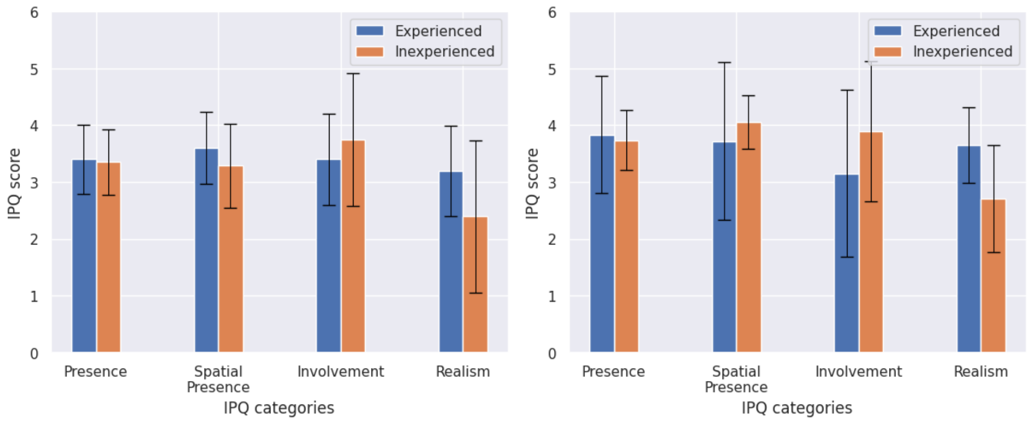


Figure 4.7: IPQ results mean and standard deviation.

users' involvement. It is observable how, although the identical scenario settings, the IPQ1 (Smart Frames) Presence, Spatial Presence and Realism are significantly lower than IPQ2 (Smart Kitchen). Given the earlier observation highlighting the presence of a non-negligible amount of motion sickness, it is reasonable to assume its influence in the participant sense of presence. To further analyze this aspect, we will categorize the results into subgroups, distinguishing once more between experienced and inexperienced users. The comparison between the Plot 4.8a and 4.8b in Figure 4.8 didn't show relevant patterns in the observed discrepancies.

Considering the similar overall sense of presence across the two subgroups, it is reasonable to explore the factors affecting this phenomenon in alternative domains. This aspect will be subject to a more detailed examination during the open-question analysis.



(a) IPQ1

(b) IPQ2

Figure 4.8: Experienced and inexperienced users comparison in IPQ

4.5 Open-ended questions

After each scenario, participants were also prompted with four open-ended questions. These questions were presented in the participants' native language, Italian, to facilitate the expression of their answers without a language barrier. These questions, reported in Tables 4.3 and 4.4, aim to collect actual feedback about their enactments, as intended by the User Enactment technique. Particularly, the design of the questions focus on obtain participants' envision of the AI assistant actions regarding their task, compared to what the current system was offering.

The 96 answers were separately recorded and utilizing Whisper, an Automatic Speech Recognition (ASR) model developed by OpenAI, they were transcribed and stored in a CSV file for further evaluation.

In user study design, employing open-ended questions proves to be a valuable approach for gathering qualitative data on the overall system. As advocated by Y. Chiang et al. [7], a proficient method for extracting and organizing meaningful insights from a plethora of user responses is the utilization of an Affinity Diagram. This tools allows to iteratively group information in recurrent themes and patterns, as we will extensively see in the following sections.

	Italian	English
1	*"Come ti ha fatto sentire il compito da svolgere?"*	*"How did the task make you feel?"*
2	*"Che impatto hanno avuto su di te le cornici smart durante il compito?"*	*"What impact did the smart frames have on you during the task?"*
3	*"C'è qualcosa che cambieresti riguardo le azioni dell'assistente AI in merito al compito da te svolto?"*	*"Is there something you would like to change about the AI assistant actions regarding this task?"*
4	*"C'è qualcos'altro che vorresti aggiungere?"*	*"Is there something else you would like to say?"*

Table 4.3: Smart Frames open ended questions.

	Italian	English
1	*"Come ti ha fatto sentire l'interazione con l'assistente AI?"*	*"How did the interaction with the AI assistant make you feel?"*
2	*"Cosa ne pensi delle azioni dell'assistente AI?"*	*"What do you think about the AI assistant actions?"*
3	*"Is there something you would like to change about the AI assistant actions regarding this task?"*	*"Is there something you would like to change about the AI assistant actions regarding this task?"*
4	*"C'è qualcos'altro che vorresti aggiungere?"*	*"Is there something else you would like to say?"*

Table 4.4: Smart Kitchen open ended questions.

Before performing the actual Affinity Diagram, it is worth to analyse the data by a quantitative perspective, therefore, as suggested by F. Beatrice et al. [21], a topic analysis is performed on the answers of each scenario.

4.5.1 Quantitative analysis

The topic analysis consists in extracting potential text topics based on a keywords-count model. For this purpose the Python Natural Language Toolkit (NLTK) library is exploited for text processing. In particular, before the computation of the word count, the original text requires the following processing:

- **Tokenization**: text separation into smaller units, named tokens;
- **Lemmatization**: word reduction in their root form (example: grouping the word "running" and "ran" in their respective lemma "run");
- **Punctuation removal**: since the punctuation is non relevant for this process, it is removed.
- **Lowercasing**: all characters are mapped to lowercase for consistent equality check.
- **Stop words removal**: natural language phrasing consists in many stop words, such as "the", "is", "a", which do not provide meaningful information to the context., therefore they are removed.

Finally, the word count function is computed on the processed text data. This process is applied separately for text answers of each scenario.

Topic analysis: Smart Frames

The results of the word count assessed on the open-questions answers regarding the Smart Frames scenario are visually represented by a word cloud [22] and a plot, shown in Figure 4.9, 4.10
From this quantitative analysis it is possible to manually extract relevant recurrent words regarding the key topics that has been covered by participants.

Figure 4.9: Word cloud of top 50 word occurrences regarding Smart Frames answers.

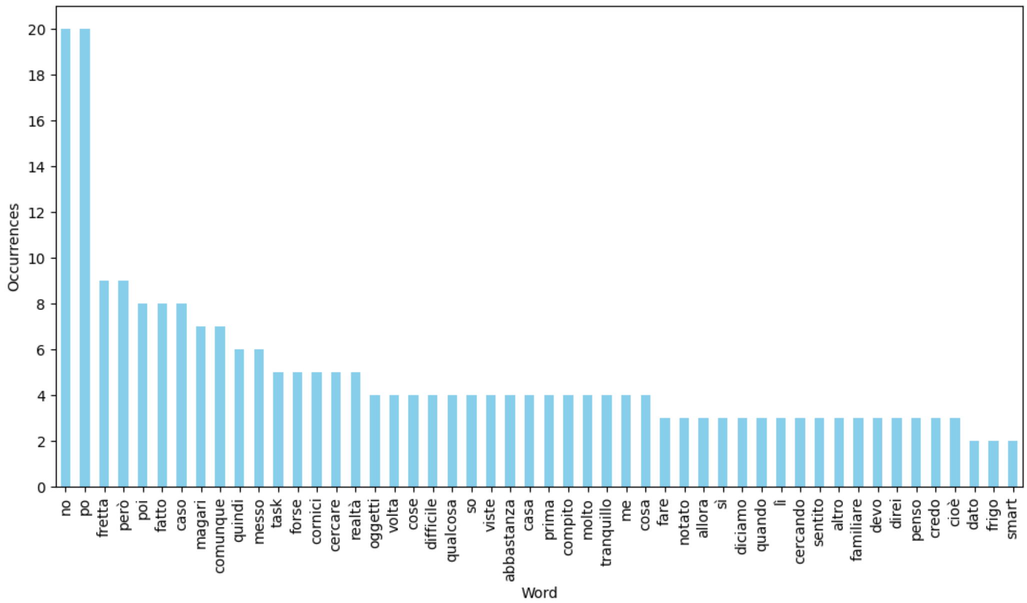


Figure 4.10: Word count of top 50 word occurrences regarding Smart Frames answers.

The manual investigation allowed to identify the following potential topics:

- **Task dominance**: it is immediate to notice how words “fretta” (rush), “task”, “compito” (task) and “cercare” (search), are dominant in the word cloud, and are all related to the task that the participant had to enact. This provides valuable insights into how participants predominantly focused on the given task rather than on the smart frames.

- **Frames visibility**: there are a few words related to the AI assistant actions on the Smart Frames, such as “cornici” (frames), “viste” (seen) and “notato” (noticed), which, while their occurrences are much lower, give meaningful insights about the reasons why, which refers to visibility.

- **Suggested improvements**: expressions like “magari” and “forse”, translated as “perhaps,” frequently appeared and typically precede participants’ suggestions. In subsequent stages, it is pertinent to investigate the specific references of these suggestions.

Topic analysis: Smart Kitchen

In an analogous manner the word count was assessed to the answers reported by the participants in regards of the Smart Kitchen open-ended questions.

The world cloud and word count are shown in the Figure 4.11 and 4.12.

Figure 4.11: Word cloud of top 50 word occurrences regarding Smart Kitchen answers.

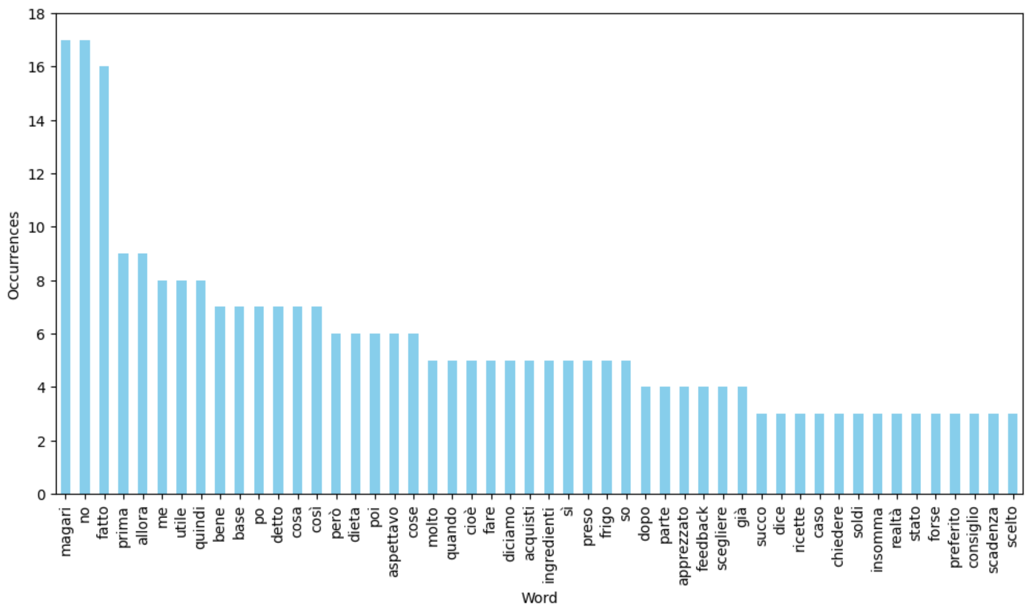


Figure 4.12: Word count of top 50 word occurrences regarding Smart Kitchen answers.

Given these results, the following potential topic were identified:

- **Suggested improvements**: the word "magari" (perhaps) is the one that occurred the most and, similarly to the previous case, most probably indicates the participants wish to suggest improvements, giving large room to detect their envision about the AI assistant behaviour in the Smart Kitchen context.

- **AI feedback**: the high occurrence of the words "fatto" (done), "bene" (good), "utile" (useful), "apprezzato" (appreciated) can be attributed the participants positive response regarding the actions performed by the AI assistant during the task.

- **Pro-active purchase**: there are also different occurrences in relation to the AI assistant action of purchasing products no longer available in the fridge, taking into account the diet change. These words are "acquisti" (purchases), "diet" (dieta), "soldi" (money). Therefore it is worth to consider a separate section for this topic, and further analyze it in the following stages.

The topics identified in the quantitative analysis are not meant to be final, but pose a solid base for the actual topic analysis which takes place during the Affinity Diagram phase.

4.5.2 Qualitative analysis

As previously discussed, the Affinity Diagram serves as a powerful tool for organizing extensive textual data into coherent categories. This facilitates the qualitative data evaluation process by emphasizing distinct aspects within each category. In this study, the previously identified topics will serve as the initial categories for the Affinity Diagram. Each participant's response will be allocated to the most pertinent category. Through an iterative process, if required, these initial categories will be further refined and potentially subdivided into subcategories.

Affinity diagram: Smart Frames

The final Affinity Diagram for the participants' answers regarding the Smart Frames is shown in the Figure 4.13. In the second, a final, iteration the Affinity Diagram contains four categories and for each category some subcategories were identified:

- **Task**: encompasses all feedback related to the activities involved in the experience, as well as the emotions elicited by those tasks. In particular, two subcategories were identified:
  - **Experience perception**: with a predominant number of participants characterizing it as "easy" or "ordinary," indicating their familiarity with the situation. Only a minority of participants described the task as "fun" or drew comparisons to a videogame.

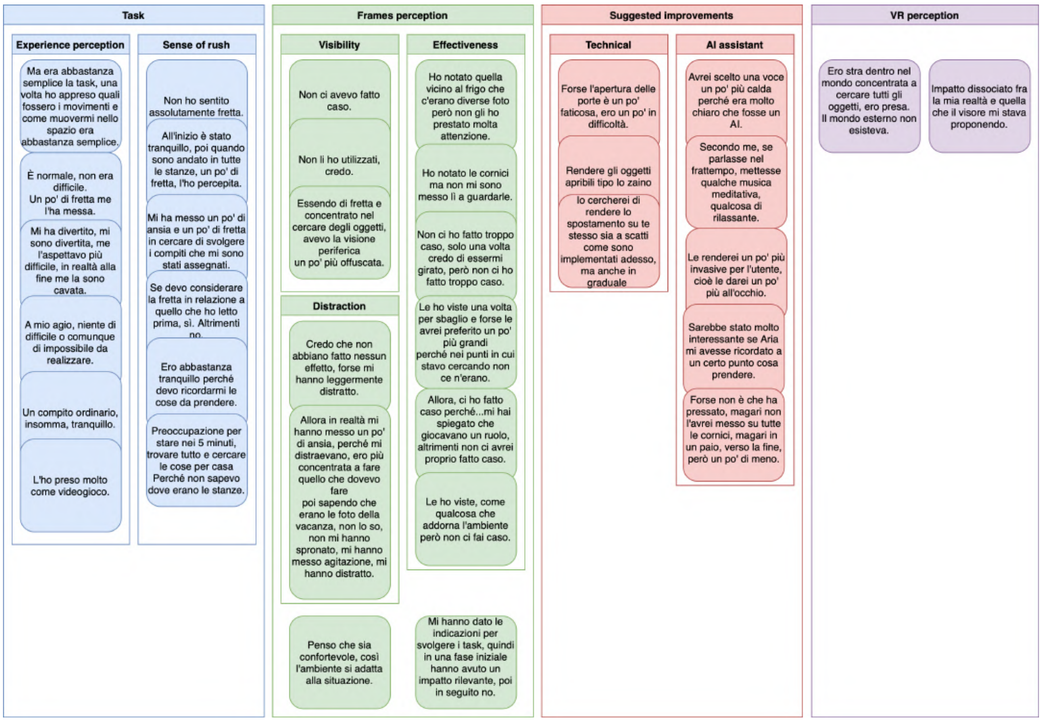


Figure 4.13: Smart Frames' Affinity Diagram.

- **Sense of rush**: in general, a significant number of participants indicated that they did not initially experience a sense of urgency. However, those encountering challenges in locating specific objects began to feel the pressure of the scenario.

- **Frames perception**: it includes three subcategories regarding the various feedback about the smart frames functionality:

  - **Visibility**: some participants have not noticed at all the smart frames, even if the scenario described their presence and functionality.
  - **Effectiveness**: while the majority did observe the smart frames, they did not pay significant attention to them, resulting in a lack of perceived benefits from their purpose.
  - **Distraction**: some participants additionally characterized the

smart frames as distracting from the task at hand, deeming them counterproductive.

- **Suggested improvements**: participants feedback included many useful suggestions to how they would improve their experience. These suggestions were divided in two subgroups:
  - **Technical**: few participants provided suggestions regarding their preferred ways of interacting with the environment, including recommendations for enhancing the opening mechanism of doors and enabling the option to open a backpack.
  - **AI assistant**: the majority of participants recommended enhancements to the AI assistant's behavior. These suggestions included a preference for the AI to prioritize reminders about objects to collect and their locations, utilize fewer but more visible smart frames, and facilitate direct interaction with the AI.
- **VR perception**: a few responses centered around the sense of detachment from reality, expressing both positive and negative perspectives.

In general, participants actively engaged in the assigned task, with the Smart Frames largely overlooked or perceived as distracting. They expressed a preference for the AI assistant to play a more supportive role in similar situations by offering assistance, rather than diverting attention with other reminders, even if they are pleasant.
These findings closely resemble those obtained through the UE study on "Family Reminders" explored in [1].

Affinity diagram: Smart Kitchen

The Activity Diagram computed on the participants responses regarding the Smart Kitchen scenario is shown in the Figure 4.14. After placing the participants answers under the categories identified during the quantitative analysis, these were adjusted in a second iteration and further subcategories

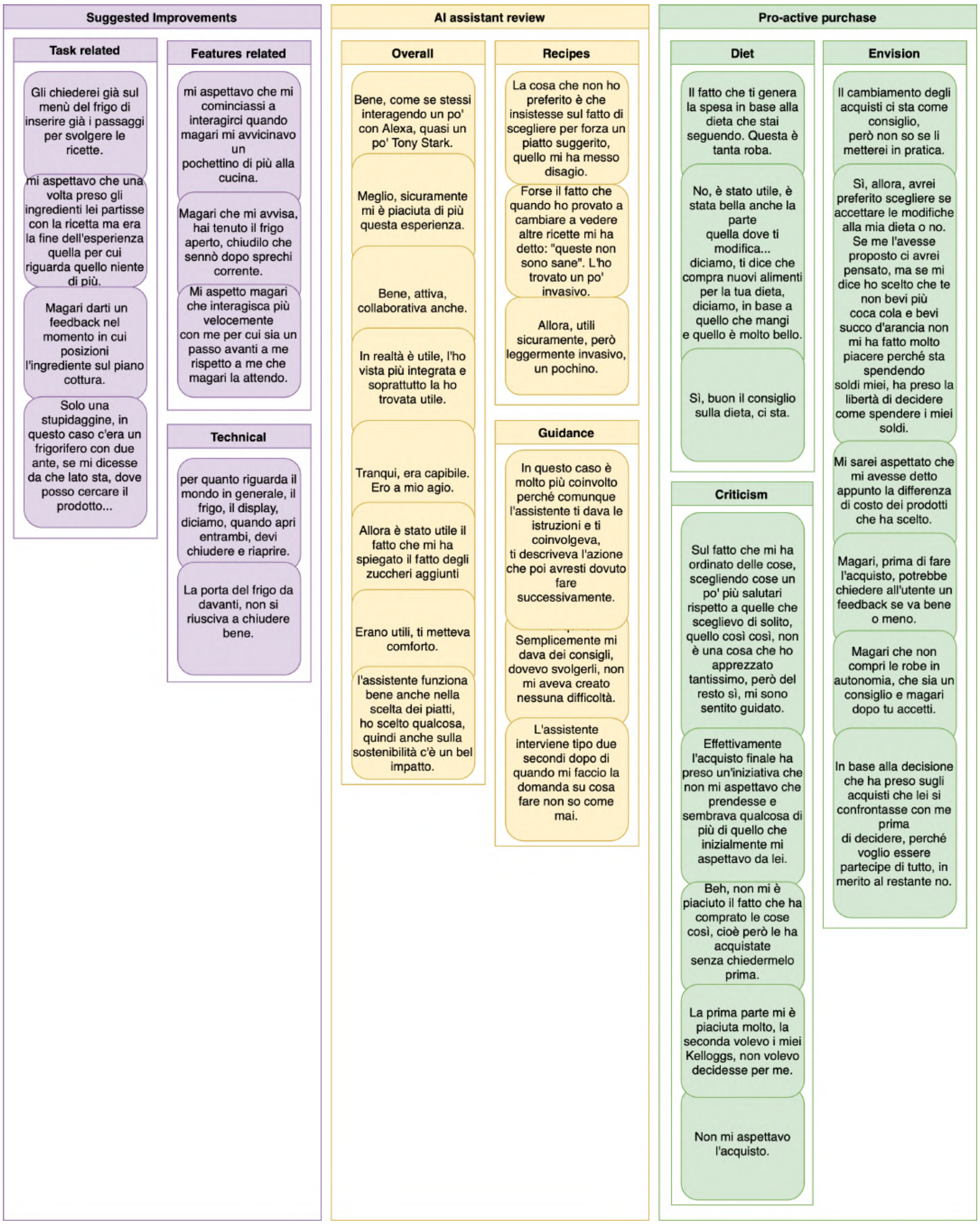


Figure 4.14: Smart Kitchen' Affinity Diagram.

have been identified. The final Activity Diagram presented the following categories:

- **Suggested improvements**: includes general suggestions about the experience improvement according their needs.

  - **Task-related**: participants reported further features they would like the AI assistant to provide regarding the task, such as a step by step guide about the recipe preparation, and the AI's ability to provide the exact position of ingredients in the fridge;
  - **Features-related**: some features regarding the interaction with smart devices have been suggested, such as the notification about the fridge not being closed properly and a more fluent and fast-pace interaction with the AI assistant.
  - **Technical**: few participants reported difficulty in interacting with the fridge doors.

- **AI assistant review**: many feedback about the usefulness of the AI assistant were provided.

  - **Overall**: the majority of participants found the AI assistant presence as collaborative and well functioning, appreciating overall its presence.
  - **Recipes**: some participants found the AI assistant's recommendations regarding the utilization of ingredients nearing their expiration date to be intrusive. This was attributed to the persistent encouragement to prioritize these specific products over others.
  - **Guidance**: the continuous presence guidance provided by the AI assistant were perceived as comforting.

- **Pro-active purchase**: most feedback were attributed to the AI assistant behaviour of autonomously choosing the purchase of missing products, with specific adjustments that aim to support a healthier diet.

  - **Diet**: some participants vividly appreciated the AI assistant feature of adjusting the current diet.

  - **Criticism**: the biggest criticism about the Pro-active purchase was in regards the lack of control that the participant had in that decision, even if the purchase was appreciated.
  - **Envision**: most participants expressed a willingness to embrace this behavior, albeit with a preference for explicit acceptance beforehand. Additionally, some participants noted the absence of pricing information for the purchased products, raising concerns about how the AI assistant was managing their finances.

Generally, participants highly valued the actions of the AI assistant in the Smart Kitchen scenario, with many expressing enthusiasm about incorporating such a system into their daily lives. However, there was a collective desire to diminish its proactive behavior and, instead, replace it with suggestions.

4.6 UE in VR evaluation

The combined quantitative and qualitative analysis of participants' engagement in both scenarios yielded significant insights, enabling us to address the study question: "How does an individual envision a proactive artificial intelligence assistant in their smart home?" The general reception of a proactive AI assistant within the smart home context was marked by a positive attitude, with participants expressing approval for its utility and seamless integration into their daily activities.
They provided different insights about its desired functionality and specific appreciation.

Guidance and Interaction

The absence of direct interaction with the AI assistant in the Smart Frames was perceived as a limitation to its usefulness. This sentiment was further reinforced by the contrasting experience in the Smart Kitchen scenario, where continuous interaction and guidance contributed to a sense of comfort and efficacy.

Sense of control

While the persistent presence of the AI assistant was generally well-received, participants hesitated to fully entrust personal matters like finances and dietary choices to the assistant. Notably, it was not outright dismissed, indicating a potential middle ground where the assistant is in charge of these aspects while the ultimate decision-making remains in the hands of the user.

Chapter 5

Conclusions

The novel approach of UE in VR extends the traditional technique by integrating immersive VR experiences. This study showcases the development process of conducting UE within a virtual environment, demonstrating its capacity to yield significant and meaningful results comparable to those obtained through physical environments.

5.1 Achievements

Incorporating virtual environments into User Enactment studies has enabled the redefinition of two fundamental variables: Fidelity and Control, central to traditional UE methodologies. These variables often face constraints, whether physical or economic, contingent upon the specific study question. However, leveraging UE in VR has effectively eliminated these limitations, providing designers the freedom to explore diverse scenarios within the expansive boundaries of the virtual reality.
While the overall UE in VR process resembles closely the traditional UE study, many aspects that could lead to the development of effective VR scenarios have been detected, such as:

- **Task design**: in the process of crafting scenarios for UE in VR, a critical aspect involves designing tasks that effectively engage users within the scenario. However, there's a potential pitfall: when implementing these tasks in a VR environment, there's a risk to fall under the phenomenon that I refer as "gamification curse". This occurs when participants perceive the tasks not as real-life challenges but as mere elements of a competitive or entertaining game, potentially preventing their ability to empathize with the task's real-world significance. To prevent this phenomenon, it's crucial to align participants' expectations closely with real-world scenarios and consciously avoid incorporating any virtual elements that could be interpreted as gaming components, especially if they are not part of the study subject.

- **Realistic presence**: unlike the conventional notion of achieving a generic "sense of being there" in immersive experiences, UE in VR scenarios prioritizes enabling users to enact within the virtual environment as they would in a physical setting. Thus, it is important that the virtual experience closely mirrors its physical counterpart, allowing users to interact and engage within the virtual space authentically. In this particular study, both the environment and the interactions within it were meticulously crafted to align with a realistic representation, effectively meeting users' expectations with their intentions.

- **Limit discomfort**: in this study the concept of motion sickness have been explored, revealing it as a significant hurdle that affects participant engagement in the experience. This issue poses a serious challenge, reducing the overall users' engagement, especially those not familiar with the VR technology. Therefore, when introducing VR experiences, it becomes imperative to aim for a balance between immersion and minimizing discomfort. In the context of this research, specifically in the Smart Frames scenario, employing the teleportation technique would have been more advantageous. Although it might slightly diminish the realism of movement, it significantly alleviates the adverse effects of motion sickness.

5.2 Limitations

Throughout the entirety of the project, the utilization of UE in VR was consistently portrayed as an extension of the traditional UE technique rather than an outright evolution. While VR proves suitable for a multitude of experiences, including those successfully implemented in this work, it is important to acknowledge that there are many scenarios where the virtual environment does not offer distinct advantages. For instance, if the project had necessitated a task centered around cooking, delivering an immersive experience with a profound sense of Presence would have been challenging. This challenge arises from the inherent limitations of certain actions in VR; for instance, while slicing vegetables is technically feasible, it lacks the feedback and sensory immersion that the real process provides. Therefore, when considering the incorporation of UE in VR, a crucial step involves conducting a feasibility analysis regarding the particular scenario and tasks to be executed. This analysis helps determine whether the utilization of UE in VR offers relevant benefits compared to the conventional UE approach.

5.3 Future work

This work represents an initial iteration of UE in VR, presenting numerous opportunities for enhancement and adaptation to address scenarios beyond the scope of this study. In particular:

- **Multiplayer**: many User Enactments studies present in the literature involved more than one participant at the same time, which interacted not only with the studied technology and environment, but also between them. Therefore it would be relevant to implement a UE in VR with a multiplayer experience, exploiting Unity's frameworks such as Photon Unity Networking (PUN).

- **UE in VR framework**: in various instances, UE involves multiple iterative phases, particularly during the initial stages of the study. While scene changes in a physical setting might be relatively straightforward, the virtual experience often encounters technical hurdles that can significantly cause delays in the overall study. A potential resolution could involve steering away from ad-hoc experience creation and, instead, constructing a versatile framework for the study. Such a framework would offer the flexibility to craft and modify scenario features, thereby streamlining the process in VR implementation.

Studying these integrations could lead to a standardized approach to UE in VR studies, making it more adaptable and accessible across a broader range of scenarios.

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