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Creating a more inclusive Augmented Reality enabled touristic experience in outdoor contexts

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Master Thesis

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If you want to go fast, go alone. If you want to go far, go together.

Abstract

Augmented Reality (AR) is an emerging technology that blends virtual objects with the real world, overlaying different types of information. Several devices can create an AR environment such as Head-Mounted displays, Hand-Held Displays (HHDs) and Spatial Displays. Due to its affordability and widespread diffusion, HHDs are becoming increasingly used for several applications, including in the tourism sector.

Given that this technology is relatively new to the public, it is crucial to focus on the usability of HHD-enabled AR experiences, especially for older adults who often have lower digital literacy and physical limitations like impaired vision and audition. Therefore, more studies on inclusive usability requirements are needed to make touristic AR experiences more accessible.

The study uses multiple case study research design to explore how AR technologies can be more inclusive for older adults, particularly in outdoor tourism where HHDs are commonly used. A touristic experience was designed in Porto (Portugal) with Kluest application, an AR mobile application that enables the creation of a metaverse. The application used multiple sensorial clues to support the exploration of three points of interest in the historical sites of the city. Two groups were created: group A with younger adults and group B with older adults. In total, 11 usability tests and interviews were undertaken during the experimentation. The data was collected during the test of the application, in-situ, by recording the audio of the interview, with notes. Quantitative data was also collected during the usability test and after with User Experience Questionnaire.

Results showed several challenges in outdoor experiences for both groups. Several categories were identified through coding, being the most significant ones outdoor experience, association of map with real world and multisensory experience. There was also a comparison between both groups, since it was shown through coding and quantitative data (such as the time of the experience) there were some topics more related to one of the groups. This study also proposes a set of recommendations for the development of mobile AR applications in the tourism sector.

By contributing to understanding the usability and accessibility issues in Augmented Reality applications for tourism, this work aims to provide guidance for the development of more inclusive AR solutions, contributing to improve touristic experiences.

Keywords: Augmented Reality, Tourism, Usability, Inclusivity, Case Study

Resumo

A Realidade Aumentada (RA) é uma tecnologia emergente que sobrepõe objetos virtuais no mundo real. Vários tipos de dispositivos podem criar um ambiente de RA com *Head-Mounted displays*, *Hand-Held Displays* (HHDs) e *Spatial Displays*. Devido à sua acessibilidade e ampla difusão, os HHDs têm-se tornado cada vez mais usados para várias aplicações, incluindo no setor do turismo.

Dado que esta tecnologia é relativamente recente para o público, é crucial focar na usabilidade das experiências de RA habilitadas por HHDs, especialmente para adultos mais velhos que frequentemente têm uma menor literacia digital e limitações físicas como problemas oculares ou auditivos. Para isso, são necessários mais estudos sobre requisitos de usabilidade inclusiva de forma a tornar as experiências turísticas de realidade aumentada mais acessíveis.

O presente estuda utiliza uma abordagem de múltiplos casos de estudo para explorar como as tecnologias de RA podem ser mais inclusivas para adultos mais velhos, particularmente no turismo ao ar livre. Foi desenvolvida uma experiência turística no Porto (Portugal) com a aplicação Kluest, uma aplicação para smartphone que permite a criação de um metaverso. A aplicação utilizou múltiplas pistas sensoriais para apoiar a exploração de três pontos turísticos na zona histórica da cidade. Dois grupos foram criados: o grupo A com adultos mais novos e o grupo B com adultos mais velhos. No total, foram realizados 11 testes de usabilidade e entrevistas durante a experiência. Os dados foram recolhidos durante o teste de usabilidade, in situ, com o auxílio da gravação áudio da entrevista e de notas. Dados quantitativos também foram recolhidos durante o teste de usabilidade e posteriormente com o *User Experience Questionnaire*.

Os resultados sugerem vários desafios nas experiências ao ar livre para ambos os grupos. Foram identificadas várias categorias através da codificação, sendo as mais significativas a experiência ao ar livre, a associação do mapa ao mundo real e a experiência multissensorial. Houve também uma comparação entre ambos os grupos, uma vez que foi sugerido, através da codificação e dos dados quantitativos, que existiam tópicos mais relacionados com um dos grupos.

Ao contribuir para a compreensão das questões de usabilidade e acessibilidade nas aplicações de Realidade Aumentada para o turismo, este trabalho visa fornecer orientações para o desenvolvimento de soluções de RA mais inclusivas, contribuindo para melhorar as experiências turísticas.

Keywords: Realidade Aumentada, Turismo, Usabilidade, Inclusão, Caso de Estudo

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AR: Augmented Reality

VR: Virtual Reality

HMD: Head-mounted Display

HHD: Hand-held Display

MAR: Mobile Augmented Reality

SAR: Spatial Augmented Reality

UI/UX: User Interaction and User Experience

UCD: User-Centered Design

POI: Point Of Interest

UEQ: User Experience Questionnaire

1 Introduction

1.1 Context

Augmented Reality (AR) has attracted a lot of attention in recent years. This technology places virtual objects on top of the physical world. It has been used in several application areas such as Medicine or Education (Dey et al., 2018). This technology has become more disseminated through the general public and gathered more attention as it became more affordable (Derby & Chaparro, 2020). Different types of displays can be used to simulate an AR environment such as mobile phones, head-mounted displays or projectors (Carmigniani et al., 2011).

A lot of potential is recognized when it comes to the advantages of the use of this technology in the tourism area. AR can enhance touristic experiences by adding more information and interactions with the virtual objects and the physical world. This can create a bigger emotional involvement and feeling of presence or increase the knowledge obtained throughout the experience. It also enhances the user experience and, consequently, the user acceptance of this recent technology (Kečkeš & Tomičić, 2017).

Since AR is still a relatively recent topic and it is gaining more popularity, usability studies are becoming more important. The result of these usability studies should be used to make the user experience with AR better to increase the acceptance of this technology.

1.2 Problem definition

Augmented Reality is still a relatively recent technology that is not yet commonly used by the general public. There are challenges related to its ease of use and the interaction of the user with the world provided by AR. Therefore, more usability studies need to be conducted to help with the improvement of usability and user experience issues. While some application areas such as Medicine or Education gather more attention when it comes to usability studies in AR, Tourism represents only 2% of the studies in this technology according to Dey et al. (2018). The addition of factors such as the sunlight or the outside noise present in outdoor experiences can bring even more challenges. The most common device used for AR in tourism is the Hand-Held Display (HHD) (Pratisto et al., 2022), which create Mobile Augmented Reality (MAR) experiences.

AR also presents challenges to older adults due to visual impairments and limited digital literacy. Although this demographic is growing and recognizes AR as a tool that can improve their lives and increase their independence from caregivers, age-related barriers become more pronounced in AR. The immersive nature of this technology and the need to interact with virtual

objects make these challenges more noticeable and impactful. The optimistic attitude and open mind of older adults towards emerging technology can, however, lead to an adoption of it (Li et al., 2022).

While there are works regarding accessibility issues in AR, there are not a lot of studies that try to understand the main issues of this technology specifically for the tourism sector in outdoor contexts. Therefore, it is important to understand the challenges brought up by these types of experiences and the barriers created for older adults. This will allow the definition of guidelines to overcome barriers and make these experiences more inclusive, especially for older adults.

1.3 Research questions

Given the challenges mentioned above, the following research questions were formulated:

RQ1: What are the main challenges in mobile augmented reality applications in outdoor tourism experiences?

RQ2: What are the differences in outdoor tourism experiences enabled by mobile augmented reality for older adults?

RQ3: How to address the challenges identified in mobile augmented reality applications in the context of outdoor tourism?

1.4 Report outline

The first chapter presents an introduction to the master thesis with the context of the project and its description, the definition of the problem, the research question and the present report outline.

The second chapter presents a literature review covering the four fundamental points of the dissertation. Firstly, the concept of Augmented Reality is presented along with its origin, the types of devices used in AR, the use by the general public and the application areas. Next, a presentation on the use of this technology in the tourism sector, namely how it is being used, its potential and what still needs to be done. The User Experience and User Interface in AR is presented next, with a broad definition of the concept, the usability problems found and research gaps. Finally, the topic of accessibility is presented with its definition, how AR is being used to solve accessibility problems, the problems related to AR used by older adults and disabled people and some accessibility guidelines already used in applications and web content. According to the information of the literature review, guidelines were defined. The research objectives (based on the research questions) are also presented in this chapter.

In the third chapter the methodology to answer to the research question defined is presented following the recommendations of Yin (2014) with the presentation of the case selection, data collection approach and data analysis.

The fourth chapter the results are presented divided in five subsections: development of AR experience with Kluest, factors that affect the experience, comparison between groups, usability test and general discussion. The first subchapter details the developed AR experience, presenting the tasks and the rationale behind their design, and relating them to the guidelines outlined in the literature review. The factors influencing the experience are identified through qualitative analysis, which includes coding and provides codes, subcodes, and supporting information such as quotes. The comparison between the two groups consists of the analysis of the subcodes that were not common between them. The obtained results are also associated and compared to the guidelines identified in the literature review. The usability test consists of the analysis of the quantitative data obtained during and after the test such as time, number of completed tasks and the results of the User Experience Questionnaire. In the general discussion, additional insights are examined.

In the fifth chapter, the contributions of this study are presented by discussing the guidelines identified in the literature review and the additional information suggested.

The final chapter discusses the conclusions, limitations and suggestions for future research.

2 Literature Review

2.1 Augmented Reality

Augmented Reality (AR) is a concept that started to emerge in the 50s, but only in the 60s it was described as a mixed reality between the real world and a virtual world (Sutherland, 1965). AR proposes a "virtual world that enriches, rather than replaces, the real world" (Feiner et al., 1993). This is achieved by adding virtual objects to the physical world that can be viewed and interacted with in real time.

AR consists of a variation of Virtual Reality (VR), which completely immerses the user in a synthetic environment (Azuma, 1997). VR describes a system that replaces much or all the user experience in the physical world with a synthesized 3D material world. Immersive technology can be considered within a spectrum in which the former end is the real environment, and the latter end is virtual environment as shown in Figure 1.

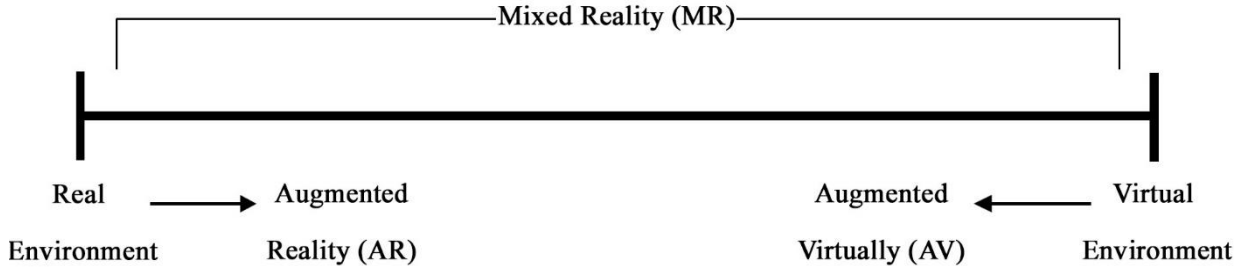


Figure 1 - Virtual reality continuum

There are several devices that can create an AR environment. The three types of displays that can be used are head-mounted displays, handheld displays and spatial displays (Carmigniani et al., 2011). Head-mounted displays (HMD) are worn in the head covering 100% of the user's vision. The user can interact with the virtual objects that appear. Handheld displays (HHD) can be small computing devices such as smartphones or tablets and they create Mobile Augmented Reality (MAR). These two devices have their advantages and disadvantages: while a smartphone is very portable, its display size is not ideal for AR; and while a tablet is not as portable, its display size is better for AR. Spatial Augmented Reality (SAR) is a type of AR that does not require the user to carry or wear anything. By using projectors or holograms, graphical elements and information are displayed into real objects. Since SAR tries to separate the technology from the user and rather integrate it into the environment, it is possible for groups of people to interact with the same environment in a collaborative way (Carmigniani et al., 2011).

Although the first studies related to AR date back to the 60s, these applications were not accessible to the general public use for a long time. With the launch of smartphones, this

narrative started to change and AR applications took over the mobile device market. The phenomenon “Pokemon Go” in 2016 spreaded awareness of the possibilities of AR within the population, leading to a bigger interest in this field by the researchers (Jingen Liang & Elliot, 2021). AR is also becoming more affordable and with a widespread adoption (Derby & Chaparro, 2020).

The application of AR is present in several field areas (Dey et al., 2018) such as:

- Education – applications that promote teaching and learning;
- Entertainment and Gaming – AR games or other type of entertaining applications;
- Industrial – applications related to manufacturing tasks;
- Medicine – used in several topics such as rehabilitation, phobia treatment or medical training;
- Navigation and Driving – applications for car-driving;
- Tourism and Exploration – museum-based applications.

Tourism and exploration are still not well explored within AR research (Dey et al., 2018) and thus, the present study focuses on this context of application.

2.2 Augmented Reality in the Tourism Sector

Touristic experiences are associated with travelling to destinations outside of people’s usual home or environment for leisure experiences (Pratisto et al., 2022). While having these experiences, the travelers look not only for something enjoyable, but also for something different to help them expand their knowledge (Abidin et al., 2018). Yovcheva et al. (2013) describes tourist experience as “a complex construct that involves emotions, feelings, knowledge and abilities resulting from the perception, processing and interaction with virtual information that merges with the real physical world that surrounds the tourist”.

The rapid rise of technology leads to a need to adapt the tourist experiences and enrich them. The technology innovation can enhance economic growth and satisfy high-demanding tourists (Yovcheva et al., 2013). This innovation can now give the tourists a sense of immersion or even simulate an environment for tourism promotion. Despite a smaller number of studies in this area comparing to other fields such as Education or Health, there is a lot of potential in the use of AR in the tourism sector (Dey et al., 2018)

The usage of this technology in this sector can help tourists access valuable information about a touristic attraction or destination by adding information and offering increased levels of entertainment. It can also help the tourist organizations to reach a wider audience by delivering more interesting and enjoyable experiences (Kounavis et al., 2012). While most of these

experiences end up enriching specifically the visual senses, some recent works have shown how a multisensory experience might enhance even more the touristic experience and make it more enjoyable (Marto, 2020). Non-visual modalities such as audio and haptic are underused and might become a good feature in some scenarios such as outdoor experiences (Wei et al., 2014).

In the work of Kečkeš & Tomičić (2017), a set of key factors are identified for the success of the AR technology in tourism in five domains: general requirements, functionalities, issues, overlay types and technologies. When it comes to the general requirements, they include interactivity, dynamics, entertainability, context-content correlation or intuitive user interface. The functionalities include search and browse, routing and navigation or map services. Some of the issues identified in this work are the hardware requirements or device-specific challenges that can include the ease of use, safety or the overall user comfort and experience. According to Kounavis et al., (2012), one of the main obstacles for the development of mobile AR applications is the interoperability across the mobile platforms and the fact that most of them require an internet connection.

Mobile devices are the AR device more used in the tourism sector (76.3%) given the fact that it is more convenient to carry during the experience and less expensive than head-mounted displays (HMD) (Pratisto et al., 2022). HMD might also make the tourist feel more isolated from the environment of the touristic attraction, taking away value from the experience and "get out of the way of the content when someone wants to enjoy the physically beautiful/important works" (Jingen Liang & Elliot, 2021).

One of the main features of mobile augmented reality is navigation with maps. This navigation might be used to find Points of Interest (POIs), which should be represented in a specific way. Several studies have been conducted on the design of landmark markers. In the work of Elias & Paelke (2008), the authors propose a matrix where different levels of abstraction are better to represent different types of buildings. When it comes to Points of Interest such as churches or buildings that are architecturally significant, sketches (such as silhouettes), images or words are the most indicated ways of representation.

Regarding future lines of research, Jingen Liang & Elliot (2021) suggest to expand studies on gamification and AR; to use different methods to capture actual behavior; to consider the negative consequences of AR; and to combine quantitative studies with qualitative studies. Therefore, the AR tourism research field still has a lot of space for development given the small number of influential articles and the fact that it is still growing and maturing (Jingen Liang & Elliot, 2021).

2.3 User Interaction and User Experience in Augmented Reality

While usability and interfaces design are very important, the success of an application will be higher if the user experience is more enjoyable (Battarbee & Koskinen, 2005). For this reason, these two concepts go hand in hand. The user experience has become more and more important over the years in the field of Human-Computer Interaction (HCI), stimulating User Experience (UX) research (Hassenzahl & Tractinsky, 2006). For this to be evaluated in a standardized way, the International Organization for Standardization (ISO) defined the ISO 9421-210 standard "Ergonomics of human-system interaction – Part 210: Human-centered design for interactive systems" (ISO 9241-210:2019(En), Ergonomics of Human-System Interaction — Part 210: Human-Centred Design for Interactive Systems, n.d.).

When it comes to the development of an application it is important to follow a user-centered approach. If this does not happen from the beginning, the possibility of re-engineering increases since it will not respond to the needs of end users (Li et al., 2022). User-centered design (UCD) consists of a set of methods that involve the end-users in the design process. According to Vredenburg et al. (2002) "UCD is herein considered, in a broad sense, the practice of (...) the active involvement of users for a clear understanding of user and task requirements, iterative design and evaluation, and a multi-disciplinary approach.".

One of the most important aspects of AR that might affect the user experience of the users to consider is the emotional involvement. Studies conducted by Soon et al. (2023) demonstrate how AR apps blend both positive and negative emotions and the patterns of elicitation of these emotions between three components: affective (subjective experience), expressive (motor expression) and physiological (neurophysiological activation). These emotions will then have an impact on the user's desire to engage with AR. Some other emotional aspects to consider are issues such as safety. Since AR applications require more interaction than ordinary applications, it is important to bear in mind the need of the users to be aware of their surroundings (Dirin & Laine, 2018). According to Carmigniani et al. (2011) one of the main acceptance problems of AR applications is the disruption level caused during conversations or in public places.

In the work of Anabela Marto (2020), multisensory AR is explored in the context of Cultural Heritage by evaluating a prototype of a multisensory application. Her work explored the combination of visual, sound and smell contents. The usability testing was done in the ancient Roman city of Conimbriga, Portugal, so the content was provided to develop a sense of presence in the city: a 360-degree virtual reconstruction of a roman house, a 360-degree soundscape of surroundings of ancient times and a smell of garum, a very common fish sauce used in roman cuisine. The addition of smell was noticed to increase the realism and feeling of presence felt,

while the addition of sound stimulated a feeling of involvement. Overall, the addition of stimulus enhances the experience when it comes to the enjoyment and knowledge and, consequently, the whole user experience.

One of the gaps found in AR usability studies is the fact that participant populations are mostly young, educated, and male participants, meaning that the field could benefit from a more diverse selection of participants (Dey et al., 2018). Moreover, most studies done in indoor environments cannot be generalized to outdoor environments. When it comes to outdoor use, being able to see the graphics in daylight is one of the main concerns. Text or image might appear washed out or faded and colors might be perceived in a different way as they would in an indoor environment (Kerr et al., 2011). In situations where the visibility might not be the best, haptic or audio might be used. In the work of Wei et al. (2014), these two non-visual interaction modalities (haptic display and audio display) and their combination were evaluated in the context of representing tourism information in mobile augmented reality. While both, in combination with visualization, have the best performance, this work showed that the combination of only haptic or audio with vision also increases performance and enhances user experience.

In the work of Shukri et al. (2017), design guidelines were developed for mobile augmented reality applications in tourism considering four variables: use the context for providing content, reducing cognitive overhead, provide easy learn ability and enhance 3D interaction. Some of the proposed guidelines were: the UI must not be complex and font must be easy to read, there should be enough contrast between the background and text overlays or provide a guide on how to use the application. On the work of Kourouthanassis et al. (2015), five principles were purposed: use the context for providing content, deliver relevant-to-the-task content, inform about content privacy, provide feedback of the infrastructure behavior and support procedural and semantical memory.

2.4 Accessibility in Augmented Reality

Accessibility is defined as “the quality of being easy to understand or enjoy” or “the quality of being able to be entered or used by everyone, including people who have a disability” (Cambridge Dictionary, n.d.). When a product is designed, it is important that it is accessible to everyone. While it is not easy to meet the needs of everyone, it is important to fill as many requirements as possible.

Older adults are generally considered people above 65 years old. However, the definition of olderadulthood may vary (National Institutes of Health, 2024). This group of people generally have lower rates of technology use than the younger public, however their technology

acceptance is becoming higher: 42% of adults aged 65-year-old or older own a smartphone, 32% own a tablet or computer and 67% use the internet. As technology keeps being perceived as having a good impact on society, the trend will be for these numbers to increase (Anderson & Washington, 2017). AR has been perceived as something that can make older adults become more independent by doing tasks such as making text more readable by making the letters bigger and bolder or even translating text to a different language. According to Seok Lee et al. (2007), the adoption of advanced technology such as AR mobile applications depends on the interaction design cumbersome: if it demands too many button clicks or text inputs, it will most likely be discarded. As a strategy to accommodate different types of users, Shneiderman Ben (2002) suggests a multi-layer interface, where a user would pass from layer to layer depending on their confidence with the applications. In the first layers, less features would be available and the user would be less prone to make a mistake.

In a society that thrives to be more inclusive and to provide equal opportunities, accessibility is an important topic and AR might be a way to get there. A study from 2017 conducted with the goal to improve accessibility of people with motor disabilities using AR gathered three main core requirements of the users: (1) feel, touch and information - being able to access information as easily as any person in an independent way and in physical stores; (2) independence and autonomy – being able to shop without receiving help; and (3) technology acceptability – seeing technology as a means to get independence and privacy (Rashid et al., 2017). People with motor disabilities are receptive to the use of technology to get better opportunities and improve experiences. In the work of Tanuwidjaja et al. (2014), a wearable augmented-reality system based on Google glass was developed to correct color-blindness, allowing people to see the correct colors in real-time. Despite its identified limitations, this type of device can improve colorblind people's daily life by providing access to different color dimensions.

Nowadays there are accessibility guidelines for websites to make the internet accessible to people with disabilities. One of the guidelines set is Content Accessibility Guidelines 2.0 (WCAG 2.0) intended for web content (WCAG 2 Overview | Web Accessibility Initiative (WAI) | W3C, n.d.). These guidelines might be used also for mobile applications, but it is important to understand that there are a lot of mobile-related issues that are not mentioned in guidelines for the web. These issues include touchscreen gestures or the small size of the screen (Mobile Accessibility: How WCAG 2.0 and Other W3C/WAI Guidelines Apply to Mobile, n.d.).

There is however very scarce scientific literature on accessibility for AR mobile applications in tourism. In the work of Madeira et al. (2021), fourteen mobile applications from Portugal in the

tourism sector were analyzed. It was concluded that these applications have an unsatisfactory level of accessibility: “These results have consequences, particularly for users with some kind of disability. Not only will these users find it difficult to use mobile applications targeted for tourism, they may also feel excluded from the technological world.” (Madeira et al., 2021) .

Table 1 summarizes the findings from the literature review, highlighting the key categories identified that have been guiding the development of AR enabled applications. These design guidelines, however, are not necessarily adapted for the outdoor context or for older people.

Design guidelines (G)		**Related References**
G1	Use context to provide information	·use of context to provide content (Shukri et al 2017; Kourouthanassis et al 2015) ·deliver relevant-to-the-task content (Kourouthanassis et al 2015) ·context-content relation (Kečkeš & Tomičić, 2017) ·represent points of interest with the right level of abstraction (images, sketches or words) (Elias & Paelke, 2008)
G2	Reduce cognition load to improve learning	·reduce cognitive overload (Shukri et al 2017) ·support procedural and semantical memory (Kourouthanassis et al 2015)
G3	Intuitive application usage	·avoid too many button clicks or text inputs (Seok Lee et al., 2007) ·provide a guide on how to use the application (Shukri et al 2017) ·multi-layer interface adaptable depending on user digital literacy level (Shneiderman Ben, 2002) ·font must be easy to read (Shukri et al 2017) contrast between background and text overlays (Shukri et al 2017)
G4	Combine multisensory feedback	·provide feedback of the infrastructure behavior (Kourouthanassis et al 2015) ·addition of stimulus (Marto, 2020) use of haptic or audio as feedback (Wei et al, 2014)
G5	Ensure privacy, autonomy and security	·inform about content privacy (Kourouthanassis et al 2015) ·seeing technology as a means to get independence and privacy (Rashid et al., 2017)

Table 1 - Design principles and corresponding literature review

2.5 Research Objectives

From the research gaps identified in the literature review, some research objectives were identified. Given the participant populations in usability studies in AR are mostly young, educated and male, this study will contribute to suggest results for a broader population specifically for older adults. Non-visual modalities such as haptic and audio are also underused in AR studies. Studies done in indoor environments cannot always be generalized to outdoor environments since there is no relation with the external environment and aspects such as noise, security or relation with other people. Other topics that are suggested to explore according to the literature review are the gamification in AR or considering the negative consequences in AR (such as the disruption with the real world).

Based on these challenges, this master thesis explores these research gaps by using a case study approach to answer the research questions. By understanding the challenges and opportunities in mobile augmented reality applications in an outdoor tourism context, it will be easier to understand how to improve these experiences and make them more inclusive.

Therefore, the research objectives are:

RO1: Identify the challenges of outdoor tourism experiences using mobile augmented reality applications;

RO2: Explore and compare differences AR enabled outdoor tourism experiences between older adults and younger adults;

RO3: Develop recommendations to design more inclusive AR enabled outdoor tourism experiences.

3 Methodology

This study uses qualitative and quantitative methods to explore the Research Questions outlined in Chapter 1 following recommendations of Creswell (2014).

Qualitative research involves a more humanistic approach. It is done to understand people's beliefs, experiences, and attitudes towards a specific situation. It is recognized for its ability to add a new dimension to studies that cannot be obtained through the measurement of variables (Pathak et al., 2013). On the other hand, quantitative data research involves the measurement of specific variables and its analysis through statistic methods. These methods can be used to identify specific trends or patterns in each situation (Watson, 2015).

For the study conducted in this dissertation, it is important to understand what people feel when using AR. Emotions such as frustration or excitement can create aversion or desire to the technology, and it is important to understand what leads to them. This includes the difficulties felt or the feelings involved. This work can be done either by talking or observation. For this reason, an approach that is predominantly qualitative is more suitable for this work.

Multiple case study research was conducted to fulfill the goals of this project. A case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context. In this type of research, the researcher will collect data in detail using different data collection procedures along a sustained period of time in order to provide an in-depth understanding of a case or cases. Multiple case study research involves studying more than one case within a single research project (Yin, 2014).

A mobile augmented reality application was used to create a touristic outdoor experience in Porto city. Eleven usability tests were conducted divided in two groups: group A with 6 younger adults and group B with 5 older adults. The application followed guidelines proposed from multiple authors in AR literature, namely the inclusion of multiple sensorial clues (i.e. sound, haptic, vision) to support the exploration of three points of interest in the historical sites of Porto (Portugal). The data was collected during the test of the application, in-situ, by recording the audio of the interview, with notes. Data analysis was undertaken iteratively with the research team.

3.1 Case Selection

The designed experience aimed to focus on the challenges of AR-enabled experiences in the tourism sector. Two groups were defined: group A, consisting of younger adults with high digital literacy, and group B, consisting of older adults who tend to have low digital literacy and/or physical problems. (i.e vision or audition problems). For this experience the Kluest

application was used. Kluest is an application where it is possible to play in adventures created by other users or create a new adventure with the help of AR (*Kluest*, n.d.). The application was used to create an experience that used multiple sensorial clues to support the exploration of three points of interest in the historical sites of the city.

The purpose of using this application was to create an AR adventure in an outdoor tourism context considering the research objectives and research questions. The designed experience is detailed in chapter 4.1.

3.2 Data Collection

Data was mainly collected by usability testing. Usability testing consists of a set of techniques to gather data about the interaction of a user with a user interface. While sometimes usability testing might be done to find usability problems and its resolutions, it can also be done to evaluate task performance. By doing so, it becomes easier for developers to understand the usability problems and create more usable products (Salvendy, 2012).

First, the test had a pre-questionnaire where people would answer some questions that would define each group. The questions involved age, education or experience with technology. The usability tests were designed following the recommendations of Nielsen Norman Group (Guidelines for Testing Mobile Augmented-Reality Apps, 2022). A context was given to the users about the definition of AR and the purpose of the usability tests. An informed consent was signed by every user with information about the experience and the recording of the voice and how it would be used.

Second, tasks that required physical activity (e.g. going to a specific place) were alternated with tasks that did not (e.g. clicking on the mobile screen). A pilot test was undertaken with one user before the usability tests in order to identify opportunities to improve the design of the application. The voice recording was used to capture behavior, thoughts and feelings.

During the test sessions, a conversation happened between the researcher and the user where different questions were made about the different tasks. Notes were taken by the research such as the number of completed tasks or the duration of the test. At the end of the usability test, an interview was conducted to tackle important points that might not have been talked about during the test. After the end of the test and recording, users were asked to fill the User Experience Questionnaire (UEQ) to evaluate the User Experience. The UEQ measures both classical usability aspects and user experience aspects (User Experience Questionnaire (UEQ), 2018).

The interview protocol which includes the tasks undertaken by the users is available in Appendix B. Additionally, the template of the informed consent can be found in Appendix A.

3.3 Data Analysis

A multiple case study research design was used to support data collection, analysis, and reporting, following the recommendations of Yin (2014). Additionally, the tenets of qualitative research outlined by Creswell (2014) were employed to facilitate cross-case analysis and data triangulation. Qualitative data gathered from voice recording was transcribed and all the notes taken in the usability tests were considered. This data was all stored and organized systematically. From all the quotes and behaviors of the participants and comments from the researcher, initial coding was conducted by the categorization of data in meaningful sentences. From the coding, some codes appeared based on the gaps found in the literature review and new themes also appeared. An adhoc strategy was used to compare predicted patterns with empirically based patterns. Cross-case synthesis was also used to identify similarities and differences across multiple cases. To ensure the validity of the findings, multiple sources of evidence were triangulated such as quotes, observations or behaviors. The coding was done manually using Microsoft Excel. The filters were constituted by: participant code, group, type of information (quote, comment, behavior), information, subcode and code.

The quantitative data gathered such as time spent in the experience and number of completed tasks were also analyzed. The UEQ was analyzed using the UEQ Handbook.

Figure 2 shows a diagram representing the methodology with the case selection, data collection, data analysis and results.

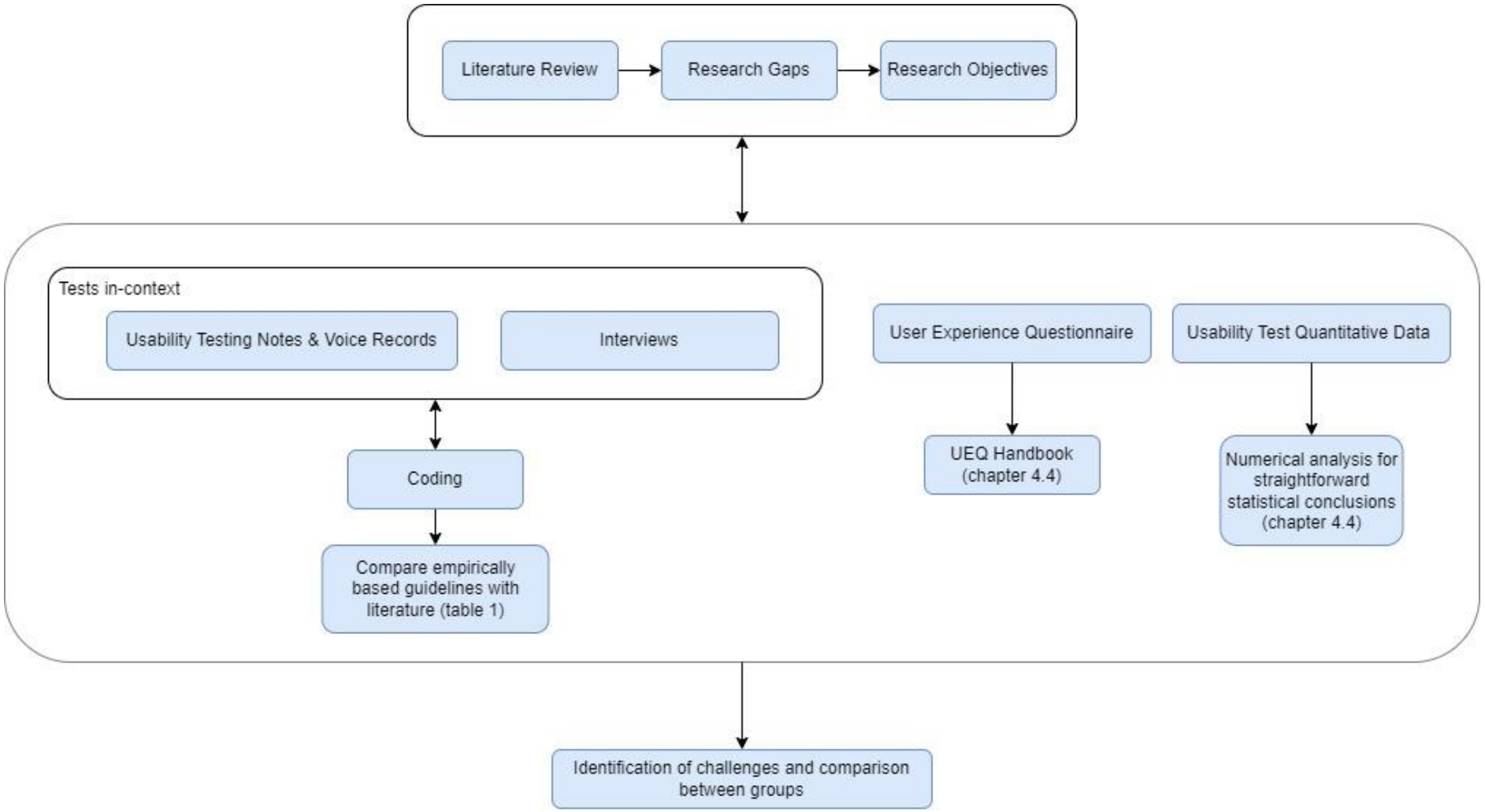


Figure 2 - Methodology

4 Results

In the results chapter, an overview of the experience design in Kluest is presented along with the explanation of the tasks created. The results of the codification are presented, namely the results of the User Experience Questionnaire and other quantitative data. The last section consists of a general discussion of results.

4.1 Development of AR experience with Kluest

For the experience design, the Kluest application and its features were analyzed. This application was run on an iPhone 13 and used in its beta version, meaning that it is not yet fully stable and is under development.

For the design of the experience, three main points were taken into consideration: the features of the application, the research objectives and the existing guidelines identified in the literature review. When it comes to the features of the application, several features were considered:

- The use of sound and haptic as feedback;
- The addition of information with sound and text;
- The interaction with virtual objects;
- The navigation with maps;
- Solving questions;
- Clues for interacting with virtual objects;
- Customization of point of interest with an image.

The features were used by creating an outdoor touristic experience in Porto, Portugal. This experience was designed to not be too physically demanding given the target audience. Therefore, three points of interest of Porto were chosen: Igreja do Carmo, Livraria Lello and Torre dos Clérigos. A route was created with these points of interest along the way, each providing information either through sound or text. The route is presented in Figure 3 using the Google Maps application.

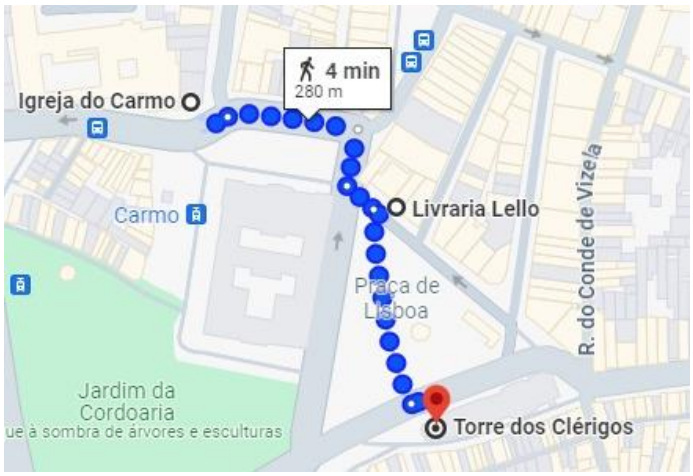


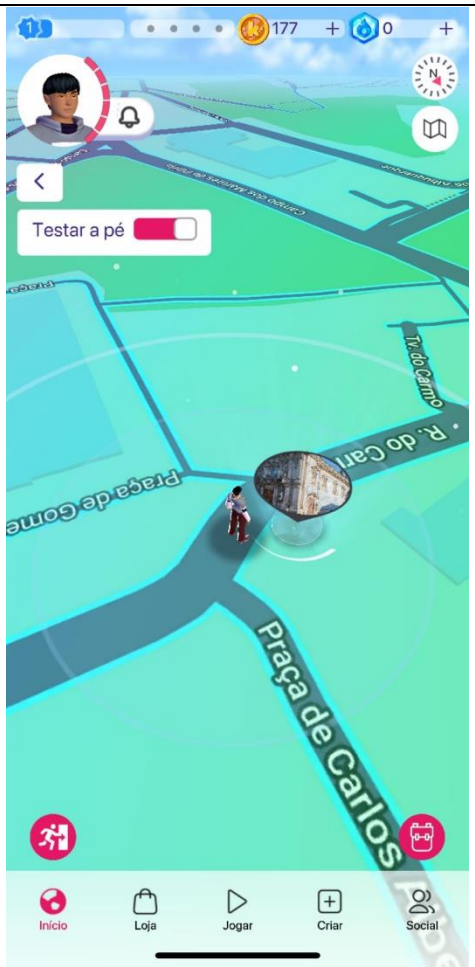
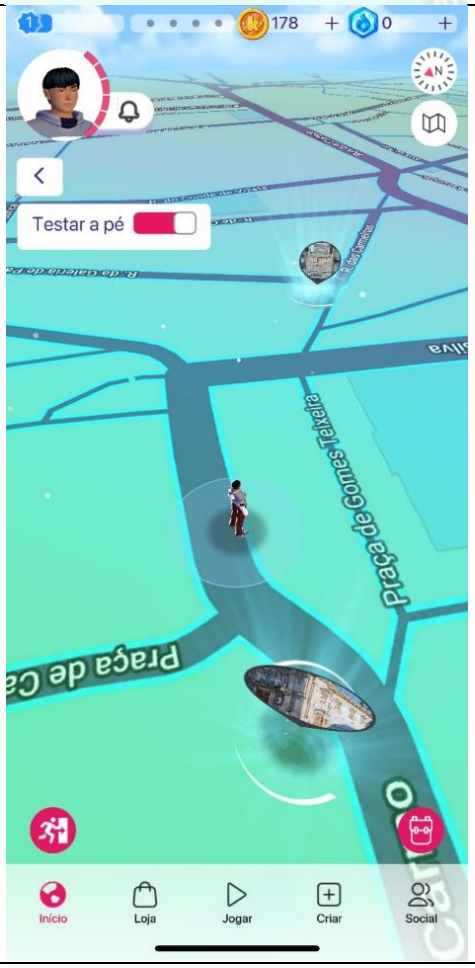
Figure 3 - Route with three points of interest

Given the guidelines for usability testing in AR (Guidelines for Testing Mobile Augmented-Reality Apps, 2022), the usability test was created taking into account the time of the adaptation of the participants to the technology.

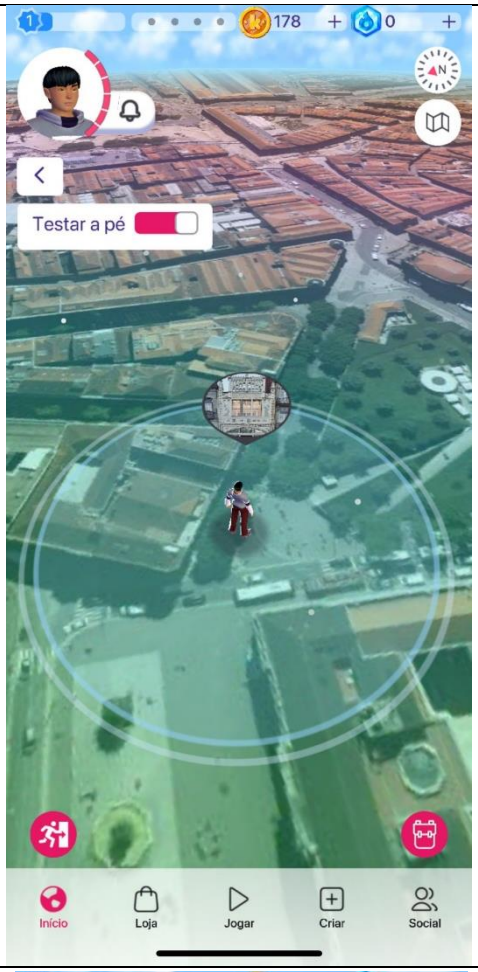
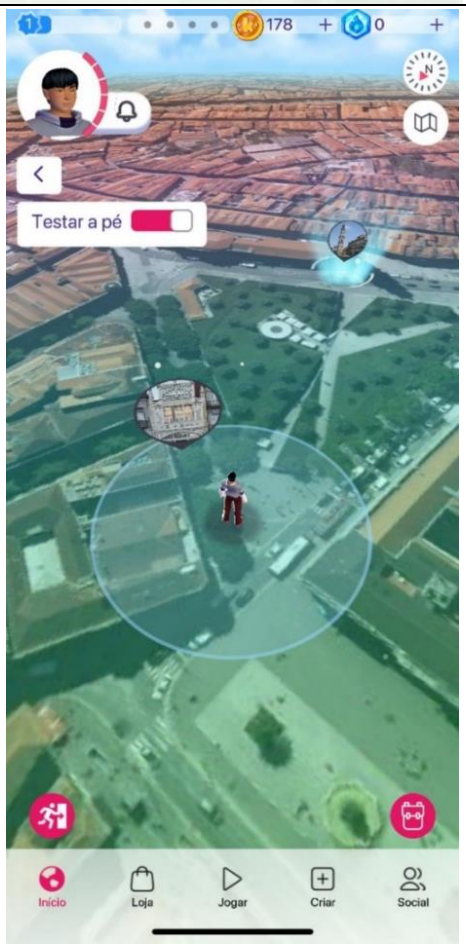
Eight tasks were created:

- Task 1 – Hear informations about Igreja do Carmo (church);
- Task 2 – Go to the nearest point of interest (Livraria Lello);
- Task 3 - Read information about Livraria Lello and interact with Márcia (virtual object);
- Task 4 – Take a centered picture to Márcia (virtual object);
- Task 5 – Change the type of map to satellite map;
- Task 6 – Go to the nearest point of interest (Torre dos Clérigos) and read information;
- Task 7 – Answer the final question to evaluate knowledge;
- Task 8 – Read message in the panel.

In Table 2 it is possible to see each task with the corresponding screenshot and guideline explored.

Task 1 – Hear informations about Igreja do Carmo (church) Features included: · a picture of the church to support identification of the location (G1) · activating sound by clicking the image (G4)	
Task 2 – Go to the nearest point of interest (Livraria Lello) Features included: · identification of POI in the map (G1) · feedback of arrival to the POI by haptic and audio (G4)	

Task 3 – Read information about Livraria Lello and interact with Márcia Features included: · a picture of Livraria Lello to support identification of the location (G1) · activating text by clicking the image (G4, G2) · interaction with virtual object Márcia (G3)	
Task 4 – Take a centered picture to Márcia (virtual object) Features included: · directing camera in with help of arrows in order to center Márcia (G3)	

Task 5 – Change the type of map to satellite map Features included: · associate map icon to the change of map typology · change map typology to "Satellite" (G1)	
Task 6 – Go to the nearest point of interest (Torre dos Clérigos) and read information Features included: · navigate through map (G1) · feedback of arrival to the POI by haptic and audio (G4)	

<table>
<tr>
<td>Task 7 – Answer the final question to evaluate knowledge

Features included:
· evaluating retention of information during the experience (G2)</td>
<td> 
</td>
</tr>
<tr>
<td>Task 8 – Read message in the panel

Features included:
· directing camera with help of arrows in order to center and read the panel (G3)
· click pink button to end the adventure</td>
<td> 


</td>
</tr>
</table>

Table 2 – Tasks and features in Kluest

The usability tests were conducted in Porto between April and May of 2024. Eleven tests and interviews were carried out, divided into two groups: 6 participants from group A, comprising younger adults with higher digital literacy, and 5 participants from group B, consisting of older adults with lower digital literacy. The six people from group A were between 25 and 31 years old and the five people from group B were between 63 and 80 years old. Participants were selected based on initial conversations to assess their availability and digital literacy. Detailed sample characteristics can be found in Appendix C.

4.2 Factors influencing the experience

From the qualitative analysis six categories were created: association of map with real world, outdoor experience, multisensory experience, touristic experience/learning, virtual objects interaction, and intuitive application usage (see Table 3 to consult codes, subcodes and supporting quotes).

Association of map with real world

In this category several subcategories were identified such as the map typology, the position marker, the orientation, the points of interest, the route or the comparison with other maps applications.

The map in the application was one of the most present features during the experiences, which resulted in being the one with the higher number of comments. For most people, the satellite map was easier to deal with since it had more information and thus created a better sense of association between the map and the real world. The use of this map respects Guideline 1 (G1) - Use context to provide information. One big complaining point was the fact that the position's marker was not moving at the same rhythm as the person, creating some confusion in the beginning and affecting the user experience. Another complaint was the poor understanding of the orientation of the marker. Since its drawing was a detailed avatar, what marked the orientation was the front of it, which did not make the orientation very clear. The dimension of the points of interest on the map was also a problem since a lot of people could not identify the point from the picture and intended to make it bigger, but this was not possible since the zoom option was not available. Since the feedback of arrival to the POI was given when people were still distant from it, it also made interpretation more difficult. The existence of the route represented with a line on the map was also a suggestion for better guidance.

KEY TAKEAWAYS

- Map typology that creates a better association with the real world, such as the satellite type, suggests enhancement of the user experience (G1).

- The position marker was too detailed, not giving a good perception of the orientation. The fact that it did not move in the same rhythm as the person created association problems.
- The usage of an image to identify the POI and the feedback when people were still away from it created identification problems (G1).

Outdoor experience

The experience was very influenced by the fact that it was outdoors. This might add some concerns such as the noise (coming from traffic, construction works, musicians in the street, other touristic experiences or even academic activities), the sunlight or the relation with other people.

The use of sound was sometimes unnoticed or difficult to be perceived, however it enhanced the user experience when perceived properly. The noise had a big influence, being mentioned by all the participants. The usage of audio support such as earphones was agreed between the users to be a good idea. The sunlight was not a problem for most people and did not have influence in the visualization of the virtual objects, suggesting that the contrast between the background and the overlays was adequate. However, for people with vision conditions, the sunlight made the experience more unpleasant and created some perception problems. It was needed at some points to look for places with less clarity to better look at the phone.

KEY TAKEAWAYS

- Sunlight did not affect the visualization of virtual objects but affected the user experience of people with vision problems.
- Outdoor noise has a big influence – earphones were suggested.

Multisensory experience

A multisensory experience is defined by an experience that uses and takes advantage of different senses such as vision and audition. In this experience a multisensory approach was used in two different aspects: feedback and getting information in the game.

The noise from the street created some problems as mentioned in the previous subchapter, but the sound from the application enhanced user satisfaction, suggesting it is something worth exploring. The combination of haptic and sound was also suggested to be a good way to give feedback, supporting the literature review and G4. However, the haptic was sometimes unnoticeable, which might be caused by the intensity of the vibration. Some visual feedback was also agreed to be a good addition, such as the images of the points of interest getting bigger

when the user is getting closer. When it comes to receiving information from text or sound, data does not suggest conclusions about which one is better, being a matter of preference rather than effectiveness. It is however suggested the possibility of combining both, so that the user can choose. The use of sound also helps not losing the perception of the surroundings since it does not demand the constant look to the phone. This suggestion counteracts one of the negative effects of AR mentioned in the literature review which is the disruption level of the users with the real world.

KEY TAKEAWAYS

- Use of haptic and audio effective as feedback when perceived properly. It can be combined with visual feedback (G4).
- The use of sound helps to counteract the disruption level.
- The combination of text and sound to pass information according to preferences and vision or audition problems is suggested.

Touristic experience/learning

The touristic experience is defined by the multisensory learning, the comparison with other touristic experiences, the learning interest and the future interest.

One behavior common to all users was the difficulty in retaining information. Data such as names or dates were given throughout the experience, but in the final question no one seemed to have retained enough to be able to answer. Some people stated that in touristic experiences it was more interesting to be able to look at the surroundings and be present rather than memorize information. Compared to other touristic experiences like guided tours, these applications offer the advantage of being used independently, eliminating the need to pay for information and guides. Although Guideline 5 (G5) from the literature review – Ensuring privacy, autonomy, and security – was not incorporated into the experience design due to the absence of available features, this comparison highlights its relevance. The feeling of novelty and gamification were important to enhance the user experience. There was a comparison to the peddy paper games, which recalls the feeling of fun. The learning interest was also present and suggested by quotes from the participants. Even without memorizing names and dates, the exploration of the city by foot and getting other types of information was still a cultural enrichment for the participants who showed an interest in using this type of applications in the future.

KEY TAKEAWAYS

- Challenges with semantical memory (G2) and preferences for multisensory learning.

- Comparison with guided touristic experiences – this type of application is seen as a mean to get independence in touristic experiences (G5).
- Gamification with a good impact in the experience.

Virtual Objects Interaction

The interaction with virtual objects consists of the relevance of objects, positioning or interaction in the real world.

The fact that the blend of virtual objects into the real world is novelty for a lot of people can create feelings such as curiosity or misunderstanding. Some participants giggled when having contact with the virtual objects and kept a conversation about how interesting it was for them. The connection of the object with the context also makes it more appealing, recalling G1. The doll on Livraria Lello created some confusion or even dislike among some users, who did not think her appearance was relevant to the experience since it did not appear to have any correlation to the context. On the other hand, the panel giving information about Torre dos Clérigos was well received.

KEY TAKEAWAYS

- Preference for objects related to the context, such as the informative panel (G1).
- Feelings of interest and curiosity related to virtual objects.

Intuitive Application Usage

Intuitive application usage refers to the ability to interact with an application in a natural and effortless manner, where users can understand and navigate its features without the need for detailed instructions or prior learning, resulting in a smooth and enjoyable experience. In this category several subcodes were identified such as screen size, font size, interaction with the camera, interaction with the map and the learning curve.

When it comes to the map, some users attempted to interact with it in a way the application did not allow, such as doing zoom on the map or on the points of interest markers. More information about the other subcodes are detailed in chapter 4.3.

KEY TAKEAWAYS

- Interest in interacting with the application in ways it did not allow.

Table 3 shows the codes and subcodes created through the usability testing, along with their supporting quotes, comments or behaviors. Participant identifiers are prefixed to each quote,

with those starting with "A" corresponding to group A of younger adults and those starting with "B" corresponding to Group B of older adults.

Association of map with real world	
Subcodes	**Supporting quotes/comments/behaviors**
Map typology	(A1) "the satellite map is easier to understand"; (B2) "the satellite map is better because it gives a better sense of where we are"
Points of interest	(A1) "I should be able to zoom the image"; (A4) "the marker's position is far away from where it should be so that I would understand that I arrived"; (B1, B3) could not understand the POIs that were already visited; (B5) "for me this was just a point in the map, not a building"
Orientation	(B1) "it was difficult to understand where the avatar was heading to"; (B4) "I don't see what the avatar is facing"; (B5) "I don't think it is very well oriented"
Position's marker	(B4) "the avatar is little, so it is difficult to understand what he is facing, also because I have vision problems"
Route	(A1) "this could have a line to follow"; (A2) "it would be better if the avatar moved while I move; (B1) "not seeing the avatar move as I moved created some difficulties"; (A5) "the avatar moves with delay"
Comparison with other apps	(A1) "if it was more like we see in Google Maps"; (A6) "when we compare with Google Maps, it moves differently"
Multisensory experience	
Subcodes	**Supporting quotes/comments/behaviors**
Multisensory feedback	(B2) "I understood I arrived because I felt a vibration"; (B4) "I did not hear anything, but given this noise and the fact that I have audition problems…";
Information by sound and text	(A2) "sound is good so that people can look around"; (A3) "I prefer text since the noise does not have influence"; (A6) "I think it would be good to have both options"
Outdoor experience	
Subcodes	**Supporting quotes/comments/behaviors**
Outdoor noise	(A5) "not having earphones and being a very noisy makes perception difficult"; "I had to maximize the volume"; (A6) "the wind makes audio perception difficult"; (B1) "I did not understand, it is very noisy"

Sunlight influence	(B4) “let’s go find a shadow”; (A5) “when the sunlight was strong, I had problems looking at the map”
Relation with other people	(A1) “I think it is going to look like I am filming people”; (A6) “Let’s wait a second, so it does not look like I am filming people”
Touristic experience/learning	
Subcodes	**Supporting quotes/comments/behaviors**
Future interest	(B4) “I would like to do it again, I think this is very interesting”
Multisensory learning	(A1) “even when I visit cities, I don’t usually read the information, I prefer to see”; (A4) “I was not paying attention to the information”; (B1) “I did not fix any dates”
Learning interest	(B4) “We pass here and are not able to understand how rich this patrimony is, with this experience we start to understand”
Comparison with other touristic experiences	(A5) “Guided experiences are usually paid, this is an accessible and independent way to explore cities”
Virtual objects interaction	
Subcodes	**Supporting quotes/comments/behaviors**
Relevance of objects	(A1) “the panel is more interesting and informative”; (A3) “I felt more connected to the panel than to the doll”; (A5) “the panel is realer which makes it more interesting than the doll”; (B5) “I did not like the doll that much, but I liked the panel”
Positioning	(A2) “the panel should be in front of the tower”; (A4) “the doll should be closer to the point of interest”
Interaction in real world	(A3) “I liked how I had to move the camera to interact with the panel”
Intuitive application usage	
Subcodes	**Supporting quotes/comments/behaviors**
Learning curve	(B1) “I am still trying and learning”, “maybe now that I have tried it first, the next time it would probably be better”; (B4) “it was difficult, I was not understanding at first”; (B3) “I think what made it difficult was the fact that I never used anything like this”
Camera interaction	(B1, B3, B4, B5) clicking in the arrows instead of using it has a guide to point the camera; (B4) turning the phone upside down to take a picture

Map interaction	(B5) “this is not well signaled”; (B4) “I am not understanding this”
Font size	(B1) “if the font was bigger, the experience would be better”;
Screen size	(B1) “the screen size might be too little”

Table 3 - Codes, subcodes and supporting quotes

4.3 Comparison between groups

Although there were many similarities between group A (younger adults) and group B (older adults) regarding difficulties and improvements, some codes and subcodes were mentioned only by specific groups. This comparison is crucial for assessing the challenges more prevalent among older adults.

Learning curve

It was noticed that people from group B (older adults) needed more time to adapt to unknown features such as the map. For the people who had no experience with maps, the beginning of the experience was made with a trial-and-error approach. From the errors made, they slowly started to understand how the map worked. During this adaptation, there were a lot of feelings of frustration, but once the problems were overcome it was also noticeable how people got happy with their achievements. As mentioned in the literature review, it is important to consider emotional involvement since it has a big impact on the user’s desire to engage with new technologies. Therefore, to avoid these problems, it is important that tutorials and initial guides are presented in these types of applications as suggested in G3.

Font and screen size

While most of the people thought that in general the letters and display sizes were suitable for the experience, participants from group B mentioned the letters were small. It was also mentioned that the experience would be better if the size of the phone was a little larger. The applications should adapt to these needs and preferences by the ability of adjusting the font-size in the application as it is possible to do in operating systems. When it comes to the screen size, the applications should be responsive, even though devices bigger than smartphones are not as suitable for outdoor experiences.

Camera Interaction

Group A showed more comfort in interacting with the camera trying to drag or resize objects. When the camera gave indications about where to point it, group B had difficulties interpreting it. When the meaning of the arrows was to guide where the camera should be pointing to, people from group B expected something would happen when they clicked in the arrows, not

attempting to interact in other way when the clicks did not show any result. Other behaviors such as turning the phone upside down were noticed in group B.

Multisensorial feedback

As mentioned previously, when interacting with virtual objects (taking a picture or reading a message), arrows were presented in the camera to guide the user where to point to. Figure 4 shows a moment during the test when the arrows appear.

Figure 4 - Presence of arrows in task 4

Márcia's feet appear in the superior right corner of the image. The two arrows on top and on the right side went unnoticed for people from group B, failing to provide the intended visual feedback. Multisensory feedback could also be explored by using haptic or audio when the figure is properly centered.

Comparing Kluest with other map applications

Group A has higher digital literacy, meaning there is a better knowledge of other applications, namely maps applications. A lot of comparisons with Google Maps were pointed out such as the position's marker and the orientation. In Google Maps, the marker consists of a simple blue

circle with a shadow pointing the direction (see Figure 6), being much simpler to understand. When doing a route, the marker moves at the same time as the person, which was one of the weaknesses identified in Kluest by the different users.

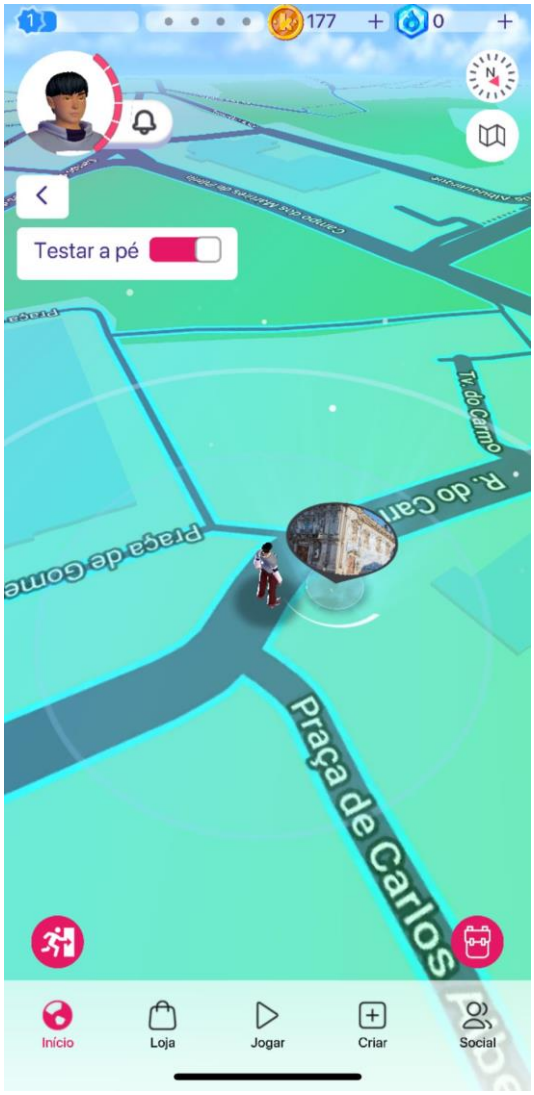


Figure 5 - Position's marker in Kluest

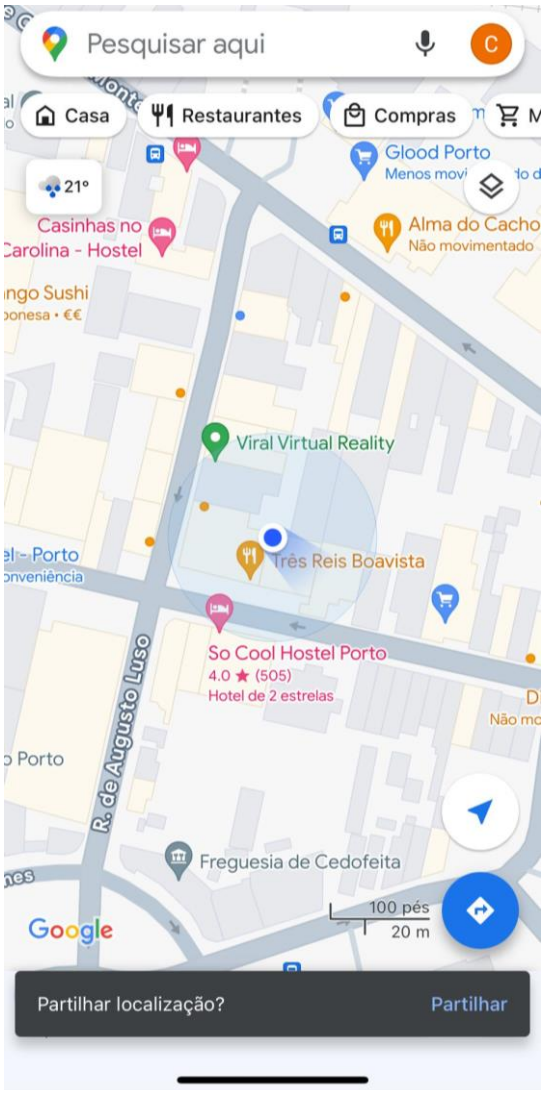


Figure 6 - Position's marker in Google Maps

Outdoor experience

One of the points mentioned in the literature review was how the light would affect how the virtual objects would be seen, as they could appear washed or faded out. This was not a detected problem during the usability testing. The sunlight affected just a specific group of people which were people with visual impairments. One of the people from group A had recurring erosion syndrome while three people of group B had other types of visual impairments associated to older people such as cataracts. While vision impairments might be detected in older and younger people, they are mainly detected in older people. People of group A also showed discomfort by the need of pointing the camera to groups of people. This was felt given the

possibility of making other people think they were being filmed by them. While this is not associated with the privacy of the application users, it is associated to the privacy of other people.

Points of interest

When it comes to the points of interest, its representation was also a challenge for group B in different aspects. The image was too little for a lot of people, but especially for older adults. The identification to the real place was difficult and there was not a way to make the image bigger. Another problem was finding the points in the map. While the interaction with it was already difficult for group B, the points were sometimes difficult to spot. Some people were unable to associate the point on the map with a point of interest; instead, they perceived it as a regular map marker without specific indication that it was a point of interest. This suggests not only that the possibility to zoom the images could be helpful, but also that the images might not be the best representation type for points of interest in a map for older people.

Another problem noticed in group B was the difficulty understanding the POIs that had been visited already. A suggestion would be to use a simple symbol in the image like a check to help understand the "visited" points and the "to visit" points. The addition of this information is aligned with G2, namely with the support of procedural memory.

Virtual objects interaction

Group A engaged with virtual objects in the real world, attempting to manipulate them through the camera by dragging or resizing. However, these actions were not supported by the application. The younger participants suggested that incorporating these features would enhance the user experience. They also interacted physically with the virtual objects, such as kicking or touching them, and observed their behavior through the camera. Additionally, this group proposed improvements for the positioning of virtual objects. They emphasized the importance of placing objects related to points of interest (e.g., the panel at Torre dos Clérigos) directly in front of them to facilitate a clearer relationship between the virtual object and the real-world point of interest.

In Figure **7** we can see the comparison between the subcodes in between the groups where the blue circle represents group A (younger people) and the red one represents group B (older people).

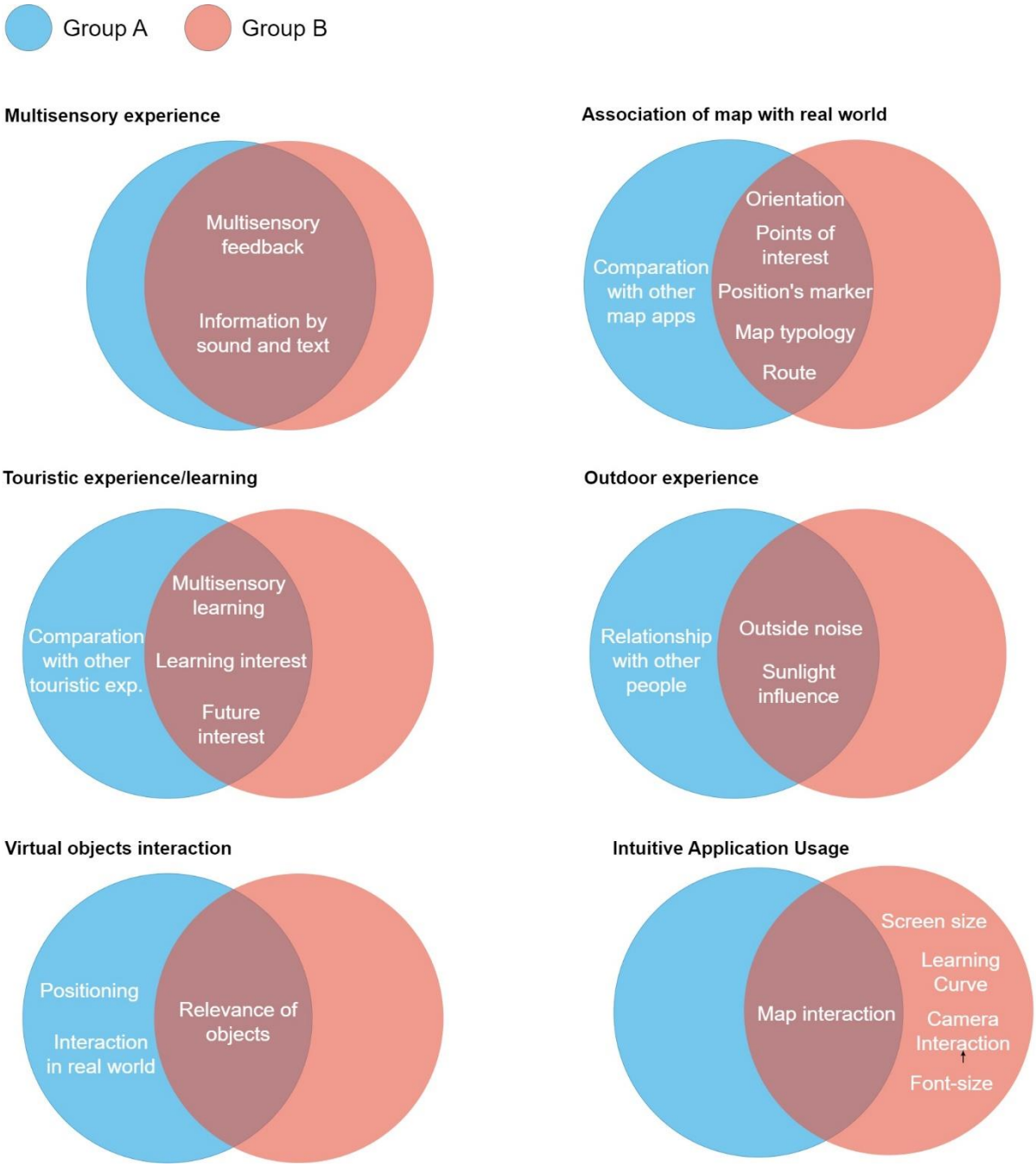


Figure 7 - Comparison between groups

4.4 Usability Test

In the end of the usability tests, the participants were asked to fill in the User Experience Questionnaire. The results were analyzed according to the User Experience Questionnaire Handbook (User Experience Questionnaire (UEQ), 2018). UEQ contains twenty-six items divided within six scales: attractiveness, efficiency, comprehensibility, reliability, stimulation and innovation. The six dimensions can subsequently be divided in three:

- Attractiveness – a pure valence dimension by itself;

- Pragmatic Quality – constituted by goal-directed scales which are perspicuity, efficiency and dependability;
- Hedonic Quality - constituted by not goal-directed aspects which are stimulation and novelty.

In the questionnaire, each of the twenty-six items are evaluated in a scale from one to seven as it is shown in Figure 8. The UEQ template filled by the participants can be seen in Appendix D.

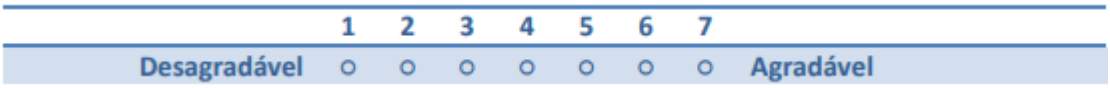


Figure 8 - Scale from Pleasent to Unpleasent

A scale from 1 to 7 is then transformed to -3 to +3 to have negative and positive spectrum. The standard interpretation states that means between -0.8 and +0.8 represent neutral evaluations. The UEQ Questionnaire also presents a benchmark of 452 product evaluations with the UEQ. This benchmark can be used to get a better picture of the quality of a product by comparing the measured user experience of the product to results of other established products.

From the UEQ tools, several graphics are generated giving information about the user experience of the participants.

The results for group A are shown in Figure 9.

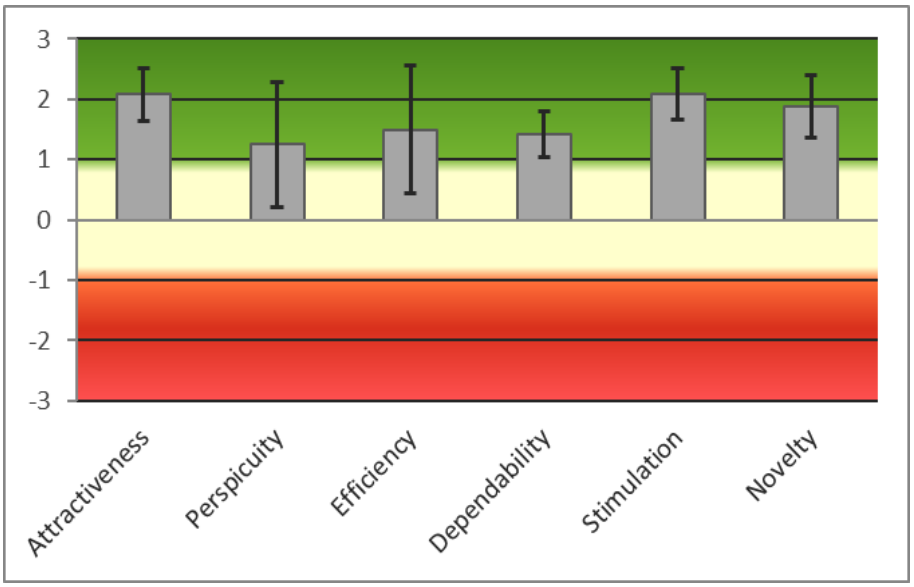


Figure 9 - UEQ results group A

All the six factors have a mean bigger than 0.8, meaning the results are positive in all of them. The Pragmatic Quality (goal-oriented) presents a bigger variance, suggesting the existence of a bigger discrepancy between the participants of group A on the three corresponding scales.

Comparing to the benchmark provided by the UEQ tool, the results are shown in Figure 10 for group A.

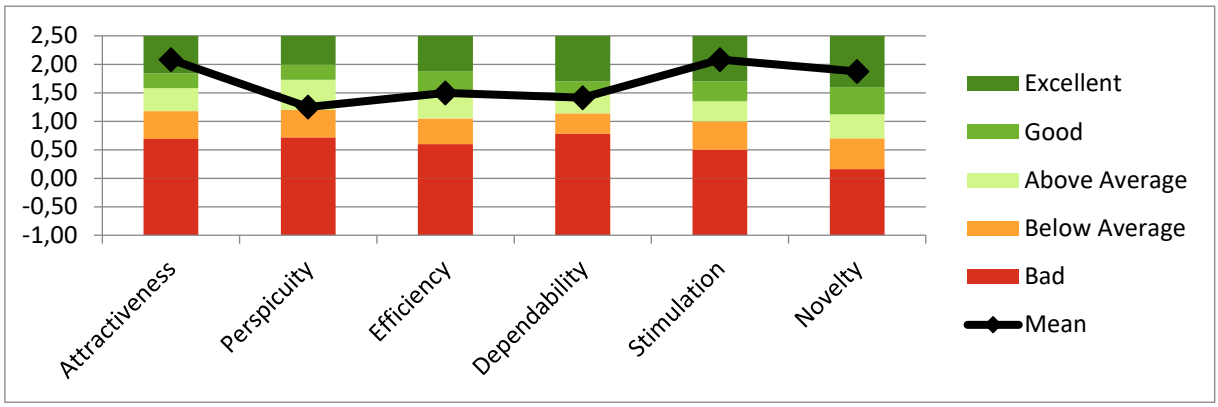


Figure 10 - UEQ benchmark comparison group A

While all the six factors are placed in a positive threshold, three of them are considered Excellent (Attractiveness, Stimulation and Novelty) while the other three are only considered Above Average (Perspicuty, Efficiency and Dependability). This result suggests a stronger component for Attractiveness and Hedonic Quality than for Pragmatic Quality.

The results for group B are shown in Figure 11.

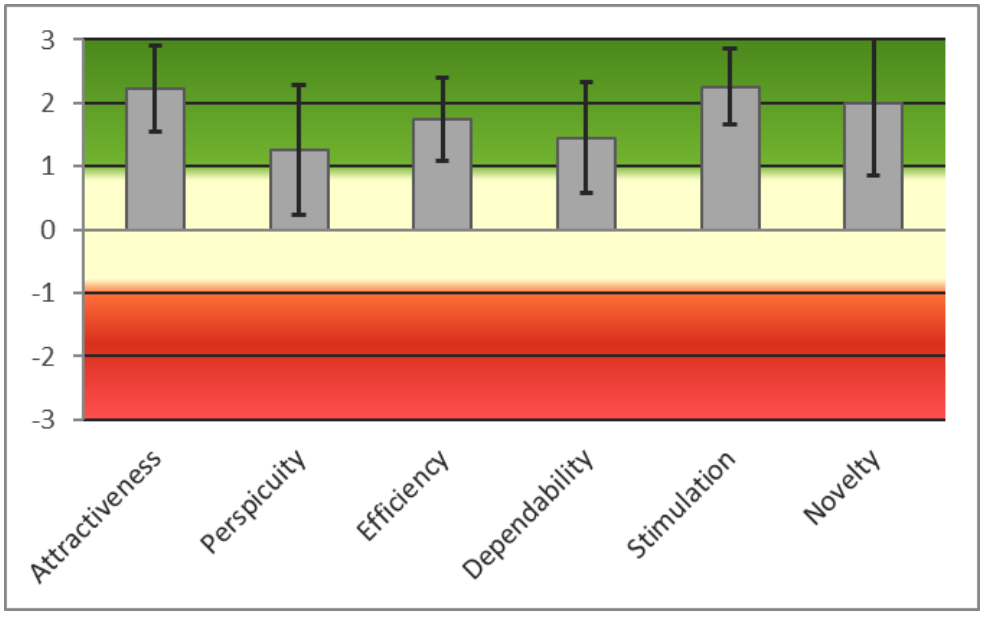


Figure 11 - UEQ results group B

Just like in group B, all the six factors are evaluated positively. However, there is a bigger variance in each scale, suggesting a bigger discrepancy.

Comparing to the benchmark provided by the UEQ tool, the results are shown in Figure 12 for group B.

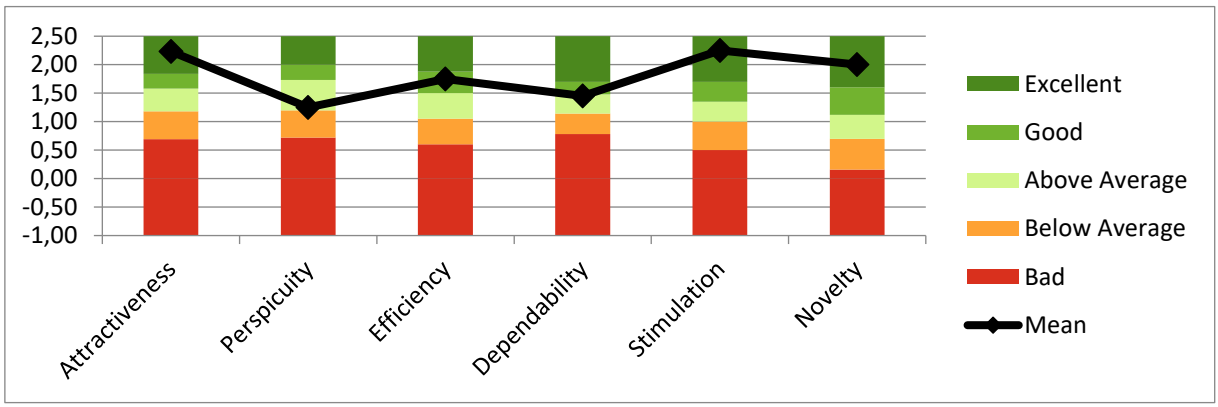


Figure 12 - UEQ benchmark comparison group B

While all the six factors are placed in a positive threshold, three of them are considered Excellent (Attractiveness, Stimulation and Novelty), two are only considered Above Average (Perspicuty and Dependability) and one of them is considered Good (Efficiency). Like in group A, this result also suggests a stronger component for the Attractiveness and Hedonic Quality than for Pragmatic Quality.

According to the User Experience Questionnaires and its Handbook, no meaningful difference was detected between either groups regarding the user experience.

Other quantitative data was gathered during the usability testing namely the test time and % of completed tasks. This data is showed in Table 4.

Participant's code	Test time (in minutes)	% of completed tasks
A1	18	100
A2	17	100
A3	15	100
A4	17	100
A5	16	100
A6	15	100
B1	40	67
B2	15	100
B3	25	83,3
B4	25	100
B5	30	83,3

Table 4 - Quantitative results from usability tests

While the test times in group A are within the range 15-20, the test times range in group B is within the range 15-40. The longer test times suggest a correlation with the learning curve:

extended test times indicate a bigger learning curve and, consequently, longer duration for the tests.

The difference between the data obtained through qualitative analysis and quantitative analysis suggests that qualitative analysis is a more suitable approach to usability studies.

4.5 General discussion

One of the biggest challenges of AR mentioned in the literature review is the level of disruption felt. In the usability testing, no comments were made by any participant about feeling unsafe or disrupted with real world. There were also no behaviors or observations made by the researcher that suggested this type of feelings. The route of the usability testing could create some minor dangers if the participants were not aware of their surroundings such as crossing the street or going against other people. Although the researcher remained vigilant throughout, she found no need to intervene in any situation.

One of the behaviors noticed in group B was the fact that the existence of a lot of icons on the screen was confusing for them. While group A knew exactly where to click in the application to execute the proposed task, the older adults had a trial-and-error approach until they understood how to interact even when a similar task had been executed before. The existence of a lot of icons suggests the creation of more errors to be done. These types of situations can be avoided by following G2 - Reduce cognition load to improve learning. The adoption of the adaptable user interface principle suggested in the work of Shneiderman Ben (2002) would be one of the approaches to be considered to solve this problem.

Another noticed behavior was the difference of the touch gestures in the interface (drag, resize, click or swipe). While younger adults appeared to use the most appropriate gestures for each task, older adults consistently began clicking and persisted with this behavior. Even the clicking actions differed between group A and group B. Younger adults could simply click to achieve the desired result, whereas older adults sometimes clicked more slowly, which the application did not always recognize, thus failing to trigger the intended action.

Overall, the usability test ended up being a more emotional experience for group B than for group A. While a lot of comments from younger adults consisted of detection of errors and suggestions of improvements, the comments from older adults were more related to frustration, happiness, surprise or doubt. The emergence of these emotions has a big impact on the adaptation of the technology and the intention of use. Providing means for a better adaptation for older adults is crucial for the adaptation of the technology and the enhancement of the user experience.

5 Contributions

In the designed experience, several gaps mentioned in the literature review were covered: the exploration in gamification, the age of the participants in usability studies for AR, the combination of quantitative and qualitative studies and the usage of different methods to capture actual behavior. The results obtained from the two groups with different age ranges support the idea that participants' age significantly impacts the outcomes and that conducting more usability studies with participants of diverse ages is beneficial. The combination of qualitative and quantitative studies did not suggest a significative impact. While quantitative analysis revealed no significant differences between the groups, qualitative analysis highlighted numerous distinctions. The gamification provided feelings of fun and accomplishment, which enhanced user satisfaction. Given that good emotions have an impact on the intent of use (Soon et al., 2023), the exploration of gamification in usability studies might be enriching. The usability tests with voice recordings aligned with observation of behaviors also created more insights.

The guidelines identified during the literature review were tested during the experience. Guideline 1 (G1) – Use context to provide information – was supported by several codes and subcodes created during the qualitative analysis. For an accurate association of the map with the real world it is important to use the information of the real world (context) and use it to pass information through the application (content). In terms of interacting with virtual objects, there was also a desire for objects that were contextually relevant and provided information about their surroundings.

Guideline 2 (G2) - Reduce cognition load to improve learning – showed its importance in different points of the experience. The retention of information such as dates did not happen to any participant, meaning that the way the experience was designed did not have the best approach for the support of semantical memory.

Guideline 3 (G3) – Intuitive application usage – was also verified in the experience in different topics. The existence of a guide on how to use the application is crucial for a good adaptation for everyone. This guide should cover a lot of different subtopics when it comes to the use of the application. Not only it is needed for people to understand the goal of the features and how they work, it is also needed for a better understanding of the types of interaction possible to do with the application. The adaptation of the font-size is a good way to make sure people feel comfortable and can read the information properly.

Guideline 4 (G4) - Combine multisensory feedback – was also supported by this experience. It is however needed to have a good perception of the different stimulus for it to be successful and take into consideration the outdoor factors. Not only is multisensory feedback a valuable

concept, but a holistic multisensory experience is also beneficial. The ability to receive information through both sound and text was a positive aspect of the experience, and combining both modalities could enhance accessibility of the application.

Guideline 5 (G5) - Ensure privacy, autonomy and security – was not explored when creating the tasks for the experience. However, participants mentioned that the opportunity for greater autonomy in their touristic experiences was a compelling reason for using these applications.

Additional guidelines emerged after the experience, one of them involving strategies for managing external factors during outdoor activities. Participants experienced noise from traffic, construction work, wind, music, and other tourists, which impaired their perception. The use of earphones was suggested as a potential solution. While sunlight did not affect the visibility of graphics and 3D objects for most individuals, it did impact the user experience for those with visual impairments.

Regarding the category 'Association of Map with Real World,' adhering to G1 was identified as a solution to many challenges encountered. Other challenges included the difficulty of interpreting detailed marker positions, suggesting that simpler markers, such as those used in Google Maps, are more suitable, particularly for older adults. Additionally, the movement of the marker should closely align with the movement of the person holding the handheld display.

For points of interest (POIs), feedback upon arrival should be provided near the POI to facilitate easier association. Additionally, there should be visual feedback indicating visited and unvisited points. Using an image to represent the POI may not be the most effective approach for older individuals.

While exploring Guideline 4 – Combine multisensory feedback – it was suggested that the use of audio and haptic could reduce the likelihood of significant disruption in the real world, as participants would not need to constantly look at their phones.

6 Conclusions

This study aimed to achieve a set of research objectives, which have been successfully met throughout the research process. The challenges of touristic experiences in outdoor contexts were highlighted with a specific focus on older adults. In response to these challenges, various strategies were discussed and proposed within this document.

6.1 Limitations

One of the limitations of this study was the difficulty finding people that fitted group B and were available to do the experience. There were different reasons for this unavailability, namely mobility issues and the lack of confidence in the use of mobile applications. While some people could have the willingness to do the experience, the use of mobility aids such as crutches made it impossible for people to use a mobile application and walk at the same time. On the other hand, the lack of confidence in using mobile applications often leads to an unwillingness to participate in studies that involve these technologies. Individuals who feel unsure or intimidated by mobile apps may be less likely to volunteer for research that requires their use, fearing they may not be able to effectively engage with the application or that their lack of proficiency might affect the study's outcomes. Consequently, this hesitation can result in a lower participation rate and potentially skew the study's demographics and findings.

As previously mentioned, Kluest was used in this study in its beta version. While this might create more space to understand challenges, the fact that it was an unsstable version made some bugs visible during the usability test, obliging to an intervention of the researcher.

This intervention was also needed for tests with group B. According to recommendations of Nielsen Norman Group (Guidelines for Testing Mobile Augmented-Reality Apps, 2022), it is crucial that the experience must stop when the participants feel uncomfortable. The learning curve created unpleasant feelings for individuals in group B, necessitating researcher intervention to provide guidance to maintain the integrity of the experience.

6.2 Future research

While the literature review says that sketches, images or words can be used to represent points of interest, the use of images created some confusion and difficult association with points of interest, especially in older adults. Additionally, the arrival feedback should clearly identify the location. Future research should explore the most effective type of POI representation for older adults and determine the optimal distance for providing arrival feedback on the phone.

This study also suggested that the application did not effectively engage participants' semantic memory, as no participants retained information about dates. This may be due to a lack of

interest in this type of information and a preference for sensory learning. Future research should investigate whether this is a matter of personal preference or a specific issue with the design of the experience or the application.

It was noted that creating tutorials and guides is important for helping users understand the features and interactions of the application. However, further research is needed to determine how these tutorials and guides should be structured to be effective.

When it comes to the use of audio support, it is crucial to determine the optimal audio support to ensure safety and minimize disruption level.

While multisensory feedback was suggested as a good approach, future research should explore how this combination can be the most effective in the scope of outdoor touristic experiences using mobile augmented reality.

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Sustainable Development Goals

The Sustainable Development Goals (SDGs) are a set of 17 goals defined by the United Nations as part of the 2030 Agenda for Sustainable Development. These goals aim to address a wide range of global challenges and ensure sustainable development worldwide, encompassing economic, social and environmental concerns.

This work relates to Goal 3 – Good Health and Well-being, which aims to ensure healthy lives and promote well-being for all at all ages. The development of inclusive mobile augmented reality applications can significantly contribute to this goal by making such applications more accessible and engaging for older adults.

Inclusive AR applications provide mental stimulation and cognitive benefits through interactive and engaging content, promoting cognitive health. In the context of tourism, these applications can also encourage physical activity among older adults, enhancing their overall physical well-being. Additionally, AR applications can offer enriching experiences that promote lifelong learning and knowledge acquisition.

By making AR applications more accessible to older adults, we can enhance their mental and physical well-being, thereby directly supporting Goal 3 – Good Health and Well-being.

APPENDIX A: Informed Consent

Contexto

A presente investigação é conduzida no contexto da escrita de uma dissertação de Mestrado em Engenharia de Serviços e Gestão da Faculdade de Engenharia da Universidade do Porto.

Este teste tem como objetivo avaliar a experiência do utilizador no uso de uma aplicação de Realidade Aumentada no âmbito do turismo. A sua contribuição será crítica para a definição de guias de acessibilidade e usabilidade para aplicações *mobile* de realidade aumentada.

Durante a sessão, o utilizador será convidado a completar uma série de tarefas a utilizar a aplicação enquanto explora o centro histórico do Porto. O tempo estimado para estas tarefas é de 20 minutos. A sua voz será gravada durante o teste de forma a obter mais informação. No final haverá também uma entrevista onde a voz será gravada. Estas tarefas exigiram também andar uma distância de aproximadamente 300 metros.

Este projeto está a ser desenvolvido sob a orientação científica da Profª. Teresa Galvão Dias do Departamento de Engenharia e Gestão Industrial da Faculdade de Engenharia da Universidade do Porto, do Prof. António Coelho do Departamento de Engenharia Informática da Faculdade de Engenharia da Universidade do Porto e pela Drª. Nina Costa do Departamento de Comunicação e Arte da Universidade de Aveiro. Caso haja dúvidas adicionais, poderá colocá-las através de rita.fernandes129@gmail.com (Rita Fernandes).

Obrigada pela sua participação.

CONSENTIMENTO INFORMADO

Percebi a explicação e fui informado/a que os dados colecionados são anónimos. Os resultados deste estudo poderão ser publicados em jornais científicos, em eventos científicos ou utilizados noutras atividades de investigação sem comprometer o anonimato ou confidencialidade.

Se não concordar com o que foi acima mencionado, por favor não assine este consentimento.

Porto, _____ de 2024

_____ _____

(assinatura do inquirido) (assinatura do investigador)

APPENDIX B: Testing Protocol

Testing protocol – Kluest

PRE TESTE

Idade: _____

Literacia Digital (1-5): _____

Profissão: _____

Educação: _____

Familiaridade com o local (1-5): _____

Experiência com Realidade Aumentada (sim/não): _____

Funções mais utilizadas no telemóvel:

◯ Chamadas

◯ Mensagens

◯ Redes Sociais (ex.: Facebook, Instagram, WhatsApp, …)

◯ Mapas

◯ Outro: _____

INÍCIO

Vamos dar agora início ao teste de usabilidade. Como já descrito no consentimento informado assinado, a sua voz vai ser gravada ao longo do teste. No final haverá uma entrevista. Ao realizar as tarefas dizer em voz alta os pensamentos e dificuldades e expressar o que está a sentir seja algo bom ou mau. Relembro que aqui não existe nada que possa dizer que esteja incorreto.

OBJETIVOS

Neste teste passaremos por três pontos emblemáticos da cidade do Porto. Deve guiar-se pelo mapa e pelos três pontos apresentados cada um com a respetiva imagem. Em cada ponto será dada informação sobre cada local e no final da experiência terá de responder a uma pergunta final.

TASKS	NOTAS DA SESSÃO
TASK 1: Ouvir informação sobre a Igreja do Carmo *Perguntas backup* A informação através de som é percetível? Mudaria algo? Tem alguma reparação a fazer em termos de volume? A vibração do telemóvel é interpretada como uma resposta ao que está a ser feito?	Tarefa completada: sim☐ não☐ Notas:

TASK 2: Ida para o próximo ponto mais próximo (Livraria Lello) Consegue associar o mapa ao seu ponto no mundo real? Consegue associar o boneco à sua posição atual? A informação através do texto é percetível? Mudaria algo?	Tarefa completada: sim☐ não☐ Notas:
Task 3 – Ler informação de texto sobre a Livraria Lello e interagir com a Márcia (objeto virtual) Há algo que mudaria na apresentação do texto? Percebe a associação entre a personagem e o texto?	Tarefa completada: sim☐ não☐ Notas:
TASK 4: Tirar uma fotografia centrada ao elemento virtual É fácil centrar a personagem na câmara? O que ajudaria a perceber melhor para onde apontar a câmara? O que sentiu a tentar centrar a personagem? Este tipo de interação com objetos virtuais parece-lhe interessante?	Tarefa completada: sim☐ não☐ Notas:
TASK 5: Mudar para mapa satélite O novo tipo de mapa parece melhor? Porquê? Sente alguma diferença entre o outro tipo de mapa e este? Consegue fazer uma associação melhor à sua posição atual como o mapa satélite ou o anterior?	Tarefa completada: sim☐ não☐ Notas:
TASK 6: Ida para o próximo ponto mais próximo (Torre dos Clérigos) Ao começar a guiar-se para o local mudou a opinião sobre o tipo de mapa? Conseguiu associar algum feedback de chegada?	Tarefa completada: sim☐ não☐ Notas:
TASK 7: Responder à pergunta final para avaliar retenção de informação	Tarefa completada: sim☐ não☐ Notas:

Qual foi a informação que memorizou melhor para responder à pergunta colocada? Porquê?	
TASK 8: Ler mensagem no painel (objeto virtual) É difícil perceber onde é o ponto central do painel (para onde a câmara deve apontar)? A luz afeta de alguma forma esta tarefa? Este tipo de interação com objetos virtuais parece-lhe interessante?	Tarefa completada: sim☐ não☐ Notas:

Tempo total: _____

Entrevista pós-teste

O uso de som e da vibração durante a experiência tornou-a mais agradável?
A tarefa foi mais divertida ao ser realizada com texto ou som?
A informação foi mais percetível através de texto ou som?
A luz natural influenciou a perceção da informação visual?
O que poderia melhorar na interação com o objeto virtual?
Sentiu que conseguiu utilizar o mapa para se guiar?
O tamanho do telemóvel é adequado à experiência?
O tamanho da letra é adequado à experiência?
O número de interações com a aplicação foi pouco, muito ou razoável?
De forma geral, como se sentiu ao utilizar a aplicação?
Tem interesse em voltar a utilizar esta aplicação para fins turísticos?
O que mais gostou e o que menos gostou?
O que mudaria na aplicação?

Notas finais:

APPENDIX C: Sample characterization

ID	Age	Digital Lit. (1-5)	Occupation	Education	Exp. AR	Vision impairments	Func. more used in smartphone
A1	22	5	Software Developer	Bachelor's Degree	Yes	No	SMS, Social Network
A2	23	4	Healthcare Consultant	Master's Degree	Yes	No	Social Network, Maps
A3	25	5	Software Developer	Bachelor's Degree	No	No	Calls, Social Network
A4	31	5	Software Developer	Bachelor's Degree	Yes	No	SMS, Social Network, Maps
A5	24	5	Designer	Bachelor's Degree	No	Yes	Calls, SMS, Social Network, Maps
A6	25	5	Software Developer	Bachelor's Degree	No	No	Social Network, Maps
B1	80	2	Retired	6th grade	No	Yes	Calls, SMS
B2	67	3	Retired	12th grade	No	No	Calls, Social Network, Maps
B3	63	2	Housekeeper	9th grade	No	Yes	Calls, SMS
B4	74	3	Retired	Bachelor's Degree	No	Yes	Calls, SMS, Social Network
B5	65	3	Retired	12th grade	No	No	Calls, SMS, Social Network

APPENDIX D: User Experience Questionnaire

Por favor dê-nos a sua opinião.

A fim de avaliar o produto, por favor preencha o seguinte questionário. É constituído por pares de opostos relativos às propriedades que o produto possa ter. As graduações entre os opostos são representadas por círculos. Ao marcar um dos círculos, você pode expressar sua opinião sobre um conceito.

Exemplo:

Atraente	o	•	o	o	o	o	o	Feio

Esta resposta significa que avalia o produto mais **atraente** do que **feio**.

Marque a sua resposta da forma mais espontânea possível. É importante que não pense demasiado na resposta porque a sua avaliação imediata é que é importante.

Por favor, assinale sempre uma resposta, mesmo que não tenha certezas sobre um par de termos ou que os termos não se enquadrem com o produto.

Não há respostas "certas" ou respostas "erradas". A sua opinião pessoal é que conta!

Por favor, dê-nos a sua avaliação atual do produto em causa.

Por favor, marque apenas um círculo por linha.

	1	2	3	4	5	6	7	
Desagradável	o	o	o	o	o	o	o	Agradável
Incompreensível	o	o	o	o	o	o	o	Compreensível
Criativo	o	o	o	o	o	o	o	Sem criatividade
De Fácil aprendizagem	o	o	o	o	o	o	o	De difícil aprendizagem
Valioso	o	o	o	o	o	o	o	Sem valor
Aborrecido	o	o	o	o	o	o	o	Excitante
Desinteressante	o	o	o	o	o	o	o	Interessante
Imprevisível	o	o	o	o	o	o	o	Previsível
Rápido	o	o	o	o	o	o	o	Lento
Original	o	o	o	o	o	o	o	Convencional
Obstrutivo	o	o	o	o	o	o	o	Condutor
Bom	o	o	o	o	o	o	o	Mau
Complicado	o	o	o	o	o	o	o	Fácil
Desinteressante	o	o	o	o	o	o	o	Atrativo
Comum	o	o	o	o	o	o	o	Vanguardista
Incómodo	o	o	o	o	o	o	o	Cómodo
Seguro	o	o	o	o	o	o	o	Inseguro
Motivante	o	o	o	o	o	o	o	Desmotivante
Atende as expectativas	o	o	o	o	o	o	o	Não atende as expectativas
Ineficiente	o	o	o	o	o	o	o	Eficiente
Evidente	o	o	o	o	o	o	o	Confuso
Impraticável	o	o	o	o	o	o	o	Prático
Organizado	o	o	o	o	o	o	o	Desorganizado
Atraente	o	o	o	o	o	o	o	Feio
Simpático	o	o	o	o	o	o	o	Antipático
Conservador	o	o	o	o	o	o	o	Inovador