Glass4Tourism: A wearable human interface for tourism

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Declaration

I declare that this document is an original work of my own authorship and that it fulfills all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

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Abstract

Tourism is an industry in constant growth and evolution, in which technology has a great impact. There are hundreds of tourism related mobile applications for tablets and mobile phones, from transportation, to flight or hotel bookings, to tour guides, although the implementation on wearable devices, such as smart glasses, is very little explored. Since the announcement of Google Glass in 2012, these devices have received more media attention, both for the possibilities they present and for the downsides that may occur, such as lack of privacy.

However, no outdoors tourism solutions surfaced since then, which could offer a commercial advantage for tourism operators, enabling the tourists to explore a new destination with all the required information available at a glance. Thus, this dissertation proposes to investigate that concept, implementing an application in a head mounted display (HMD) that guides the user through an outdoors tourism route. Among several options, the device chosen for the proof of concept was Recon Jet, mainly due to functioning independently from a mobile phone. The results show that, despite the verified potential of the concept, the existing technology is not yet developed enough for this kind of application. The evaluation was conducted by means of a questionnaire to the participants, who tested the solution.

Keywords

HMD, Tourism, Mobile Application, Smart Glasses

Resumo

O turismo é uma indústria em crescimento e evolução constantes, na qual a tecnologia tem um grande impacto. Existem centenas de aplicações orientadas ao turismo para tablets e telemóveis, desde aplicações de transportes, até marcação de voos ou hotéis, ou guias turísticos, contudo a implementação em dispositivos wearable, como *smart glasses*, ainda está pouco explorada. Desde o anúncio do Google Glass em 2012, estes dispositivos têm recebido mais atenção mediática, tanto pelas possibilidades que oferecem como pelas possíveis desvantagens, tal como falta de privacidade.

Até à data, não surgiu nenhuma solução para turismo *outdoors*, que pode oferecer uma vantagem comercial a operadores de turismo, permitindo aos turistas explorar um novo destino com toda a informação necessária disponível com um olhar. Dessa forma, esta dissertação propõe investigar esse conceito, implementando uma aplicação num dispositivo *head mounted display (HMD)* que guia o utilizador por uma rota no exterior. Entre várias opções, foi escolhido o dispositivo Recon Jet, principalmente devido ao seu funcionamento independente de um telemóvel. Apesar do potencial deste conceito ter sido verificado, os resultados mostram que a tecnologia existente ainda não está suficientemente desenvolvida para este tipo de aplicação. A avaliação foi feita através de um questionário aos participantes, que testaram a solução.

Palavras Chave

HMD, Turismo, Aplicações Móveis, *Smart Glasses*

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Abbreviations

API application programming interface

APK Android package

AR augmented reality

ARM Advanced RISC(reduced instruction set computer) Machines

BO back office

CPU central processing unit

DDR double data rate

ETA estimated time of arrival

GPS Global Positioning System

HD high definition

HMD head mounted display

HUD heads-up display

JSON JavaScript Object Notation

MP megapixel

NA (information) not available

OMAP Open Multimedia Applications Platform

OS operating system

POI point of interest

QR quick response

RAM random-access memory

REST Representational State Transfer

SDK software development kit

SOAP Simple Object Access Protocol

SP Service Pack

SQL Structured Query Language

UI user interface

UX user experience

WKT well-known text

WQVGA Wide Quarter Video Graphics Array

1 Introduction

This chapter presents the motivation for the work of this dissertation, followed by the proposed objectives and finalising with a description of the structure of the document.

1.1 Motivation

The curiosity to travel and learn about new places and cultures is one of the motives that drives people to leave their homes and the places that are familiar, either to somewhere as far as the other side of the planet, or as close as a nearby city. Overtime, this led to the development of tools to aid in the process of visiting a foreign place, from maps and travel guide books to the most recent technological tourism applications.

According to the World Tourism Organisation, "Tourism is a social, cultural and economic phenomenon which entails the movement of people to countries or places outside their usual environment for personal or business/professional purposes. These people are called visitors (which may be either tourists or excursionists; residents or non-residents) and tourism has to do with their activities, some of which involve tourism expenditure." [1]. Tourism is nowadays one of the fastest growing economic sectors in the world and the world's third largest export category [2], which justifies the need to keep investing in this sector, achieving new ways of travelling and renewing old ones. Also, not only is tourism a growing sector, it is also a key development factor for many countries, since it promotes the creation of new jobs and gives visibility to the country [3]. Using the panoply of technological innovations available today, it is possible to innovate and discover new creative forms of attracting and supporting tourists, and one of the possible approaches for this innovation is through wearable technology, or wearables. Although their presence in the market is still reduced, the range of applications they can be applied to is very wide, and their exploitation is only in the beginning.

The announcement of Glass, by Google, in April 2$^{\text{nd}}$, 2012 and its launch in April of the following year [4] drew attention to the glass-like type of wearables, head mounted displays (HMDs) that project a screen in the field of vision of the user, creating a hands-free experience with potential applications in multiple fields, among which tourism is included. It becomes even more valuable in activities in which the user's hands are occupied. Enjoying a tourism activity and, at the same time, being able to record and share the experience, have extra insights about the surroundings, or ask for directions instantly with minimal perturbation to the experience itself are potential advantages. For instance, wearing an HMD that allows image and video capture has the potential of making the experience even more enticing, as it offers the possibility to capture the scenario without interrupting the experience by holding a camera. Besides a traditional walking tour, examples of activities that could be further explored with the use of an HMD are hiking, riding a bicycle, skiing or scuba diving.

This project was proposed by and developed in Card4B - Systems S.A.[1], a company that already provides technological solutions to operators of the tourism sector, with applications designed for tablets and smartphones. One of those, Boost, facilitates outdoors tourism and team building activities. This application belonged to and was managed by a tourism operator. The proposal was to adapt Boost to a glass-like wearable in partnership with the mentioned tourism operator, testing and evaluating the final prototype with their customers. It is worth mentioning that the solution is not meant to be publicly available, as an application to be downloaded from a public mobile applications' store. It is, instead, a tool to be configured by the tourism operator and used by its customers. However, during the course of this project, due to business decisions, the tourism operator ceased being a client of Card4B - Systems S.A., making the planned testing non-viable. The concept was still tested, although by volunteers in a testing location, instead of by tourists in a real tourism tour. In the past few years, the market of HMDs has suffered only minor updates and no new solutions or studies with applications for outdoors tourism using these devices were developed. Thus, despite the aforementioned hindrance and the delay, due to professional reasons, since the original proposal, the study of such a solution remains nonetheless pertinent.

1.2 Solution Proposed

The concept proposed in this dissertation is to build an outdoors tourism solution in an HMD device, based upon an existing application, Boost. Hence, to give an appropriate context, it is first important to give an overview of that application. Boost has two components, the back office (BO), where the tourism operator defines all the contents of the tourism experience, and the mobile application, which uses those contents to guide the user through a route. The focus of the solution proposed in this project is solely the HMD application component, with the BO platform being used as is. In summary, the main functionalities of Boost are:

- To receive as input a set of previously created routes, each consisting in a set of points and activities associated with each point;
- To guide the user to follow that route;
- To launch the activities at each route point;
- To allow the exchange of messages between the mobile application's user and a monitor with access to the BO.

[1] http://www.card4b.pt/default.htm

The glassware application to be developed during this project, Glass4Tourism, should comply to the basic functionalities of the original application. Therefore, the following features are proposed to the new application:

- To receive all contents configured in the BO;
- To identify the current location;
- To identify the next point of the route;
- To give directions to the next point;
- To launch the route activities when at a route point;
- To allow the user to send messages to the monitor of the experience at any time;
- To receive messages from the monitor of the experience at any time;
- To view the map at any time.

In addition to this set of features, it should also be able to explore what new possibilities are permitted by the new device. The goal is to complement the solution with new enriching features and to remove existing ones that are not adequate for a wearable device, which has reduced control options and a different display. An example of an enhancing element to be explored for an HMD is augmented reality (AR), that allows to superimpose information on the user's field of vision. Furthermore, as the display will permanently be in the user's field of vision when turned on, the main aspects to consider when designing the user interface (UI) are simplicity and directness.

Subsequently to the adaptation, the purpose is to evaluate the impact, benefits and disadvantages of using an HMD in outdoors tourism, exploring the features of the device, understanding how the tourist's experience can be improved and what new challenges may arise, as well as identifying behavioural changes in users' interactions. This will be done by testing the final prototype with a group of volunteers.

1.3 Thesis Outline

This dissertation consists of 6 chapters. After the short motivation and brief presentation of the solution proposed in this dissertation in chapter 1, chapter 2 introduces the state of the art of HMD devices and its applications, as well as the presence of technology in the context of tourism. Later, in chapter 3, an explanation of the functional and technological architecture is provided, followed by the description of the implementation in chapter 4. The testing use cases and the criteria used to evaluate the project, as well as the results and corresponding discussion, are presented in chapter 5. Finally, chapter 6 presents the conclusions of this dissertation and suggestions for future work.

2 State of the Art

In the past years, technological evolution in general, and mobile technology in particular, extended its reach to many areas, including tourism. Research has established a relationship between mobile technology and the tourism industry [5], making mobile devices a powerful tool for tourists and, therefore, an obvious partner for tourism operators and organisations.

As an emergent form or mobile technology, wearable technology has the potential to follow this trend and revolutionise tourism, opening doors for new experiences and possibilities, many of them not yet thought of. While smartphones and tablets allow tourists to stay connected, well informed and fully equipped for travel related events, hands-free wearable devices could enable these processes to be more immediate and less cumbersome. HMDs are a new and little explored technology that may reveal great potential in enhancing tourism experiences. Since the purpose of this work is to develop an application to be implemented on a glass-like wearable device for outdoors tourism, it is of essence to learn what technologies are available, what already exists and how are people reacting to tourism oriented technological solutions, both in wearable devices and in "traditional" tablets or smartphones.

This chapter covers the analysis of HMD devices and of existing technological solutions in tourism. First, it is presented an extensive research of available HMDs, its functional characteristics and constrains, the device chosen for this project and the reasons for that choice. Afterwards, on the electronic tour guides topic, it is first made an assessment of the present and past presence of smart glasses in tourism, followed by a comparison of both commercial and research mobile tourism applications according to its main functionalities.

2.1 Head Mounted Displays

An HMD is a particular case of wearable technology, an information-viewing device that projects that information into the user's field of view and can be made to react to head and body movements [6]. There are several names to reference these kind of devices, such as head-worn displays, heads-up displays (HUDs), or smart glasses. Their current version usually consists of a glass like device projecting a screen or an image in the user's field of vision, with the physical structure, type of display and general functionalities varying depending on the manufacturer.

Despite the attention HMDs received back in 2012, following the announcement of Google Glass, depicted in section 2.1.2 ahead, in Figure 2.2(a), these devices are not a new concept. A patent for a monocular head-mounted cathode-ray tube viewer was registered in 1963 [7] - Figure 2.1 - and a head-mounted three dimensional display was created in 1968 by Ivan Sutherland [8].

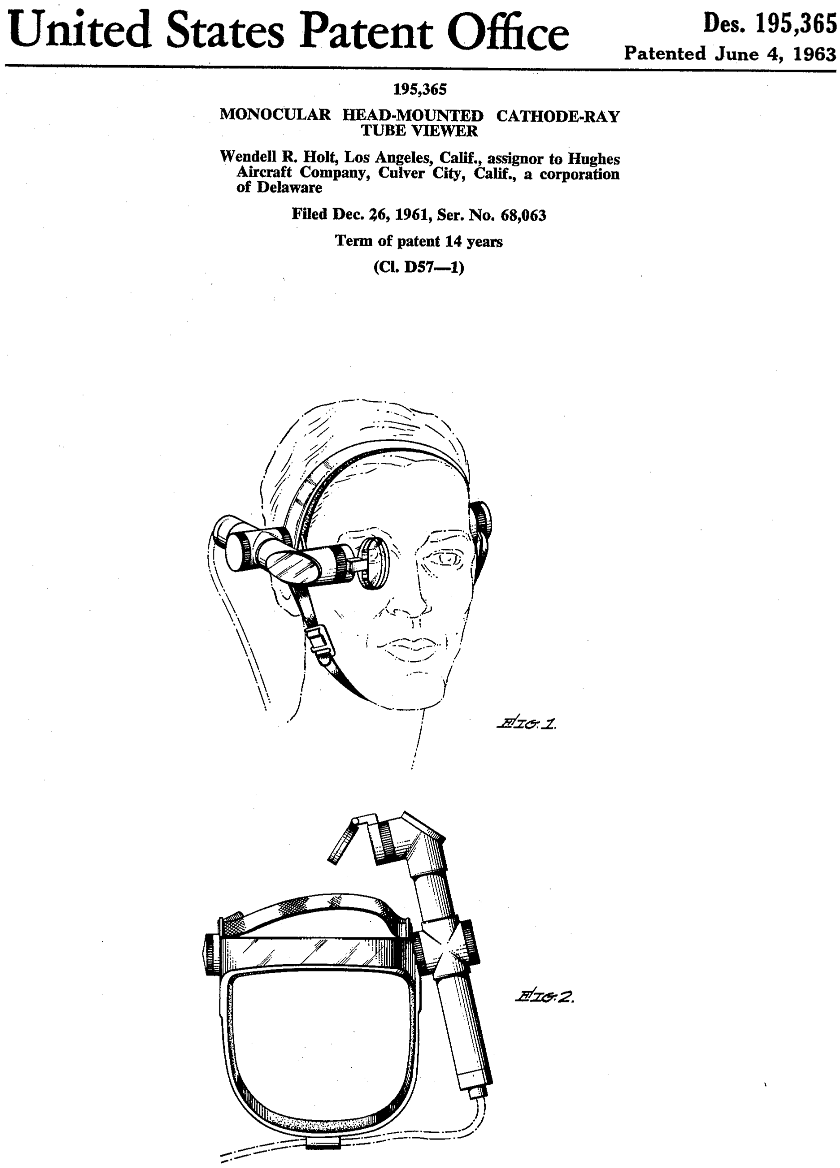


Figure 2.1: 1963 patent of an HMD device.[7]

Due to recent technology, the possibilities of HMDs have greatly expanded in the past decade, bringing both positive and negative aspects. Generally speaking, a device connected to a smartphone that can display e-mails, messages, incoming calls, etc. in front of the eyes, without the need to stop and hold a cellphone, presents an efficient solution. Its features may also include taking pictures, making videos, performing online searches via voice commands or giving directions. These are advantages to the everyday user but, adding development and research, it can be applied in a wide range of areas, from health care and surgery to firefighting and ludic purposes. It could also be a valuable aid to those who are physically impaired in some way, increasing their quality of life.

The devices can be monocular, meaning the image is displayed only to one eye, or binocular, where the image is presented to both eyes. Besides, HMDs can either be see-through or opaque, allowing or not the user to see the image superimposed on a view of the real world.

2.1.1 Disadvantages of HMDs

Despite all the possibilities that HMDs have to offer, one very important factor when dealing with a new technology is to identify its potential impact and to understand how it is perceived by the users and what consequences its use might have. As it happened with other technologies, such as cellular phones, microwave ovens, computers and televisions, it raises worries about harmful side effects, however, being reminiscent of similar concerns with almost every new technology is not a reason to discard those concerns. One of the first complains the launch of Google Glass generated was the lack of privacy such a device can bring, with people using it to record, take pictures or film unknowingly to those who surround them. The other major concerns involve driving or even walking with an HMD computer, due to the distractions it may cause, and the discomfort or blockage of the field of vision that may occur using such devices is also a factor to consider.

On the issue of privacy, the concerns range from simply being filmed while having a conversation with someone wearing Glass to a real-time 24 hour vigilance of the whole world combining the videos from everyone using Glass [9]. Data protection commissioners from several countries grouped together to contact Google in order to incentive the company to dialogue with data protection authorities about Glass and asking how it complies with data protection laws. Other issues raised were about possibilities of face recognition software and how Google was intending to deal with the data collected through the device [10]. Many of these concerns are also valid for smartphones and, nowadays, it is difficult to find someone without one. However, the added risk of HMDs comes from the fact that they are, or might be, permanently active in front of one's eyes and thus allowing uninformed and unauthorised image recording. There is also the discomfort associated with engaging in a conversation with someone and being uncertain whether that person is focusing in the conversation or dividing his attention, simoultaneously performing another activities in their HMD, which may lead to social disconnection [9, 11]. Not only engaging with a person wearing smart glasses may present a challenge, the wearer himself might feel socially uncomfortable. As HMDs represent a major evolution when compared to prior technologies, a study on the psychological mechanisms that lead to the adoption, or not, of this technology revealed that expected peer evaluations of its use are much more likely to influence an individuals use of smart glass, when compared to the use of less visible wearable technologies, such as smart watches or mobile phones [12].

On the matter of moving around with extra information in front of the eyes, a study on how HMDs affect task performance and motion concluded that a person's natural performance can be critically altered both in moving and in the task they are performing in the HMD. This is due to the human difficulty to process information from two sources at the same time, the environment and the display, in this specific case. The ability to guide and control one's gait can be considerably impaired, hence, visual tasks that involve constant monitoring of the device should be avoided [13].

Another frequent concern when talking about monocular HMDs is the ophthalmological effect of having a screen constantly in front of one eye, creating an unnatural visual environment. This leads to asymmetries in what is perceived by each eye and has been suggested to result in several visual difficulties, related to binocular rivalry[14], visual interference[14], depth of focus [14, 15], phoria [14], eye movements [14, 15] and eye dominance [14]. Binocular rivalry is a phenomenon that occurs when dissimilar images are presented to each eye, causing periods of "monocular dominance" [14] and visual interference happens when two images are not clearly distinguishable from each other and it is difficul to separate them visually [14]. Depth of focus concerns the focal distance of an image from the user, which is fixed in HMDs and can cause interference with real-world images that are at an approximate focal distance, making them difficult to distinguish [14], while phoria is the direction at which the eye is gazing when there is nothing to look at and that can be changed when there is a prolonged occlusion of one of the eyes [14]. Eye movements are the natural gaze redirections people do when scanning an environment, affected by the use of HMDs due to their fixed position with respect to the head, causing the compensatory head movements that accompany eye movements to not have the usual result when scanning the HMD display [14]. There are two issues concerning eye dominance and monocular HMDs. On one hand, the eye in front of which the HMD is should be the dominant eye, the eye from which imagery is "preferred", so that the images from the display are more easily perceived, on the other, if the HMD is in front of the dominant eye, it will the make real-world imagery in the other eye harder to perceive. Increase of eye strain, eye heaviness, eye dryness, brain clarity, sleepiness and body weariness are also associated with the use of HMDs [15].

For the utilisation of HMDs during short periods of time, several studies [14, 15] concluded that it does not permanently affect the eyes, although a prolonged and continuous use of such devices is not advised. Nevertheless, those temporary changes to the eyes affect perception, so its use is not advised in environments where maintenance of visual attention is critical or when operating moving vehicles [14].

The purpose of this dissertation's work is to create a tourism interactive application using the hands-free possibilities of HMDs, with activities that would not last more than one day, implying the use of an HMD for a few hours and not repeating its use in a near future. Therefore, although being a concern and contemplated in the user evaluation, worries about long-term health implications are not expected due to the short term use. The privacy issue is also diminished, as it is not to be used connected to a personal smartphone and whatever content recorded by the device is of the responsibility of the tourism operator in charge of the activity. The people around those involved in the activity may not be comfortable with the camera included in the device, but if a tablet or a smartphone was used instead of an HMD the situation would be very similar, since those devices also have a camera. Hence, it is an issue that might be aggravated in the case of HMDs but it is not exclusive and it is also mitigated by the short-term usage.

However, performing tasks while using an HMD is an issue that must be addressed. The application has to take into consideration the size of the display, and it has to be simple and functional, in order to provide an interface that has minimal interference with the user's environment and his motion.

2.1.2 HMD Technology

In order to understand which solutions are available, as well as its features and limitations, it was conducted a search for HMDs, gathering information about each device, its technical characteristics and its state of production. Furthermore, several manufacturer companies were contacted by e-mail to further inquire about the product's specifications and availability. A total of 8 devices matching these requirements were found, many of them still in a developing or early production stage, and hence not available for sale. A complete list of those devices, as well as an extended comparison of their technical and physical characteristics is displayed in Appendix A. Devices released posteriorly to the acquisition of the device used in the proof of concept of this dissertation were not considered as an option and, thus, are not included in that number. However, the main improvements in the newer models are related to technical specifications of the devices, they have better central processing units (CPUs) and cameras, more storage and random-access memory (RAM) memory, etc., but the usage and main functionalities are the same, and even the design has not had a remarkable evolution. Examples of these devices are Vuzix's Blade [16], ODG's R-9 [17], Solos Smart Glasses [18], EPSON's Moverio BT-300 [19], Sony's SmartEyeglass [20], or Microsoft HoloLens [21]. The devices that did were considered are presented in tables A.1 and A.2.

In this section, it is presented a subset of all the devices analysed consisting of the ones deemed a better fit for this project, as well as the reasons that lead to that choice. The aspects that were dimmed relevant to include in the table for further analysis were connectivity options, Global Positioning System (GPS), display size, resolution and location, camera, video and audio features, storage, memory, processor, operating system, autonomy, integrated sensors, maps availability, price and weight, as shown in Table 2.1.

Table 2.1: Criteria for analysis and comparison of HMDs

Connectivity	Input/Output	Audiovisual	Hardware	Other
Wi-Fi	Display resolution	Camera (MP)	Memory	OS
Mobile Data	Display position	Video	Processor	Sensors
Bluetooth	Speakers	Audio	Storage	Maps
GPS	Input methods		Battery autonomy	Price
				Weight

Connectivity contemplates whether the device has network, WiFi or bluetooth connections, as it is a fundamental requirement that the application is able to communicate with a server at some point. To understand how information is presented to the user, it is necessary to know the sound and display characteristics, due to its relevance to the user experience in how the information is absorbed, as well as the input methods, such as touch or voice commands, that determine how the user interacts back with the device.

Aiming to allow the user to record the experience in the form of pictures or videos, a frequent action in tourism, the camera characteristics of the device were analysed. It is indispensable to know the device's processor, memory, and storage capacity, in order to decide whether the device is capable of running the software, or even how computationally demanding the application can be. The autonomy is also a key factor, not only when considering the possible interactions and its computation needs, but also to define the duration of typical usages.

To evaluate both possible constrains and additional features of the application, it is important to know what sensors the devices contains, along with the possibility of integrating maps.The price is a decisive factor from an economical point of view, since the hardware is provided together with the software, it will be a part of the final cost of the product, whereas the weight is important as a comfort factor to the user.

After collecting data on the possible solutions available, the 4 devices chosen as better fitting this solution were GoogleGlass (Figure 2.2), Recon Jet (Figure 2.3), Optinvent ORA (Figure 2.4) and Vuxiz M100 (Figure 2.3). Table 2.2 shows the specifications and main advantages and disadvantages of each device.

One of the decision criteria was how independent the device is. Some of the devices do not have processing capacity, serving only as an extended, hands-free display of a smartphone, and others do have a processor but still require a smartphone for certain functionalities, like GPS signal. Since the purpose of this work is a tourism application, for which location is an important aspect, the location capabilities of the device were a very relevant factor. As the purpose was to provide both the software and hardware to the user so, if the device also required a smartphone to be functional, it would increase both the cost and the size of the product, and for the user to carry an additional device with him. The option of installing the application in the user's personal smartphone, assuming he has one, is not valid, since it would be unprofessional and inadequate to request to make changes in the user's personal property. The display seen by the user should not be too small, in order to allow to expose all the information properly, nor too large, in order not to obstruct the user's field of view and to minimize the distractions and distresses that might occur while wearing the HMD. Another feature preponderant for decision is the autonomy, although the application could be designed considering the device's autonomy, it should not be less than 2 to 3 hours on full use, otherwise the possibilities are very reduced, diminishing the advantages of an hands-free device when comparing to a similar application running in a tablet or smartphone. Of course, aesthetics also played a role in choosing the device, as the product is for commercial purposes and users will be using it outdoors.

As a proof of concept is one of the objectives and the choice is not theoretical, the availability of each device had to be taken into consideration in order to deliver a functional prototype. Considering that smart glasses are a recent technology, by the time of the acquisition, many products were still in the research stage and only prototypes or special editions were available, or the release date was not yet known. This information was gathered consulting the official website of each manufacturer company and contacting them by e-mail. In case the equipment was not sold to the public at the time or there was a release date announcement, the e-mail would ask for or to confirm the release date and ask if it was possible to acquire an exemplar of the device, to start developing for the project.

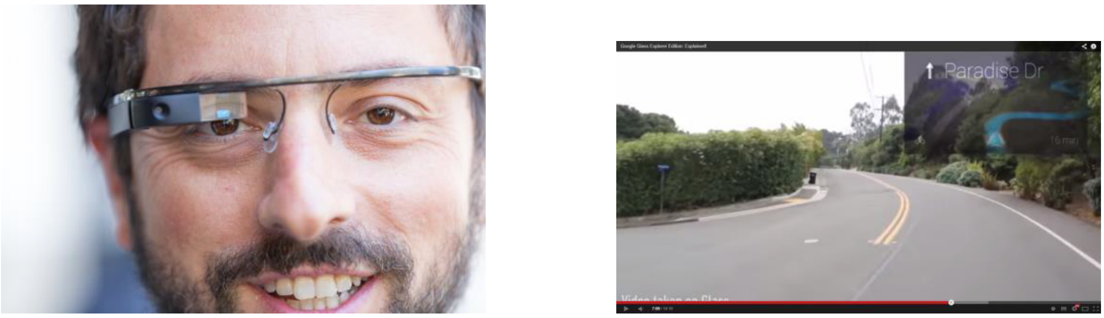
The four devices mentioned before - Google Glass (Figure 2.2), Recon Jet (Figure 2.3), Optinvent ORA (Figure 2.4) and Vuzix M100 (Figure 2.5) - comply with most of these criteria and, except for

Table 2.2: Comparison of the four devices that better fit this solution.

	Google Glass [22]	Recon Jet [23]	Optinvent ORA [24]	Vuxiz M100 [25]
Wi-Fi	Yes	Yes	Yes	Yes
Mobile Data	No	No	No	No
Bluetooth	Yes	Yes	Yes	Yes
GPS	No	Yes	No	Yes
Display Resolution	25" HD Screen 640x360	16:9 WQVGA 428x240	4:3 640x480	16:9 WQVGA
Display position	Above, right	Below, right	Center or below	
Speakers	Yes	Yes	Yes	Yes
Input methods	Touch Voice	Touch	Touch	Touch Voice Movement
Camera (MP)	5	HD	5	5
Video	720p	720p	1080p	1080p
Audio	Yes	Yes	Yes	Yes
Memory	NA	1 GB DDR2	1GB DDR	1 GB
Processor	NA	1 GHz Dual-Core ARM Cortex-A9	Dual Core 1.2Ghz ARM Cortex	OMAP4460 1.2GHz
Storage (GB)	16	8 (flash)	4 flash	4 (plus microSD)
Battery autonomy	One day typical use	4 - 6 h	4 - 8 h	2 h
Operating System	Android 4.4.2		Android 4.2.2	Android 4.04
Sensors	Microphone Accelerometer Gyroscope Magnetometer Luminosity Proximity	Microphone Accelerometer Gyroscope Magnetometer Altimeter Barometer Thermometer	Microphone 9 Axis orientation	Microphone Accelerometer Gyroscope Magnetometer Luminosity Proximity
Maps	Yes	Yes		
Price ($)	1500	499	950	800 + 150 (SDK)
Weight (g)	50	60	80	
Advantages	Autonomy Aesthetics Marketing Support/more available apps	GPS Outdoor activities oriented	Large display See-through display 2 visualisation modes 4 hours autonomy in full use	GPS Wearable over glasses Extendible storage
Disadvantages	Limited functionalities without a smartphone No GPS Expensive	Size/aesthetics Display size	Aesthetics No GPS	1 hour autonomy in full use SDK not included in price Small display

Google Glass, were available for sale at the time of the acquisition.

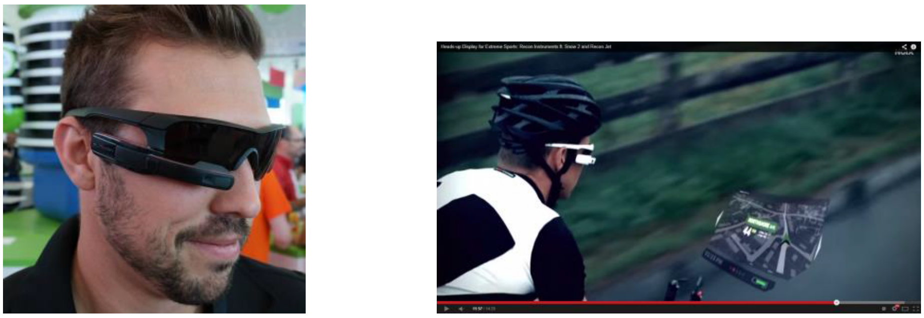
Google closed the Explorer Program and January 19, 2015 was the last day Glass was available[33],



(a) User with Google Glass. [26]

(b) Display of Google Glass as seen by the user. [27]

Figure 2.2: Google Glass.



(a) User with Recon Jet. [28]

(b) Display of Recon Jet. The screen with the maps seen in the picture is a representation of the device's display. [29]

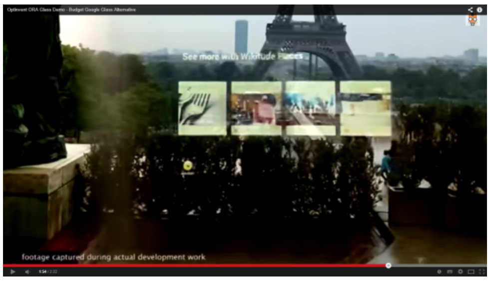
Figure 2.3: Recon Jet.

causing this device to be excluded from the viable devices options. In spite of no longer being commercially available, Google Glass was kept as a relevant option in this comparison because it was the device that led to the concept of this dissertation, and it is still a reference in the smart glasses research and market. Google Glass and Optinvent ORA do not have location capabilities, requiring a smartphone connection for that. However, they are among the best options due to marketing reasons, in the case of Google Glassas, as it is the most publicly know of all the devices and, in the case of Optinvent ORA, due to its see-through and changeable display position.

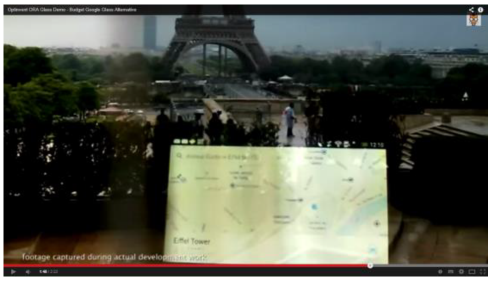
Among these four options, Recon Jet was the device chosen for the proof of concept. Ideally, all four devices would be tested to effectively decide which would be more appropriate, however, for economical reasons, that was not possible, and only one device was acquired. Google Glass was excluded due to not being available for sale and for its dependency on a smartphone for some functionalities, Optinvent ORA was excluded for the lack of built-in GPS, and Vuzix M100 was excluded for its low autonomy.

After the careful analysis and comparison of all possible options, from stand alone HMDs to extensions of smartphones, and the decision to acquire and implement the solution in Recon Jet, the goal was to understand its possibilities and its limitations to the fullest, in order to build an application that satisfied the objectives of this work. The expectation was that the application aided the user while moving in a tourism circuit, giving the necessary information when required and not disturbing the user when that

(a) User with Optinvent ORA.



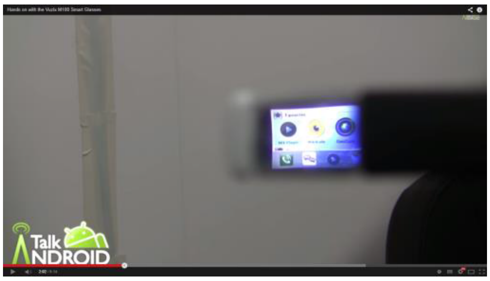
(b) Display of Optinvent ORA in front of the user's field of view. [30]



(c) Display of Optinvent ORA below the user's field of view. [30]

Figure 2.4: Optinvent ORA.

(a) User with Vuzix M100. [31]



(b) Display of Vuzix M100. [32]

Figure 2.5: Vuzix M100.

was not relevant. It was intended to understand that possibility by investigating the adequacy of the screen size and resolution, how much of a modified version of Android the OS was, which had a direct impact on the difficulty of the implementation, and also if the device was comfortable to wear, or if it caused tiredness or sickness or any other discomfort to the user. In case the device was too heavy or too uncomfortable, or if the autonomy of the battery was considerably inferior than indicated in the device's specifications, it would be very limiting in terms of commercial usage. On the other hand, if the development of Recon's SDK was in its early stages, it could be limiting in terms of added functionalities.

2.2 Technology in Tourism

With the growing presence of technology in everyday lives, it is a logical strategy to also use it in the tourism industry. To respond to this demand, tourism companies are investing in online advertising and making their products available online. More than studying what solutions are already available to enhance the tourism experience, it is necessary to understand what tourists expect and how they react, how can the tourism experience be improved and what new challenges may arise. Tourism technology should not only make tourism more efficient, it should make it more enjoyable, and mobile tour guides applications can be used to attract and add interest to tourism activities.

2.2.1 HMDs in Tourism

On February 2013, Google held a contest to allow the winners the chance to purchase the Explorer Edition of Glass. This contest consisted in using the tag #ifihadglass in a Google+ or Tweeter post, describing what use the author would give to Glass. Even though it was not exclusively tourism oriented, this contest made it possible to know people's expectations for the use of HMDs. From the answers to this contest, a study concluded that one of the main reasons people would use Glass in a tourism or travel application is to share the experience in a first-person point of view, whether with a particular person or group of people or to the world [34], this use suggests the users would enjoy an application like Instagram for smart glasses. This findings agree with a study in Switzerland affirming the main motive for young international tourists to use their mobile devices while travelling is to "take pictures" and "connecting to social media" [35].

HMDs presence in tourism is still scarce and not widely spread, found mostly in research projects or pilot programmes and as a particular case in one commercial solution - GuidiGo [36]. A solution that received attention from the media using GuidiGo was an exhibition in an Arts museum in San Francisco [37]. This will be explained in a greater detail below, in 2.2.3.

An article explored the usage of wearable devices, where smart glasses are included, in the tourism industry and its influence on the behaviour of the tourists, presenting evidence that it paves the way to revolutionize the tourism industry, thus creating added value for both suppliers and consumers [38]. This author stated that the wearable devices would transform consumers from tourists to explorers, while also voicing concerns with regard to privacy and security.

Further, a study using AR in Google Glass in the Manchester Art Gallery, aiming to explore a visitor's first time usage behaviour of Google Glass within the context of an art gallery, found that users were able to quickly adjust to the interaction method of Google Glass and, in general, perceived the device to enhance the experience [39]. Still in the museum context, in the Royal Ontario Museum, through the usage of the META smart glasses, the visitors were able to see cultural artefacts within the museum's "Ming Tomb" [40]. Applications of smart glasses in tourism were also briefly exploited in hotels and air travel [41–44], however, no new projects were found after the discontinuing of Google Glass.

Despite the common association between HMDs and AR, it is not always true that AR applications run in HMDs or that applications in HMDs include AR functionalities. AR is a technology that allows the user to see the real world with virtual objects superimposed upon or composited with the real world, complementing reality [45]. In an ideal AR scenario, the real and virtual objects would appear to the user as coexisting in the same space.

2.2.2 Mobile Tourism Applications

Whereas HMDs have a slow growth rate, smartphone applications are an exponentially growing tool in the tourism business. There are many travel and tourism related applications available for download, such as maps and GPS navigation, hotel booking, air travel booking, tour guides, currency converters, etc. The applications that work as travel guides have maps of one or many cities or regions, a collection of points of interest of that place that may range from monuments and famous streets to hotels and restaurants, their location in a map and, in some cases, several tours through those points of interest.

There is currently a large number of tourism related applications in mobile application stores, of which only the ones that fitted the subcategory travel guide were taken into consideration, due to being the ones in the context of this project. However, as previously mentioned, the implementation of tourism mobile guides in HMDs is scarce, thus the analysis of related work will focus in mobile tourism guides in general, howbeit the device it is implemented in, as the comparison of technological capabilities and of the resulting output information provided to the user is still valid.

The applications presented in this chapter are electronic tourism guides, both from commercial applications and research projects. Using the keywords 'travel guide', a sample of 6 applications was chosen for comparison both from Google's PlayStore[1] and Apple's AppStore[2], consisting of the top five applications from each of the stores. By March 2, 2018, the results according to this criteria are: World Travel Guide (Android)/Triposo - Your smart Travel Guide (iOS), by Triposo, Thomas Cook Travelguide (Android and iOS) by Thomas Cook Touristik GmbH, Guides by Lonely Planet (Android and iOS), by Lonely Planet, PocketGuide Audio Travel Guide (Android and iOS), by PocketGuide Inc., World Explorer - Travel Guide by Tasmanic Editions (Android and iOS), tripwolf - Travel Guide & Map (Android and iOS), by tripwolf, Paris Travel Guide (Android) / Paris Travel Guide and Offline City Map (iOS), by Ulmon GmbH. Boost, the application that serves as a foundation for the solution proposed in this dissertation is, of course, mentioned in this review of which solutions are already available. GuidiGO [36] is also worth mentioning here, as it was found to be the most similar the solution proposed in this project, with customisable content via a BO and the possibility of deployment in Google Glass.

In research literature there is also a vast number of published articles proposing mobile travel guide applications. The first criteria for this selection was that the article was published in or after 2011, by reason of the rapid evolution in mobile technologies verified in recent years, the next criteria is to have a diversified sample, and the last criteria is completeness, meaning the chosen applications or prototypes possess a set of features whereas other similar solutions only present a subset of those features. When possible, it was given preference to solutions of which the result is a route with a planned path, with a reference path and indications on how to move between each point, even more if there were some type of activities along the route. A set of 8 applications were selected: A mobile 3D-GIS

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[1] `https://play.google.com/store/apps/collection/search_results_cluster_apps?clp=ggEOCgx0cmF2ZWwgZ3VpZGU%3D:S:ANO1ljKhLpU`

[2] Search performed in an iPhone

hybrid recommender system for tourism & Route and Map Features[46], Context-Aware Points of Interest Suggestion with Dynamic Weather Data Management[47], iTravel: A recommender system in mobile peer-to-peer environment[48], Mobile Application for Guiding Tourist Activities: Tourist Assistant – TAIS[49], A Mobile Tourist Guide for Trip Planning[50], Mobile application to provide personalized sightseeing tours[51], MyTourGuide.com: A Framework of a Location Based Services for Tourism Industry[52] and World Around Me Client for Windows Phone Devices[53]. The selection of the applications by no means reflects a rating or a preference of these over others, but simply an attempt of efficiently surveying related solutions. It is also worth referencing that all existing similar solutions may not have been discovered, particularly in the case of commercial applications whose client is not the general public.

Literature on classification and categorisation of mobile tourism applications were used to compare all the above mentioned applications [54–57]. Each source proposed a different classification system, summarised in Table 2.3.

Table 2.3: Mobile guide categorisation criteria proposed in the literature.

Emmanouilidis et al. [54]	Kenteris et al. [55]	Karanasios et al. [56]	Kennedy-Eden and Gretzel [57]
Functionalities offered	Information models	Service delivery	Services Provided
Context categories	Input/output modalities	Customisation	Preferences
Data retrieval method	Unique services	Information transfer initiation	Location sensitive
Localisation method	Architecture	Application type	Security
Supported context awareness	Network infrastructure		Control through web
Device characteristics and software	Positioning and map technologies		Content added
Mobile user interface features			Aesthetics

In the taxonomy of tourism mobile guides proposed by Emmanouilidis et al., the functionalities offered could be, for instance, games, messaging or navigation, and the context categories considered could be location, environment, time, etc. The data retrieval method criteria refers to whether the data is stored in the device or in a remote server, and the localisation methods could GPS, bluetooth, etc. Another criteria is how context awareness is handled and supported, such as user preferences and history, or system network conditions. Device characteristics and software mean whether the app is native, web based, etc., and what is the OS and type of the device it runs on, while the interface features refer to allowing tab navigation, having a back button, voice recognition, etc. [54] The evaluation criteria of mobile tourism guides design principles proposed by Kenteris et al. consists of five categories: what is the information model, that is, if the mobile guide is context aware, if it provides personalised content, if it is updated, etc.; what are the input methods and how is the output presented; what unique services are provided, such as communication or content sharing; what is the architecture of the application, what technolgy platforms were chosen to implement it, in what programming languages it is available, etc.; what type of network technologies are supported and if the application is capable of adating to changing network environments; if and how position and map technologies were used to support the mobile guide's use, if it supported route finding, etc. [55]. Karanasios et al. had a broader approach, establishing a classification of mobile tourism applications in general, and not restraining only to tourism guides, thus the divergence in the criteria in comparison to the other three sources. These authors suggested four main categories: how does the service delivery work, i.e., whether the user receives information about objects of interest, is able to initiate a tourism transaction or is provided with opportunities to participate in real time feedback; what is the level of customisation of the application, if it is context aware and allows adaptation of services with respect to context; if the information is automatically sent to the user without a specific request, requested by the user or both situations can happen; and whether the application is pre-installed on the device or web based [56].

In the article by Kennedy-Eden and Gretzel, the intention was also to provide a taxonomy to include all tourism related applications, based on seven categories: what services are provided by the application, such as navigation, transactional, entertainment services, security and emergency, etc.; what personal preferences can be changed, such as medical or purchase experiments; if the application is aware of te user location or allows the user to manually insert his location; who can see the user's information, and how is the control of data retrieval; whether the application requires the user to interact through a webpage; if there are changes on the application as content is added to them; and if aesthetic changes such as color choices can be made by the user [57].

Table 2.4: Set of criteria used to compare tourism applications

Automatic Response Features	Content Features	Route and Map Features	Social Features	Additional Features
Recommender System	POIs Types	Map	Friend Positioning Finding	Favourites/Bookmarks
Recommendation Criteria	Personalised Content	Show POIs in Map	Messaging / Group Communication	Multilingual
Rate Recommendations	Content Update	Route Finding	Reviews/Ratings	Offline Use
Context Aware	Content Sharing	Route Planning		Ticket E-services
Context Responses		Visit Tracking		Entertainment

After a careful analysis of the afore mentioned literature, the parameters used to evaluate each app are displayed in Table 2.4. Neither a set of criteria by a specific author nor a compilation of them were used directly, due to some of the criteria being outdated, considering the evolution of mobile applications since its publication, and also due to additional parameters found necessary while reviewing the state of the art material. The used criteria is divided into five main categories: automatic response features, content features, route and map features, social features, and additional features, which include the features that do not fit in the previous categories. Automatic response are defined by whether the system provides recommendations, whole routes or isolated POIs, based on a set of recommendation criteria, what are those criteria, and if the user has the option of rating the recommendations that the system made, as well as by whether the system is context-aware, that is, if it reacts to the current user situation, and what types of context does it react to, such as location or weather. The content features category includes what type of POIs the system considers, if the content could be custom-tailored for the user, if it is possible to update the content after the application is installed and whether it is possible to share content through the app, either pictures, videos or information about a given POI. Route and map features include whether the application shows a map of the tourism location and if it shows POIs on that map, if the user can find a route by choosing from a set of pre-defined routes, if the system plans a route based on user inputs, such as available time or POI preferences, or if it allows the user to plan a route from a given set of POIs. This category includes also route tracking, meaning if, during the visit, the application guides the user throughout the route, marking POIs that were already visited and indicating where to go next. The criteria of the social features category are whether it is possible to find friends using the same application, whether it is possible to communicate, through a chat feature in the application, with other users or with a person who can help in the tourism experience, and if it is possible to rate or review the suggested routes and tours or the visited POI. The features that do not fit in a specific category are whether there is an option to save favourite routes or POIs, if the app is available in more that one language, and if it is available for offline use after downloading the application and additional required contents. It is also analysed whether the application allows the user to buy tickets to paid-entrance attractions, such as museums or shows, either by an in-app functionality or through a link to an external service, and if it has gamification features, like attributing points to tasks, asking questions about tourism sites or allowing a treasure-hunt like route.

A comparison of the 17 evaluated applications according to the aforementioned criteria is presented in Tables B.1, B.2, B.3, B.4, and B.6, in appendix B. From this sample, 10 (59%) have recommender systems, with diverse criteria, such as location, distance to POIs, similarity between users, functioning and transportation schedules,budget, etc. However, only 3 of those allow the users to rate the recommendations. All applications are context aware, and one of the context responses is always the location of the user. Other than that, it could be orientation, weather conditions, open and closing times of POIs, etc. The types of POIs presented are very diversified, including, but not exclusive to: restaurants, hotels, nightlife, tours, sightseeing, monuments, beaches, and parks, and only 5 applications allow personalised content. 11 applications (65%) allow content update, but only 8 (47%) allow content sharing. Of all the applications, only 2 do not have map features. Of the 15 that do, 12 (80%) show POIs in map. The applications that allow route finding are only 6 (35%), with the same statistic being true for the route planning feature. As for route tracking, only 5 (29%) of the analysed applications possess that functionality. None of the applications have a friend positioning finding feature, with only 3 (18%) having communication features. 7 (41%) possess a reviews or ratings functionality. 8 applications (47%) allow to save favourites, and the same number have multilingual options. About 59% (10) function offline, 24% (4) have the possibility to buy tickets and only 12% (2), have gamification option, those 2 being GuidiGo and Boost.

From the above explained results, it is possible to conclude that recommender systems, context awareness, content update, having a map and showing POIs on it and having the application available offline are the most common features.

2.2.3 GuidiGo

GuidiGo [36] is mentioned isolated and explained in detail due to the considerable similarity with this project and due to also running not only in Android and iOS but also on Google Glass. It provides a tool for the creation of a customisable application that is intended for the route's author and not for the final user. The platform allows anyone to create a tour for a chosen destination and then publish that application for Android, Glass, or iOS. Anybody who as an interest in the subject can develop an application using GuidiGO's platform, from professional tour guides to museums, tourist offices or locals who want to show the best their city has to offer. The author develops his application in his personal area in GuidiGO's website, choosing the tour's main attributes and characteristics and deciding whether he wants to include gamification options. The author chooses which POIs are featured in the route being created and what information and games to associate with each stop, as well as the order in which those stops should be visited. When finished, the author can publish the resulting tour as a free or paid application [58].

After creating and publishing for the other platforms, the author has got the possibility to test the tour on Google Glass. The first museum to try this feature was Fine Arts Museums of San Francisco in a Keith Haring's exhibition [37], an indoor tour, that only adds extra information when needed, "revealing stories within art work", using sound and video resources, allowing visitors to notice particular details and to access additional content when approaching an artwork through AR.

Besides the pilot multimedia tour using glass, by September 2018, GuidiGO had another 946 tours all around the world and in 14 languages. Of those, 250 are available for Google Glass, according to the GuidiGo page in the Glass store [59].

From all the features of tourism applications studied in this section, context awareness, maps, content update, functioning offline, and route tracking are relevant in the context of this project and were taken in consideration during development. Also, sharing the experience from the user's point of view seems to be one of the motivations of the early adopters of Glass, thus, it was contemplated while developing the application. Features such as recommendation systems or route planning are very interesting in the tourism area, however, they are not applicable to the context of this work.

The next chapter describes the architecture of this project, presenting the concepts the application proposed in this dissertation is based upon, the main features of that application, and the technical architecture.

3 Architecture

The solution proposed in this dissertation is not a stand alone application thus, in order to function properly, it relies on external services to provide its content. All the information about routes, points, activities, and also translations, is manually inserted in the BO, a web interface created for the purpose, stored in a database in a server, and later provided to the application via web services. Figure 3.1 shows a schematics of this communication BO UI - server - application.

The front end BO and the web services to retrieve the information were already implemented and being used in several commercial applications by the date this dissertation work started. The BO platform and web services will be used as-is, since it is out of the scope of this project to create or modify them.

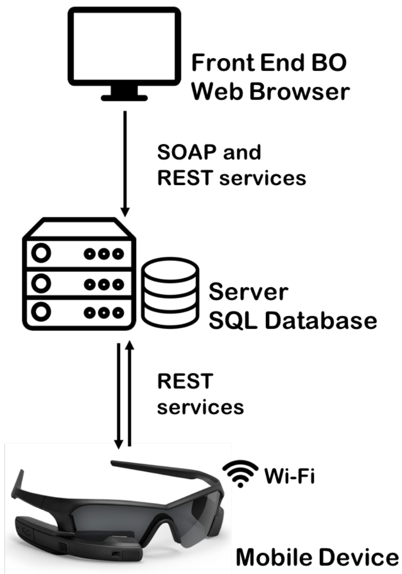


Figure 3.1: The data is inserted via a front-end BO in a web browser, stored in a SQL database in a server, and then retrieved by the mobile application through specific requests to that server.

Therefore, to contextualise the environment in which the mobile application was developed and what information was available, it is necessary to explain what is the BO platform and what kind of data is possible to insert, as the solution relies on those concepts. Besides an overview of the concepts of the BO, this chapter describes the main functionalities of Glass4Tourism and how it makes used of the BO concepts, along with the technical specifications of the server, the application and the Jet glasses.

3.1 Back Office

As previously mentioned, Glass4Tourism is meant to comply with an already existing structure, all the contents of the application have to be defined in a front-end BO platform by the tourism operator. The BO is accessed via a web browser and is the graphical interface in which the client inserts all the required data for the application to function properly [60]. All the information about the tourism tour, POIs, and activities is defined here. Translations for all these contents in several languages can also be provided. Using this platform, it is also possible to exchange messages with the tourist during the experience. It is worth mentioning that this platform is not exclusive for Boost, it is also used with other applications, thus some of the properties of the main concepts are not applicable in this context.

Although the BO is not included in the work of this dissertation and it suffered no related modifications during the course of this project, it is important to explain its general structure in order to understand how the data that feeds the application is structured and how the client (the tourism operator) creates it. The menus of the BO are: points, activities, routes, route access codes, roadbooks, messages, games, and translations. The points, activities, routes and roadbooks menus contain a list of all objects of each type, allowing editing and creating new instances. In the route access codes menu, as the name implies, it is possible to assign a code to a route, and in the messages menu is where it is possible to send and receive messages from the users. The games menu is empty.

This section gives an overview of the features and functionalities of the objects defined on the BO. Even though the explanation may be biased by their current use and the purpose for which they were originally intended, it does not mean that they might not be put to a different use or discarded according to the specifics of this work and an HMD platform.

3.1.1 Point

There are three types of points: route, activity and hidden. A route point is meant to be visible to the user in the path of the route, whereas an activity point is not meant to be visible in the route but to to unlock a set activities, either by location or by quick response (QR) code reading. A hidden point, as the name implies, is not meant to be seen by the user at all and is intended to help manage precedence amongst points. The following properties are mandatory and common to all point types: point type, name, latitude, longitude, and radius. All other properties are optional. The remaining properties common to all three route types are: place, app name, keywords, and link, while the following are exclusive to route points: category, description, and multimedia (images, audio and video files).

3.1.2 Activity

As with points, the type of activity is the first option when creating or editing an activity and it also determines the available options. There are six types of activities: instructions, free text answer, multiple choice answer, challenge, suggestions vote and QR code. An instructions activity consists simply of instructions to perform a given action, a free text answer activity is a question to be answered in writing by the tourist, and a multiple choice answer activity consists of a question with multiple options. Challenge activities are a challenge the user needs to complete, such as photographs, video, reading QR codes, etc. As of suggestions vote activities, they were in a development stage during the course of this project and its purpose was not yet completely defined. Finally, the QR code activity is meant to attribute points for finding a given QR code, differing from an Activity Point, in which the reading of a QR code unlocks a set of activities.

The properties common to all types of activities are name, description, keywords, and multimedia (images, audio or video), with only the name and descriptions being mandatory fields. Furthermore, each type of activity, except instructions activities, have an exclusive set of options. The additional properties of free test answer activities are timer, password, answer and points; and the additional properties of multiple choice answer activities are timer, password, options and points. Challenge activities have as additional options a password and check boxes with QR code, photo and video; suggestion vote activities' additional properties are timer and password; and QR code activities' only additional property is points.

3.1.3 Route

Points and activities are used to create routes. A route is a collection of points, and each point can optionally have activities associated with it. A point can only be added to a route once, however it can be added to as many routes as desired. The same is valid for activities and points: an activity can only be added to a point once, but it can be added to an unlimited number of points, even if they are on the same route. The activities in each point always have a predefined order. After adding points to a route, it is possible to mark them as conflict points, to mark a point with precedence over the other, meaning that, if point A is a conflict point of point B, point B is always only visited, in the application, after visiting point A. Conflict points can only be points of the same route.

The mandatory properties of a route are route type, name, start date, and end date, while the non-mandatory are color, timer, POI fence (m), summary, description, keywords, image, and audio. Unlike points and activities, the properties of a route are always the same, regardless the route type. There are five route types: sequential, no sequence, invisible sequence, sequential indoor, and no sequence indoor. Sequential route types have a defined sequence of points, which must be visited in the predefined order and, except in the invisible sequence case, the user is aware of that order. In the non sequential route types, the points do not have predefined order. All route types allow drawing paths between points in the map.

3.1.4 Roadbook

Roadbooks are simply a collection of routes, there is no limit to the number of routes added to the roadbook, but the same route can only be added once. The only mandatory fields are the name and the date, this date is the last in which the roadbook is available. The other fields are company, description, keywords, image, and three check-boxes: real time videos, real time photos, real time tracking and real time messages. The mentioned check-boxes must be checked in order for the BO to allow the real-time functionalities.

3.1.5 Route Access Codes, Messages and Translations

Route Access codes, messages and translations are complementary functionalities of the BO and not concepts that define the contents of the application. The route access codes are meant to password protect a route in the application, if this option is active, a code is required to unlock the route. The same route can have several access codes with different active periods, which do not, however, override the validity of the route itself. The BO offers the possibility to exchange messages with the user of the application, with a chat UI to view the conversation history. The translations menu allows to define which languages are available for translation and to effectively translate the contents of points, activities, routes and roadbooks into those languages. It is also possible to add alternative multimedia contents according to each translation.

The BO is a platform which allows the creation of several objects, of which the more pertinent, concept-wise, to a tourism oriented application are points, activities, routes, and roadbooks. These, along with the additional features of route access codes, messages and translations, support a vast array of possible implementations by a total or partial use of those objects. The goal was to make the most advantage of these features in order to create an application for an HMD, however, it is important to mention that the BO was not created with an application for this type of device in mind, which presented some challenges and limitations.

3.2 Application

Following the presentation of the concepts of the BO in the previous section, it should be noted, once more, that Glass4Tourism was moulded around those concepts. This was a request of the company and part of the proposal of the dissertation, so that the application could work as a commercial solution on a similar format to other products owned by the same company. Furthermore, Glass4Tourism is supposed to evolve from one of those products, Boost, which receives its contents from what is defined on the BO. Boost supports roadbooks, routes, points and activities, in as many languages as defined in the BO for each, as well as message exchange and password protected routes. Although it was a requisite that the new solution had a similar format, the condition was that it supported the same basic structure and not to build a copy of Boost in a different type of device. To comply, the application makes use of webservices, the responses of which contain all information previously introduced in the BO. As with the BO, the webservices are not part of the scope of this project and were used as-is, without any modifications or adaptations.

The application developed in this project should, therefore, possess the following functionalities:

1. Communicate with the server to receive roadbooks, routes, points, activities and translations;
2. Allow the user to choose a language, from the options introduced in the BO, and present all contents in that language;
3. Give directions to the user to follow a route from point to point, according to the route type;
4. Display the activities associated with each point and allow the user to complete them;

5. Allow the user and a monitor of the tourism activity to communicate through the BO.

Glass4Tourism is to be implemented in a mobile device in an early stage of development and usage. Therefore, the restrictions imposed by this hardware must be taken into consideration, such as restricted autonomy, limited computing power, small display size, limited controls and limited connections. For these reasons, several adaptations were made. Indoor route types were discarded, as the solution is oriented towards outdoors tourism. Non sequential route types were also discarded, as, due to software limitations that will be explained later in section 3.3, Recon Jet does not allow navigation in map. It is very impractical to give directions between two points pointing to the destination as the crow flies, instead of according to the path that connects those two points. Thus, only routes of the types sequential and invisible sequence were considered. Route points are the backbone of the route, with the users being oriented from one to the other. Activity points are used either as QR code points, unlocked by the reading of a QR code, or as surprise points in a location between two route points. Hidden points are never visible to the user, they are only used to prevent incorrect arrivals at a point, by establishing a hidden point as a mandatory precedent of a route or activity point. Furthermore, free text answer and suggestions vote activities and route access codes were not be considered, the first due to the difficulty of typing text in an HMD device (and Jet does not support voice commands), the second due to still being under development and bringing no advantage when compared to the other types of activities, and, in the case of route access codes, for the sake of simplicity in the early stage of development, as the first objective was simply to understand user's reception of the concept. It was decided to build the application as stand-alone in Recon Jet, making it independent of a mobile phone, for the commercial advantage of requiring only one device, not due to restrictions of the device, since it supports connection and provides application programming interfaces (APIs) for communication with mobile phones.

To facilitate the user's interaction with the device and to maximise the tourism experience, a tutorial with the controls used during the route should be always available before starting the tour, aiming to facilitate and improve the experience and to allow the user to familiarise himself with the technology. During the tourism tour itself, it should be easily available at all times a map, a view giving directions between points, and a chat view to exchange messages with a tour monitor, with access to the BO. Camera functionalities should also be always available, to take pictures and make videos, as, according to section 2.2.1, one of the main advantages perceived by the user while wearing an HMD is sharing experiences in a first person point of view.

Another feature commonly associated with HMDs is AR, which could be valuable in enriching the tourism experience. However, the display of the device used in the proof of concept, Jet, is not see-through and is not at eye-level but below and to the right. Therefore the only option for AR, from the device standpoint, would be to have the camera on during most of the tour. This is not feasible due to autonomy restrictions, as having the camera permanently on is extremely battery consuming. On the other hand, the BO is not prepared to introduce information that would work with AR seamlessly throughout the tour. As a midway compromise, AR should be used only upon the arrival at a route point, using the camera, the location, and the orientation of the user, to show the name of the route point when the user is oriented towards it. It is logical to experiment this approach only on route points, since the user is conscientiously moving towards the point and expecting to arrive, whereas activity points appear as surprise points during the route. The success of this approach is subject to the resolution of the camera and to the accuracy of the location and orientation.

The resulting structure of the application is presented in Figure 3.2, where Main represents the core of the application, where the users will be guided through the points ans activities of the route.

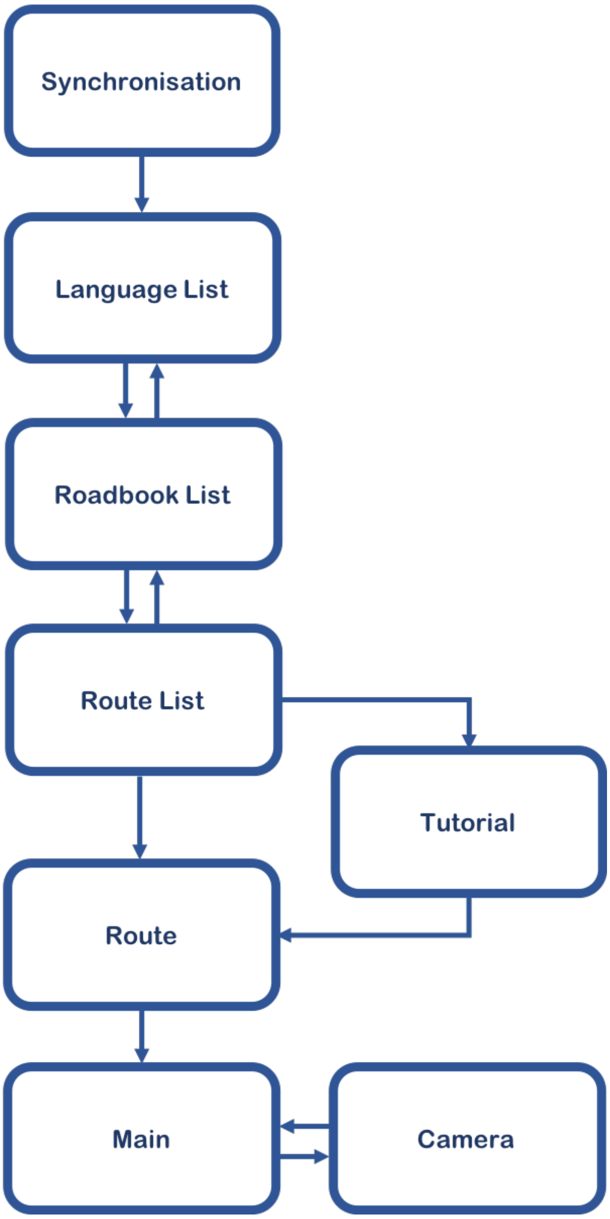


Figure 3.2: Structure of Glass4Tourism.

In summary, the goal is to develop a new application for an HMD device, following the same basic structure of the "parent" application, with roadbooks, routes, points, and activities. However, this type of device presents both new possibilities and limitations, thus, features that are not adequate should be removed, such as non sequential routes our free text answer activities, and new features should be added, such as an AR experience in specific parts of the application. Also, to facilitate the interaction with the device, the user should go though a usage tutorial before starting the tour.

3.3 Technical Architecture

The device used in the development of mobile the application, Jet, is an HMD developed by Recon Instruments launched in 2015 and oriented for sports, specially cycling and running, according to Recon's marketing of the device. As a device oriented to outdoors sports, it was deemed a good fit to use Recon Jet for outdoors tourism activities.

Jet runs a modified version of Android (mobile OS developed by Google) 4.1, ReconOS 4. The programming language used in this project was Java, the standard language of the Android software development kit (SDK) and also the language of Recon's SDK. The Android SDK includes a wide range of libraries oriented for mobile programming and the Recon SDK includes tools, documentation, and samples necessary to write third-party applications for Jet. The Recon SDK extends the Android SDK with extensions specific to Recon's devices hardware, providing several APIs that allow the developer to take advantage of the features of the device, such as the heading API, the Recon UI API, or the glance API. For the location features of the application, the device's built-in GPS is used, employing the native Android API to receive location updates.

One of the limitations of Recon's SDK is that it does not have an API to interact with its maps. ReconOS does have a native maps app, and it is possible to integrate that app in a third-party application, however, the only customisation possibility is to open the map in a given location, not other functionalities are possible, such as marking points or drawing paths. Google Maps, Android's native maps, that do has an API that offers the mentioned features and many others, is not an option, as it requires Google Play Services to be installed on the device. Google Play Services is installed together with Google Play Store, Android's application store, which is not available in Jet. This limitation implies that the directions from point to point in the tour could not be given with the visual aid of a map.

All technical specifications of Jet, such as processor, memory, display and camera characteristics, storage capacity, estimated autonomy, connectivity options, and available sensors are displayed in Table 3.1. The Bluetooth capacity of the device was not used, nor the altimeter, barometer and thermometer sensors.

All the roadbooks, routes, points and activities defined in the BO, as well as the relationships amongst them, are available through Representational State Transfer (REST) web services, the answers of which are in JavaScript Object Notation (JSON) format. There is a request for the list of roadbooks, which contains a list of route; a request for a given route, which contains a list of points; and a request for activities by route, with indication of which point they belong to. The responses to these requests also contain translations, when they are available. There are services to receive and send messages, as well as a service to update the messages status, informing the server that the client (in this case, the application), has received a specific message. The data introduced manually in the BO is stores via Simple Object Access Protocol (SOAP) and REST web services in a database, using Microsoft Structured Query Language (SQL) Server 2008 R2, in a server running Windows Server 2008 R2, SP1, and the web services that consume information from that database to generate the JSON responses run on the same machine. To make requests to these web services, the Jet device connects to the internet via Wi-Fi.

Table 3.1: Technical specifications of Recon Jet.

Processor	1 GHz Dual-Core ARM Cortex-A9
Memory	1 GB DDR2
Storage	8 GB (flash)
Battery autonomy	4 h - 6 h
Connectivity	Wi-Fi, Bluetooth
GPS	Yes
Display Resolution	16:9 WQVGA 248x240
Display position	Below eye-level, to the right
Speakers	Yes
Input methods	Buttons and optical touchpad
Camera	720p video (1.2 MP still)
OS	ReconOS (based on Android 4.1)
Sensors	Microphone Accelerometer Gyroscope Magnetometer Altimeter Barometer Thermometer

Thus, to exchange messages during the tour, an Wi-Fi connection is required, which could be provided by a portable access point (hotspot).

Recon Jet is an HMD device running ReconOS 4, a modified version of Android 4.1, and the application developed for the device was written in Java. To build the solution, the development has made use of Android's and Recon's SDKs. Among the technical specifications of the device are Wi-Fi and GPS, which have been used for internet connection and location services, respectively. The internet connection is required to make requests to the web services responsible for delivering the information inserted in the BO to the application.

The application developed in this work, Glass4Tourism was structured around the objects defined in the BO: roadbooks, routes, points, and activities. Besides, the functionalities of messaging and multiple languages are also derived from the BO. Other of its concepts, however, were discarded for this proof of concept, such as non sequential routes, free text answers, or route access codes. Therefore, the main features proposed for Glass4Tourism are following a route from point to point, showing the respective activities at each point, showing a map with the user location, a chat to receive and send messages to the BO, and having the camera functionalities always available, for pictures and videos at any time. The next chapter details how the solution was implemented in Recon Jet.

4 Implementation

In this section, the details and challenges of the implementation of the application in Jet are presented. First, the design constraints and guidelines while developing for a new, not yet very explored, and with limited screen capabilities device are explained, followed by the presentation of the resulting application, its implementation, challenges, and how it conforms to the guidelines.

4.1 Interface Design and Usability Constraints on HMDs

One of the considerations when developing to a new type of device should be how to design the UI and the user experience (UX) so that the adaptation of a user to that device is as easy and possible. The type of device used in this project is not yet extensively explored and, therefore, there is little material concerning its design specifically. However, there is no lack of material in UI and UX design in general and for mobile phones, which, in their early stages, had challenges similar to the ones smart glasses now face. This section explores the existing literature on the subject, both from a broader and a more mobile oriented approach, in order to support the choices made when developing the application.

4.1.1 General UI and UX Guidelines

For whatever kind of device or application, the first references to be taken in consideration are Nielsen's heuristics [61]:

1. Visibility of system status;
2. Match between system and the real world;
3. User control and freedom;
4. Consistency and standards;
5. Error prevention;
6. Recognition rather than recall;
7. Flexibility and efficiency of use;

8. Aesthetic and minimalist design;

9. Help users recognize, diagnose, and recover from errors;

10. Help and documentation;

4.1.2 Guides for Glassware

Glassware is the software for glass-like wearable technology. A master thesis dweling on design principles for glassware UI, based on Google Glass, formulated the following guidelines [62]:

- To plan carefully how information is presented, as it is very important and strongly influences audience response to the application;
- To make all visual elements serve a functional and beneficial purpose;
- To use icons only for supplementary information and to use existing, well-known icons;
- To avoid central alignment and filling the screen in a uniform block, using instead left alignment and implementing a diagonal flow;
- If using colour, to not use muted tones;

This project opted for the use of Recon Jet for the proof of concept, for the reasons already explained, that concept being independent of a specific device. Nonetheless, the design guidelines by the manufacturer of this device [63] must still be considered, not only because some are likely valid across smart glasses, but for a seamless integration with the OS. In a summary form, the guides given by Recon for developing applications for their devices are:

- Horizontal swipes are the easiest to execute and the recommended primary navigation method;
- Applications should have 30-pixel margins along all four sides of the screen, except when the status bar is visible, in which case the bottom margin should be only 10 pixels;
- Comply with the ReconOS's building blocks: navigation, options menus, notifications, etc.
- Comply with the ReconOS's font, font size, colours and icons.

Furthermore, Google's own design guidelines for Glass should also be taken into consideration [64]. As with Jet, most of their design guidelines hold true for many HMDs:

- "Design for Glass", focusing on how the device and the services provided can complement each other;
- "Don't get in the way", offering engaging functionality that supplements the user's life without taking away from it;
- "Keep it relevant", delivering information at the right place and time;
- "Avoid the unexpected", not sending content too frequently or at unexpected or inappropriate times;

- "Build for people", designing interfaces that use imagery, colloquial voice interactions, and natural gestures.

4.1.3 Guides for Mobile Phones

From articles about developing applications for mobile phones in the early stages of the smartphones, it is clear that the challenges and constraints faced then, such as small screens and limited input options, are similar to the ones faced now for smart glasses [54, 65, 66]. As many principles still hold true in wearable glass-like devices, the conclusions drawn can be used or adapted. Therefore, the restrictions considered when building applications for other devices were analysed and its applicability to this type of device was studied. Most of the articles used as references here are about tourism oriented applications. Of course, an application does not have to be tourism oriented in order for its UI and UX guidelines to still be valid, but when the subject is the same there is a greater probability of similar challenges. Thus, the considerations contemplated while developing the application were as follows:

- The interface must be appealing to a wide range of users, regardless of their skills and expertise [66];
- The information must be short and concise, providing only the information thatis essential for the user [65, 66];
- The interaction with the application must require minimal effort and not distract the user's attention from other activities [66];
- The application's presentation must follow a hierarchical multi-level structure [66];
- Design menus in order to allow the user to easily reach the desired information [66];
- Label buttons and menus clearly ans consistently [66];
- Avoid long lists of choices [66];
- Build menus' structures to allow the user to finish tasks with minimum interaction with the device [66];
- Fit page content on one screen [66];

When creating the interface, the notion that it is aimed for an HMD device should always be present. The application should have a clear interface design and present the contents in a concise manner, giving only the essential information and not overwhelming the user. It should present as well a clear and structured flow between the different actions, with confirmation to the actions deemed as critical and the possibility to go back. It should be easy to use, with consistent commands for the same actions and following "real-world conventions". In order to comply with the chosen device's OS, it should comply with its navigation flow, colors, and icons.

4.2 HMD Application

The application was developed using Recon and Android SDKs, in Java, the language in which both SDKs are written, using Java 8. In order to give a clearer explanation of the process of the development, two basic Android concepts should be introduced: Activities and Fragments, Java classes that the user interacts with directly though the UI. Generally, an Activity represents the whole view of an active application, while a Fragment could be just a piece of that view. Only one Activity can be active at any given time, but an Activity can contain multiple Fragments, simultaneously active or not. The Android Activity here introduced should not be confused with the route activities introduced in section 3.1.2.

The Android OS such as it is known and used nowadays is primarily oriented to be controlled with touch inputs, allowing the user to click anywhere on the screen. In Recon Jet, as mentioned, the user has limited input possibilities, which demands less input variations. The main focus during the development was to make the application as simple as possible and requiring minimum inputs from the user to function properly, according to what is presented in section 4.1. Therefore, the core of the application is a single Android Activity, containing a horizontal swipe list that should be composed by three Fragments: map, navigation, and chat. However, for reasons explained later in this section, Recon Maps were not available. The colors of the application - black, white and yellow - were also chosen to maintain coherency with the colors of ReconOS, in compliance with Nielsen's 4$^{\text{th}}$ heuristic [61], not only for consistency and to follow the platform protocols, but also because the manufacturer of the device has undoubtedly studied what UI works best. The control icons follow the same logic, those already existing were used (select, back, and camera), and the new icons added for this application (vertical scroll and audio playing) follow the same design principles and comply with what is already known by the user.

Before the tourism activity itself starts, a roadbook and a route have to be chosen, which is done by a monitor and not by the tourist. Therefore, there are two distinct users of the application, the monitor, who makes the decisions about initial configurations and may act as support, and the tourist, who will actually perform the activities.

In the hands of the final user, the tourist, and after a usage tutorial, the first Android Activity is a route overview, adapted to the route type, and then the Main Activity, containing the main tourism component of the application, guiding the user through the designed route and route activities in each point of interest. In Figure 3.2, in the previous chapter, each box corresponds to and Android Activity.

In accordance with the guidelines described in the previous section, Glass4Tourism has a defined structure, with a logical "path" to follow. Also, at all times during the tour, it is indicated what commands are available for each action, and the user has always information about the state of the system, whether it is in transit or in point, and there are dialogs confirming all important actions, with indication of which commands lead to what result. Errors are prevented by not reacting to a command that is not available at a time. The user is not always allowed to go back and never to redo a route activity or a route point, contrary to what is recommended by Nielsen's 3$^{\text{rd}}$ heuristic [61], due to the purpose of the application itself and its gamified nature. However when the route activities of each point actually start is decided by the user. With the design guidelines in mind, the application aims to be unobtrusive, of quick consultation, and as little distracting as possible. The symbols and texts are as close to the "real-world" as possible, with a compass-like arrow indicating the motion orientation, a camera icon marking the camera features are available or up and down arrows symbolising that vertical scroll is possible.

The behaviour is consistent across different functionalities, text based lists are presented in a vertical manner and may require a vertical scroll, and image based lists (as in languages, roadbooks and routes) or menus (as in the change between navigation and messages, and between camera functionalities) are presented in a horizontal scroll view. The design is always based on a black background with yellow for highlighted information, white for regular information and grey for less relevant but necessary information. Where possible, unnecessary or device-inadequate information was removed, such as less relevant titles or videos (which would not be easily visible in the Jet display). Nielsen's 7^{th} heuristic was not addressed, as Glass4Tourism is intended to be used occasionally and short term by each individual user.

Although Boost was also developed in Java using the Android SDK, its source code was not reused in Glass4Tourism, due to the many updates suffered by the Android SDK and other third-party libraries used by Boost, making an adaptation of that application more difficult than creating a new one.

4.2.1 Content Synchronisation

As aforementioned, all the required information is defined in the BO and, thus, the device has to communicate with it to access that data. For this reason, in the first launch of the application after being installed, it requires an internet connection. This is the only situation in which an internet connection is mandatory for functioning. After launching, the application starts synchronising with the server and, if the synchronisation is not successful, a message is displayed and the application will not evolve to the next phase. All content data is downloaded in this stage, allowing the application, after, to be functional without an internet connection - Figures 4.1 and 4.2. The REST services and their responses were developed by Card4B Systems and used without modifications [67].

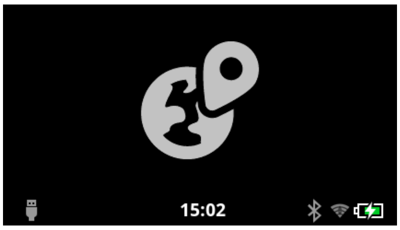


Figure 4.1: Launch screen of the application.

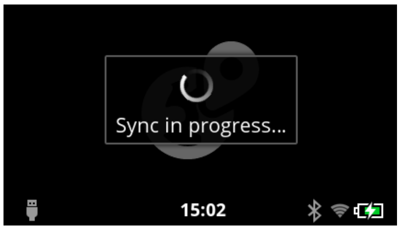


Figure 4.2: Screen for synchronisation in progress.

For the REST requests, several network libraries were considered, such as OkHttp[1], Retrofit[2] and Volley[3] but, in the end, Retrofit was chosen. This was due to good feedback with dealing with custom objects and being a good library to use standard REST API with JSON responses. All the content is saved in a SQLite[4] database, using the OrmLite[5] library for the database operations. Figure 4.3 shows

[1] `https://square.github.io/okhttp/`
[2] `https://square.github.io/retrofit/`
[3] `https://developer.android.com/training/volley/`
[4] `https://www.sqlite.org/index.html`
[5] `https://http://ormlite.com`

a simplified sequence diagram of the general flow of the data synchronisation.

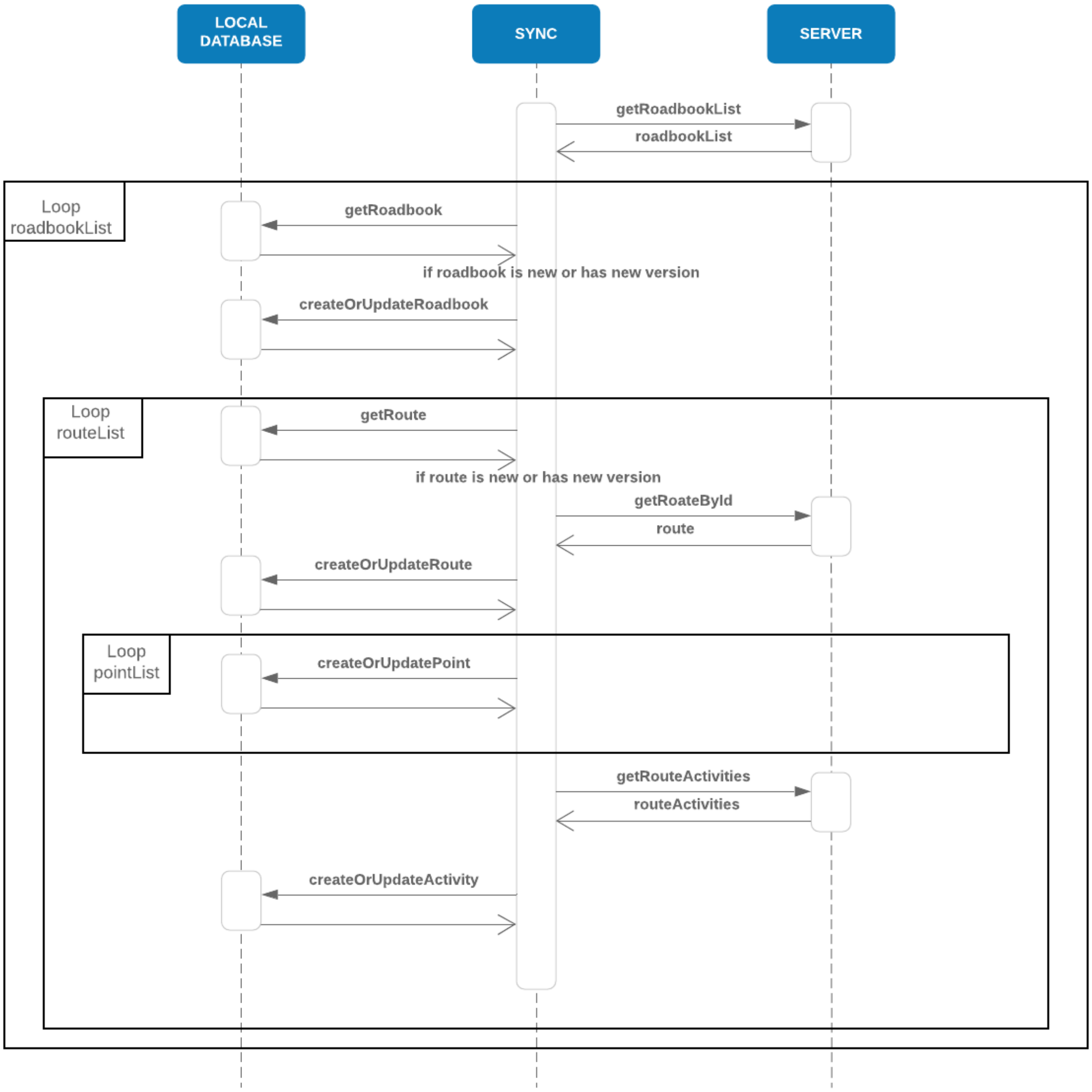


Figure 4.3: Simplified sequence diagram of the general flow of the data synchronisation.

To download the image, audio and video files, the chosen option was also Retrofit. Android's DownloadManager[6] was the first option considered, and it is the most recommended for large file downloads, due to memory issues, however, it does not allow to download files to the internal application storage. It is important that the media files stay in the application internal folder in order to delete them when uninstalling the application. Otherwise, the files would have to be deleted manually, which, if not done, could lead to a quick exhaust of the device space. After all the data is downloaded and stored in the application's database, the multimedia files are downloaded.

One of the main difficulties in importing data and then saving it in a ready to use format in the database was the assignment of path points do each point of the route. The object `mapPoint` in the

[6] `https://developer.android.com/reference/android/app/DownloadManager`

response of the route request contains a list of coordinates corresponding to the paths between route points, drawn in the BO. However, this list is in the well-known text (WKT) format, which is prepared to be plotted on a map, but has no association between the route points and the coordinates of the path. As Glass4Tourism does not rely on a map to give directions, it is required a match between route points and path sections. To solve this issue and assign a path to each point, the following assumptions are made:

1. The list of coordinates is sorted according to the order of the points in the route.
2. All points are part of the path and, thus, part of this list of coordinates.

None of the assumptions are mandatory when building the path in the BO, but they are required for this solution to function properly.

The path of each Route Point is the set of coordinates the user must pass to arrive to that Point. The algorithm to assign the paths to each point is as follows:

1. Loops through each route point.
2. Loops through every set of coordinates.
3. For each point, checks if the first coordinate is the coordinate of the previous point (if exists). If it is, discards that coordinate.
4. For each subsequent coordinate, until finding a coordinate that matches the coordinate of the current point, adds the coordinate to the list of coordinates that form the path leading to the current point.
5. When the coordinate is the coordinate of the current point, that coordinate is discarded and increments point.

Here, matching the coordinate means being in a 5 m radius of the coordinate. One coordinate belongs only to the path of one route point therefore, once it is attributed to a given path, it is no longer considered. This is only valid for sequential routes. For non sequential routes, the paths between points are discarded, as there is no way of knowing where the user will start the navigation to a given point from.

4.2.2 Language, Roadbook and Route List

The first required input is the choice of a language. The languages presented are those for which valid available roadbooks have translations, sorted alphabetically. For a roadbook or route to be valid, its end date (defined in the BO) has to be posterior or equal to the current date of the device. In the response of the requests, only valid roadbooks and routes are returned but that parameter is also checked when querying the local database. After choosing a language, all translations of roadbooks, routes, points, and route activities texts for that language are loaded into memory and all the roadbooks with translations for that language are retrieved from the local database. As there is not a direct connection, in the roadbook object, of with which translations are available, it is determined that a roadbook has a translation in a given language if its name is translated in that language. Application translations refer to the translations of the texts that are part of the ”skeleton” of application, such as the texts that appear during the synchronisation or in the tutorial, the labels of the commands, etc. These, as well as possible translations, are defined in the application and not in the BO. After choosing a language, the text contents of the application are also set to that language. If there are no application translations for that language, the default language is English. The language selection menu is displayed in Figure 4.4.

As the list of Roadbooks is limited by the chosen language, the routes available for selection are limited by the chosen language and roadbook, that is, the ones contained in that roadbook and with contents translated to the chosen language. Having a valid route in a certain language does not guarantee that a roadbook containing that route will have that language available - that connection needs to be made manually in the back end. The Route and Roadbook selection menus are displayed in Figures 4.5 and 4.6, respectively.

Figure 4.4: Screen with the list of languages.

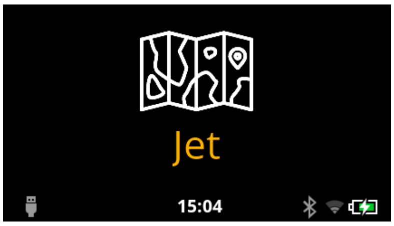


Figure 4.5: Screen with the list of Roadbooks.

Figure 4.6: Screen with the list of Routes.

After a language, a Roadbook and a Route are chosen, there is the option of going through a usage tutorial, explaining the main controls and general functionality of the device and the application, or go straight to the information about the chosen Route. These options are displayed in Figures 4.7 and 4.8. These initial selections are made by the monitor of the tourism activity and not by the tourist. When the route is confirmed, all route objects are loaded into memory: Route Points, Activity Points and Route Activities.

The language, roadbook, and route selection Android Activities use the Carousel Activity from the Recon SDK, a horizontal swipe menu with tabs temporarily visible on top right after a swipe, as visible in Figure 4.6. The menu to choose between starting the route or choosing the tutorial makes use of Carousel Dialog, also derived from Recon's SDK. All these menus require the horizontal swipe action, the one deemed easier to perform by Recon, as mentioned in section 4.1.2.

Figure 4.7: Dialog: option to start Route.

Figure 4.8: Dialog: option to see the usage tutorial.

4.2.3 Usage Tutorial

A tutorial was created in order to familiarise the user with the commands of the device before actually starting the route. A sequence of Android Activities guide the user through the commands necessary to use Glass4Tourism: select, back, scroll vertically, double click select to access the camera features and horizontal swipe. Nielsen's 6th heuristic suggests that this instructions should always be visible however, for the sake of simplicity and due to the limited command options available, the tutorial is displayed only before starting the route and cannot be retrieved later. Furthermore, it is assumed that a monitor with full knowledge of the device and the application will be present to assist the tourist in case of doubts, at least in the beginning of the experience.

In Figure 4.9, the tutorial for the select command is displayed. Here, it is only required that the user clicks select to proceed. The symbol shown - the white circumference with a yellow circle inside - represents the select symbol. The back command takes the user back to the previous screen if that action if possible, with a yellow arrow pointing to the left symbolising this action - Figure 4.10. If the user presses a different key than required in each step, a warning appears giving that information, as shown in Figures 4.11 and 4.12 for the vertical scroll and open camera commands, respectively.

Figure 4.9: Tutorial: select key.

Figure 4.10: Tutorial: back key.

Figure 4.11: Tutorial: pressing a different key when expecting a vertical scroll.

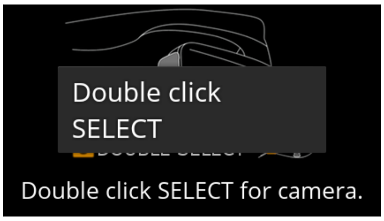


Figure 4.12: Tutorial: wrong key when expecting command to open the camera.

Every time an action is accessible, the respective symbol is displayed in the screen. This tutorial is intended for the tourist user, and not for the tourism monitor user. For the monitor, it is assumed he will have time to acquire himself to the device or receive instruction, so he can help the tourist with any questions during the tourism activity itself.

4.2.4 Route

After the optional tutorial, the first Android Activity intended for the tourist user is an overview of the route. Two types of routes are considered: sequential and invisible sequence. For the visible route type, a preview of the route is presented, in the form of a list of all its points, presented in the order they are meant to be visited, as in Figure 4.13, and, when the users presses the select key, he is presented a dialog asking for confirmation to start the route - Figure 4.14. For the invisible route type, no preview is shown, only this dialog confirming the beginning of the route (Figure 4.15).

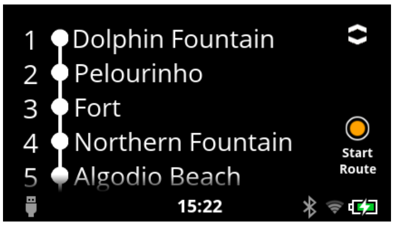


Figure 4.13: Screen showing the all the points of the chosen sequential Route in order.

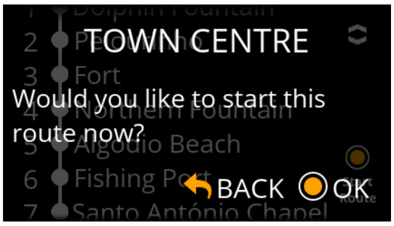


Figure 4.14: Dialog confirming whether the user wants to start the sequential Route.

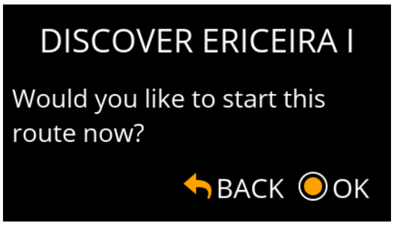


Figure 4.15: Dialog confirming whether the user wants to start the invisible sequence Route.

4.2.5 Camera

To allow the users to take pictures, make videos or read QR codes at any time during the route, the camera is almost always available via a double click on the select button, not only when it is specifically required by a route activity. The layout of the camera Android Activity was based on the native layout for the camera of the ReconOS, due to layout conformity reasons, and modified to include QR code reading. Swiping horizontally in the touch pad allows to switch between the photos, videos and QR code reader modes, the three options are displayed in Figures 4.16, 4.17 and 4.18. The device has a native access to the camera always available by a long press on the select button, which could not be overridden nor, however, could be used as-is, as it does not allow QR code reading, a requested feature for Glass4Tourism.

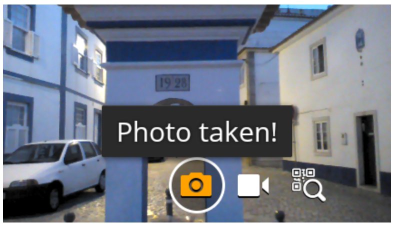


Figure 4.16: Using the camera to take a photograph.

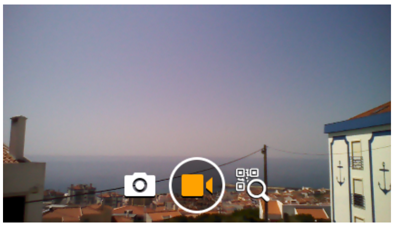


Figure 4.17: Using the camera to make a video.

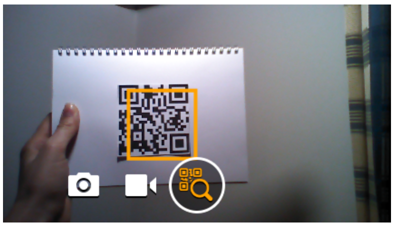


Figure 4.18: Using the camera to read a QR code.

To take pictures and make make videos the native Android APIs were used. The video has a duration limit of 30 seconds, a restriction imposed by the application and not by the system, to prevent exhausting the storage of the device with accumulated video files. There are no restrictions in the number of pictures or videos taken during a route.

To decode QR codes, a Google barcode API[7] was used, which allows to convert the QR code in a string and compare it with the expected QR codes.

4.2.6 Main Activity

After starting a route the user is taken to the Main Activity, the core of the application. The basis of this Android Activity is a horizontal swipe menu, based on Recon's Carousel Activity, as with the initial choice menus. The original plan was to have three horizontal pages: a map view on the left, the

[7] `https://developers.google.com/vision/android/barcodes-overview`

navigation and route activities on the central page, and the chat functionality on the right page. However, for reasons that are further explained in section 4.2.6.A, it was not possible to include maps and the final version of the application has only two pages. The chat and map pages are compose of one single Android Fragment, whereas the left page (previously the central page), the default page, where the user is guided between points, warned when he arrives to a point and guided through the route activities of each point, switches among different Android Fragments, as depicted in Figure 4.19. Besides the various Fragments, when the user first arrives to a route point, after a warning that he has arrived to that point, the AR Activity is launched, an Android Activity superimposing the name of the route point on the camera view when the user is looking in its direction, further explained in section 4.2.7. When the dialog and the AR Activity are active, the horizontal swipe is not available, thus the different colour in Figure 4.19.

All the transactions between Fragments, opening the camera during the route, and opening the AR Android Activity when arriving to a point, as well as launching all the required services (location, heading, and messaging) are managed by the Main Activity. The Fragments represent simply the different views of this Android Activity, with all the processing being done here. When the user arrives at a point the navigation stops, after finishing all route activities of a point, the application returns to the Navigation Fragment and the state changes back to in transit.

From the moment the location services are started, all location readings are stored in a file in the device, to later evaluate the accuracy of the GPS. Also, the battery status at the beginning and end of a route is also recorded, to evaluate the device's autonomy.

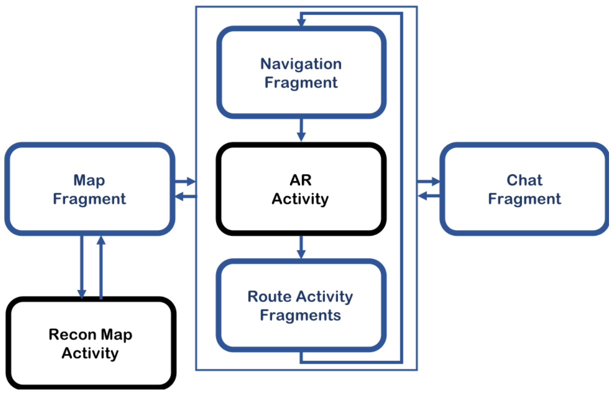


Figure 4.19: Sequence of fragments of the Main Activity.

Although it is possible, in the BO, to add multimedia content to route points, be it pictures, audio or video, in Glass4Tourism it was decided against showing any kind of multimedia, or even description, in a point for the sake of simplicity. To add this extra information when arriving in a point but before starting the point activities would add confusion. Furthermore, in the BO, only Route Points contain a description or allow to add multimedia contents, but not Activity Points and, with glassware as the target device, it makes sense to keep functionalities as simple and clean as possible.

4.2.6.A Map Fragment

As mentioned in section 3.3, there is no API to allow direct interaction with the native Recon maps, and Google Maps were not a viable option. Thus, to include maps in the application, aiming to help the users in navigation, it was planned to show the Recon maps, allowing to open the map in the user's current location, zoom in and out, and navigate the map. This would be done opening a third party application, Recon Maps, when swiping to the left page of the Main Activity. To use Recon Maps, the maps themselves need to be downloaded using Engage[8], a Recon platform to synchronise the contents of the device. However, by the time of the development of the application, it was no longer possible to download maps from Engage, so the Map Fragment was omitted from the application as it would only display an error message saying no maps could be loaded for the location and would add no value to experience.

4.2.6.B Chat Fragment

The Chat Fragment allows the user to communicate with the monitor of the activity, who has access to the BO during the tour. The message service is launched when the route starts, in the Main Activity, a request for new messages is sent to the server every 5 seconds. If new messages exist, a reply is sent to the server acknowledging that those messages are received, so they are not sent again in the next request. Of course, this service requires an internet connection to function properly.

From the user's perspective, the communication is not free due to the lack of a friendly keyboard in the device, the user can either send a predefined message ("Help" or "I'm lost") or answer the monitor choosing an option from a list provided by the sender of the message. If the message typed in the chat box in the BO if of the form `message begin_reply_json:["option 1", "option 2", "option 3", ...]`, the list of options appears to the user when that message is selected, along with the two default option, as in Figure 4.20.

When a new message is received and the user is not in the messages view, an alert appears, giving him the option to either visualize the message immediately or go back to the current activity - Figure 4.21. While in the message view, the user can scroll all the chat history and select and respond to the received messages.

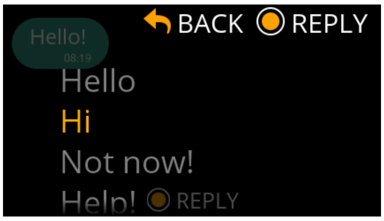


Figure 4.20: Options to reply to a message, two default options and three additional from the server.

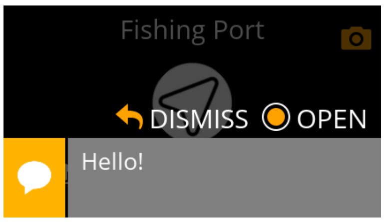


Figure 4.21: New message notification.

4.2.6.C Navigation Fragment

The Navigation Fragment is the first view shown to the user, consisting of an arrow to guide him through the path, as well as information about the total distance to the point, the remaining time and the estimated time of arrival (ETA). For invisible routes, the name of the route point is not displayed. Figures 4.22 and 4.23 show this view for each type of route.

[8]`https://engage.reconinstruments.com`

Figure 4.22: Sequential route: navigation to a route point.

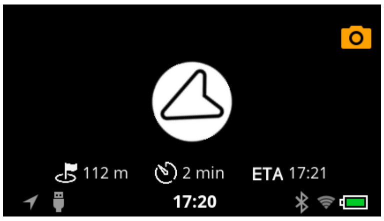


Figure 4.23: Invisible sequence route: navigation to a route point.

When starting the navigation to a route point, two Locations variables are set: `nextPointLocation` and `nextLocation`. The first is the location of the route point itself and the second is the location of the first point of the path leading to that point. If there is not a path defined, or after passing all path points, the `nextLocation` is identical to the `nextPointLocation`. When the route starts, the location and heading services are launched and kept running in the background. These services use the Android Location API[9] and the Recon's Heading API. The location service returns the current location and speed of the user, and the heading service returns the current yaw, pitch and roll angles of the device, of which only yaw is used for navigation, and it should match the user's head yaw if it is properly placed.

To guide the user along the path, the arrow in the view of the Navigation Fragment always points to `nextLocation`. All the processing is made in the Main Activity and reflected in the view of this fragment.

The location and heading services feed this view by providing the necessary information to update the orientation arrow and the distance and time values, and make it possible to know when in the radius of the route point. When a location update is received, the current coordinates and the motion speed of the user are updated and the distance, time until the next route point and ETA are recalculated. The orientation of the arrow is updated on both a location or a heading update, using the most recent value of the other.

The location is only updated when there is GPS signal available. The GPS is set to return every 1 meter or every 3 seconds, whichever happens first. These return not only the user's current location but also his current speed. Before there is enough data about the speed of the current user, the speed used for the calculations is compared to the reference human walking speed in a "leisure walk", 1.4 m/s. If the speed returned by the sensor is above or below this value by at least a factor of 3 (the accepted walking speeds are between 0.47 m/s and 4.2 m/s), it is discarded and the reference value is used instead to compute the remaining time, to account for errors in the sensor and for when the user is stopped. The same is valid to compute the ETA, as it is simply the sum of the current time with the time calculated to arrive at the route point. After 30 sequential readings with values within the accepted walking speed, the median of the user speed is used as a reference value instead of the human walking speed.

While in transit between route points, which is true whenever a user in not in a Route Point performing Route Activities, when a location update is received, that location is processed in the following order:

1. Compared to the location of the next route point - if the locations coincide, the user states changes from in transit to in point;

[9] `https://developer.android.com/reference/android/location/package-summary`

2. Compared to the location of all the unvisited activity points - if the locations coincide, the state also changes;

3. Compared to the location on the `nextLocation` - if the locations coincide, the state does not change but the variable is updated.

The first and second situations happen if the current location is within the radius (defined in the BO) of the route or activity point, respectively. A dialog is shown to the user for 7 seconds announcing his arrival to the point - Figure 4.24, and then it is displayed the AR Activity, detailed in section 4.2.7. When returning to navigation, in case an activity point was visited, the application resumes navigation to the next route point, the same one as before. In the third situation mentioned above, the only change is in the `nextLocation` variable, which is incremented to the next of the path point list of the current route point or to the location of the point itself.

After all route points are visited in the defined sequence, the route is finished and the user is informed - Figure 4.25. Thus, it is mandatory that all Route Points are visited to finish a route but not that all Activity Points are. Before finishing a route activity, there is always a confirmation dialog that allows the user to go back if the select button was pressed by mistake, in accordance to the UX guidelines.

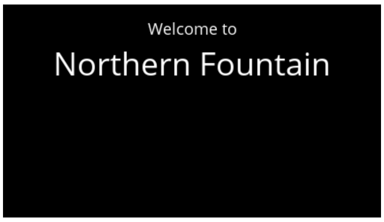


Figure 4.24: Arrival at route point.

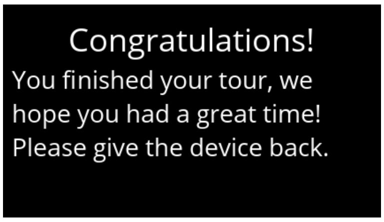


Figure 4.25: Screen for route finished.

Route points can only be accessed by arriving to its location but activity points can be triggered either by location or by QR code reading. If, during navigation, the user reads a QR Code corresponding to an activity point, the a dialog is shown informing the user that the QR Code represents a point and asking if he wants to start the route activities of that point. If the user chooses to start the route activities, the state changes to in point and that QR code is marked as read. On the other hand, if the user tries to read a repeated QR code - not only one that has been read before but one that has both been read and the corresponding action started - he receives an error informing that QR code has already been acted upon.

The main challenge for this screen was how to guide the user along the Route. The initial idea was to show the map and the path on top of that map, giving the information of the current location and the path to follow simultaneously, in a simplified way, adapted to this device. However, to the date of completion of this thesis, there was not API available to use Recon Maps in such a way. This screen was carefully tested to understand if the users found it easy to follow the path. After the first tests, the navigation screen was changed from only showing the total path distance to the next route point to showing, to showing also the remaining time and the ETA. Besides, during navigation, there are alert sounds for when the path changes orientation or arrives to a point, signalling an event that requires the user's attention, abiding by the UX guidelines for smart glasses.

One other challenge was related to activity points, as they do not have a parameter indicating if they are also QR code points so, from the application's perspective, they are equally triggered by location or QR code, whichever appears first. Programmatically, it was not found a solution to deal with this situation. However, it can be contoured by the BO configuration if, when creating a QR activity point, it is set it a location that will not be detected during the route.

4.2.6.D Route Activity Fragments

There are two options to start route activities: by arriving in a point with activities or by reading an activity QR code. There are 4 types of activities in the application, with a different Android Fragment for each:

- Instructions Activities
- Multiple Choice Activities
- Challenge Activities
- QR Activities

When in a point, the activities are presented sequentially, in the order defined in the BO, after the AR Activity, and the user can only advance to the next activity after confirming the completion of the previous one. If the activity is launched through a QR code, it is a stand-alone activity, when the user reads the corresponding code, a dialog appears confirming with the user whether he wishes to execute the route activity. In case of a positive answer, navigation is temporarily interrupted and resumed when the route activity is completed.

As with other elements, route activities can have multimedia files. In case an activity has an audio file, the audio is played and a symbol indicating that event is present on the screen.

While performing the route activities, the camera features are always available. However, except in QR activities and challenge activities where QR code reading is required, this functionality is disabled, in order not to create an error prone situation for the user, as it is not possible to start an activity point while still in another point.

Instructions Activities consist of a description and an optional image - Figures 4.27 and 4.27. In case the activity has audio and image, and no description, it would preferable to show the image in full screen while the audio is playing. However, the field description of a route activity cannot be left empty in the BO, thus there is always space for the text in the layout of every type of activity.

Figure 4.26: Instructions activity without an illustrative image but with audio.

Figure 4.27: Instructions activity with an image.

Multiple choice activities present the user with a question and a list of answer options, besides optional image and audio files. Each answer has points associated with it and, after confirming that the activity is finished, the points are displayed to the user - Figure 4.29. There is an optional time parameter in this type of route activity, which, if not zero, means the user has a limited time to complete the activity and that information is displayed on the screen - Figure 4.28. If the time finishes before an answer is given, the user is informed and the activity is marked as not completed. All answers answers are saved in a file in the device that can later be retrieved by the monitor of the activity, as there is not a service available to send the answers.

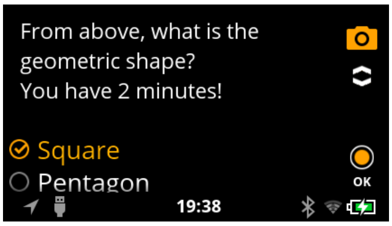


Figure 4.28: Screen of a multiple choice activity with timer.

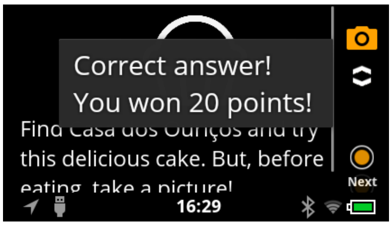


Figure 4.29: Multiple choice activity - correct answer.

Visually, challenge route activities are identical to instruction route activities, with a description and an optional image. However, there is an additional parameter in its configuration that indicates whether the activity requires photos, videos, or QR code reading. If ate least one is true, the user is warned and cannot proceed without performing that action.

The videos or photos are saved on the device with their names indicating the activity under which they were taken, for later retrieval of the monitor of the activity. If a QR code is read, its code is saved in a file associated with the current activity. This data cannot be sent directly to the server because there is not a service that supports it.

QR route activities behave slightly different depending on whether they are in a point or stand-alone. In a point, visually, the QR Activity Fragment is identical to the Instructions Activity Fragment. However, as it is possible to associate points with this type of activity, the user gains points by discovering a given QR code. On the other hand, if it is a stand-alone activity, when the user reads a QR code from a QR route activities during navigation, a toast appears informing the user of how many points he won. As with multiple choice activities, the points, in both situations, are stored in the device for later retrieval.

4.2.7 AR Activity

With the purpose of exploring AR capabilities in the HMD device, when arriving to a route point and before starting the route activities, the Main Activity is temporarily paused and the AR Activity is launched. This Android Activity opens the camera of the device, showing the user the name of the point when he is oriented towards it. Figures 4.30 and 4.31 show both cases, when the user is oriented towards the route point and when he is not.

Here, the current location, yaw and pitch are used. The name of the route point is only shown on the screen if the pitch angle is between -15^{o} and 15^{o} (a pitch of 0^{o} is when the device is parallel to the ground) and the yaw angle is $\pm15^{o}$ of the desired yaw to be oriented towards the route point. The desired

Figure 4.30: AR Activity with the device oriented towards the route point and displaying the name.

Figure 4.31: AR Activity with the device deviated from the route point.

yaw angle is computed by the `bearingTo` method of Android's Location API, which returns the bearing in degrees East of true North when travelling along the shortest path between the user's location and the point's location. This is not used in activity points as they may not point to a specific monument or view, but are most commonly used as a manner of grouping activities between route points.

The application developed in this dissertation, Glass4Tourism, fulfilled the specified requirements, synchronising all the contents defined in the BO by means of REST web services, presenting the user with initial configurations to choose from (language, roadbook and route), and then allowing the user to follow a route in the defined order of points and route activities. The only objective that was not possible to achieve, due to software limitations of Recon Jet, was the inclusion of a map to aid in navigation.

The size of the resulting Android package (APK), the Android installer file, is 18.9 MB, for which the 8 GB of storage of the device are quite sufficient. While running, the application occupies the most RAM memory while in camera mode, near 17 MB, due to the QR reader, and between 8 MB and 9 MB during navigation, with the location and heading services constantly working, route activities and even in the AR Android Activity, alls values well within the 1 GB of memory of the device.

The flow of Glass4Tourism is fairly simple, its core functionality consists of navigation through a route and performing activities when the route or activity points are reached, also allowing communication with the server through the Chat Fragment. This simplicity was intended, giving that the target device is an HMD with a small screen, the aim while developing was always to simplify as much as possible, in order to make using the application in Recon Jet a pleasant and fun experience to the user. It is meant as an aid to a tourism activity, presenting only the essential information and letting the user explore its surroundings. Thus, long texts are avoided and some contents are omitted. For instance, texts and multimedia contents are only present if part of a route activity, but not in routes nor route points. Also, video contents were omitted altogether, as the screen is not appropriate for its visualisation.

The current code would work in a different Android device with minor modifications, which was also a goal of this project, using Jet only for a proof of concept. However, in a different device, further adaptations could be made, specially if Google Maps or another map API was available.

However obvious it may seem, in order to create a good user experience, an effort was made to research and comply to UX and UI design guidelines.

In the next chapter, it will be described how the evaluation of this application was conducted, through tests with a group of volunteers, and the results of this evaluation, aiming to understand how a tourism application with this structure in an HMD is received by the public.

5 Evaluation and Results

Following the implementation of the application in the Recon Jet device, the next step is to present how the project was tested and evaluated, as well as what motivated the criteria. Then, the results of the evaluation are presented and discussed. The evaluation first defines a profile of the user and it has questions targeting both the device and the application.

5.1 Use Cases

Now that the application, its design and its usability are explained, this section details the testing use cases. To test and evaluate this project, two identical sequential routes were created, one visible and the other invisible, to compare the results of both cases. The routes are in Ericeira, as it is a convenient tourism location, and have 9 route points and 4 activity points, two of those triggered by location and the other two by QR code, and one QR code route activity. Each point has at least one route activity. Figure 5.1 shows a schematics of the routes tested by the participants and Figure 5.2 shows that same route drawn in the BO. The QR code activated activity points and activity are not shown in the schematics as they do not have a determined location or order in the route and can be activated whenever the user reads the specific code.

Volunteers were asked to perform the tests and fulfil a questionnaire, with a section about the user, to draw a profile, a section about the device and another about the tour itself. No particular group of testers was targeted, the purpose was to have testers with different characteristics to evaluate how those impacted the results. The tests were also performed under different luminosity conditions to analyse whether it affected the visibility of the device and the results of the experience. The start and finish time of each test was registered, resulting in a tour duration of about 1 hour.

In the following sections, the methodology and results of these tests are presented.

5.2 Evaluation Criteria and Methods

Once the development was concluded, the usability of the application had to be tested, in order to understand if the proposed project, using an HMD in tourism, is a viable solution. To understand how

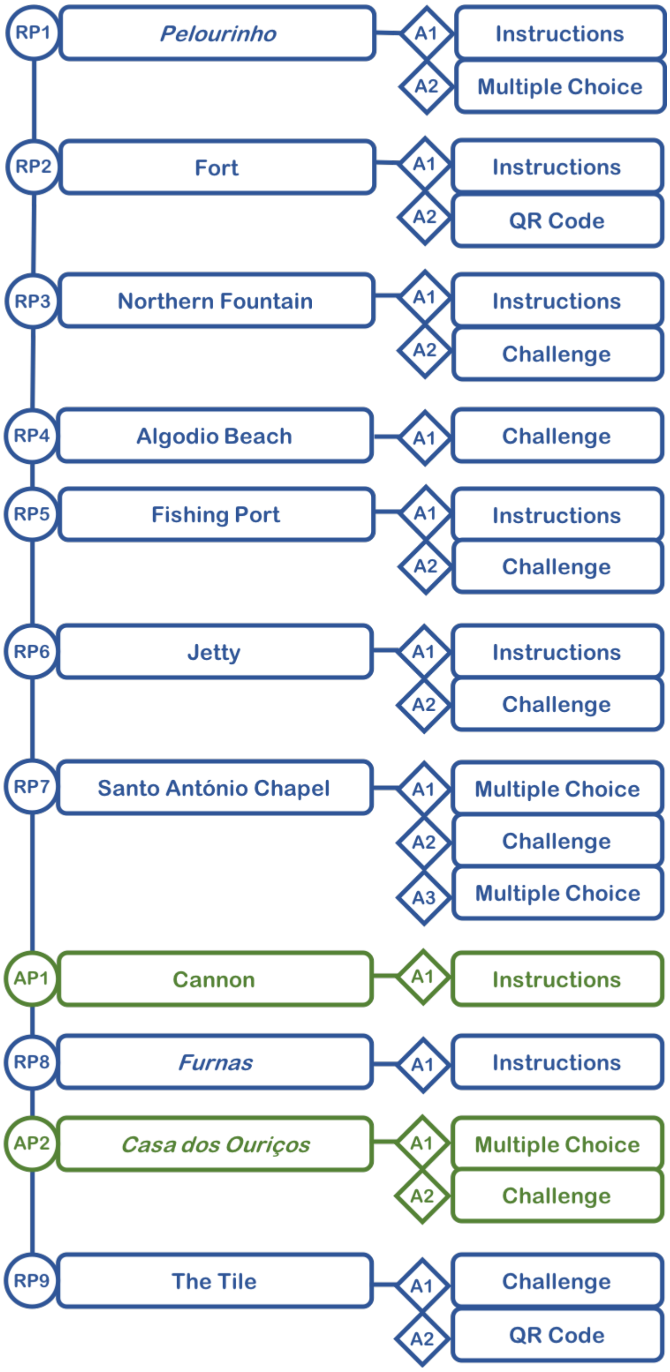


Figure 5.1: Overview of the route and activity points, as well as the route activities of each point in the order they were performed. RP indicates a route point, AP an activity point and A an activity.

to evaluate the application and the user experience, it was studied how other applications with similar outputs were evaluated. Besides recent applications, applications developed for mobile phones in its early stages are also important to consider in this context, since the difficulties encountered then for mobile phones are similar to the ones existent now for glassware devices, as mentioned in section 4.1.3. The evaluation of the experience was done by requesting the volunteers to answer a questionnaire.

The application should be tested on real users, both male and female, with a wide range of ages and technological know how[66]. In all reviewed evaluations, at least 20 participants participated in the tests[66], so that is the minimum number set for this project. Another relevant aspect is whether the

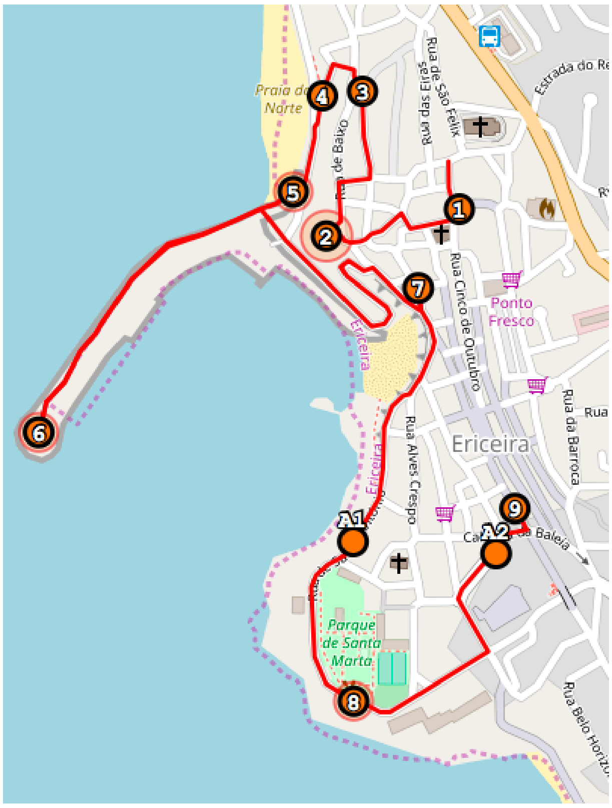


Figure 5.2: Path and order of the routes created to test the application, drawn in the BO. The numbers indicate the route points and A1 and A1 are activity points.

user had previous knowledge of the location visited during the test[66].

To establish a profile of the user, the following topics are addressed: age[15, 66, 68, 69]; gender[15, 66, 68, 69]; Visual status [15]; previous usage of electronic tour guides[66]; previous usage of HMDs (adapted from [15, 66]); previous knowledge of the location[66] For the evaluation of the device itself and its usability, questions about the user visual and general well being were considered, based on effects tested in or reported to be caused by the use of HMDs devices. For visual discomfort the following symptoms were considered: blurred vision [15, 70]; double vision [15, 70]; eye dryness [15, 70]; eye irritation [15]; eye tiredness [15, 70]; watering or runny eyes [15, 70]; and general visual discomfort [15, 70]. For other types of discomfort, the following symptoms were addressed: physical discomfort [15]; sickness [15]; headache [15, 70]; sleepiness [15]; general discomfort [15, 70]; fatigue [15, 70]; disorientation [15, 70]; vertigo [70]; faintness [70]; and confusion [70].

In order to evaluate the interface of the application and the tasks performed during the test, the following topics were addressed int the questions: user satisfaction [15, 66, 69]; simplicity [66]; comprehensibility [15, 66]; perceived usefulness [15, 66]; clarity of audio-visual outputs [15, 69]; flow of information[69]; suitability of information[69]; flow of information[69]; suitability of information[69]; wheter the user would use the system again[69]; and ease-of-use[15, 69].

The possible answers to evaluate the above mentioned tasks are "Yes" and "No", or a five point scale system [15, 69], depending on the purpose of each question. The resulting questionnaire, contemplating all of these topics, is in attachment C.

5.3 Testing Users

Here are presented and discussed the answers to Section 1 of the questionnaire in Appendix C. It is given a general overview of the test users, such as their age and attitude towards technology. These questions aim to draw a profile of the user, with characteristics oriented to this project and, for that reason, personal details about the user are not necessary.

5.3.1 User Data

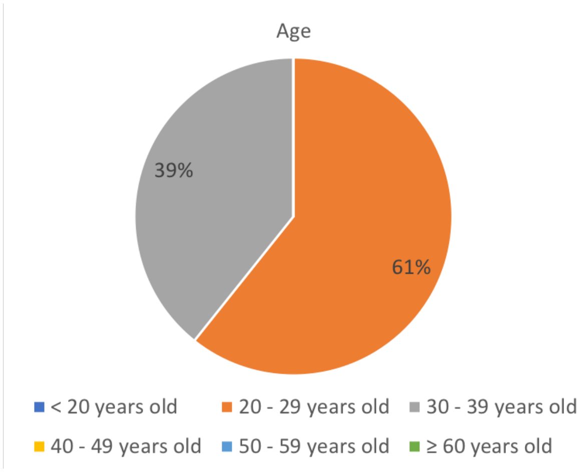
A total of 28 volunteers tested the application developed during this project and gave their feedback. Although this number is minimum number of testers of the applications presented and discussed in section 2.2.2, for a more thorough analysis and more solid conclusions, a larger set of testers would be preferable. The questions asked in the first section of the questionnaire are not directly about the project, their purpose is to create a profile of the user and a reference of the luminosity conditions at the time of the testing, in order to make a comparison with the answers of the subsequent sections. The distribution of users between visible and invisible route types was purposefully even, with 14 participants for each type, in order to test if one route type has better results than the other.

Regarding the age distribution, as seen in Figure 5.3, the majority of the users, 61%, were in the 20 - 29 years old interval, 39% were between 30 and 39 years old, and none of the participants belonged to the other age groups. Ideally, however, the users would be evenly distributed among the 6 age intervals. 13 of the participants were female and 15 were male - Figure 5.4. This was asked in order to understand whether there is a correlation between the gender and the results . The distribution of testers by gender is approximately even, which is good to understand whether this factor impacts the results.

A simple ocular evaluation of the participants was made by asking them if they wear glasses or contact lenses, and the results are displayed in Figure 5.5. Most of the participants, 68%, wore neither glasses nor contact lenses. Once more, the ideal situation would be an even distribution of the three to draw stronger conclusions on the impact of the "visual status" of the user on his feedback. It is worth mentioning that it was not possible for participants to wear Jet and other glasses at the same time, thus people with greater visual impairment could not test the application at all, as they could not see the screen without their prescription lenses. The users who wore glasses and tested the application had to remove their glasses.

Only 2 participants had previous experience with electronic tour guides, and none of them had previous experience with HMD devices, which deems these characteristic useless for comparison. The users were asked their position where technology and wearable devices are concerned, in a scale of 1 to 5, from "I don't like the concept at all" to "I am very enthusiastic about it", and the results are displayed in Figure 5.6. Again, the distribution is not even among the 5 classifications, with a tendency towards classifications 4 and 5 in both cases, .

In Figure 5.7 is a chart of the luminosity conditions at the time of the experience. This is important to evaluate the impact of the light intensity in the results. Most of the users tested the application in bright sunlight. Unlike the other criteria, where an even distribution was preferable, this situation was intended, since the device is meant to be used outdoors and early testing revealed very low visibility of the display with bright sunlight.



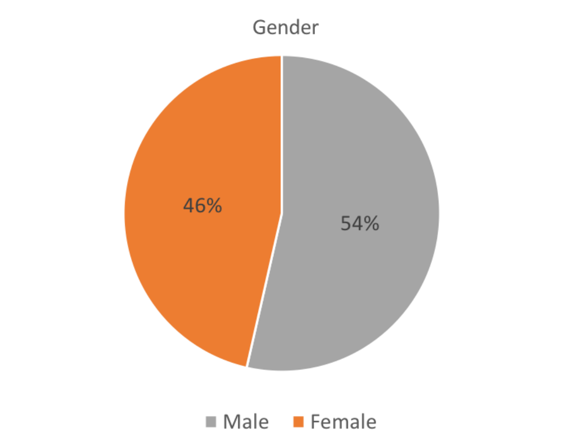


Figure 5.3: Age distribution of the participants.

Figure 5.4: Gender distribution of the participants.

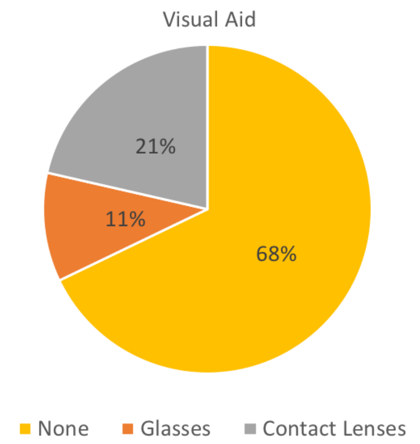
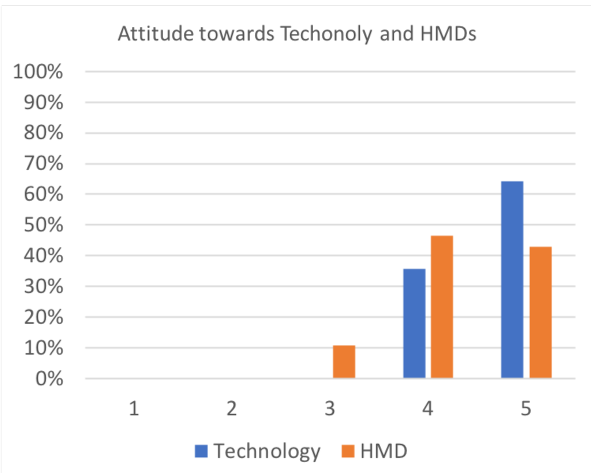


Figure 5.5: Distribution of the visual status of the participants.



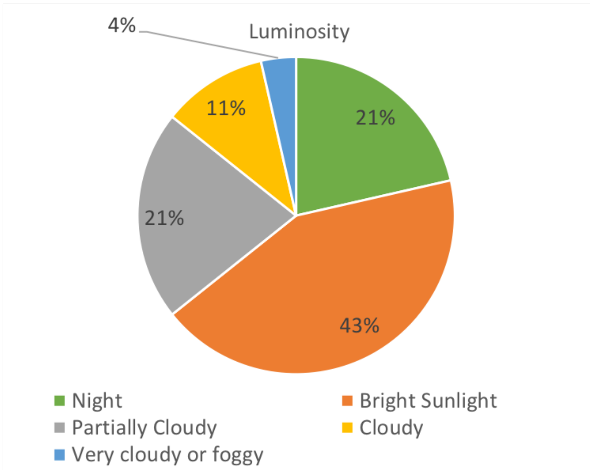


Figure 5.6: Attitude towards technology and towards HMD devices, in a scale of 1 to 5.

Figure 5.7: Luminosity conditions during the tour.

The application was tested by 28, the majority of them in the 20 to 29 age interval, with an approximately even gender distributions. Of these participants, 11% wear glasses, 21% wear contact lenses and the remaining 68% do not wear any visual aid.

Only 1 user had previous experience with electronic tour guides, and none of them had previous experience with HMDs devices. When asked about their attitude towards technology and HMDs devices in a scale of 1 to 5, 100% and 89% of the users answered 4 or 5, respectively. These skewed statistics make these factors non-viable for comparison. Nonetheless, this statistics mean that negative evaluations in the following sections, about the device or the application, are not influenced by a negative attitude towards technology.

Despite not being the case, an ideal sample of users would be evenly distributed among all these 7 evaluated criteria. By itself, this data is not significant, yet, when put together with the results presented in the two following sections, it is used to understand how the above mentioned traits impact the evaluation of the project.

Although the current luminosity conditions are not about the user, it is a parameter that may impact the results, like the rest of the parameters evaluated in the first section of the questionnaire. Most of the users, 43%, tested the application with bright sunlight, followed by 21% of the tests in partially cloudy conditions.

5.4 Device

It has been previously stated that the Jet device is not a key part of the purpose of this dissertation but rather the device chosen for the proof of concept, for the reasons explained in section 2.1. That being said, it is unavoidable that the device impacts the results. For that reason, the questionnaire targeted the device specifically, in order to try to separate the user evaluation of the concept from the reaction to this specific device. This section presents the results of that evaluation.

5.4.1 Device Evaluation

Even before starting the route, the participants were asked to put the device on and answer a few questions, first with the device off and then with the device on. The charts in Figures 5.8 and 5.9 show the answers to the questions about how much the device affects the user's field of vision and whether he finds the device distracting, with the device both off and on, and the level of comfort of the device while off, all in a scale of 1 to 5. 36% of the users found the device uncomfortable (with a level of comfort between 1 and 2), due to being too big and bothering the nose. Curiously, no users attributed a classification of 3 to comfort. Four users also pointed that the device does not fit the head very well, and another user, despite classifying the comfort as 4, noted that she felt like an alien in the street and that the device was not fashionable. The distribution of how much the device affects the user's field of vision is near even among levels 2, 3, and 4, and it is almost identical with the device turned or off, whereas the level of distraction while walking changes from being distributed mostly between levels 2 and 3 with the device off to a concentration on level 3 by 75% of the users with the device on. This indicates the device, when the display is on, does not perform very well in being unobtrusive.

Filtering the data of these four topics by gender, the most relevant differences observed were the comfort of the device and how much the field of vision is affected with the device on. Typically, male users find the device more comfortable, with an average classification of 3.60 against 2.92 for female users.

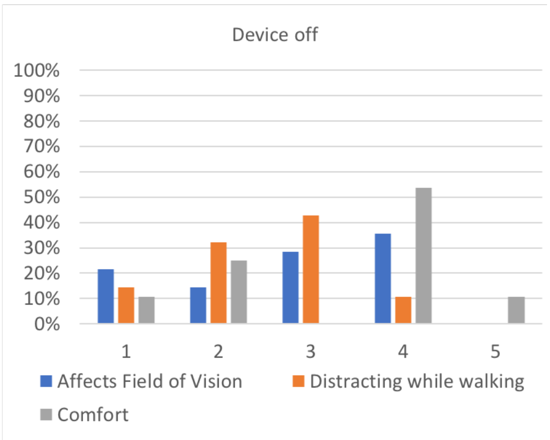


Figure 5.8: With the device off, testers' evaluation on how much it affects the field of vision, how distracting it is while walking, and how comfortable it is, in a scale of 1 to 5.

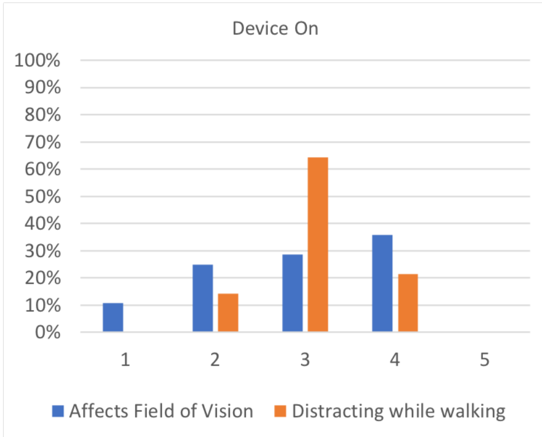


Figure 5.9: With the device on, testers' evaluation on how much it affects the field of vision, and how distracting it is while walking, in a scale of 1 to 5.

On the other hand, the field of vision of male users is more affected by Jet, specially with the device on, with an average classification of 3.27, whereas female users attributed an average classification of 2.46 for this parameter. Also, male users find the device equally distracting while walking whether it is on or off, with an average classification of 2.80, while female users find it less distracting when it is off (average classification of 2.15) than when it is on (average classification of 3.38). Notwithstanding, the distinctions found are not so pronounced that definite conclusions can be drawn from a sample of 28 participants.

Even though the amount of testers who wore glasses or contact lenses was relatively small, it was attempted to verify if a relation could be drawn between the use of some type of visual aid and the results of these first questions, in particular how much the device affects the field of vision, with Jet on and off. Other than that the device being on or off does not significantly influence how much it affects the field of vision, as seen in Figures 5.8 and 5.9, is not dependent on the visual of the users, no definite conclusions were achieved.

Still before the route, the users were asked to classify, in the same scale of 1 to 5 mentioned above, whether they can see the totality of the screen, whether its size is adequate, and if the display itself has good visibility. The results are displayed in the bar chart in Figure 5.10. Most of the participants, 75%, found the screen size adequate (classifications 4 or 5), half could see the whole screen (classifications 4 or 5), and only 46% found the display had a good visibility (classifications 4 or 5). On average, all three categories have better classifications by participants that wore some type of visual aid. For the users that wore nor glasses nor contact lenses, the average classifications are between 3.20 and 3.50, whereas for users that did, the classifications are between 4 and 5, even for the users who usually wear glasses, who were not wearing them at the time. However, as only 9 out of 28 users were in this situation, these results are not enough to draw conclusions.

Filtering the answers about the screen and display by luminosity conditions, it is clear that the greater the illumination, the worst the visibility. For this evaluation, the luminosity conditions were grouped in three categories: night or very cloudy or foggy, cloudy or partially cloudy, and bright sunlight, "Night", "Cloudy", and "Bright Sunlight", respectively, in the labels of the chart in Figure 5.11. The most noticeable distinction is on the visibility of the display, with an average evaluation of 4.57 at night or in foggy or very cloudy conditions, 3.33 when cloudy or partially cloudy, and 2.83 in bright sunlight. This distribution is displayed in the chart in Figure 5.11. The screen visibility and adequacy of the screen size follows the same pattern, being considered best, on average, when the luminosity conditions were worst.

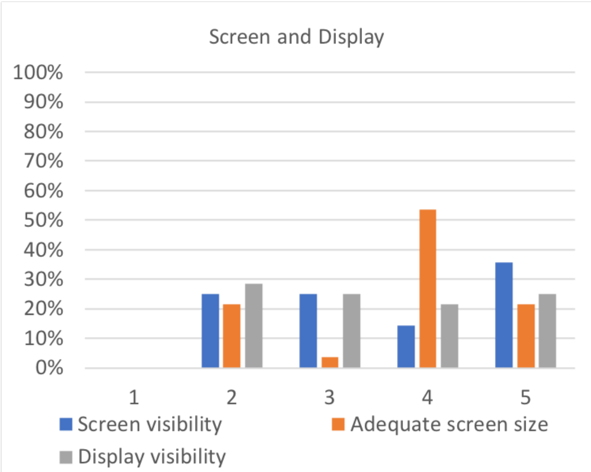


Figure 5.10: Testers' evaluation on whether the whole screen is visible, if the display size is adequate, and if it has good visibility, in a scale of 1 to 5.

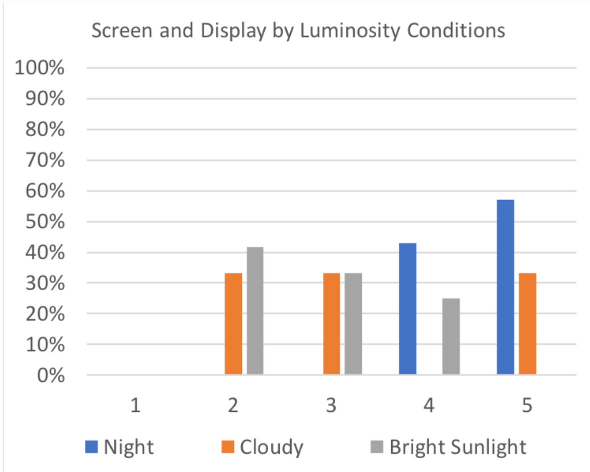


Figure 5.11: Evaluations of the display visibility of the device according to the luminosity conditions at the time. "Night" means night or very cloudy or foggy, "Cloudy" means cloudy or partially cloudy, and "Bright sunlight" just bright sunlight.

The last question before starting the tour is an estimation on how long each participant would feel comfortable wearing the device, the results are in the pie chart in Figure 5.12. The majority of the users, 32%, estimate they could only wear the device for less than 30 minutes, however, the distribution is nearly even among less than 30 minutes, from 30 minutes to 1 hour, from 1 hour to 2 hours, and from 2 hours to 3 hours. None of the users estimated more than 3 hours of use, which corroborates what was presented in section 2.1, not recommending the use of HMDs for long periods of time. This estimation varies from male and female participants, with 40% of the male users stating they could wear the device for 1 hour to 2 hours, whereas 46% of the female participants estimated less than 30 minutes. No relations could be drawn when filtering by the visual status of the users or by the luminosity conditions at the time of the experience.

After completing the route, the users were asked to answer the remaining questions, one of them concerning the device, asking whether they experienced any of a list of 9 symptoms, such as headaches, blurred vision, fatigue, disorientation, etc., with the possibility of indicating a visual or physical discomfort that is not listed. The results are displayed in Figure 5.13. 79% of the users reported at least one symptom after using the device for about 1 hour (average duration of the tour), with the most common being tired irritated or dry eyes, and discomfort due to weight or pressure of the device on the nose, ears or other part of the head ("Head discomfort" in 5.13). Crossing this data with the luminosity conditions, no correlation was found. When trying to find a relation between these results and the visual status of the user, the only conclusion is that users wearing glasses or contact lenses always experience some type of ocular discomfort (tired irritated or dry eyes, blurred vision, or watery eyes) or headache, whereas only

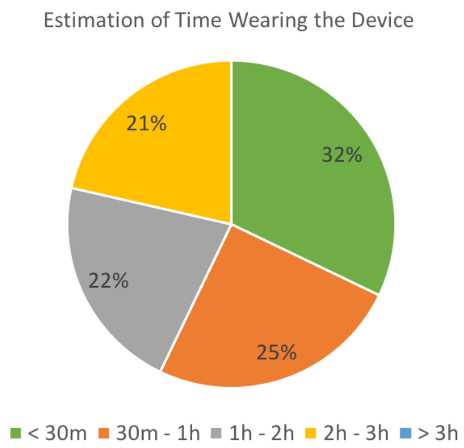


Figure 5.12: Estimation, made before the tour, on how long the testers think they could wear the device.

68% of the users who did not wear visual aid present those symptoms. Thus, the device is more likely to cause discomfort to users who wear glasses or contact lenses.

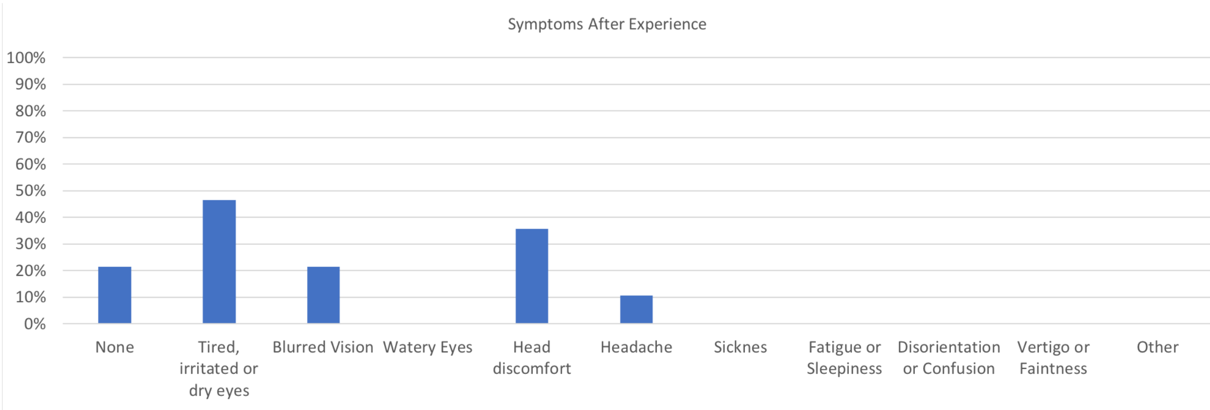


Figure 5.13: Symptoms reported by the participants after a route of about 1 hour, with "Head discomfort" meaning discomfort due to weight or pressure of the device on the nose, ears or other part of the head.

5.4.2 GPS Accuracy

As the application depends largely on the GPS of the device, to guide the user from point to point, its accuracy has a direct impact on the results. To evaluate it, the latitude and longitude were recorded while wearing the device in two types of location: between buildings and in open ground. In each type of location, the user stood in a location for 10 minutes. These measurements were taken in the the same town were the tests were performed, thus, the buildings are typically 2 or 3 stories high. To calculate the accuracy, it was first calculated the distance between each measurement and the point the user was actually at, seen in Open Street Maps. This distance was calculated using the haversine formula (expressions 5.1 and 5.2), where d is the distance between two coordinates A and B, R is the earth radius ($R = 6,371,000\ m$), φ_A and λ_A are the latitude and longitude of A in radians, respectively, φ_B and λ_B and are the latitude and longitude of B in radians.

$$a = sin^2(\frac{\varphi_B - \varphi_A}{2}) + cos\varphi_A \times cos\varphi_B \times sin^2(\frac{\lambda_B - \lambda_A}{2}) \tag{5.1}$$

$$d = 2 \times R \times atan2(\sqrt{a}, \sqrt{1-a}) \tag{5.2}$$

Following the calculation of each distance, it was then calculated the mean and standard deviation for each location type. The results are presented in Table 5.1.

Table 5.1: Accuracy of the device.

Open Ground	Between Buildings
$3.1 \pm 1.7\ m$	$6.6 \pm 1.0\ m$

5.4.3 Autonomy

To evaluate the autonomy of the device, the current level of the battery was saved every time the tourism experience started, right after choosing a route, and finished, when the user completed the route. On average, the device lost 0.9% of battery per minute in the route used for testing, which lasted around 1 hour. It was observed a loss of battery of 56%, on average. From a commercial standpoint, this autonomy would not be sufficient, as two routes with a duration similar to the one used for testing could not be performed without charging the device in between.

As a general evaluation of the device, 64% of the participants found the device comfortable (classification of 4 or 5) and, in average, male users find it more comfortable. With the device off, 43% of the users found it averagely distracting while walking (classification of 3), with an average of 2.50, with those values increasing to 54% and 3.07 with the device on. The participants found their field of vision nearly equally affected by the device either off or of (2.79 and 2.89 on average, respectively), and, again, male users found their field of vision, on average, more affected by the device, specially with the device on. No relation was found between how much the device affected the field of vision and the visual status of the user, whether on or off, perhaps due to the low percentage of participants wearing visual aids. It was expected from the studies with other HMDs devices analysed in section 2.1 that the device would be distracting while walking and affect the field of vision, and it is for that reason that the routes used for testing did not include any means of transport other than walking and were in roads and paths with little or no traffic.

The bad visibility of Jet's display, specially in bright sunlight luminosity conditions, is another limitation of the display, as the activities are not, generally speaking, restricted to any particular light conditions. The incidence of symptoms of discomfort after completing the route is of 68%, and 100% in participants who wore glasses or contact lenses. To lower these statistics, routes of shorter lengths should be evaluated. However, these symptoms are short term and do not impact the long term well being of the user.

The autonomy of the device was sufficient to complete the testing route, however, it would not be enough for two consecutive routes without recharging the device in between. The accuracy of the GPS will be further discussed in the following section, as it has a direct impact on the navigation and AR features.

5.5 Application

The questions of third and last section of the questionnaire in appendix C target the application specifically, its usability and design, to evaluate the responses of the users to the proposed concept. After completing the route, the testers were asked to fulfil the remaining of the questionnaire, about the experience during the route itself. This section displays the results of the users' feedback about the application, its design and its functionalities.

Aiming to discern whether previous knowledge of the visited route points impacted the usability of the application, specially the navigation feature, the first question of the third section was whether the visited locations were previously known by the users. Most of the participants, 79%, already knew the locations they were visiting. A more even distribution would be preferable to reach a better understanding of its impact.

The chart in Figure 5.14 presents a general overview of the results of the experience, with the user's feedback on ease of use, whether they enjoyed using the application, and whether they found the application's structure adequate. 64%, 54%, and 89% of the answers were levels 4 or 5 for ease of use, enjoyment, and adequate structure, respectively. Not discarding limitations and faults of the application, the lower evaluations are also related to lower evaluations on the visibility of the display. When considering only the answers of the 10 users who evaluated the screen and display visibility with 4 or 5, 100% of them classified the ease of use, enjoyment, and adequate structure with 4 or 5. Even with such statistics, such a small sample of users is not enough to draw solid conclusions, but it is a promising result, encouraging the implementation and testing of a similar solution in a device with a better screen and better visibility. Extending the the mentioned filter to users who classified the screen and display visibility, obtaining a total of 20 users, the 4 or 5 classifications are 70%, 70% and 100%, for ease of use, enjoyment, and adequate structure, respectively, which is still a good classification.

The assessment of font, icon and symbol size, as well as of how easy it is to understand the information presented are displayed is Figure 5.15, in the same scale of 1 to 5. Here, classifications of 4 or 5 compose 86%, 82% and 75% for information easy to understand, font size, and icons and symbols size, respectively. Performing the same filtering by screen and display visibility, it is also observed the same effect of better classifications when the lower screen and display classifications are removed. However, the differences are not so accentuated.

When asked about the difficulty of performing the tasks of receiving and sending messages, also in a scale of 1 to 5, the participants found those tasks, in general, easy to perform, as the charts in Figure 5.16 show, with an average classification of 4.46 for the ease of reading messages and of 4.29 for the ease of sending messages.

The distribution of answers to the questions of the usefulness of the tutorial and ease of interaction with the device are presented in Figure 5.17, with an average classification of 4.11 and 4.50 for the interaction with the device and the usefulness of the tutorial, respectively. Even though the ease of interacting with the device seems to target the device and not the application, it was included in this section due to the question being asked in the end of the tour, therefore this ease of interaction reflects

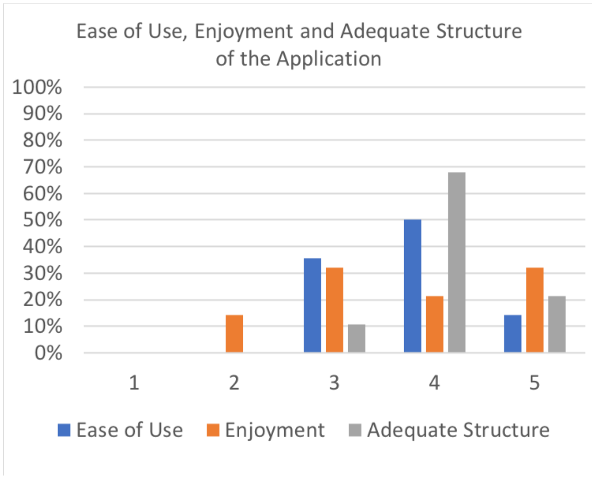


Figure 5.14: Participants classification on the ease and enjoyment of use of the application, and on the adequacy of the application's structure, in a scale of 1 to 5.

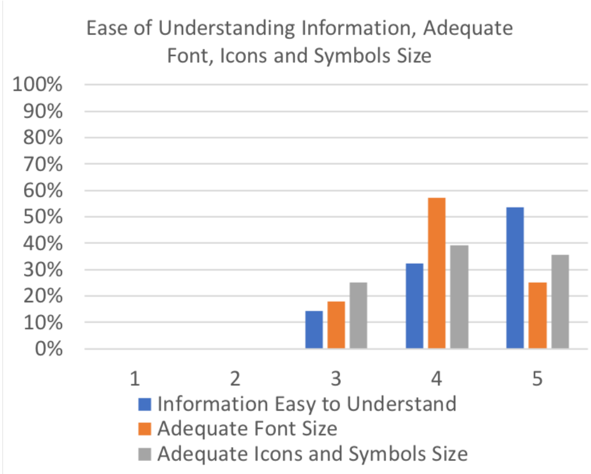


Figure 5.15: Evaluations of the information presented, the font size of the texts, and the size of icons and symbols, in a scale of 1 to 5.

not only the interaction with the buttons and touch pad of the device, but also the interactions required to perform each task of the application. It was also verified, by observing the users during the tests, that after the first few interactions, controlling the device and interacting with the application became easier. Often, in the beginning, the monitor of the activity had to help the testers with the controls.

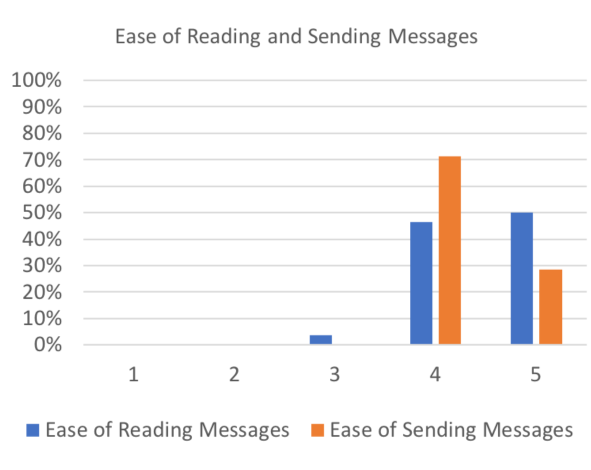


Figure 5.16: Participants classification on the ease of reading and sending messages, in a scale of 1 to 5.

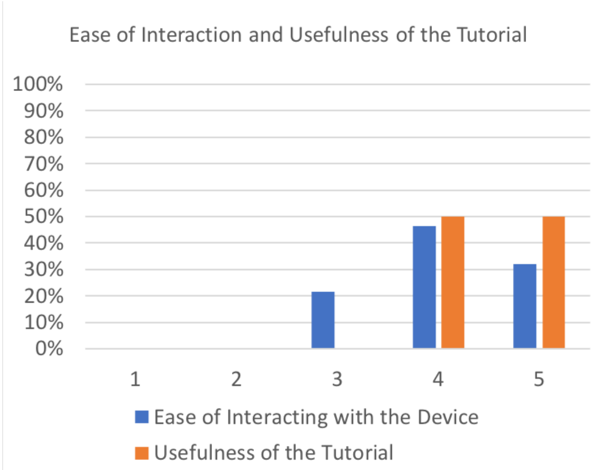


Figure 5.17: Evaluations of ease of interacting with the device and of the usefulness of the tutorial, in a scale of 1 to 5.

Figure 5.18 presents the results about whether the users would prefer a similar solution in a tablet or smartphone, whether they found the design of the application appealing, and whether they would like to repeat the experience in a different route, again, in a 5 point scale. Despite 79% of the users stating they would like to try a different route (average classification of 4.00), 61% would prefer a similar solution in a tablet or smartphone, indicating that even with difficulties in the use of the device, the concept was appealing, otherwise they would not want to repeat. Here, the evaluation of the users on the device itself should also be considered. When considering only the 10 users that classified the visibility of the screen as the display as 4 or 5, 0% would prefer a solution in a tablet or smartphone and 100% would like to experiment another route (classifications 4 or 5 on each question). Considering also the users that answered 3 on the visibility questions, those numbers change to 50% and 85%, respectively, showing, as expected, that the visibility has impacts the user perception of the experience.

The design of the application was considered average, with an average classification of 3.04 and 54% of the users attributing a classification of 3. This facet of the application could be improved with the aid of a professional UI and UX designer.

In the scale of 1 to 5, 96% of the participants considered the amount of information presented adequate, with a classification of 4 or 5 (4.25 on average), and 71% found the commands of the application well labelled (4.07 on average), as displayed in Figure 5.19. These results support that the amount of information introduced in the BO for the testing case was adequate for this type of device. When disregarding the users who classified the visibility of Jet's screen and display by 1 or 2 (8 users), the percentage of 4 or 5 classifications on the labelling of the commands increases to 95%. Thus, this aspect could be improved both with further developments targeting this issue specifically and with a device with a better visibility.

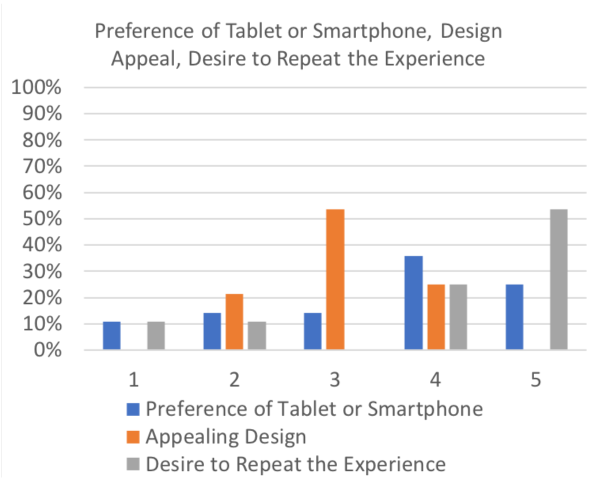


Figure 5.18: Participants classification on whether they would prefer a similar solution in a tablet or smartphone, whether they found the design of the application appealing, and whether they would like to repeat the experience in a different route, in a scale of 1 to 5.

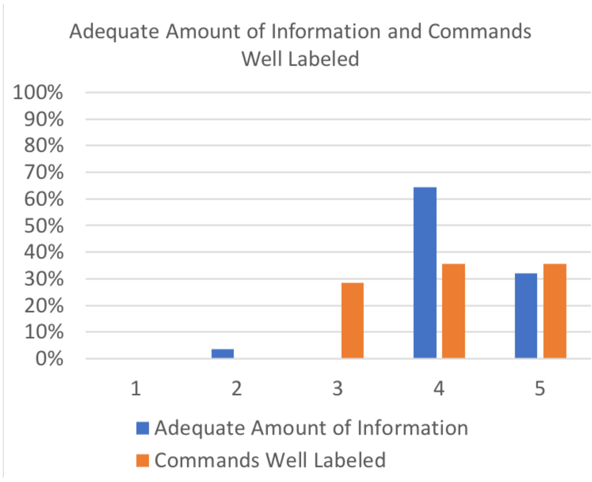


Figure 5.19: Evaluations of whether the amount of information presented was adequate and whether the commands were well labelled, in a scale of 1 to 5.

The classification results for the accuracy of route point locations, the orientation between points, and whether the sound effects helped during navigation are presented in Figure 5.20. The average evaluations are 3.86, 3.79 and 4.00, respectively. The first two points are dependent on the accuracy and quality of the GPS signal during the route, which, has mentioned in section 5.4.2, is of 6.6 ± 1.0 m in areas between buildings and 3.1 ± 1.7 m in open ground. Each point has a radius defined in the BO to prevent not being found due to GPS errors, which can be adjusted according to the location of the point. However, if that radius is too big, the system may assume it has reached the point before the user is actually at the location, if it is too small, the system may not assume it is in the point at all. The radius for the intermediate path points can also be defined in the BO, to allow the same type of adjusting according to the locations, but for the whole route and not for individual path sections. The application was always tested outdoors, and the GPS accuracy was also tested outdoors, yet the discrepancy in classifications in route point arrival and orientation are due to the different rates of accuracy verified when in a wide open space versus street areas with more buildings, and how rigorous, or nice, each user was when answering these questions.

The sound effects during navigation are also affected by the accuracy of the GPS signal, of course, as they are played when there is a change in direction, that is, when an intermediate path point (from the path defined in the BO) is reached, or upon the arrival to a point. Besides, they are also affected by the environment sounds, from cars passing, people speaking, dogs barking, etc. If these noises are too loud, the user might not hear the sound effects of the application, thus, the conditions at the time of the tour influence its usability .

Trying to discern whether previous knowledge of the route disturbs these results, they were filtered by that criteria, yet, no correlation was found. Slight differences in results exist, however, due to the small percentage of users that did not know the route and to those differences also being present in the other answers, they were not deemed relevant.

It was also evaluated the clearness of point arrival, that is, if, in the application, it is clear that the route point the user was navigating towards or the activity point that appeared by surprise was reached, independently of the accuracy of its location, and the AR effects of the application, asking the user whether the name of the point was aligned with the monument or place. The results are shown in Figure 5.21. The arrival to a point was clear to the testers, with all classifications 4 or 5 with an average of 4.68, but the AR effects were not successful, with an average classification of 2.89. As with the navigation and point location accuracy, the AR is affected by the accuracy of the GPS. Though, in this case, the influence is even greater, due to the small distances. When a user is standing at a distance of 2 m from, for instance, a fountain, with a GPS error of around 3 m in open ground, the system often shows the name of the point when the user is not oriented towards it, and it oscillates constantly, due to the location updates.

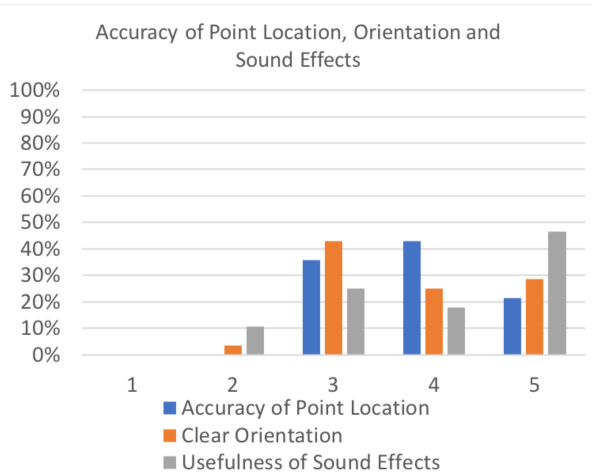


Figure 5.20: Classification, in a scale of 1 to 5, of the accuracy of point locations, orientation between points, and usefulness of sound effects during navigation.

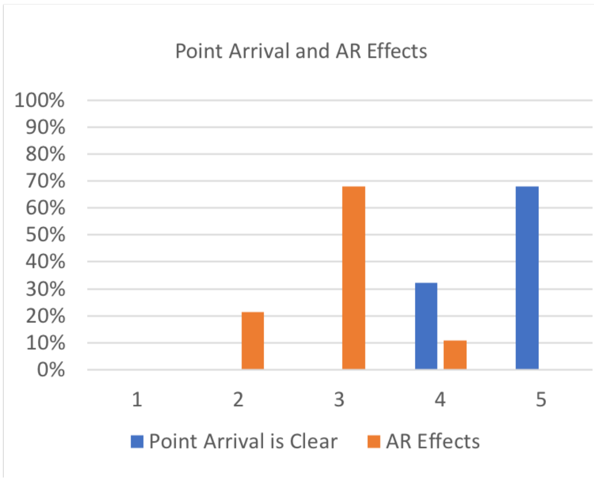


Figure 5.21: Classification of clearness of point arrival and AR effects when arriving to a point, in a scale of 1 to 5.

When filtering each of the evaluation criteria by the route type, no correlation was found. As the application is very similar for each route type, with the main difference being that the neither the preview of the route nor the name of the next route point is shown during navigation, this result was expected. Thus, distinct uses for both route types could be, for instance, a traditional tourism tour for visible routes and a treasure hunt-like tour for invisible routes.

Despite the poor feedback on the device and its inevitable negative impact on the user experience, the results of the evaluation of the application and the overall experience indicate the concept has potential. It was verified that the bad visibility of the device is a hindering factor in the users' perception of the application and of the proposed concept. The worst classification is the AR effects and the second worst is the UI design, while the best are the clearness of point arrival and the usefulness of the tutorial.

Only 54% of the users enjoyed using the application, and 61% would prefer a similar solution in a tablet or smartphone. These values respectively increase to 70% and decrease to 50% discarding the users who had difficulty seeing the display, still, with half the users preferring a solution in a tablet or smartphone, this solution is not commercially appellative.

The main challenges while performing the analysis of the results were related to the small amount of testers and their uneven distribution by the user profile defined in the first section of the questionnaire, making it impossible to filter the evaluation by the users' previous experience with electronic tour guides, for instance, as only 1 user was i this situation. Besides, the small percentage of users who wore glasses or contact lenses made the analysis of the device's effects on user's who required visual aid statistically insignificant. On the other hand, all the volunteers considered themselves enthusiast of technology, thus the results are not impaired by users' preconceptions. Not to forget, the average results of the experience itself depend not only on the limitation of the device and the functioning of the application, but also on the route used for testing and the route activities themselves, which could be richer and more creative.

6 Conclusion and Future Work

6.1 Conclusions

The project of this dissertation consisted of an application oriented for tourism and team building activities implemented in an HMD device, and Recon Jet was chosen for the proof of concept. The application oriented the user through a set of pre-defined points, with activities in each point. At almost every stage of the application, the user could take pictures or make videos. Since smart glasses are closely associated with AR, and even though this device is not the most appropriate for this use, AR was included in the solution using the camera. To evaluate the solution, volunteers were asked to test the application in a defined route and answer a questionnaire with information about the testers, such as age or previous experience with electronic tour guides, and with their feedback on the device and the experience.

The evaluation showed the device used, Recon Jet, has several limitations, both on the hardware and software fronts. Hardware limitations are, for instance, that it is too big and it bothers the head, it has a small screen that is difficult to adjust to the users field of vision, or that its display is difficult to view in bright sunlight. On the software side, the device imposed limitations on features that are otherwise simple in other Android based devices, such as access to Google Maps, without offering an alternative, and, in a tourism oriented solution, maps are important to help the user navigate from point to point.

Even with the limitations of the device, the evidence gathered in this dissertation shows that the concept of a tourism or team building experience with an HMD has commercial potential, as the testers found, on average, the experience with the application enjoyable and most would like to repeat it, showing that for the specific purpose of tourism this area is worth exploring. However, a few users, even enjoying the experience for being something new and different, commented feeling like an alien on the street while wearing the device, again reiterating the idea that smart glasses technology still has a long way to go. About taking and sharing pictures in a first-person point of view, the predominant tourism related purpose users indicated they would have for Google Glass, as mentioned in section 2.2.1, the participants did not use the constantly available camera to take pictures or make videos when not specifically required by the application. In this particular test case, this situation was expected, as most of the users knew the location and were doing it more as a test than a real tourism experience.

For the past 6 years, since the announcement of Google Glass in 2012 and the subsequent ending of the Explorer beta program three years later, there has not been an HMD that received nearly the same attention from the media and the general public. Research is still being poured into these devices and new products are being launched in the market, though none has yet captivated the public. The devices are still too bulky, too new-edgy, too "weird", and consumers are not prepared to walk around wearing smart glasses on their heads in their everyday lives [71–74]. Many of the brands that sell HMDs market-orient their products to specific business areas, namely manufacturing, logistics, or healthcare, even Google itself with the Glass Enterprise Edition launched in 2017 [75, 76]. In these areas, the downsides of the device are not so relevant, as they are meant to be used in a specific context with a specific function, where its added value surpasses the disadvantages. BMW announced in 2015 a project to enhance the driver experience using AR in MINI [77], but even with such a brand behind it, the glasses did not make it to a second version.

In the tourism sector, no significant solution emerged in the referred time interval, which supports the results of this dissertation, that the technology is not yet in a state to be used by the general public. Its limitations far surpass its possibilities, and the price of the devices is another hindering factor. To invest in, for example, 10 of these devices to try a new tourism product and then see the experience fail and that investment go to waste may not be an option for smaller businesses. Or, on the other hand, even if the experience succeeds, it may not be possible to acquire more devices by cause of the manufacturer having stopped selling, which is also a common reality in this area.

For all these motives, despite the perceived potential of conjugating tourism and smart glasses, the early stage of development that these devices are still in does not allow that potential to be explored to the fullest. The HMD technology needs many improvements before it is a viable solution for tourism. Even considering newer and more advanced devices, the differences are mostly the technological specifications, but the issues with the design and size of the devices remain.

6.2 Future Work

Despite all the limitations in the technology stated in the previous section, aiming towards further improvements of this project, the first step would be to test the prototype in different devices, in order to understand which ones receive a more positive feedback from the users.

The current version of the application should have a more robust algorithm to deal with the location fluctuations derived from the errors of the device's GPS, which would improve navigation and the AR feature, specially in areas with more buildings. Uber, faced with this same problem, has developed an algorithm to deal with the issue [78]. From the feedback of the volunteers that tested Glass4Tourism, it was suggested to give information about progress during the route (for instance, having the information of 3 out of 10 when arriving to a point). Besides, further tests with a larger group should be made, and the received feedback built upon.

Following that, the BO and the back end services could also be updated with this specific use case in mind, implementing the features of allowing real time tracking of the users and uploading multimedia content, as well as having services that receive the actions of the route activities in real time, such as answers to questions or points for completing the challenges. More than that, the BO could have functionalities that supported the use of AR on the device beyond the simple use implemented in this project. With a more appropriate device and a BO that is oriented to the product, the application should be modified to include map navigation in a map that this glassware friendly, improve the messaging feature, have a stronger gamification component, and have a more expressive AR presence, as that is one of the biggest strengths of HMDs. On the subject of maps, there is a possibility that was not explored in this dissertation, the use of Open Street Maps, which have an API for Android[1] that could work on Recon Jet or other device with the Android OS.

In the future, with the constant evolution of technology and more solutions in terms of HMDs devices appearing, more commercial applications will be though about, including in the tourism field.

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A

HMD Devices

Table A.1: HMD devices

	Google Glass [22]	Recon Jet [23]	Optinvent ORA [24]	Vuxiz M100 [25]
Wi-Fi	Yes	Yes	Yes	Yes
Mobile Data	No	No	No	No
Bluetooth	Yes	Yes	Yes	Yes
GPS	No	Yes	Yes	No
Display	25" HD Screen 640x360	16:9 WQVGA 428x240	4:3 640x480 see-through	16:9 WQVGA
Display position	Above, right	Below, right	Center or below	
Speakers	Yes	Yes	Yes	Yes
Input methods	Touch Voice	Touch	Touch	Touch Voice Movement
Camera (MP)	5	HD	5	5
Video	720p	720p	1080p	1080p
Audio	Yes	Yes	Yes	Yes
Memory	NA	1 GB DDR2	1GB DDR	1 GB
Processor	NA	1 GHz Dual-Core ARM Cortex-A9	Dual Core 1.2Ghz ARM Cortex	OMAP4460 1.2GHz
Storage (GB)	16	8 (flash)	4 flash	4 (plus microSD)
Battery autonomy	One day typical use	4 - 6 h	4 - 8 h	2 h
Operating System	Android 4.4.2		Android 4.2.2	Android 4.04
Sensors	Microphone Accelerometer Gyroscope Magnetometer Luminosity Proximity	Microphone Accelerometer Gyroscope Magnetometer Altimeter Barometer Thermometer	Microphone 9 Axis orientation	Microphone Accelerometer Gyroscope Magnetometer Luminosity Proximity
Maps	Yes	Yes		
Price ($)	1500	499	950	800 + 150 (SDK)
Weight (g)	50	60	80	

Table A.2: HMD devices

	Epson Moverio BT-200 [79]	Glass Up [80]	ChipSiP Smart Glasses [81]	Atheer Developer Kit [82]
Wi-Fi	Yes	No	Yes	Yes
Mobile Data	No	No	No	No
Bluetooth	Yes	Yes	Yes	Yes
GPS	No	No	Yes	Yes
Display	16:9 3D 960x540		1280x720 see-through	1024x768 see-through
Display position				Center
Speakers				
Input methods	Touch	Touch	Touch	Virtual Touch
Camera (MP)			5	5
Video			1080p	
Audio			No	Yes
Memory	1 GB	—	DDR3L (2 units)	
Processor	NA	1 GHz Dual-Core ARM Cortex-A9	Dual Core 1.2Ghz ARM Cortex	OMAP4460 1.2GHz
Storage (GB)	16	8 (flash)	4 flash	4 (plus microSD)
Battery autonomy	One day typical use	4 - 6 h	4 - 8 h	2 h
Operating System	Android 4.4.2		Android 4.2.2	Android 4.04
Sensors	Microphone Accelerometer Gyroscope Magnetometer Luminosity Proximity	Microphone Accelerometer Gyroscope Magnetometer Altimeter Barometer Thermometer	Microphone 9 Axis orientation	Microphone Accelerometer Gyroscope Magnetometer Luminosity Proximity
Maps				
Price ($)	700			
Weight (g)	88			850

B Tourism Applications

Table B.1: Comparison of tourism applications

Criteria	A mobile 3D-GIS hybrid recommender system for tourism & Route and Map Features [46]	Context-Aware Points of Interest Suggestion with Dynamic Weather Data Management [47]	iTravel: A recommender system in mobile peer-to-peer environment [48]
Recommender System	Yes	Yes	Yes
Recommendation Criteria	Location Distance to POIs User preferences If previously visited	Birthdate Gender Assessed personality [1] User's rating of POIs	Similarity between users Distance to POIs User's rating of POIs
Rate Recommendations	No	No	No
Context Aware	Yes	Yes	Yes
Context Responses	Location Orientation Speed	Weather Temperature Distance Time available Crowdedness Knowledge of surroundings Season Budget Daytime Companion Mood Weekday Travel goal Transport	Location
POIs Types	NA	NA	NA
Personalised Content	Yes	No	No
Content Update	Yes	No	No
Content Sharing	No	No	No
Map	Yes	Yes	No
Show POIs in Map	Yes	Yes	No
Route Finding	No	No	No
Route Planning	No	No	No
Route Tracking	No	No	No
Friend Positioning Finding	No	No	No
Messaging/Group Communication	No	No	No
Reviews/Ratings	No	No	Yes
Favourites	No	No	No
Multilingual	No	No	No
Offline Use	Limited	No	No
Ticket e-services	No	No	No
Gamification	No	No	No

Table B.2: Comparison of tourism applications

Criteria	Mobile Application for Guiding Tourist Activities: Tourist Assistant – TAIS [49]	A Mobile Tourist Guide for Trip Planning [50]	Mobile application to provide personalized sightseeing tours [51]
Recommender System	Yes	Yes	Yes
Recommendation Criteria	NA	NA	Interests Personal values Wishes Constrains Disabilities Functioning and transportation schedules User preferences
Rate Recommendations	Yes	No	Yes
Context Aware	Yes	Yes	Yes
Context Responses	Location Company (used for ratings)	Work hours Open/close area and Coordinates Visited/not visited Weather condition	Location Travel direction Speed Weather Time
POIs Types	NA	NA	Interesting places to visit Attractions Restaurants Accommodation
Personalised Content	No	Yes	Yes
Content Update	No	No	No
Content Sharing	No	No	Yes
Map	Yes	Yes	Yes
Show POIs in Map	No	Yes	Yes
Route Finding	Yes	No	Yes
Route Planning	No	Yes	Yes
Route Tracking	No	Yes	Yes
Friend Positioning Finding	No	No	No
Messaging/Group Communication	No	Yes	No
Reviews/Ratings	No	No	No
Favourites	No	Yes	No
Multilingual	No	No	No
Offline Use	No	No	No
Ticket e-services	No	No	No
Gamification	No	No	No

Table B.3: Comparison of tourism applications

Criteria	MyTourGuide.com: A Framework of a Location Based Services for Tourism Industry [52]	World Around Me Client for Windows Phone Devices [53]	World Travel Guide (Android) / Triposo (iOS)) [83]
Recommender System	Yes	No	No
Recommendation Criteria	Interest and community Rating Destination to visit Preferences Budget	—	—
Rate Recommendations	No	—	—
Context Aware	Yes	Yes	Yes
Context Responses	Location Preferences Community	Location	Location
POIs Types	NA	NA	NA
Personalised Content	Yes	No	No
Content Update	NA	Yes	Yes
Content Sharing	No	Yes	Yes
Map	No	Yes	Yes
Show POIs in Map	No	Yes	No
Route Finding	Yes	No	No
Route Planning	Yes	Yes	Yes
Route Tracking	No	No	No
Friend Positioning Finding	No	No	No
Messaging/Group Communication	No	No	No
Reviews/Ratings	No	No	No
Favourites	No	Yes	Yes
Multilingual	No	Yes	Yes
Offline Use	Yes	No	Yes
Ticket e-services	No	No	Yes
Gamification	No	No	No

Table B.4: Comparison of tourism applications

Criteria	Thomas Cook Travel-guide [84]	Guides by Lonely Planet [85]	PocketGuide Audio Travel Guide [86]
Recommender System	No	No	Yes
Recommendation Criteria	—	—	Popular places
Rate Recommendations	—	—	No
Context Aware	Yes	Yes	Yes
Context Responses	Location	Location	Location
POIs Types	Sightseeing Eat & drink Nightlife Hotels Cycling Experience Tours & shows Activities Day and multi day tours City walks	NA	NA
Personalised Content	No	Yes	No
Content Update	Yes	Yes	Yes
Content Sharing	Yes	Yes	Yes
Map	Yes	Yes	Yes
Show POIs in Map	No	Yes	Yes
Route Finding	No	No	No
Route Planning	Yes	No	No
Route Tracking	No	No	No
Friend Positioning Finding	No	No	No
Messaging/Group Communication	No	No	No
Reviews/Ratings	No	Yes	Yes
Favourites	Yes	Yes	No
Multilingual	Yes	Yes	Yes
Offline Use	Yes	Yes	Yes
Ticket e-services	Yes	No	Yes
Gamification	No	No	No

Table B.5: Comparison of tourism applications

Criteria	World Explorer [87]	tripwolf - Travel Guide & Map [88]	Paris Travel Guide [89]
Recommender System	Yes	No	Yes
Recommendation Criteria	classification	—	POI types
Rate Recommendations	Yes	—	No
Context Aware	Yes	Yes	Yes
Context Responses	Location	Location	Location
POIs Types	Cities Universities Monuments Zones Shows etc.	Sight City Beach Region Museum/gallery Shop Restaurant Theater/opera Café Tour/activity Park/zoo Hotel	Food & drink Nightlife Shopping Events & activities Historical architecture Hotels & guesthouses City & urban life Family friendly etc.
Personalised Content	No	No	No
Content Update	Yes	Yes	Yes
Content Sharing	No	No	No
Map	Yes	Yes	Yes
Show POIs in Map	Yes	Yes	Yes
Route Finding	No	Yes	No
Route Planning	No	No	No
Route Tracking	No	Yes	No
Friend Positioning Finding	No	No	No
Messaging/Group Communication	No	No	Yes
Reviews/Ratings	Yes	Yes	Yes
Favourites	Yes	Yes	Yes
Multilingual	No	Yes	No
Offline Use	No	Yes	Yes
Ticket e-services	No	Yes	Yes
Gamification	No	No	No

Table B.6: Comparison of tourism applications

Criteria	GuidiGo [58]	Boost
Recommender System	No	No
Recommendation Criteria	—	—
Rate Recommendations	—	—
Context Aware	Yes	Yes
Context Responses	Location	Location
POIs Types	—	Architecture Religious Theatres Sports Parks & Gardens Places of Interest Squares Markets Services Universities Museums Zoos & Aquariums Shopping Restaurants Leisure
Personalised Content	No	No
Content Update	Yes	Yes
Content Sharing	Yes	Yes
Map	Yes	Yes
Show POIs in Map	Yes	Yes
Route Finding	Yes	Yes
Route Planning	No	No
Route Tracking	Yes	Yes
Friend Positioning Finding	No	No
Messaging/Group Communication	No	Yes
Reviews/Ratings	Yes	No
Favourites	No	No
Multilingual	Yes	Yes
Offline Use	Yes	Yes
Ticket e-services	No	No
Gamification	Yes	Yes

Questionnaire

C

SECTION 1 – USER DATA

1.1 Age ______________

1.2 Gender
- ◯ Female
- ◯ Male

1.3 Do you wear glasses or contact lenses?
- ◯ No
- ◯ Glasses
- ◯ Contact lenses

1.4 Do you have previous experience with electronic tour guides?
- ◯ Yes
- ◯ No

1.5 Do you have previous experience with an HMD device?
- ◯ Yes
- ◯ No

1.5.1 If yes, what device? ____

1.6 In a scale of 1 to 5, where 1 stands for “I don’t like the concept at all” and 5 stands for “I am very enthusiastic about it”, how do you classify your attitude towards technology?	1	2	3	4	5
1.7 In a scale of 1 to 5, where 1 stands for “I don’t like the concept at all” and 5 stands for “I am very enthusiastic about it”, how do you classify you attitude towards HMD devices?	1	2	3	4	5

1.8 Please, choose the option that best describes the current luminosity conditions.
- ◯ Night
- ◯ Bright sunlight
- ◯ Partially cloudy
- ◯ Cloudy
- ◯ Very cloudy or foggy

SECTION 2 – DEVICE

Please, answer the following questions after trying the device but with the device turned off.

Classify the following questions from 1 to 5, with 1 meaning totally disagree and 5 meaning totally agree. Please, choose only one option.

2.1 The device affects my field of vision.	1	2	3	4	5
2.2 I find the device distracting while walking.	1	2	3	4	5
2.3 The device is very comfortable.	1	2	3	4	5

2.4 If you find the device uncomfortable, what are the reasons? You may choose more than one option.

- ☐ Too small
- ☐ Too big
- ☐ Bothers the nose
- ☐ Heavy
- ☐ Other. What? ____

Please, answer the following questions after trying the device and turning it on.

Classify the following questions from 1 to 5, with 1 meaning totally disagree and 5 meaning totally agree. Please, choose only one option.

2.5 The device affects my field of vision.	1	2	3	4	5
2.6 I find the device distracting while walking.	1	2	3	4	5
2.7 I can see totality of the display.	1	2	3	4	5
2.8 I find the size of the display adequate.	1	2	3	4	5
2.9 The display has a good visibility.	1	2	3	4	5

2.10 For how long do you think you could wear the device?

- ◯ < 30 minutes
- ◯ 30 min - 1h
- ◯ 1h - 2h
- ◯ 2h - 3h
- ◯ > 3h

Please, answer the following questions after completing the route.

2.11 Please mark if you have felt any of these symptoms during the experience. You may choose more than one option.

- ☐ Blurred or double vision
- ☐ Tired, irritated or dry eyes
- ☐ Watery eyes
- ☐ Other type of visual discomfort not listed above. Which? ______________________________________
- ☐ Sickness
- ☐ Discomfort due to weight or pressure of the device on your nose, your ears or other part of your head.
- ☐ Headache
- ☐ Fatigue or sleepiness
- ☐ Disorientation or confusion
- ☐ Vertigo or faintness
- ☐ Other type of physical discomfort not listed above. Which? ______________________________________

SECTION 3 – EXPERIENCE

Please, answer the following questions after completing the tour.

3.1 Did you already know most of the locations of the route?

- ◯ Yes
- ◯ No

Classify the following questions from 1 to 5, with 1 meaning totally disagree and 5 meaning totally agree. Please, choose only one option.

3.2 I found the application easy to use.	1	2	3	4	5
3.3 I enjoyed using the application.	1	2	3	4	5
3.4 I found the information presented easy to understand.	1	2	3	4	5
3.5 The font size of the texts was adequate.	1	2	3	4	5
3.6 The size of the icons and symbols were adequate.	1	2	3	4	5
3.7 The structure of the application was adequate.	1	2	3	4	5
3.8 I found the commands well labeled.	1	2	3	4	5
3.9 I found it easy to read messages from the monitor.	1	2	3	4	5
3.10 I found it easy to send messages to the monitor.	1	2	3	4	5
3.11 I would prefer a similar solution in a tablet or smartphone.	1	2	3	4	5
3.12 The design of the application was appealing.	1	2	3	4	5
3.13 The location of the route points was accurate.	1	2	3	4	5
3.14 The orientation between points was clear.	1	2	3	4	5
3.15 The tutorial helped in using the application.	1	2	3	4	5
3.16 I would like to repeat the experience in a different route.	1	2	3	4	5
3.17 The arrival to a point was clear.	1	2	3	4	5
3.18 In the camera when arriving to a point, the names were aligned with the monuments or places.	1	2	3	4	5
3.19 The sound effects helped during navigation.	1	2	3	4	5
3.20 It was easy to interact with the device.	1	2	3	4	5
3.21 The amount of information presented was adequate.	1	2	3	4	5