Enriching the Visit to an Historical Botanic Garden with Augmented Reality

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Abstract: The use of Augmented Reality in mobile guide applications for natural parks and gardens enables compelling and memorable experiences that enrich visits. But the creation of these experiences is still riddled with several challenges concerning technology and content production. This paper presents guidelines for the development of AR experiences in mobile applications that support visits to gardens or natural parks, providing a list of technological and multimedia content elements that should be considered. We applied these guidelines in the development of a mobile application for a Botanical Garden, implemented for Android and iOS. We conducted a study with volunteers during visits to the garden and the results revealed high levels of perceived app usability and strong agreements about app features, which allow us to accept that the app was evaluated positively.

1 INTRODUCTION

The JBT (Jardim Botânico Tropical) Garden is located in a monumental area of our city, Lisbon, next to the Mosteiro dos Jerónimos and occupies seven hectares. The garden provides a rich plant collection consisting mainly of species from tropical and subtropical regions. Besides the remarkable natural heritage and botanic vocation of this Garden, the visitors can also explore the historical buildings and statuary from the 17th to the 20th centuries, observe several bird species and a diversity of bryophytes and lichens. The JBT organizes scientific, educational, cultural and leisure activities for a varied audience, such as, tourists, families with children, students, and botanical experts. These activities are fundamental to disseminate specialized knowledge on tropical science and to highlight and preserve heritage and collective memory concerning a remarkable period in the History of our country.

Nowadays, it is important to complement the existing guided tours and explore the available technological developments to offer to visitors new interactive and engaging experiences. The use of Augmented Reality (AR) in mobile guides to enrich visits, namely adding information to the real world, has been applied in several projects and domains (Santos et al., 2020; Andrade and Dias, 2020; Siang et al., 2019; Pombo and Marques, 2019). Although AR mobile applications are now widely used, there are still several challenges related to technology and multimedia content creation. For instance, how to select the appropriate tracking method according to the characteristics of the environment and visitors' smartphones and how to decide which experiences should be created and associated to which PoIs (Point of Interest).

Our main contribution is to organize the challenges and requirements associated with the development of AR experiences in mobile applications (apps) that support visits to gardens or natural parks and to apply them in an actual app, JBT app, implemented for Android and iOS.

2 BACKGROUND AND RELATED WORK

AR makes possible the interaction with the surrounding real world, enriching it with a virtual world, where real and virtual object are combined (Feiner et al., 1993). Within this context, it is mandatory to track

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the user's viewpoint to superimpose virtual contents over real environment views (Bekele et al., 2018).

AR tracking techniques are used to determine the current pose (position and orientation) of users in the environment, enabling the alignment of virtual content with the physical objects. Tracking techniques have been categorized as sensor-based, vision-based, and hybrid (Zhou et al., 2008; Rabbi and Ullah, 2013; Kim et al., 2017; Siriwardhana et al., 2021).

Sensor-based tracking techniques use sensors that are placed in the environment or integrated in the mobile device. Different kinds of sensors can be used, such as optical, acoustic, mechanical, magnetic, inertial, or radio (RFID, Infrared, Beacons, NFC, Wi-Fi, and GPS) (Jain et al., 2013). Inertial-based tracking uses accelerometers and gyroscopes to estimate the user pose based on previously estimated or known poses. The accelerometer measures the motion to calculate the position of the user relative to some initial point. The gyroscope measures the rotation to calculate the orientation of the user relative to some initial one (Bekele et al., 2018). The compasses uses magnetic sensors for orientation, identifying which cardinal point the device is pointing to. An overview of each kind of sensor-based tracking can be found, for instance, in (Rabbi and Ullah, 2013).

Vision-based tracking techniques rely on the camera and can use image processing techniques to determine the current pose. This type of tracking is further divided into marker-based and markerless (also called as natural feature tracking). Early vision-based tracking was marker-based and used fiducial markers (artificial landmarks) added to the environment, such as QR codes. More recently, vision-based tracking proposals are based on markerless approach, which allows natural landmarks to be used for tracking, instead of artificial ones. Moreover, Simultaneous Localization and Mapping (SLAM) algorithms are used to create maps in unknown environments and, simultaneously, to localize users inside them. Virtual objects are added to the map and shown considering their position and the user location (Tan et al., 2013; Klein and Murray, 2007).

Following a different approach, image-assisted alignment (also named Instant Tracking in (Andrade and Dias, 2020)) transfers to users the responsibility for the recognition and the initial alignment. In this case, a virtual element is shown on the device screen and the user has to align it with the corresponding real object which is being captured by the camera of the device.

Hybrid tracking, also called fusion tracking, combines different tracking techniques to increase tracking robustness.

The use of AR in mobile applications for gardens has been widely evaluated considering the educative and the visitors experience perspectives (Huang et al., 2016; Pombo et al., 2017; Harrington et al., 2019; Pombo and Marques, 2019; Siang et al., 2019; Santos et al., 2020; Andrade and Dias, 2020; Bettelli et al., 2020; Harrington, 2020; Santos et al., 2020).

Bekele et al. (2018) identify areas in cultural heritage for AR mobile applications and suggest the most appropriate technology for each case, not covering the particular case of botanical gardens. Chong et al. (2021) focus on usability and accessibility challenges in using virtual reality in cultural heritage.

More aligned with our work, Santos et al. (2020) define a framework with a set of guidelines for mobile applications of natural parks. In (Postolache et al., 2021), the authors systematize a set of requirements for this type of applications, organizing them in four main categories, namely, objectives, contents (including its organization and presentation), enabling technology, and other non-functional requirements. While these proposals present a broader approach, we focus on the AR experiences comprising the technology perspective, as well as, the contents perspective.

3 AUGMENTED REALITY FOR BOTANICAL GARDENS' VISITS

Developing AR experiences for a botanical garden gathers people from different backgrounds and raises several challenges involving technological issues and content creation. After defining the objectives of AR experiences, we will present our strategy to the conception of these experiences.

3.1 Objectives

The goal of introducing AR experiences is to enrich the visit, providing both entertainment and educational contents in an immersive and interactive way. In a botanical garden, flora and fauna change throughout the seasons and the garden may have collections that evolve over time. Therefore, during a visit, the visitor has only a glance of the richness of the garden. With AR, digital information can be added to the image of the real world, thus allowing visitors to observe elements that might not be visible in the garden at the time of the visit.

3.2 Conceiving Experiences

To idealize and conceive the AR experiences it is crucial the collaboration between the experts, who know

the flora, fauna and the history of the garden, and the technological team responsible for their implementation. To motivate the experts and to raise ideas and awaken their imagination to the requirements of the AR experiences for the JBT app, our strategy was to show them examples of what can be done with the available technology. In the following, we explain the guidelines established to choose the technology and the guiding principles to create the contents.

3.2.1 Conceiving Experiences - Technology

When choosing the technology to create the AR experiences we have to consider different aspects, such as, the tracking techniques that should be suitable for the experiences, the type of contents that we want to show and the tools to develop the AR experiences. Considering the "where", "what" and "how" questions (Prabhu, 2017) may help us in this process. "Where" is the place of use of the experiences which is decisive for choosing the methods for recognition and tracking of the AR experiences. "What" is the type of content to be shown in AR experiences. "How" involves the means to implement the AR experiences, namely, the software to be used in the development.

In a botanical garden the experiences are used outdoors which answers the "where" question. Therefore, we have to deal with variations in luminosity over the day and also in the orientation of the shadows cast on objects, which may impose restrictions in the use of marker recognition. The location and orientation of the markers need to be carefully studied to minimize appearance variations throughout the day. Moreover, these markers should be natural elements in the garden, like tile panels, avoiding adding physical artifacts strange to the place.

In outdoor environments, location can be obtained by a GPS receiver, which provides tracking of user location. However, we need to be aware of the lack of signal in some places provoked by the treetops. Accuracy problems may also occur when the orientation is provided by sensors integrated in the smartphone, such as, gyroscope, accelerometer or magnetometer. Therefore using GPS and other sensors may compromise the correct alignment between virtual contents and real objects. This type of tracking may be used when the precision of the alignment between the real and the virtual objects is not critical.

A more precise alignment may involve the user, as in the image-assisted alignment, where the user is asked to perform an initial precise alignment (Andrade and Dias, 2020).

The set of tracking techniques may be even more limited. If we want to reach a diverse audience, the experiences cannot require high-end equipment. This excludes the use of tracking techniques that require large amounts of processing power, like SLAM. In addition, to limit maintenance requirements, we should avoid resorting to locally placed equipment such as RFID.

The answer to the "what" question is not straightforward when there is no predefined content associated with a PoI (detailed ahead). So, ideally, the best tool is the one that supports the wider variety of content types (text, image, video, audio and 2D/3D object) to allow greater freedom for content creation.

There are several commercial and free AR development tools (Bekele et al., 2018), consequently, the answer to "how" will depend on the budget, the target operating system (Android, iOS), the selected tracking methods and the type of contents supported.

3.2.2 Conceiving Experiences - Contents

Regarding the contents of AR experiences we have to consider: the type of media used - it may be text, image, video, audio or 2D/3D virtual models; the goal of the experience - entertainment, educative or informative; period of time to which they refer - a snapshot in time or the evolution over the year.

In any case, the development of the AR experiences needs the contribution and validation of experts, either based on their scientific knowledge or daily activities. The garden curators experience year-round variations in the appearance of plants and the behaviour of animals in the garden. Nowadays, with the widespread of mobile phones with good resolution cameras, it is easy to capture images and videos at a moment's notice that reveal the life in the garden. These snapshots may unveil to the visitors what they may not be able to observe in their visit. Besides, these live moments, more structured contents may be created, for instance, to show the evolution over the year of specific trees.

Animations with 2D/3D models may support scientific explanations of occurrences in the garden or may be used for entertainment purposes.

4 AUGMENTED REALITY AND MULTIMEDIA EXPERIENCES IN JBT

Considering the guidelines presented above, we describe in this section the technology adopted, the contents gathered and the experiences developed.

4.1 Conceived Experiences - Technology

In JBT app, as no AR experiences were previously defined, the choice of tools was made towards the ones with the best possible room for manoeuvre and would not imply a setback in the solution's development, especially in a way that would not jeopardize the completion of the project.

Hence, it would imply choosing the tool that offers more functionalities to create the experiences, tracking techniques for aligning and to use any contents' type, since we were sure that the ideas would arise as a result.

Without a budget to be spent on software tools, we decided to use licensed free or open-source augmented reality tools. EasyAR[1] was chosen for the Android operating system, having a free license, recognition and tracking of marks and images, solving the questions: "Where", being able to recognize any JBT's possible object, when you cannot use the GPS component properly; and the "What", being able to render over the possible objects, text, image, video and 3D object contents. DroidAR[2] turned out to be the second choice, complementing EasyAR. It is an open-source framework for AR on Android, which we had to modify and contribute with new code to fit our needs on the creation of the AR experiences. Resolving the issues: "Where", by allowing the tracking of the user's GPS location and rendering text, image, 3D object and playing audio contents in specific GPS coordinates; and the "What", using the inertia and orientation sensors to render the same type of content at specific points in space to the user, when it is not possible to have an adequate GPS signal, nor recognizable planes or well illuminated so that the recognition capabilities of EasyAR can be effective.

For the iOS operating system, we decided to use its native frameworks: ARKit[3] for recognition and tracking of marks and images to render over the possible objects, text, image, video and 3D object contents; ARKit, SceneKit[4] and CoreMotion[5] using the inertia and orientation sensors to render the same type of content at specific points in space to the user; finally AVKit[6] and AVFoundation[7], to play video or audio content.

There are cases where the capabilities of EasyAR and ARKit cannot be effective, with no recognizable or well-illuminated planes, and a more precise alignment is crucial in a specific PoI. So, we created an image-assisted alignment tool for Android and iOS with their native frameworks and libraries, capable of rendering atop the wanted objects the same type of content described before for each platform needs.

4.2 Conceived Experiences - Content

The development of the JBT app involved a large group of experts from distinct areas of knowledge to ensure that all the contents are correct and accurate from the scientific point of view.

The creation of AR and multimedia experiences integrated contents from different sources:

- Videos and images collected by the experts who work or have interest in the thematic areas of the garden;

- Videos provided by Centro de Ciência do Café that is an institutional partner of the garden;

- Animations and 2D/3D models produced by students;

- Scheduled image collection throughout the year of a set of iconic trees.

In their daily activities, the curators of the garden capture images and videos that show the living nature in the garden. For instance, videos showing specimens that are not easy for the visitor to watch in the garden, like woodpeckers in a tree hole and a walk of a squirrel. Moreover, the experts also purposely prepared videos for the application, like a close up of the beautiful Bauhinia's pink flower. The experts also provided photos of 36 different birds that inhabit the garden. To match the bird's images we searched for each bird's sound from the public domain to copyrighted ones and asked each author to use them in the experiences.

To go beyond what can be seen in the garden, the visit to the coffee greenhouse can be complemented with a video that describes the history and the complete process to obtain a coffee drink, since the plantation until the cup of the user. This video combines 3 videos provided by Centro de Ciência do Café and, resorting to Kdenlive[8], it includes new frames, which add the title and the provider's credits and logo.

Some of the contents of the experiences were produced by students of master degrees in Informatics Engineering and Informatics Teaching.

The method that was applied to involve students derives from previous experiences that also involved

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[1] https://www.easyar.com/

[2] https://github.com/rafaisen/droidar

[3] https://developer.apple.com/augmented-reality/arkit/

[4] https://developer.apple.com/scenekit/

[5] https://developer.apple.com/documentation/coremotion

[6] https://developer.apple.com/documentation/avkit/

[7] https://developer.apple.com/documentation/avfoundation/

[8] https://kdenlive.org/

students in the production of virtual models in digital heritage (Redweik et al., 2017; Cláudio et al., 2017).

A way of rewarding the work of students is to pose the challenge of producing contents as part of the evaluation elements of a curricular unit, so that the result of the work is recompensed with a grade. So, the themes/proposals were presented in a curricular unit in the area of modelling and animation (Animation and Virtual Environments). Additionally, a factor that has impact in the enthusiasm of the students is that the garden is part of their own University.

The students created the videos using Blender[9] to learn the three-dimensional features of the tool. Videos should have two versions, with and without a green background, so we could choose when creating the experience the best option. The Android and iOS AR Component created, and the AR tools use this green background to make it invisible when recognized and tracked. The EasyAR tool can only make it possible through the Alpha Channel technique. Thus, using the video editing software, Kdenlive, the video was converted to an Alpha Video so that EasyAR could make the video background invisible. This way, the immersion of the video in the environment was guaranteed.

Tile panels in the JBT inspired the creation of ludic videos. Animals depicted in those tiles were reproduced, animated and associated with their sound in nature to bring them to life. The vegetation is also animated simulating the movement with the blowing wind. Another video created by the students gives life to a seemingly disorganised tile panel by ordering it and solving the puzzle.

To observe the evolution of trees throughout the year a set of trees that show the most changes in colour and fall of leaves, fruit and flowers over the year was selected. Therefore, during a year, every week, a photo session was held with these trees with the same camera on a tripod, keeping the same position, direction and inclination of the camera. In each session, at least three photos were taken of each tree with three types of focus and brightness so that when creating the sequence there could be a wide variety of choices for the ideal photo.

4.3 Conceived Experiences

The JBT app includes AR and multimedia experiences, being each one available in a particular PoI in the garden where it really enriches the visit. All these places where suggested and validated by the experts. The set of AR and multimedia experiences include:

- Time-lapses composed by sequences of images that show the evolution of a tree along the year;
- Animated 2D and 3D models superimposed over tile panels;
- Virtual images of birds which, through touch, trigger the emission of the respective call or song of the specie;
- Informative and garden's natural life videos.

A set of trees whose appearance varies significantly throughout the year was selected. In these PoI a sequence of images, 1 to 5 per month, depending on the tree changes, shows the evolution of the tree over the year. The photographs of trees taken throughout the year passed through a stage of selection and edition using GIMP[10] graphical editor. This way, the experience would provide the visitor with a smooth sequence of images to feel like a timelapse (Figure 1a).

The user interface allows the visitor to know the month of the photograph and to control the sequence of images of the chosen tree. Thus, the user always has the temporal perception of the sequence. In addition, three buttons were included, one for play and pause and two for changing the direction of the sequence or manually changing the image. Finally, we created an interactive seek bar with open-source libraries. So, the visitor can interact in different ways with the sequence of images. The starting month is the one the user is visiting the garden and ending in the previous month. The result can be seen in Figure 1a. Since the appearance of trees varies over time, image recognition alignment is not recommended. In addition, sensor-based tracking can also bring inaccuracies, which is why we decided to use image-assisted alignment to ensure the user gets the best time-lapse experience pointing to the selected trees.

The tiles in the Garden were used as natural marks to trigger the playback of videos inspired by these tiles. A target image was created from the tile. This way, the video can be reproduced exactly on top of the real object. When appearing in the field of view of the device's camera, EasyAR and ARKit will recognize and reproduce the video. The result can be seen in Figure 1b.

The AR tools would hardly recognize some tiles and places in the Garden, whose illumination, shadows or appearance interfere with its recognition. The image-assisted alignment tool created was used in all these situations.

Birds may not be the first thing we notice when visiting a Botanical Garden, but within JBT it is possible to observe more than 50 bird species. To highlight the birds that can be observed in different areas
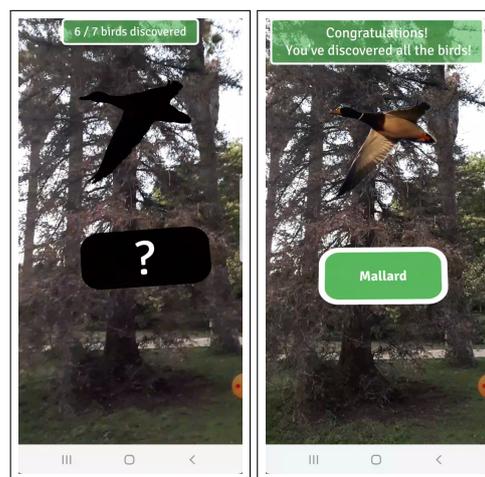
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[9]https://www.blender.org/

[10]https://www.gimp.org/
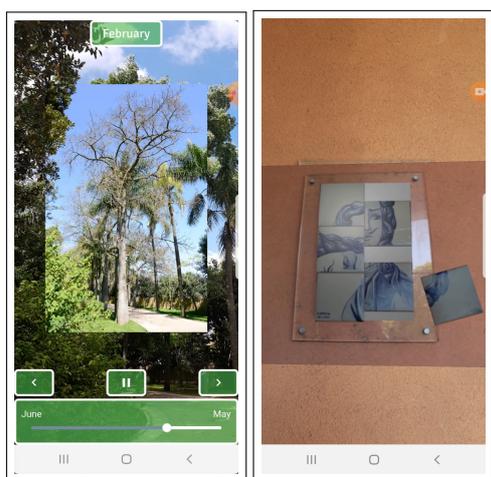
(a) Silk Floss Tree time-lapse experience.

(b) Tile panel AR experience.

Figure 1: AR experiences.

(a) Bird silhouette with question mark.

(b) Mallard image with its labelled name.

Figure 2: Birds experience.

of JBT we designed an AR experience that associates birds' images with the respective call or song. This experience may be played in different observation areas and, in each one, with the species which are more probable to find there. The user is invited to search around him/her the silhouettes of birds with a question mark in the centre of the caption (Figure 2a). By clicking on the silhouette, it turns into a coloured image, the name of the specie is displayed and the respective sound is played. An informative text box is presented on the top of the screen with the number of birds already discovered and the total number of birds to be discovered, ending with a success message to congratulate the visitor after all birds have been found (Figure 2b).

These experiences rely on the sensors of the device: magnetometer and gyroscope. The silhouette of the bird is placed where it is more likely to find a real one, for instance, at the top of a tree, on the soil or near the lake. To prepare these experiences, 36 photographs of the species more often observed were edited with GIMP to cut around each bird and remove the background. Then, they were resized to be as close to its actual size compared to all other birds' image sizes.

The audio files obtained for each specie were also prepared using Audacity[11]: the sound is cut at the maximum of 20 seconds and the background noise existing in the various recordings was muffled. Additionally, all recordings were placed with the maximum decibel peaks of -6, leaving approximately the same volume levels and decibel amplitude.

Besides AR core experiences, some of the col-

lected videos already mentioned were associated with PoI to enrich the visit. It did not make sense to align these videos with any kind of AR alignment, as they were not recorded with that purpose. The videos with longer duration, like the explanation of coffee beans processing, are presented with an interface that allows the user to have greater control over the experience: to know the duration of the content and be able to stop or choose a part of the video that they want to review, or even search for the part that interests them most to freely view.

5 JBT APPLICATION

This section describes the development of JBT app including the AR and multimedia experiences previously described and following the set of requirements associated with the development of mobile applications to support visits to Botanical Gardens (Postolache et al., 2021).

5.1 Objectives

The JBT app was developed as part of a project by the Rectory of the University of Lisbon aiming to complement the cultural and educational guided tours and provide an interactive and engaging experience between the visitors and the Botanical Garden. The app offers a guide for visitors providing information about the main PoIs and provides AR and multimedia contents to enrich the experience of the visitors.

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[11]https://www.audacityteam.org/

5.2 Methodology and Contents

The project followed a User-Centred Design (UCD) (Abras et al., 2004) and integrated a multidisciplinary team that included researchers from multiple disciplines.

The JBT app development comprised several iterations where the app was progressively refined according to the feedback of domain experts and users. The first cycles evolved the design, creation, and validation of low and medium fidelity and the last ones included the implementation, test, and validation of the application with end-users.

The application is freely available to Android and iOS in four languages (English, French, Portuguese, and Spanish) and can be downloaded without requiring mobile data consumption in certain locations in the Garden. The application collects authorized demographic data of the visitors and location data during the visit to understand the visitor use patterns and to improve the offered services.

The JBT app was developed for three main groups of users: tourists; students and experts; and families with children and offers four different thematic tours:

- "Trees you must see": includes the 20 most important and emblematic plants, among the hundreds present in the Garden. For each, it presents the species name and family, taxonomic notes, etymology, common names, common uses, geographic distribution, ecological preferences, flowering and fruiting period, and interesting morphological or reproductive characteristics of the species, mainly those that can be seen by the visitor;

- "Garden with history": shows the different historical layers of the JBT and presents information about historical buildings and statuary, dating from the 17th to the 20th century;

- "Birds": includes information about 36 bird species that can be observed in the Garden, that goes from passerines to aquatic species. For each species, it presents a description, images, species habitats, curiosities, and details on the probability of being seen and when does it occur (e.g., if it is a resident, summer or winter visitor);

- "Biosensors": presents a large number and diversity of bryophytes and lichens, and their importance as environmental bio-indicators. For each species, it shows the description, an image and a pollution sensitivity scale of each taxa. It includes 24 most common species, 14 species of mosses, 2 species of liverworts and 8 species of lichens.

The rational for the selection of these tours, the associated PoIs and respective contents, can be found in (Postolache et al., 2021). In addition to these contents, the three first tours also include AR and multimedia contents (already mentioned in Section 4).

5.3 Application Overview

This project evolved the development of a mobile application for the Botanical Garden with a list of tours tailored to the various visitor profiles and a back-end component of the system to manage the contents and data that are collected and used in the mobile application.

As such, the proposed system follows a client-server architecture. The client component comprises the various instances of the mobile application running on the Android and iOS operating systems, which communicate with the server to synchronize visitor trajectory (sequence of timestamped locations points followed by the visitor), demographic data and to retrieve data regarding tours and associated PoIs. The NGINX[12] server software dispatches requests to a web application implemented using the Lumen Framework[13]. The web application provides a REST API, enabling client applications to safely access the data stored in a PostgreSQL database with the PostGIS extension to store geographic data.

The JBT app starts with an initial screen with the available list of tours, and for each, indicates the estimated duration and the number of PoIs. Next, the user can choose a specific tour and access to their description. All the contents associated with the tour are dowloaded and the next screen displays a map, an orange dashed line indicating the recommended route and the icons of the PoIs (Figure 3a). The routes design took into account several criteria, namely, inclusion of the most important PoIs, accessibility and safety of the visitors, passing through strategic points (e.g., souvenir shop and cafeteria), and the GPS signal strength.

The PoIs are represented by coloured icons, similar to Google map markers, with a white circle and a number in the middle to indicate their order in the tour. Markers are represented without the white circle, so that the visitor can recognize the PoIs already visited. At the map screen, the visitors can tap on the menu in the upper right corner, which gives access to the list of PoIs or can select a marker to directly enter the PoI description screen (Figure 3b). To represent PoIs with AR and multimedia experiences, the respective marker appears with a green icon drawn at

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[12]https://nginx.org/
[13]https://lumen.laravel.com/
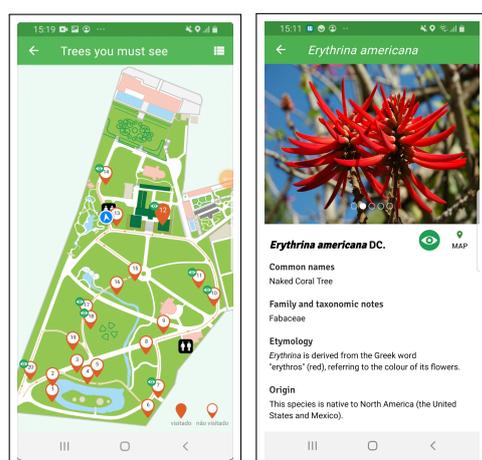
(a) Map of a tour.   (b) PoI with AR.

Figure 3: Information about tours and PoIs.

the top of the marker or in the list of PoIs and description (Figure 3b). The colour palette used for all application contents, including AR and UI contents (e.g. PoI markers, icon tours) was chosen in order to be accessible for people with colour blindness. The "Garden with history" map screen also has filters to select only the PoIs associated with a specific historical period. In "Birds" and "Biosensors" tours the PoI icon represents an area of observation, where is a high probability of encounter several birds, bryophytes and lichens species.

5.4 Maps and Positioning Systems

The map view of JBT app is used to represent, for each tour the PoIs, the recommended route and the current user's location. To obtain a map that includes all important pedestrian paths, buildings, lakes and other remarkable geographic features with their correct positions, we analyzed several interactive map SDKs, such as Google Maps and Open Street Maps (OSM). We realized that either some paths of interest were not represented, or they were wrongly represented in shape or position, and it would be necessary to correct and add many regions and paths. Since this could be a time consuming and paid process (e.g., Google Maps) it was decided to implement our own map of the Garden based on three main sources.

The first source considered was a map in the form of a shapefile containing accurate data for all the paths, buildings, lakes and other built objects that could serve as references for the visitor. This map has many features, like trees, elevation and buildings outside the garden which are not relevant to the representation of the Garden. The information was transformed from shapefile to SVG using the open soft-

ware QGIS[14] and all the irrelevant details of the map were removed using GIMP.

Additionally, as some regions and paths suffered changes during the rehabilitation of the Garden in 2019, we considered another SVG version of the Garden map. Based on this information, we incorporated the missing features elements, such as paths in the oriental garden, and other paths that lead to the green houses. In the end, all this information was validated in loco. Finally, the resulting version was colored using the color palette from the official map available at the entrance of the Garden and exported to PNG format. This format was used instead of the SVG to support zooming, panning, and overlaying of objects operations.

The map served also as georeferenced base for the positioning of the visitor relative to the path and to the PoIs in the garden. The visitor position and orientation are represented on the map by a blue circle with white outline and an arrow in the middle of the circle, respectively (Figure 3a). The position is calculate using the GPS receiver and the orientation is obtained using a sensor fusion algorithm that combines data from accelerometer, magnetometer and gyroscope to solve problems of inaccuracy from the magnetic field sensor and gyro drift [15].

5.5 Integration of AR and Multimedia

The AR and multimedia experiences are associated with PoI of the tours "Trees you must see", "Garden with history" and "Birds".

To start any experience it is necessary to click on an existing green button, already mentioned, on the corresponding PoI interface, thus making the connection between the JBT app and the AR Component. A PoI can be associated with 1 or 2 experiences, each one with a specific button (Figures 3b and 4a). So that the user could distinguish which of the experiences he/she wanted to start, small cropped images relating to those experiences were added to the upper left corner of the buttons for these experiences.

After selecting the experience, there are instruction dialogues to guide the user (Figure 4b). When tracking is performed with image-assisted alignment, the image of the real-world object is displayed with a button below showing the text "Lined up" (Figure 5a). The user is invited to align the image with the real-world object and then click on the button to start the experience.

For tracking with natural markers, a dialogue window is shown while the target image is not detected.

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[14]https://www.qgis.org/

[15]http://plaw.info/articles/sensorfusion

(a) PoI with 2 AR experiences.

(b) An instruction dialogue.

Figure 4: AR integration.

In this case, the target image is displayed at the centre of a transparent PNG image, delimited by 4 corners marked in white and with an informative text box at the centre of the screen (Figure 5b). This way the user is always aware that the camera has not yet capture the correct alignment and is still needed to point the camera to the target image. When the target image is recognized, the dialogue window disappears.

(a) Image-assisted alignment.

(b) Image recognition alignment.

Figure 5: Dialogues for alignment techniques.

6 PRELIMINARY EVALUATION

The evaluation of the JBT app was concerned with usability, given its intended general user base. To increase the validity of the evaluation, we asked volunteers if they would like to visit the garden and try the app there. In this way, the evaluation was carried out in a realistic environment and the positioning on the map and AR features were exercised.

6.1 Participants, Tasks, and Procedure

A total of 39 participants volunteered for the study, 20 female and 19 male, the median age was 23 years, ranging from 11 to 50 years. The most common age band was 20–30 years, corresponding to 82% of the participants. About 74% had an Android mobile phone and 33% had experience with digital guides. A convenience sampling was used to select the participants, who were recruited from social contacts and no monetary award was offered, but the admittance to the garden was free.

During an evaluation trial, participants carried out tasks covering most features of the JBT app, namely: selecting a tour; interacting with the map and its PoIs; using the list of PoIs; reading information about a PoI; following a tour; applying filters to the PoIs shown on the map; and interacting with at least one AR experience of each type.

A trial started when a participant arrived at the garden, after which a brief presentation about the JBT app was given by a researcher. The participant was informed about the rights to privacy and to leave at anytime and then filled out an entrance questionnaire about gender, age, model of his/her mobile phone, and experience with digital guides. A *training* phase came next, during which the participant was asked to install the JBT app on the mobile phone and explore it freely, putting questions if needed. The *testing* phase comprised the tasks mentioned in the previous paragraph and lasted between 40 and 90 minutes, with a mean time of 66 minutes. At the end of a trial, the participant was given a link to an online system usability scale (SUS) questionnaire (Brooke, 2013).
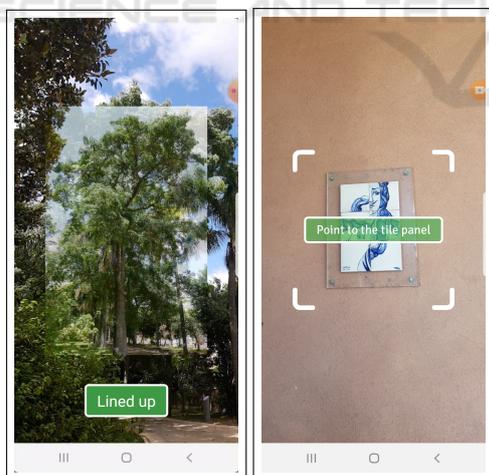
At the end of the SUS questionnaire, we added a block of statements about several features of the JBT app, that participants evaluated using a five-point Likert scale. The statements were: 1) it was easy to choose a tour; 2) the current position and orientation symbol on the map helped me do the tour; 3) it was clear on the map the PoIs about which I consulted information; 4) it was easy to find the list with the names and images of the PoIs of the tour; 5) the list with the PoIs of the tour was useful; 6) the organiza-

tion and presentation of information about each PoI was adequate; 7) it was easy to see on the map which PoI have augmented reality experiences; 8) I understood the instructions for performing the augmented reality experiences; 9) in the "Garden with history" tour, I found the functionality to filter the PoI pertinent; and 10) in the "Birds" tour, in the augmented reality experience, I understood the instructions to look for the birds. Besides the Likert scale, each statement had an optional comments field.

6.2 Results and Discussion

Results from the SUS questionnaire revealed high levels of perceived usability for the JBT app. The median score was 90.0, which is well above the average SUS score of about 70 reported in the literature (Brooke, 2013). The boxplots in Figure 6a show a larger variability of scores around the median for the female participants and also that the lowest scores were given by male participants. Even so, the median scores were essentially the same for both genders.
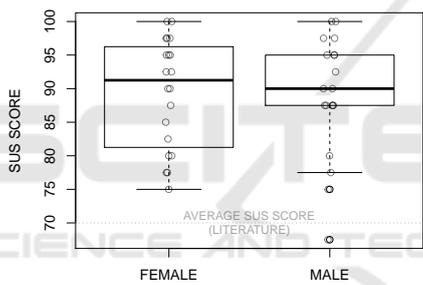
(a) SUS scores by gender.
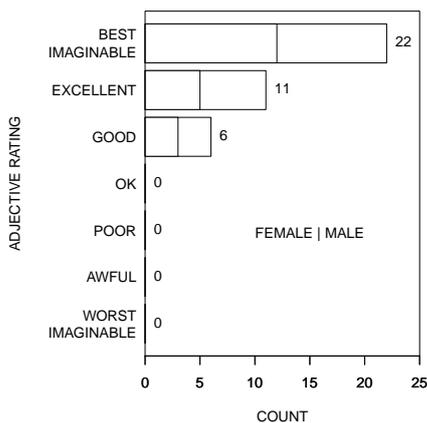
(b) Ranking of SUS scores.

Figure 6: Results of SUS questionnaire.

Another way of interpreting the SUS scores is to convert them using a qualitative rating scale (Bangor et al., 2009), as shown in Figure 6b. The majority

of scores, were for the "best imaginable" and "excellent" usability levels, with 56% and 28%, respectively. However, in 16% of the cases, the usability was "good", which prompted us to make an analysis of the responses for the individual SUS questions. We found that the most important causes for the more modest scores were as follows: lower intention to use the app frequently; higher need of a technical person to be able to use the app; and a less favourable opinion about the integration of the app functions. The two latter causes could be related to reported difficulties in locating some PoI, perhaps due to the GPS inaccuracy, and in finding app functions, namely the filters in the "Garden with history" tour.

Regarding the evaluation of the JBT app features via the ten statements mentioned at the end of the previous section, Figure 7 shows a strong agreement with all those statements. Since we always expressed the statements in positive terms, reflecting our desire that the app is successful, we can accept that the features were mainly approved by the participants. To understand why there were disagreements, we analysed the comments and highlight the following: about statement 2, three participants argued that the map itself should rotate, not the symbol representing the user; concerning statement 3, there was one opinion that a distinction should be made between signaling that information pages of PoIs were accessed (which can be done at home) and indicating that PoIs were actually visited in the garden; on statement 4, three participants did not notice or could not find the list of PoIs; and, finally, about statement 7, the meaning of the AR experiences symbol (an eye) was not clear for two participants. We note that less than 8% of the users point out some less positive detail that will help us to improve future versions of the app.
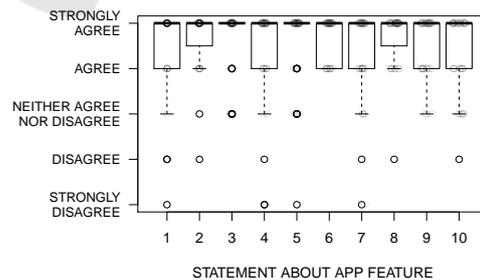

Figure 7: Results of the app features evaluation.

The comments provided by users in the optional field text reinforce the positive overall opinion revealed by the quantitative questions. Some positive observations are quite general, but others are more objective, for instance, appreciating the dynamism of the experiences, namely the evolution over the year of

specific trees. The added value of this app compared with a traditional guide in paper was also pointed out. Moreover, some adults that visited the garden with their children, observed that these were highly enthusiastic about the AR experience to find the birds, experiencing it over and over again.

7 CONCLUSIONS

This paper proposes contributions for the creation of AR experiences in mobile applications for Botanical Gardens. Conceiving AR experiences for these natural spaces present specific challenges, namely the selection of appropriate tracking methods for the experiences, the type of multimedia content to be shown and appropriate development tools. We have applied these guidelines to the development of the JBT app, which is already available to visitors. To evaluate the JBT app, we conducted a user study in loco with several participants and the results pointed to an excellent usability and easy to use. Additionally, the participants expressed an overall enthusiasm and positive opinions about the AR experiences and the app content. The feedback received will help improve future versions of the app.

Besides JBT app is available for over a year, due to the pandemic and the difficulty to obtained consent for data collection, we still do not have a significant number of visitors. However, with the data already collected, we are carrying out the analysis of data trajectories, in order to understand the moving patterns of visitors. We intend to analyse how much time visitors spend in specific locations, the most visited PoIs or tours, the distribution of visitors, among others. This information will help the JBT managers to improve the offered services, namely designing personalized tours based on the profile of the visitor or new tours to raise the engagement in guided visits.

Finally, we intend to use the JBT app in a learning context, aiming to validate the educational value of the experiences and content, for example, with high school biology students.

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