UNIVERSIDADE DE LISBOA
FACULDADE DE CIÊNCIAS
DEPARTAMENTO DE INFORMÁTICA

Augmented reality in the field of visual arts

Rodrigo Ramalho Martins

Mestrado em Engenharia Informática

Trabalho de Projeto orientado por:
Maria Beatriz Duarte Pereira do Carmo
Hugo Alexandre Teixeira Duarte Ferreira

2024

Agradecimentos

Este projeto só foi possível ser realizado graças à ajuda da Professora Maria Beatriz Duarte Pereira do Carmo, cuja orientação e apoio foram fundamentais para a realização deste trabalho, devido à sua disponibilidade, paciência e dedicação. Agradeço igualmente ao Professor Hugo Alexandre Teixeira Duarte Ferreira, cuja ideia inicial permitiu a criação deste projeto. Um agradecimento à artista Ana Fonseca, cuja disponibilidade e colaboração enriqueceram este projeto através da criatividade e apoio que foram indispensáveis para a realização desta pesquisa.

Quero agradecer aos meus Pais, que sempre estiveram lá para mim, tanto fisicamente como emocionalmente. Especificamente à minha mãe pelo apoio emocional e por me persuadir a vir para a FCUL, e ao meu Pai por me ajudar sempre que foi preciso. Um enorme obrigado ao resto da minha família, à minha irmã que me atura desde que nasci, aos meus irmãos que amo tanto, aos meus avós que nunca param de se preocupar comigo e ao meu primo Loureço que é quase como um irmão.

Quando entre na faculdade em 2018 era uma pessoa bem diferente, muito mais ingénua, tímida e insegura, mas depois de 6 anos escrevi esta tese, que oficialmente simboliza a passagem para a minha vida adulta, sou uma pessoa bem diferente e segura de si própria graças a todas as pessoas que falo de seguida.

Primeiro quero agradecer à Praxe por me dar mais do que pedi após sair do secundário: crescimento não só profissionalmente, mas como pessoa, laços de amizade profunda, uma nova Família, memórias que vou levar para a vida, e um ”significado para a vida”, pelo menos nos anos que estive presente em Talhão.

Regras, não foste a minha primeira amizade quando entrei na faculdade, mas sem qualquer dúvida foste das mais importantes para mim, não consigo expressar isso com palavras, mas sei que vais ser das poucas pessoas que vou levar para o resto da minha vida.

Zágora, foste das minhas melhores amigas logo desde o início, a tua boa disposição com tudo e o quão estavas a marimbar para o que o resto das pessoas pensava quando fazíamos coisas estúpidas, inspirava-me a ser mais eu próprio. Vou levar no meu coração todos os nossos momentos em Talhão, tanto em Caloiros a encher 200 flexões de seguida, como em Pastranos a fazer material e tomar o pequeno-almoço no McDonald’s depois das 7h30, como em Doutores a fazer planos às 2 da manhã e a fazer coisas *cringe* por Discord

para os nossos Caloiros. Sei que a vida leva cada pessoa para o seu caminho, acabando por levar-nos para sítios diferentes, mas quando penso em momentos felizes no meu percurso académico estás quase sempre lá.

Snoopy, foste o meu primeiro amigo da Praxe e coincidentemente vieste a ser meu Irmão, quando precisava de alguém com cabeça fria e pés firmes em terra ia ter contigo, ah e obrigado pelos projetos que me ajudaste.

Eterno, tive das experiências mais esquisitas contigo em Caloiro como aquela vez depois do Rally FCUL no comboio, mesmo depois destes anos todos continuas um mistério.

Pérola, eras tu que estavas no Talhão às 7h30 em Caloiros, não me deixavas sozinho nisso, e com o passar do tempo tornaste numa das minhas amizades mais próximas da faculdade.

Madrinha, quando vocês Doutores de Praxe pediram para escolher Padrinhos, eu sabia sem qualquer dúvida que era a ti que queria como Madrinha, não sabia bem por quê, mas identificava-me contigo. Mostraste-te muito fofa e inteligente, inspiraste-me muito a ser melhor pessoa e aluno.

Padrinho, pedi-te simplesmente porque o Regras virou-se para mim e para o Snoopy e disse "vamos ser uma Família", mas foi a melhor escolha que podia ter feito, olhava para o quão te esforçavas para a Praxe, vais até ao limite do que é fisicamente possível para ti, se isso significa ajudar outra pessoa, colocaste sobre mim um standard muito alto que eu até hoje tento meter em prática. Obrigado por todos os momentos, conselhos e consultas de psicologia gratuitas.

Vizy, Confeti, Tubas e Rosato, sempre fui agradecido confiarem em mim para ser vosso Padrinho, tento não mostrar, mas esforço-me para ser melhor e dar um melhor exemplo para vocês.

Norte e Mecânico, vocês são das poucas pessoas pelas quais ainda vou à faculdade e tenho boas conversas, não são meus Afilhados, mas tenho muito prazer de ser vosso Tio.

Quero agradecer ao resto da minha Família de Praxe que me deram um porto seguro para quando estava mais em baixo.

Quero agradecer especialmente aos meus Doutores de Praxe e à restante Comissão de Praxe que me proporcionaram uma estadia na faculdade muito melhor do que simplesmente vir ter aulas, fazer projetos, voltar para casa e ir a uma festa ou outra por ano, vocês fizeram com que ficasse com os meus Coleguinhas até muito depois das aulas, a criar memórias.

Quero agradecer ao meu grupo de amigos fora da Praxe, ao Falcão, Canhoto, Mafalda, Natércia, Chico e especialmente à Maria porque provavelmente não passaria a algumas cadeiras do mestrado à primeira sem ti, já que me passavas sempre as informações todas do que era para fazer.

Por último, mas não menos importante, queria agradecer a alguém que sempre esteve lá por mim muito antes de o conhecer, nos meus momentos mais sombrios e nas minhas vitórias mais importantes, que me guiou sempre na vida, que não me deu tudo o que queria, mas tudo o que precisava e que me proporcionou estes últimos 6 anos da minha vida que vão servir de base para o resto da minha vida, obrigado Deus.

Para os meus pais

Resumo

A Realidade Aumentada (RA) integra conteúdo digital interativamente com o ambiente físico em tempo real. A popularização dos dispositivos móveis globalmente pode ser atribuída ao aumento da capacidade de processamento e à melhoria dos sensores, tornando-os essenciais para comunicação, acesso à informação e diversas atividades diárias. Além disso, a integração de sensores como GPS, conexão sem fio, bússola, giroscópio, acelerómetro e câmaras de alta definição permitiu o desenvolvimento de aplicações mais avançadas, incluindo tecnologias de RA.

No âmbito do Património Cultural, a RA é aplicada de diversas formas para ampliar a compreensão, preservação e interação com artefactos históricos. Essas ferramentas melhoram a experiência do usuário, proporcionando uma vivência mais imersiva, interativa e educativa, tornando-a mais memorável. Este projeto foi realizado em colaboração com a artista Ana Fonseca. O uso da RA nas artes plásticas é uma área ainda em desenvolvimento, estabelecendo bases para futuras pesquisas e inovações nesse campo específico.

Devido à saturação do mercado com a abundância de opções disponíveis para os consumidores, empresas, locais turísticos e museus buscam inovação através da tecnologia. O uso crescente da RA nessas experiências culturais visa melhorar a entrega de informações aos turistas, tornando-as mais envolventes e explicativas, podendo impulsionar produtos e serviços premium. No turismo, a RA é valorizada por museus, promovendo uma experiência virtual intensificada para os visitantes, gerando disposição para pagar mais e estimulando o interesse em repetir experiências presenciais após interações virtuais cativantes. Na arte, a RA mantém a originalidade criativa, oferecendo experiências que combinam a realidade aumentada com a verdadeira essência dos conteúdos, criando interações genuínas e profundas, melhorando a compreensão e a exploração de obras de arte de forma educativa e personalizada.

Um dos principais desafios na RA é o rastreamento, essencial para alinhar elementos virtuais com precisão no mundo real. Existem duas abordagens principais: rastreamento baseado em sensores, que utiliza tecnologias como ótica, magnetismo, acústica e inércia; e rastreamento baseado em visão, que emprega técnicas de visão computacional, incluindo métodos com e sem marcadores. A integração destes métodos, através de abordagens híbridas, reflete a evolução dinâmica do rastreamento de RA, permitindo experiências mais imersivas e contínuas.

A RA na Web é uma opção emergente e multiplataforma em relação à RA móvel. No entanto, enfrenta desafios devido às limitações nas capacidades de rede e computação. Aplicações de RA baseadas em hardware são dispendiosas, enquanto as baseadas em software dependem do sistema operativo. As atuais implementações de RA na Web, incluindo abordagens baseadas em navegador e JavaScript, buscam um desempenho comparável ao nativo, mas enfrentam obstáculos de padronização e eficiência computacional. Os obstáculos para a adoção generalizada incluem capacidades de computação limitadas, atrasos de rede, restrições de bateria e falta de padronização. A terceirização da computação para a nuvem é uma solução potencial, mas introduz atrasos de comunicação e custos de implementação. Embora avanços em redes como o 5G possam melhorar a viabilidade da RA na Web, os custos elevados e as capacidades limitadas das redes atuais fazem da RA baseada em software uma escolha mais prática neste contexto.

Diversas ferramentas de RA oferecem componentes para reconhecimento, rastreamento e renderização de conteúdo. Foram analisados SDKs de RA como Vuforia, Wikitude, ARCore e ARKit. Optou-se pelo Unity3D como a base do projeto, devido às suas capacidades multiplataforma e ao amplo suporte da comunidade. Após a análise, Vuforia foi selecionado para integração com Unity por permitir rastreamento com e sem marcadores, oferecer suporte a várias plataformas e ser mais acessível do que as outras opções, reduzindo assim os custos do projeto. Utilizou-se o Blender para a modulação 3D e para a redução de polígonos, garantindo compatibilidade com dispositivos móveis.

Nas técnicas de rastreamento do projeto, utilizou-se o rastreamento sem marcadores do Vuforia, destacando o Ground Plane e Mid-Air Anchors. A tecnologia Fusion do Vuforia, incluindo VISLAM, forneceu um rastreamento adaptável, demonstrando bom desempenho em ambientes com alguns recursos visuais distintos. Além disso, implementou-se o rastreamento baseado em marcadores para garantir uma experiência imersiva e uniforme em todos os dispositivos móveis. Para dispositivos mais antigos, foi implementado o instant tracking, uma técnica que sobrepõe uma imagem semi-transparente sobre a imagem captada pela câmara do dispositivo. O utilizador alinha o conteúdo das duas imagens e toca no ecrã para iniciar a experiência. Esta técnica foi escolhida por integrar os dados de orientação recebidos do giroscópio, assegurando uma experiência suave e tornando a experiência acessível a todos, independentemente das especificações dos dispositivos. Na interação com ambientes virtuais, nomeadamente os objetos virtuais, foi utilizado o motor de física do Unity3D.

O tema central deste projeto foi a justiça, demonstrando aos utilizadores a complexidade de alcançar uma justiça absoluta. Foram exploradas experiências de realidade aumentada divididas em navegação virtual e experiências estacionárias, com o objetivo de imersão dos utilizadores no tema da justiça através de interações inovadoras. Desenvolveu-se uma experiência de navegação virtual, iniciada por um marcador, onde os utilizadores movimentam-se livremente, participando em atividades como a busca pela escala da justiça, simbolizando a procura pelo equilíbrio, e a participação em uma manifestação virtual, onde escolhem o seu senso de justiça e um objeto virtual "para levar para casa". Além disso, foram desenvolvidas duas experiências estacionárias, onde os utilizadores alinhavam os dispositivos a objetos fixos no mundo real para ativar conteúdos virtuais: "Monument Showcase"permite manipular a visão de um artista desenhado por Ana Fonseca, enquanto "Justice Guess"desafia a associar vídeos a conceitos de justiça, promovendo uma reflexão sobre suas diversas interpretações. Esses grupos de experiências foram adaptados para diferentes capacidades de dispositivos, garantindo acessibilidade e desempenho. Cada experiência aborda um aspecto único da justiça, desde sua representação simbólica até ações que convidam à reflexão sobre seus princípios. A interface do utilizador foi cuidadosamente projetada para apoiar a interatividade, com instruções claras e elementos visuais que guiam os utilizadores. Isso inclui diálogos e sinais visuais para facilitar a compreensão e a interação nas atividades propostas. Este conjunto de experiências de RA utiliza o rastreamento sem marcadores (Mid-air anchors e Ground Planes), rastreamento com marca para determinar a orientação dos objetos, e vídeos em ecrã verde para criar interações simples.

Foram realizados testes com utilizadores para avaliar a usabilidade da aplicação e compreender como os desafios foram interpretados nas experiências de RA e na navegação e interação com o mundo virtual. Os participantes completaram tarefas e forneceram feedback através de um questionário que abrangia detalhes demográficos, perguntas sobre aspectos específicos da aplicação e as questões do System Usability Scale. As sessões de teste ocorreram em locais diversos, com voluntários de diferentes origens. Os resultados indicaram um desempenho positivo nas tarefas, com os participantes refletindo sobre experiências relacionadas com a justiça. A pontuação SUS teve uma média de 68,75, sugerindo uma usabilidade satisfatória. No entanto, foram identificados desafios, como a necessidade de melhorar a usabilidade dos objetos, clarear a compreensão dos utilizadores e resolver problemas para uma experiência mais coesa e intuitiva. As respostas às perguntas abertas revelaram percepções para melhorias futuras, enfatizando a necessidade de uma narrativa mais eficaz, melhor orientação de interface e resolução de questões técnicas. De modo geral, os resultados foram promissores, destacando a facilidade de utilização da aplicação, mas apontando áreas para aperfeiçoamento.

Palavras-chave: Realidade aumentada, Virtualidade aumentada, rastreamento, Património Cultural, Artes plásticas

Abstract

The project delves into Augmented Reality (AR) applications, specifically targeting cultural and educational experiences by innovatively integrating virtual elements with real-world environments. Leveraging AR's potential, the initiative aims to enhance user engagement with historical artifacts and art through immersive and interactive sessions. The theme of the app is justice, showing users that achieving true justice is hard. This project was a co-production with an artist, Ana Fonseca, that wants users to be challenged by this idea and come to terms with reality. This venture uses tracking technologies, including both marker-based and markerless approaches, to ensure seamless integration of digital content into the physical realm.

Key development tools, such as Unity3D and Vuforia, were selected based on their robust multi-platform support and comprehensive tracking capabilities. Unity3D's versatility and Vuforia's proficiency in both marker-based and markerless tracking stand out, facilitating the creation of mobile-compatible 3D models and enriching AR experiences. The project focused on developing AR experiences in two main areas: virtual navigation and stationary interactions. Virtual navigation allows users to engage freely in activities designed to invoke reflection on justice, such as searching for a symbolic scale of justice or participating in a virtual demonstration. Stationary experiences, on the other hand, enable users to align their devices with real-world objects to trigger virtual content.

User testing played a critical role in evaluating the application's usability and the effectiveness of the AR challenges. Despite achieving satisfactory usability scores, the feedback highlighted areas for improvement, particularly in enhancing the user interface and narrative to foster a more intuitive and cohesive experience. This feedback underscores the project's potential to significantly improve cultural and educational engagement through AR, indicating a promising direction for future enhancements and optimization efforts.

Keywords: Augmented Reality, Augmented Virtuality, Tracking, Cultural Heritage, Visual Arts

Contents

List of Figures **xx**

List of Tables **xxiii**

1 Introduction **1**

1.1 Motivation 1

1.2 Objectives 2

1.3 Contributions 3

1.4 Document's Structure 3

2 Concepts and Related Work **5**

2.1 Augmented Reality 5

2.1.1 Augmented Reality Devices 6

2.1.2 Tracking in AR systems 7

2.1.3 Web Augmented Reality 12

2.2 Related work 15

2.2.1 Art Related Apps 15

2.2.2 Cultural Heritage-related Apps 17

2.3 Conclusion 20

3 AR Tools **23**

3.1 Unity3D 23

3.2 Vuforia 24

3.3 Wikitude 24

3.4 ARCore 25

3.5 ARKit 25

3.6 Tools Comparison 26

3.7 Choice of Tools 26

4 Design **29**

4.1 Implementing AR tracking techniques 29

4.1.1 Previous Work 29

4.1.2 Tracking techniques for the project 32
4.2 Interacting with the Virtual Environment 38
4.2.1 Markerless experience 38
4.2.2 Instant tracking experiences 39
4.3 Chapter Summary 39
4.3.1 Technical Decisions and Implementation: 39

5 Implementation **43**
5.1 Development of the AR experience 43
5.1.1 Virtual navigation experience 43
5.1.2 Stationary experiences 50
5.2 User Interface of ARJustiça App 53
5.2.1 Color Selection 53
5.2.2 Initial Menu 54
5.2.3 Main Menu 54
5.2.4 Information delivery 55
5.2.5 Stationary Experiences' Interface 56
5.2.6 Virtual Navigation Experience Interface 56
5.3 Conclusion 57

6 Testing and Evaluation **59**
6.1 Questionnaires 59
6.2 Testing Sessions 60
6.3 Participants 60
6.4 Test results 61
6.4.1 Task Accomplishments and SUS test results 61
6.4.2 Open-ended Questions 64
6.5 Conclusion 64

7 Conclusion **67**
7.1 Acquired skills 67
7.2 Challenges found 68
7.3 Future work 69

Bibliography **80**

Index **81**
.1 Apendix A: Questionnaire 82

List of Figures

2.1 Virtual continuum diagram. Adapted from [54] 5
2.2 Illustration of the Six Degrees of Freedom on Standard Axes. Source: [62] . 7
2.3 Classification of AR Tracking. Source: [66] 8
2.4 Example of marker-based tracking, Source: [60] 9
2.5 Example of markerless-based tracking, Source: [74] 10
2.6 Testing an application that uses a hybrid approach. Source: [80] 11
2.7 Instant tracking example of displaying a virtual Nintendo Switch, overlapping a real one 11
2.8 Two experimental cases of the use of MWAR5 for sales promotions by China Mobile and Fendi. Source: [64] 15
2.9 Daily art app. Source: [56] 16
2.10 Painting enhanced by the Reblink exhibition App. Source: [77] 17
2.11 Artwork at the Hyde Park from the Deep Listener App. Source: [71] 17
2.12 Example of AR experience: historical reconstitution of templar ceremony in the chapel. Source: [6] 18
2.13 3D Model superimposed in the Garden signage. Source [31] 18
2.14 Mockup of what a similar app will look like. Source: project proposal from byAr 19
2.15 Augmented Reality Component of the App. Source [16] 19
2.16 Mandrill overlapping its bones from the Bones and Skin App. Source: [59] . 20
2.17 Examples of bird images after the user touches their silhouette, Source: [79] 21

4.1 Map menu overview 30
4.2 Third experience overview in Unity 30
4.3 Second experience overview 31
4.4 Third experience overview in Unity 32
4.5 Ground plane feature example 32
4.6 Vuforia Fusion Technology Stack: Adaptive AR Tracking Method Selection. Source: [42] 33
4.7 Low feature enviroment example without any anchor, making recognition challenging 34
4.8 Mid-air anchor example. Source: [38] 35

4.9 Ground Plane and Mid Air Anchor default placeholders 36
4.10 Application logo made by the artist 37
4.11 The left-handed and right-handed coordinate systems. Source: [34] 38
4.12 Gaming images illustrating an interaction involving the movement of objects. Source: [83, 20, 27] 40
4.13 Frying pan, initially positioned on the ground and then lifted 41

5.1 Initial view and the scale of justice on top of the sphinx. 45
5.2 Protest experience 46
5.3 Objects from the exhibition experience 46
5.4 Exhibition experience 47
5.5 Exchange interface and selected objects on top of the pedestal 48
5.6 Tags related to the chosen objects 48
5.7 Choosing the objects and the resulting text 49
5.8 Ending of the virtual navigation experience 50
5.9 Start of the stationary experiences, using a pillar 51
5.10 Stationary experience: watching the monument from outside 52
5.11 Stationary experience: guess the virtues 53
5.12 Cover of both apps 54
5.13 Initial menu 55
5.14 Experience menus from both apps 55
5.15 The five separators 57

6.1 Testing session in the Escola Rainha Dona Leonor 61
6.2 Age range of participants 62
6.3 Frequency of the virtues guessed 63

List of Tables

2.1 Summary of Sensors based Tracking. Adapted from: [66] 9

3.1 Comparison of the AR SDKs. Source: [76] 27

6.1 The percentage of completion of the scale of justice and protesting experiences (question 11 and 12) 62
6.2 Frequency of the responses from the question 13 63
6.3 Frequency of the responses from the question 21 63
6.4 Average value assigned by users in the SUS. 64

Glossary

6 DOF Six Degrees of Freedom.

API Application Programming Interface.

AR Augmented Reality.

ARCore Google's Augmented Reality Technology.

ARKit Apple's Augmented Reality Technology.

CTAs Calls to Action.

CV Computer Vision.

D2D Device-to-Device.

HMD Head Mounted Display.

IPS In-Plane Switching.

MEC Multi-access Edge Computing.

MR Mixed Reality.

MWAR Mobile Web Augmented Reality.

RT3D Real-Time 3D.

SDK Software Development Kit.

SLAM Simultaneous Localization and Mapping.

SUS System Usability Scale.

UI User Interface.

UI/UX User Interface/User Experience.

UWP Universal Windows Platform.

VIO Visual-Inertial Odometry.

VISLAM Visual-Inertial Simultaneous Localization and Mapping.

VR Virtual Reality.

Chapter 1

Introduction

As cultural and tourist markets worldwide grapple with increased saturation and competition, the challenge of distinguishing unique attractions has intensified. Consequently, the number of tourist organizations exploring the implementation of technologies in their experiences has risen [58]. With augmented reality, information can be delivered more appealing and explanatory, improving tourists' experience and potentially upselling more premium products and services [19].

Tourism is vital in numerous countries, consisting of a large part of exports of goods and services, such as Portugal [57]. AR in tourism is perceived as having substantial value by external and internal stakeholders in museums, stating that it adds value to the visitor learning experience and creates managerial, strategic and operational value [78]. Moreover, when perceiving the environment from an art piece, using AR increases the visitor's sense of virtual presence, leading to a willingness to pay more for the experience [32], as well as returning to the actual destination [47].

In the scope of the Project in Informatic Engineering of the Department of Informatics of Faculdade de Ciências da Universidade de Lisboa DI-FCUL, the project of Augmented reality in the field of visual arts is oriented by professor Dr. Maria Beatriz Duarte Pereira do Carmo, co-oriented by professor Dr. Hugo Alexandre Teixeira Duarte Ferreira, with the involvement of the visual artist Ana Fonseca. The main goal of this project was to create an app that provides users with AR experiences related to the artists' artwork. The initial plan was to implement the AR experiences at Marquês de Pombal Palace in Oeiras. However, we relocated the project to an indoor location. The app was mainly tested at Rainha D. Leonor High School. This project builds upon the work of Bárbara Teixeira [76], serving as the foundation for its development.

1.1 Motivation

Considering the challenges highlighted in the introduction about the crowded cultural and tourist markets, it's clear that museums and art spaces have a great opportunity with augmented reality (AR) to stand out. They need to attract a tech-savvy audience while keeping their art and history true to its roots. With most people now familiar with smartphones, there is a big chance to change how we see and learn about art and history. Using AR can make visits more interactive and fun, help people learn in new ways, and allow for creative ways to show art and historical facts [4].

Due to the widespread usage of smartphones by the general population, we are already seeing the acceptance of augmented reality (AR) in more traditional settings. This situation presents a tremendous opportunity to transform the entertainment industry and several commercial sectors, including tourism and cultural heritage [47].

AR in art maintains creative originality by allowing creators to produce experiences that are richer and more authentic to their intended notions. As a result, it is possible to take a more exciting and participatory approach, which improves the viewer's experience. Additionally, AR piques people's interest and curiosity, encouraging them to examine museums and artworks in greater depth. This strategy also has an educational component, offering a tailored learning experience that enables people to explore at their own pace and better comprehend the displayed works of art [78].

1.2 Objectives

The aim was to develop a mobile app using AR technologies, that helps users understand and think about justice, similar to what is done in some museums and exhibitions. The theme of the app is justice, showing users that achieving true justice is hard. The artist wants users to be challenged by this idea and come to terms with reality, encouraging a deeper interaction with the concept of justice as they recognize the difference between what is ideal and what is real.

This project's primary objective was to create interactive art experiences with augmented to be used in a high school and in indoor spaces, including:

- Exploring the potential of augmented reality in enhancing the visitor experience in museums and art spaces;
- Investigating the technical challenges and solutions in implementing AR experiences in cultural settings;
- Creating AR experiences and content related to artists' artworks;
- Creating a narrative in collaboration with the artist, where the users will understand her creative take on the subject;
- Testing the app and the experiences with users;
- Evaluating the impact of AR on visitors' comprehension, engagement, and appreciation of art;

- Contributing to the field of cultural heritage by integrating technology with traditional art appreciation methods.

1.3 Contributions

This project created an application for mobile devices with an “Android” operating system to develop the understanding of justice of its users using augmented reality.

The AR element of the app allows for the observation of the virtual monument created by the artist, so the user can be immersed in the art piece without the cost of having to build it in real life. It allows for observation, and users can interact with the surrounding environment to get a richer and engaging experience. Decisions were made concerning the following challenges when building the app:

- Selection of the most appropriate AR tracking to be used in a free or closed space, arbitrarily;
- Insertion of videos in an AR environment, using green screen;
- Implementation of a solution to interact with objects in the virtual environment using a physics engine;
- Selection of AR tools and techniques for superimposing an image with a physical object in order to achieve image-assisted alignment (often referred to as instant tracking);
- Selection of AR tools for navigation within a closed environment in AR;
- Explanation to the user on how to use the technologies created by this project.

1.4 Document’s Structure

This document is structured as follows:

- Chapter 1 – The work’s context and the advantages of using these technologies in conjunction with tourism related contexts, the motivations that gave rise to the project, the objectives that were aimed and the contributions that this research gave to this field;
- Chapter 2 – Applications connected to this research that served as inspiration are provided, along with many crucial theoretical concepts that are fundamental to comprehending this thesis;
- Chapter 3 - AR software development tools, presenting the libraries utilized in creating AR applications;

- Chapter 4 – Application development decisions and challenges involved in creating the application to be used in the artwork;
- Chapter 5 - Experiential Development exploring the creation of stationary and virtual navigation experiences within the app, addressing UI/UX design, technical challenges, and user interaction.
- Chapter 6 – Tests made by users, along with the conclusions drawn;
- Chapter 7 – Conclusion and Future Work, optimal direction for this project to pursue in the future.

Chapter 2

Concepts and Related Work

This chapter looks closely at several related works that have inspired and provided the basis for our project. We also explore fundamental concepts, issues, and techniques relevant to our research area. These insights help create a more comprehensive understanding of our subject.

2.1 Augmented Reality

Augmented reality is a revolutionary technology that was created around 60 years ago [72]. By expanding our view of real-world objects and spaces with virtual information [54], which seamlessly integrates virtual and real, AR can be a powerful tool to enhance the user's experience. It is currently being used in many industries, particularly tourism [32]. With its impact felt in recent years, one of the most searched terms on Google in 2016 was "Pokémon Go", introducing AR to the masses.

To fully understand the concept of Augmented reality, it is mandatory to understand the concept of mixed reality (MR). MR can be many things, depending on the context, so we will focus on the most popular definition, the virtual continuum. It is the full spectrum of all environmental possibilities between the physical and virtual worlds. Anything between the two ends is called Mixed Reality.

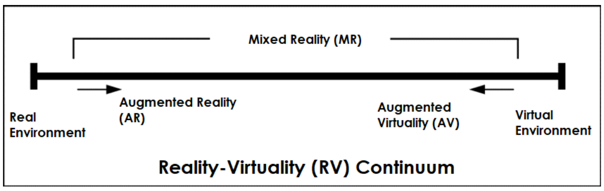

Figure 2.1: Virtual continuum diagram. Adapted from [54]

When taking into account the visual senses (figure 2.1), the spectrum can be divided into four categories:

- **Real environment**: consisting entirely of physical objects, it represents the left side of the virtual continuum.

- **Augmented Reality**: the real world is augmented with digital objects.
- **Augmented virtuality**: the virtual world is augmented with physical objects.
- **Virtual environment**: consisting entirely of digital objects, it represents the right side of the virtual continuum.

This definition is the most used for Mixed Reality, with 8735 [54] and 4760 citations [55] on Google Scholar as of December of 2023. However, the definition was presented at the beginning of the 90s. Since then, this technology field has evolved substantially, and other definitions of Mixed Reality have sprouted. One of the flaws of this definition is that it only encompasses visual displays, not including other displays such as auditory or smell ones, meaning that multi-user or multi-environment experiences cannot be covered by the continuum [70]. R. Azuma [10] describes AR as "[A technology that] allows the user to see the real world, with virtual objects superimposed upon or composited with the real world."

2.1.1 Augmented Reality Devices

Head Mounted Devices

Head-mounted displays (HMDs) are devices worn on the head and placed close to the sensory receptors in charge of how we perceive sight, hearing, and smell. HMDs are especially well-suited for mixed reality and augmented reality applications because this proximity makes it straightforward to enhance or modify the user's sensations.

HMDs are primarily made for solitary, private use, making sure that the data they transmit is kept secret and hidden from others. The sensory experiences of individuals near the user are unaffected or uninfluenced by HMDs because of this feature.

These devices stand out for their wearability, hands-free functionality, and ability to fit into various mobile situations[50]. They make it possible to implement augmented reality experiences in two different methods [67]:

Optical see-through This approach allows the user to see the real world nearly intact through the lenses, merging it with the computer-generated images, creating the illusion that these objects are integrated into the scene. Some examples of these devices are Google Glass, Microsoft's Hololens, Magic Leap One, Meta Quest Pro and, more recently, Apple Vision Pro.

Video see-through This approach is more evasive because a screen blocks the real-world view, so it effectively merges the two scenes. Some examples of these devices are Meta Quest 2, Valve Index and Sony PlayStation VR2.

2.1.2 Tracking in AR systems

To develop an AR application, the overlap between real and virtual objects is the most challenging part; this technique is called tracking, which can be achieved by identifying the real-world objects, their position and rotation; ideally, this should be done with six degrees of freedom (6DOF): three coordinates for the location (x,y,z) and three coordinates for the rotation (yaw, pitch, roll), as can be seen in the figure 2.2.

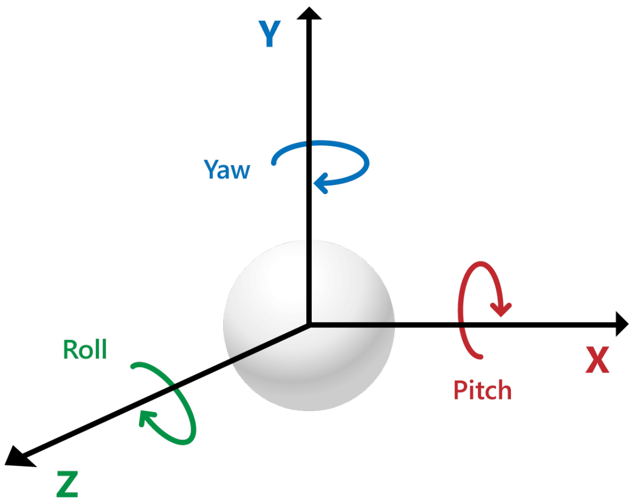

Figure 2.2: Illustration of the Six Degrees of Freedom on Standard Axes. Source: [62]

This technology is repeatedly used to localize the user's or several real objects' positions and orientations. To do so seamlessly is the most challenging part [48] because the slightest movement from the user or the camera can influence the alignment of the real object with the virtual one.

Ideally, we could have an AR application where tracking methods work perfectly without any problem. It is hard to deal with the registration problem (the proper alignment of virtual with real) indoors, and it is even more complex in outdoor environments [11]. Tracking outdoors without previous preparation is complicated because of the system's limited resources due to mobility constraints. Additionally, unprepared environments introduce factors like lighting conditions, weather, and temperature that must be considered. Moreover, the need for environmental control further limits the selection of tracking technologies. [9, 11].

Tracking techniques can be divided into vision-based, sensor-based and hybrid tracking [88, 66, 82], as can be seen in the figure 2.3

Sensor Based Approach

The Sensor-based approach is based on active sensors used in sensor-based tracking, which are then used to track the position of camera movement. Each sensor has its advantages and disadvantages. The sensor selection is based on different factors such as accuracy,

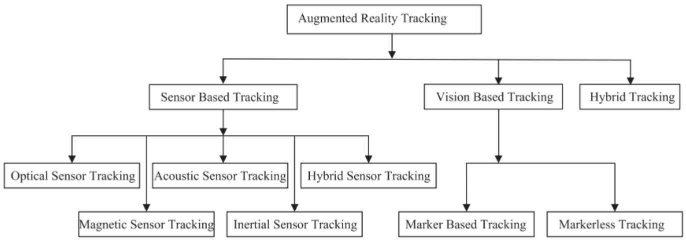

Figure 2.3: Classification of AR Tracking. Source: [66]

calibration, cost, environmental temperature and pressure, range and resolution, as seen in table 2.1. The sensors have different levels of accuracy indicated by their degrees of freedom (DOF), and the coordinates must be mapped appropriately to the virtual coordinates[61]. The sensor-based approaches are divided into optical, magnetic, acoustic, and inertial tracking [88].

Optical Tracking The video camera is used for optical tracking, which may be visible light or infrared type. With the help of one camera, 2D tracking is possible. For 3D tracking with 6DOF, at least two cameras are needed. Optical tracking is inexpensive and provides more accurate and robust tracking, but it is slow due to the heavy computation [48].

Magnetic Tracking In a magnetic tracking system, numerous variations of magnetic fields are used. The position and orientation of receivers are measured relative to the source. The magnetic field is usually affected by surrounding electronic devices [48]. The results in accuracy vary with distance and sensitivity to electromagnetic noise. The entire process is relatively inexpensive.

Acoustic Tracking In acoustic tracking, ultrasound transmitters and acoustic sensors are used. The ultrasound emitters and sensors worn by the user are fixed in the surroundings. The position and orientation of the user are calculated based on the time taken for sound to reach the sensors. The speed of sound varies with the temperature and humidity of the environment, affecting the efficiency of the tracking system[66]. As sound travels relatively slowly, the acoustic tracking system is slower than other sensors tracking.

Inertial Tracking This type of tracking is conducted by keeping the axis of rotation or the position as the origin. The rotational encoder's angles can calculate the direction of the movement of the virtual object. The advantage is that it does not involve any other peripheral reference for its functioning. The sensor is very lightweight. Problems may arise in this system with a slight shift in the axis of rotation or the position [48].

Sensors Tracking	Accuracy	DOF
Optical Sensors	Accurate	3/6 DOF
Magnetic Sensors	Less Accurate	6 DOF
Acoustic Sensors	Less Accurate	3/6 DOF
Inertial Sensors	Accurate	6 DOF
Hybrid Techniques	Accurate	6 DOF

Table 2.1: Summary of Sensors based Tracking. Adapted from: [66]

Vision Based Approach

In vision-based tracking, different computer vision techniques are used to calculate considering the camera's viewpoint and understand the real-world object. In marker-based tracking, the marker must be recognized and stored in a database. A marker can be an image or descriptor distinct from its environment. The markers can be categorized as active or passive. The former emits a signal to be detected by a sensor, and the latter does not emit a signal, which is the most used because they can blend in an environment easily. A camera is used alongside AR software to detect AR markers as the location of the virtual objects. Vision-based approaches can be divided into marker-based tracking or markerless-based tracking.

Marker-based tracking

Marker-based tracking uses images to trigger the AR experience, presenting multimedia such as videos, images, objects or animations (figure 2.4). It is based on mobile phone technology, where the camera is the only source for tracking. If the environments are identical, with reflective surfaces or have repetitive features that are difficult to bifurcate, or the environment is dynamic, markerless tracking becomes impracticable. If markers are added in such situations, tracking becomes more effortless. Given the highly efficient nature of the marker-based approach, if the app's emphasis is not tracking implementation but rather a demonstration of the application concept, this type of tracking is recommended [48]. There have been studies showing that QR codes do not negatively affect the visitors' experience and QR technology could represent an excellent cost-effective alternative for delivering digital content in museum-like spaces and open spaces [80].

Figure 2.4: Example of marker-based tracking, Source: [60]

Markerless-based tracking

Markerless tracking does not require marker recognition or images to start the AR experience. Fiducial markers were employed for the early vision-based approaches. Still, most recent approaches are based on the markerless approach (figure 2.5).

In the first processing step of markerless tracking, the feature points or edges are detected to interpret the camera images. The feature-based methods extract features from the objects to recognize them. In contrast, the model-based methods are used to estimate the camera pose in the feature-based methods. The matching relation between the 2D-image features is first discovered, and then the features' 3D world-frame coordinates are estimated. In contrast, the model-based methods use models of the tracked-object features or templates [49].

SLAM is a principal technique used to construct a map progressively within an unprepared environment. At the same time, its current location is tracked based on the extracted scene features. This technique has been applied for robust tracking of objects in small places. However, updating the 3D environment is not considered, so the working scene must be stationary.

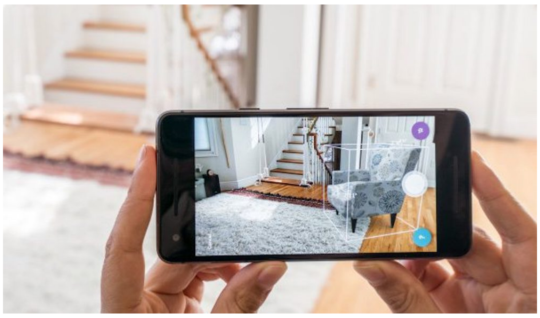

Figure 2.5: Example of markerless-based tracking, Source: [74]

Hybrid Approaches

Fusion of the mentioned tracking methods can yield better results than when each is employed separately (figure 2.6). For instance, an inertial tracker suffers from positional drift but provides better accuracy for orientation measurement, and marker-based and optical tracking are affected if the markers are occluded. In these situations, we can rely on the inertial tracker to estimate the position until the marker is recognized again. The hybrid technique solves the recognition issue in cases where the other methods are not applicable, and users favourably accept it [80]. There is a trend to combine GPS and vision-based tracking, which is a good solution when the points of interest are near each other [13].

Figure 2.6: Testing an application that uses a hybrid approach. Source: [80]

Instant Tracking

Instant tracking, or as stated in Torres, 2020 [79], Image-assisted alignment, shows a semi-transparent image of a real-world object or scene to the user. Hence, the user overlays the image with the target area and touches the screen to begin the experience. The virtual objects are displayed on the screen (figure 2.7) [6, 24].

Figure 2.7: Instant tracking example of displaying a virtual Nintendo Switch, overlapping a real one

2.1.3 Web Augmented Reality

Mobile Augmented Reality is earning increasing attention from industry and academia. Still, most AR applications are Hardware-based Mobile AR or App-based Mobile AR. Mobile Web AR (MWAR) is a growing area of interest due to the growing development of user devices and networks, creating a possibility of achieving a cross-platform, lightweight and pervasive service solution for Mobile AR. However, the limited networking and computing capabilities are the big obstacles to its practical application [63].

Hardware-based applications are known to be costly, have a small number of users, and need additional hardware (e.g., Meta 2), making them heavy. Each one has its platform that is developed on, creating a problem of flexibility. App-based Mobile AR lacks cross-platform and has to be downloaded. Many of these Apps depend on the platform they were built for. Not every AR SDK supports both of the most used Operating Systems in mobile devices (Android and iOS). Having to download it beforehand makes it inconvenient and unfriendly for users who want to access it on the go.

Current MWAR

The current Web AR implementations can be categorized as web browser-based or JavaScript-based:

Web browser-based This approach aims to achieve near-native performance by extending the browser to support AR applications, creating a better experience for the end-user. Mozilla and Google's state of the art are WebXR, WebARonARKit and WebARonARCore, based on ARKit and ARCore. The lack of standardization across the different MWAR-supported browsers hinders the cross-platform criterion of MWAR.

JavaScript-based Meeting the cross-platform criterion using JavaScript Libraries. The state-of-the-art of this implementation is AR.js, which, through WebGL and WebRTC Techniques, can create AR experiences in any browser. The performance of this approach is still limited due to the low computing efficiency of JavaScript. With the outsourcing of computation tasks to a cloud server, this problem can be mitigated.

Challenges of AR in the Web Context

In order to achieve a pervasive usage of AR on the web, there are obstacles to be dealt with to have a responsive and pleasant experience for the user:

1. Limited Computing Capability: all the tasks are demanding and may lead to low FPS (Frames Per Second) when using JavaScript on a Mobile browser. JavaScript may perform well in tracking fiducial marks but performs poorly on markerless tracking.

2. Network Delay: Cloud servers have powerful computing capabilities and could perform MWAR applications better. Since AR is a data-intensive application, offloading computing tasks to the cloud would introduce communication delays. This option is impracticable since the current 3G/4G mobile networks cannot provide us with the right amount of bandwidth and latency.

3. Limited Battery Capability Versus Extreme Energy Consumption: Since Web AR require intensive tasks, the mobile device's battery will run out quickly. Outsourcing the computing tasks to the cloud would alleviate the energy consumption of the end device.

4. Standardization: The diversity of platforms and the lack of standardization of MEC (Multi-access edge computing) and D2D (Device-to-Device) techniques, which we will talk about in the following subsection, mobile hardware which have different levels of support for AR, the modern web browser have different capabilities to support AR applications and the lack of standard for Web 3D objects, hinders the development of MWAR applications.

Computation Outsourcing

Although the performance of the web-based approach is better than the JavaScript one, it's not enough to create complex environments due to computational capability. As stated before, by outsourcing computation tasks to the cloud, end-users can achieve a better AR experience through the cloud server's capabilities.

Using computation outsourcing leads to additional communication delays and deployment costs. These issues deserve our attention simultaneously [63]. Advances in networking technologies make computation outsourcing possible through the use of 5G. 5G networks aims to provide 1000x system capacity, 25x average cell throughput and extremely low latency (1-10ms) when compared to current 4G LTE networks[64]. Emerging D2D techniques allow for short-distance communication. All of these features make it possible for Web AR to be pervasive and perform well as well.

Due to the high costs of cloud server deployment, there needs to be a reasonable service of computation outsourcing, so there are a variety of frameworks and approaches.

Back-End Solutions This type of solution can be:

1. Mobile cloud computing-based, outsourcing rendering tasks to remote servers for processing acceleration. This framework leads to better performance but meets bandwidth and latency problems that can be dealt with when using a 5G network. Another problem with this framework is concurrency, and processing costs will occupy the centralized server a lot.

2. Multi-access edge computing-based: using MEC for AR services, the end-user will be accessing a platform with better computing capabilities at the edge of the network near the user, resulting in a quality-of-service improvement and can hold cached data at the edge nodes, improving overall storage efficiency of the system.

Collaborative Solutions Back-end solutions have limited computing capabilities, which limits its broad usage. Therefore, adaptive and scalable collaborative computing and communication are needed. Osmotic computing is a paradigm that achieves this through automatically deploying microservices over an interconnected cloud data centre and an edge data centre. These types of solutions can be classified as follows:

1. Terminal + Cloud collaborative solution: Osmotic computing encourages us to offload part of the computation from cloud servers to mobile devices to alleviate computing and deployment cost pressure on central sites. There is still a lot of room for performance optimization since reducing the computing capability threshold will reach more users at the cost of the app's performance.

2. Terminal + Edge + Cloud collaborative solution: this method combines mobile devices' computing and storage capabilities, network edges and remote cloud servers. The mobile devices alleviate edge nodes and cloud servers, network edges provide a temporary place for Web AR application migration, giving computational power to the AR app and providing lower latency, and the cloud servers are usually used for big database queries, considerable data-based model training and others.

Experiments and conclusion

Qiao et al. [63] report a real Web AR advertising campaign for China Mobile by WeChat using the Terminal + Cloud collaborative solution, achieving 2 080 369 unique users in 10 days, showing that a reasonable computation offloading can achieve good results. However, they have reported that there is a lot of room for performance optimization.

Qiao et al. [64] have also conducted experiments in 5G networks using collaborative solutions with mobile device and edge networks, mobile device and cloud servers and the three altogether (figure2.8), showing that by gathering distributed computing and storage capabilities with the help of 5G networks it is possible to achieve good performance, low latency and low power consumption.

Conclusion

Due to the current 3G/4G networks not being capable of meeting real-time interaction requirements and the high costs of cloud servers and edge network deployment, the AR experience will be App-based.

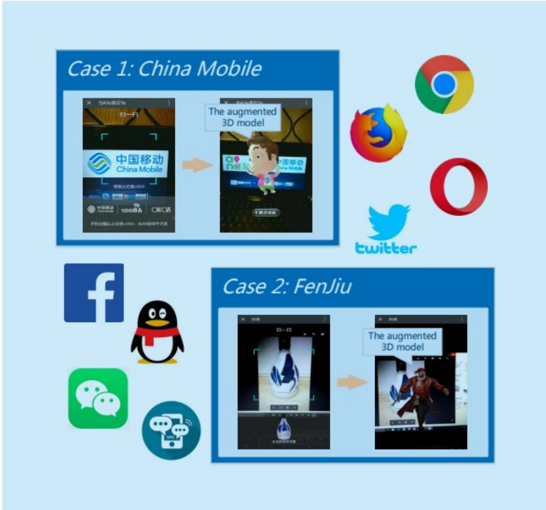

Figure 2.8: Two experimental cases of the use of MWAR5 for sales promotions by China Mobile and Fendi. Source: [64]

2.2 Related work

Several applications have been presented in this section to display artistic creations, cultural heritage and public spaces.

Expanding on this, we will examine a range of augmented reality applications designed especially for the world of art. We will present these applications to give a thorough overview and gather knowledge to help us develop our art-focused application.

2.2.1 Art Related Apps

Without AR

Daily Art DailyArt is an app for art history enthusiasts. It presents the user with classic, modern, and contemporary art daily (figure 2.9). It also presents captivating narratives about these artworks, delving into their essence and providing insightful explanations behind their creation.

It provides users access to over 3,800 masterpieces, 1,200 artist biographies, and 600 museum collections, establishing itself as the go-to app for those eager to immerse themselves in art and culture every day [56].

Sotheby's The Sotheby's app offers art collectors and enthusiasts an exceptional window into the world of fine art, precious objects, wine, and jewellery, all guided by the unmatched expertise of Sotheby's specialists. It provides a comprehensive view of upcoming auctions across various global locations, inviting users to explore diverse offerings, from Old Masters to contemporary art, classic furniture to modern design, photography, prints, and exquisite jewellery, watches, and wine.

The app also features a zoom-in function for closely examining objects, narrated audio

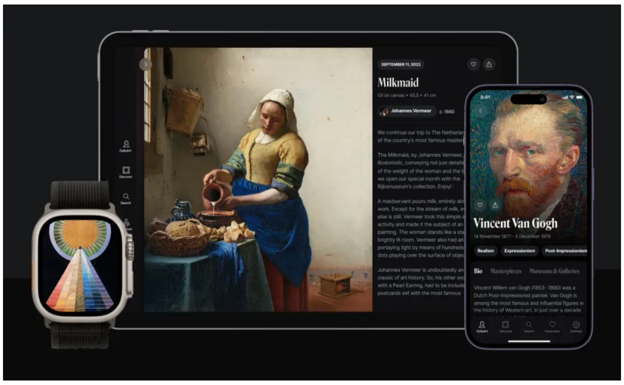

Figure 2.9: Daily art app. Source: [56]

recordings to enhance the experience, and live streaming of marquee auctions. Additionally, users gain access to Sotheby's complete video library and a rich collection of articles, making it an invaluable resource for art enthusiasts and collectors [69].

With AR

Google Arts & Culture and Acute Art Google Arts & Culture is an app-based or online App that offers a collection of cultural and art content from artists worldwide, allowing everyone who accesses it to explore real-world collections, galleries and museums. It offers some AR features such as Art Projector, which places art pieces anywhere the user points, can choose from more than 2000 cultural institutions, or Pocket Galleries, which allows the user to experience an art gallery from the phone, with the additional audio explanation. It is available for iOS and Android [30].

Like the previous app, Acute Art presents many artworks from artists using virtual and augmented reality. It has hosted many events, such as Unreal City, a festival of AR art in London featuring 36 sculptures along the river Thames [1].

Artivive & Spark AR Artvive is an app that expands an existing artwork into an Augmented Reality experience. Bridge is the creative tool of Artivive, where users can generate the digital layer to bring their augmented reality artworks to life. It is a user-friendly option for artists who want to bring life into their artworks without the need to program[29].

Spark AR Studio is an augmented reality platform similar to Artivive that allows for the creation of AR effects and filters for AR experiences. Meta created it, providing compatibility with Instagram, Facebook and Messenger. Not only can it create related art, but it can also be built into marketing advertisements in Meta's social media[53].

Reblink Reblink is an exhibition that blends traditional art with augmented reality in the Art Gallery of Ontario (figure 2.10). The exhibition comments on the changing nature of the human condition, such as images of modernization, alienation, and distraction. It is a satirical take on modern society, critiquing how people consume internet content. One example is a painting of a 17th-century couple with a bounty of wild-caught boar and grapes replaced with their 21st-century equivalents, canned fruit and hot dogs [77].

Figure 2.10: Painting enhanced by the Reblink exhibition App. Source: [77]

The Deep Listener The Deep Listener is an AR experience by Jakob Kudsk Steensen hosted by the Google Arts and Culture app in collaboration with Serpentine Augmented Architecture (figure 2.11). It selected 5 locations in London's Hyde Park to exhibit innovative 3D animations and sounds of five of London's species: London Plane Trees, Bats, Parakeets, Azure Blue Damselflies and Reedbeds part of the park ecosystem that might otherwise be invisible [71].

Figure 2.11: Artwork at the Hyde Park from the Deep Listener App. Source: [71]

2.2.2 Cultural Heritage-related Apps

A Phygital Approach To Cultural Heritage: Augmented Reality At Regaleira Regaleira 4.0 is the first AR app launched by a cultural heritage site in Portugal (figure 2.12). It displays 70 interactive experiences, 40 AR animations with 3D avatars, 30 videos with 3D agents, and over 100 information entries using digital storytelling [6]. The app offers five tours to give visitors a richer and more interactive visiting experience.

The app relies on the instant tracking technique to display the objects and the device's GPS location to indicate where in the route of the park they are and to tell the user that he can point at the content near experiences.

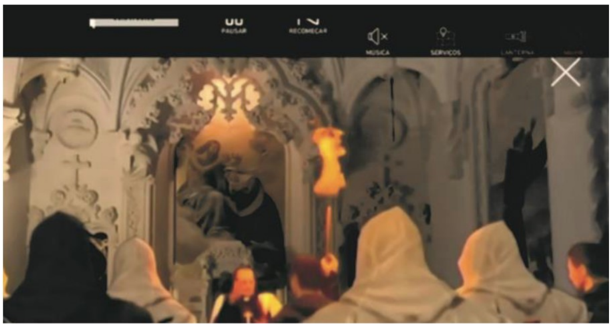

Figure 2.12: Example of AR experience: historical reconstitution of templar ceremony in the chapel. Source: [6]

Application in Public Gardens: Caloust Gulbenkian Foundation Garden Augmented Reality and Storytelling in Heritage is a research done by Guimarães et al. [31], focusing on ”Fan Faction”, finding a way to integrate user narratives in the general historical narrative (figure 2.13). Having achieved preliminary results such as showing the garden creation, representing the kingdom through routes and garden components (flora and fauna) as characters, and juxtaposition of content in the public space of the garden.

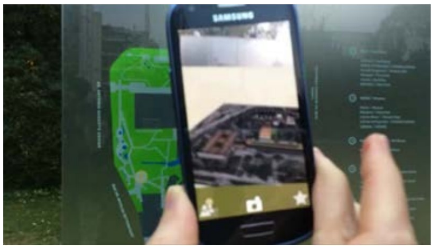

Figure 2.13: 3D Model superimposed in the Garden signage. Source [31]

Centro Interpretativo das Levadas da Madeira This project is a proposal for a future museum in the centre of Funchal, Madeira, to be developed by the company byAr [15]. There will be various experiences related to levadas (an irrigation channel or aqueduct flanked by a pedestrian path that are tourist attractions for hiking) [84]. It will exhibit a simulation using IPS Monitors on the floor, an interactive app showing information about them and more experiences.

One of the significant features of this project is the Augmented Reality App, which allows users to look at the floor, see the island in 3D (figure 2.14), and look at the map of levadas and content related to them. This application will also be designed for outdoor usage, with a pre-defined route visit to Levada of Santa Luzia, in which points of interest will be marked.

Garden of Iasi with the Help of Smart Devices and Augmented Reality GB Play is an application developed for the botanical garden of Iasi, Romania. This app

Figure 2.14: Mockup of what a similar app will look like. Source: project proposal from byAr

encourages teenagers to do sports outside and children to learn about nature. It offers a regular quiz and a Treasure hunt, where the user has to find a specific plant given a description, having clues such as distance, a map and a compass (figure 2.15), which is placed on the ground plane using ARCore's ground planes to see the direction of the plant [16].

Figure 2.15: Augmented Reality Component of the App. Source [16]

Bones and skin Showcasing 13 animals whose skeletons are displayed in the Bone hall [59, 51]. Bones and Skin is an iOS Augmented reality app made for the Smithsonian's National Museum of Natural History (figure 2.16). It lets users see how the animals look, pointing the device at their bones. Co-produced by Portuguese graphics producer Diana Marques and a team of museum educators, software developers, animators and others, the app delivers 32 videos, four games, and ten augmented reality experiences.

Jardim Botânico Tropical The app presents four thematic routes, a map with interest points, images, and descriptions about each one of them, thematic experiences through multimedia and augmented reality experiences that allows the user to find virtual birds that are common in that area (figure 2.17), among other features that give additional information about the gardens for those who visit Jardim Botânico de Lisboa [79].

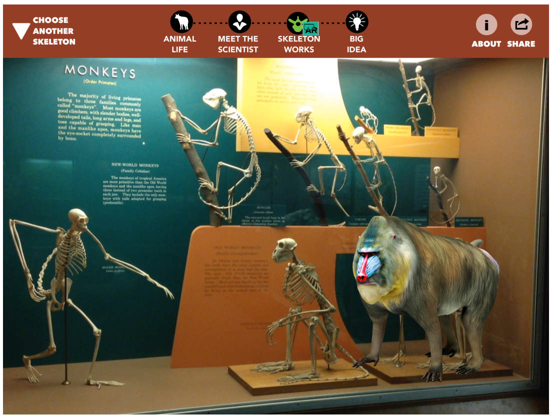

Figure 2.16: Mandrill overlapping its bones from the Bones and Skin App. Source: [59]

2.3 Conclusion

This chapter introduced several key concepts essential for understanding the world of AR. It highlighted various issues and challenges associated with AR applications and presented various related works.

Due to the current 3G/4G networks not being capable of meeting real-time interaction requirements and the high costs of cloud servers and edge network deployment, the AR experience will be App-based.

In the next chapter, we will delve into various tools at your disposal for crafting AR applications.

Figure 2.17: Examples of bird images after the user touches their silhouette, Source: [79]

Chapter 3

AR Tools

The usage of augmented reality is expanding faster than virtual reality, with big enterprises investing in various sectors such as healthcare, education, retail, and the gaming sector leading [33]. Some examples are Apple releasing its SDK ARKit in 2017 for iPhones and iPads[7], and Google releasing ARCore in 2018 for Android devices[28].

As of today, many options enable the developer to create an AR experience, each with its benefits and drawbacks. The Augmented Reality SDK mainly provides three components: AR recognition, tracking, and content rendering. The recognition component works as the brain of the AR app. The tracking component can be stated as the eyes of the AR experience, and the content rendering is simply imaginative virtual objects and scenes on real-time information. We have various tools available through the SDK to recognize, track, and render AR applications most efficiently [5].

We first must consider the operating system, which is not a trivial choice since not all available frameworks are compatible with the most commonly utilized operating systems. To reach as many people as possible, we must consider this matter [13]; this project will only analyze options supporting mobile devices to achieve that result.

3.1 Unity3D

Unity is the world's leading platform for creating and operating interactive, real-time 3D (RT3D) content. It is renowned for its capability to create both 2D and 3D games [75].

What sets Unity apart is its ability to enable developers to craft cross-platform experiences, making it possible to reach audiences on iOS, Android, PC, and various gaming consoles using the same source. Additionally, Unity's robust support for external plugins and assets allows creators to enhance their projects efficiently. Another advantage of Unity is its extensive community support, possessing a large and active community of developers. This means you can find solutions to common challenges and access support forums and resources [21].

In the context of this work, all the tools mentioned in this chapter offer integration plugins available for this platform. This platform was used as the basis of the project for both early testing and the entire development process. Every test began with importing the SDK. The companies often provide demo environments for specific features, allowing for an easy understanding of their usage.

3.2 Vuforia

Vuforia is one of the most popular SDKs used to create AR applications, indicated for both personal and enterprise use. It was initially developed by *Qualcomm Connected Experiences, Inc.*, and was later acquired by *PTC* [35]. It is compatible with the most popular platforms, such as Android, iOS, UWP, Eyewear devices, and Unity [44].

The tool's features are based on computer vision technology (CV). It allows AR devices to understand and interact with the real-world environment by recognizing and tracking objects and surfaces [43].

Vuforia allows for different types of tracking/targets, such as 2D and 3D objects, markerless support, 3D recognition with multiple targets, and its fiducial marks known as "VuMark." Some examples of additional features of Vuforia are advanced cloud recognition, text recognition and smart terrain and area targets.

The Vuforia features Image Recognition, Object Recognition, 2D and 3-D Recognition, Multi-Target Detection, Smart Terrain Extended Tracking, Cloud Recognition Text Recognition, Barcode Recognition, Digital Eyewear Support, Unity Integration Cross-Platform Development, Analytics and Cloud Services, Model Targets, Area Targets, Extended Tracking, Device Tracker, User-Defined Targets, VuMark Generation and Recognition, Virtual Buttons, Ground Plane Detection, Plane Detection (horizontal and vertical), Video Playback and Augmentation, Spatial and Temporal Device Tracking. [40].

The basic features of the engine are free, but they come with a Vuforia watermark for each app developed. The cloud license costs 99$, and the premium plan requires contact from the sales team [41].

3.3 Wikitude

Wikitude was created in 2008. This SDK allows for complex application development, and its native API enables you to embed the AR SDK into the Android or iOS app, making app development easier [3]. It also allows for development for Windows and Smart Glasses[25]. The professional version expands its compatibility, allowing for development in JavaScript, Unity, Cordova, Xamarin and Flutter [45].

This tool encompasses almost every feature in AR possible: Image-based Tracking, 3D Object tracking, Markerless tracking (using the SLAM technique), tracking of multiple and simultaneous images, Extended tracking beyond the target, Geo Tracking (location-based AR); Advanced camera settings; 3D data encoder; Integration of cloud-based image recognition into Unity; Both ARKit and ARCore support; Ability to track large-scaled environments using SLAM technology, such as small rooms, outside architecture and big spaces [85, 65, 86];

Wikitude's premium pricing reflects its top-edge features. The standard edition costs 490 euros per year, while the cloud edition costs 1990 euros per year.

The biggest problem with this tool is that the end-of-life service is scheduled for September 2024, meaning there will not be any technical support or updates from the developer team[87].

3.4 ARCore

ARCore, also known as Google Play Services for AR, is a Google-developed software development kit that empowers developers to create augmented reality applications for Android 7.0 and above [28].

It is the successor of Project Tango, which required dedicated hardware with multiple cameras and special sensors. In contrast, ARCore executes without requiring specialized hardware, relying only on the device's camera and internal sensors, making no additional requirements necessary.

Not only is it available for most mid to top-range devices, but it also provides API for Apple devices with iOS 15 or above [17].

The tool makes use of three key capabilities: motion tracking using the SLAM technique to understand the phone's positions relative to its environment; environmental understanding, also using key points in the same horizontal/vertical plane; light estimation, which analyses the light and shadows of the environment, to cast lights to the virtual object. It can determine the boundaries of each geometric plane, providing this information for applications. Its depth mapping feature facilitates immersive and lifelike experiences, ensuring virtual objects bump into real surfaces correctly [45].

3.5 ARKit

ARKit is an SDK launched by Apple in June 2017. It is the technology developed by the same company that specializes in providing tools for developers to create AR experiences exclusively for iOS devices to compete with other big companies such as Facebook and Microsoft.

ARKit offers compatibility and scalability within the Apple ecosystem due to its great compatibility with older devices. However, ARKit requires iOS 11.0 or later and an iOS device with an A9 or later processor, meaning the only devices compatible are the ones developed after 2015, such as iPhone 6s/iPhone 6s Plus [23].

The Main features are Multiuser AR experience; Serialize a world-tracking session to resume it later on; image tracking and recognition; 3D object tracking and recognition; SLAM based Markerless tracking; Tracking and Visualizing Planes; World Tracking; Estimated scene lighting information associated with captured video frame; Tracking and Visualizing Faces using TrueDepth; Visual Odometry, estimating the 3D pose of a moving camera relative to its starting position, using visual features; option to capture a 4K video feed using the back camera; Depth API, advanced scene understanding capabilities built into the LiDAR Scanner [8].

This tool has the biggest thread count on Stack Overflow among all SDKs, meaning it is one of the most used.

3.6 Tools Comparison

Regarding Pricing, ARcore and ARKit are the best choices since they are free. However, it is necessary to use other features or platforms. In that case, Vuforia is better since it delivers more subscription plans and cheaper ones than Wikitude.

Regarding community size, as of November 2023, ARKit is the preferable choice since it counts 7261 results on Stack Overflow, followed by ARCore with 3855 results, Vuforia with 3732 results, and Wikitude with 704 results.

Concerning platform and device coverage, ARKit only supports iOS 13.0+ on iPhone 6s or newer and ARCore only supports Android 7.0/8.0+ on specific mobile devices. Vuforia and Wikitude cover both iOS and Android devices with older versions of the OS.

As to features, they all allow for 2D/3D recognition and marker and markerless-based tracking. However, SLAM ARKit provides reliable tracking, and ARCore leads in mapping and reliable recovery [46]. While Vuforia has limited capabilities compared to ARKit and ARCore in some areas, it benefits from being designed to leverage the strengths of both ARCore and ARKit through its engine.

ARKit benefits from the Apple ecosystem in terms of usage, making development more straightforward. Benefiting from excellent real-time position tracking and integration of virtual and real objects, ARCore is an excellent tool for AR in e-commerce apps [46]. Wikitude has an impressive customer list, although most are retail, consumer, or media companies. These companies must avoid falling into fast training, improved field service, repair operations and reduced production errors. Meanwhile, Vuforia has been focused on industrial organizations, covering many areas such as aerospace and defence, automotive, industrial machinery, life sciences, and retail and consumer products.

In summary, each SDK has its features, supported devices, and license pricing. The table 3.1 shows the analysis of each SDK with its characteristics.

3.7 Choice of Tools

We will use Android smartphones for our devices because that is where our project will be developed and used. Plus, there is the possibility of exporting the project to iOS in the future using cross-platform tools.

Features	Vuforia	Wikitude	ARCore	Arkit
Licenses	Free with watermark 441,59€ one time payment 87,61€ per month Costumized	Free with watermark 2490€ one time payment 2990€ per year 4490€ per year Costumized	Free	Free
2D Recognition	Yes	Yes	Yes	Yes
3D Recognition	Yes	Yes	Yes	Yes
Localization Recognition	Yes	Yes (varies by license)	Yes	Yes
SLAM	Yes	Yes	Yes	Yes
Cloud Recognition	Yes	Yes (varies by license)	Yes	Yes
Supported Devices	Android 8.0 or newer iOS 13.0 or newer	Android 6.0 or newer iOS 12.0 or newer	Android 7.0/8.0 or newer iOS 11.0 or newer and ARCore App	iOS 13.0 or newer and A9 Processor or newer
Supported Platforms	iOS Android Windows Smartglasses Unity3D UWP	iOS Android Windows Smartglasses Unity3D UWP	iOS Android Windows Smartglasses Unity3D Unreal Engine	iOS Android Windows Smartglasses Unity3D

Table 3.1: Comparison of the AR SDKs. Source: [76]

Vuforia was selected in conjunction with Unity 3D from the available SDKs for the project. The choice was influenced by Vuforia's capabilities: marker and markerless tracking, multi-platform support, and a budget-friendly approach. This combination allowed for facilitated and cost-effective development while ensuring the experiences were complex enough for the final product. Unity was chosen due to prior experience with the platform. The seamless integration with Vuforia, along with the ease of importing external tools and assets, supported the decision to use Unity for this project.

ARCore and ARKit were also considered since they allow for a more interactive markerless experience; however, a cross-platform SDK was needed to reach as many people as possible, making these tools incompatible.

Combining Vuforia and Unity presented a challenge, as the AR SDK was not designed to interact with Unity's physics engine, leading to specific difficulties. Moreover, neither Vuforia nor Unity provides an API for Instant Tracking, adding an extra layer of complexity to the project.

Additionally, Blender, an open-source software for 3D modelling, was used to adjust the already available monument from the artist and reduce the polygon count from the objects imported to the project since mobile devices have a lower computing capability. Blender was chosen for its cost-effectiveness and extensive toolkit.

Chapter 4

Design

This chapter will explore the development of the resources needed for creating the application, in which the tools of Vuforia and Unity3D will be explored more deeply to assess their capabilities and how to use them to create AR experiences for visual arts, as well as every step and decision taken in the development of the software solutions of the ”ARJustiça” application.

First, the initial project we started, which Barbara [76] crafted, will be described. Following that, we will dive into how we added AR alignment techniques to create the experiences, using the tools we discussed in the previous chapter 3.

Lastly, we will discuss the interaction methods designed to enable users to engage with the virtual world in AR.

4.1 Implementing AR tracking techniques

In this section, we offer an overview of the app ARJustiça, which served as the foundation for this project, and analyze it to extract valuable insights that informed our development efforts.

Subsequently, we delve into implementing AR alignment techniques, which involve mark and image recognition and tracking, sensor-based alignment, image-assisted alignment, markerless alignment techniques, and various techniques.

4.1.1 Previous Work

The project was previously submitted to the Municipal Council of Oeiras. It was supposed to be used in the Marquês de Pombal Palace gardens. The submission was later denied, but the first approach to this project was designed for these gardens.

In preparing the project proposal for the gardens of the Marquis of Pombal's palace, Bárbara [76] developed a prototype with 3 experiments. First the application asks the user to choose the language (Portuguese or English) and then the user is led to a map with the user's current location so that the person can walk to one of the three experiences (figure 4.1).

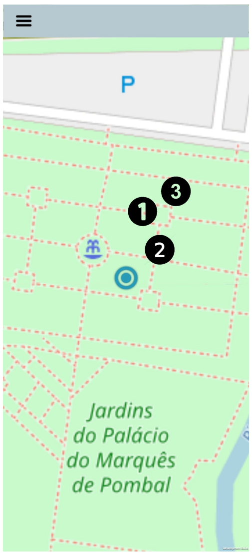

Figure 4.1: Map menu overview

First experience

The first experience was made to show the user an overview of the monument of justice created by the artist, where the person who yields the device could look around and appreciate the artwork.

The experience uses marker-based tracking, where the device needs to point to the marker. A miniature of the monument appears, allowing the user to see its outside (figure 4.2).

Marker-based AR experiences work well when we are looking at a location and have a constant line of sight to the marker at all times.

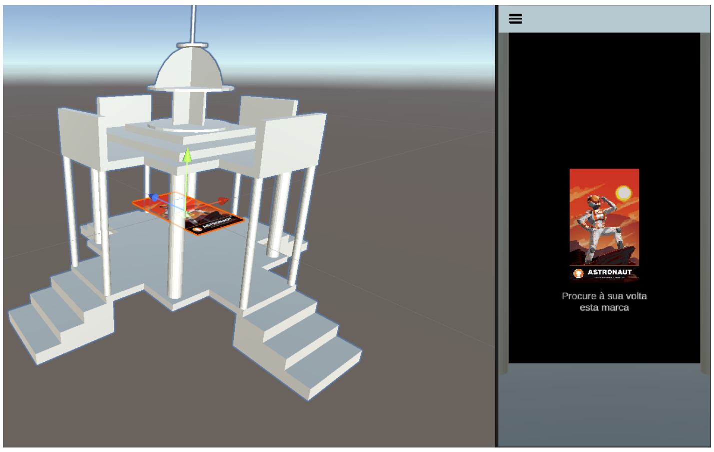

Figure 4.2: Third experience overview in Unity

Second experience

In the second experience, the user would point the mobile device toward the cardinal directions which were aligned with the doors of the monument. In each door, a different 3D virtual object should appear (figure 4.3). This experience used the phone's compass. However, the values of the phone's direction fluctuated considerably if the device was not parallel to the ground, making the objects appear and disappear frequently.

Figure 4.3: Second experience overview

To solve the issue with the compass, the sensor was replaced with a gyroscope, resulting in an improved overall stability of the experience. This type of experience works well when the user is in a specific location, where aligning the device with certain cardinal points corresponds to real-world structures, resulting in a blend of the virtual and real world.

However, the objects will not necessarily align with said real objects unless the user does so; for that reason, it is preferable to resort to instant tracking in this type of situation.

Third experience

The third and final experience is similar to the first, with the difference that the monument is on a real scale, so the user could be inside the monument and observe the artwork (figure 4.4).

Something other than marker-based tracking would work better for this experience. Still, Vuforia offers a feature called extended tracking that allows AR experiences to continue tracking objects even when they move out of the camera's field of view or when the tracking marker is temporarily lost, which allows the user to continue seeing the monument after the camera losing sight of the tracking marker [39].

This approach is unsuitable when using a marker that will display an object that we will be inside, for example the monument, since doing so will lead to a poor user experience,

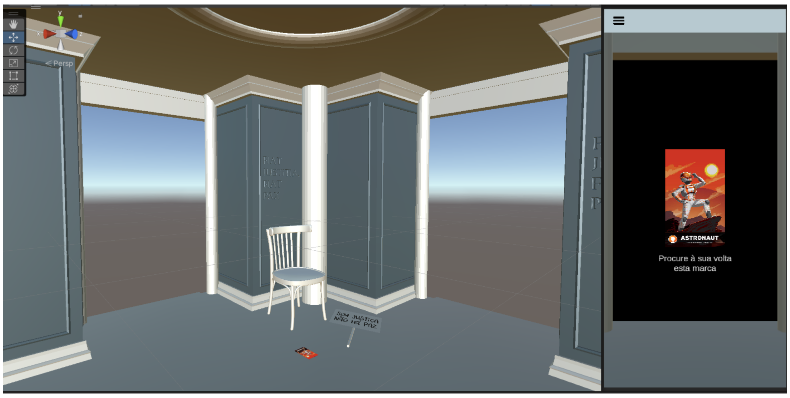

Figure 4.4: Third experience overview in Unity

as the object's position will drift, it will appear and disappear numerous times. For that reason, it is advisable to use markerless tracking, making the object visible from every angle, which we will see next.

4.1.2 Tracking techniques for the project

We aimed to provide an immersive experience, allowing users to explore and interact with the virtual world freely. To make this possible, we sought a solution that ensured smooth navigation, making the AR experience engaging.

Markerless tracking: Ground Plane and mid-air Anchors

Vuforia Ground Plane enables digital content to be placed on horizontal surfaces in your environment, such as floors and tabletops (figure 4.5). It supports the detection and tracking of horizontal surfaces. Also, it enables you to place content in mid-air using Anchor Points [37].

Figure 4.5: Ground plane feature example

This API allows users to roam the experience in an open setting without many problems.

Ground Plane leverages Vuforia Fusion to utilize the best core technologies available on each device (figure 4.6). Ground Plane is only compatible with devices supported by Platform Enablers (ARKit/ARCore) or devices specifically calibrated by Vuforia. This means that not everyone can participate in this type of experience.

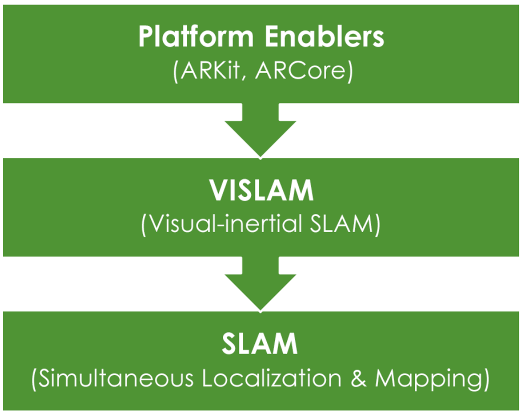

Figure 4.6: Vuforia Fusion Technology Stack: Adaptive AR Tracking Method Selection. Source: [42]

Vuforia Engine's AR experiences build upon foundational technologies, progressing from higher-level components downwards, ensuring adaptability and optimization at each stage. Another thing that sets Vuforia apart from other SDKs is the VISLAM technology. Visual-Inertial Simultaneous Localization And Mapping (VISLAM) is an algorithm implemented by Vuforia, combining the benefits of Visual-Inertial Odometry (VIO) and Simultaneous Localization And Mapping (SLAM) [42]. Visual-inertial odometry integrates camera imagery with inertial sensor data to accurately track device movement and position in real-time. VISLAM compared to VIO solutions, work better in low-feature environments and recover more effectively when tracking is completely lost.

During testing, the Ground Plane and Mid-air Anchor features performed well in low-feature environments (example: figure 4.7) as long as the user remained relatively close to the initial anchor position. However, if the user moved too far from the anchor, tracking was lost, requiring the device to be pointed back at the anchor's position for a potential recovery.

In contrast, when transitioning to medium to high feature environments, there would be few tracking losses. The primary experience of the project was supposed to begin outside the monument. However, for added safety, we chose to separate the experiences inside the monument of justice and outside the monument after being unable to do both and maintain a stable experience.

Vuforia provides two features to achieve markerless tracking: Ground Plane and mid-air anchors. Both can be used to place the main stage of the application. However, both

Figure 4.7: Low feature enviroment example without any anchor, making recognition challenging

have their advantages and disadvantages.

Ground Plane Ground Plane allows for an estimation of the distance between the device and the ground, placing the user at its supposed height and the anchor on the ground, making for a genuine experience.

The downside of this approach is that while initiating the experience, the user has to place the anchor on the ground. As we are going to see next, the placeholder of the anchor will have to match an actual image. Hence, every user has the same experience, and the feature does not allow for the rotation of said placeholder, confusing the users about how to proceed.

Mid Air Anchors Mid-air anchors follow a similar approach, where the user must also place an anchor in the environment. Still, this time, it can be anywhere (figure 4.8). The Vuforia engine will find a place to put the anchor above and place the content where the user intended to. With this approach, everyone will be at the same height, which can be good or bad, depending on the situation.

The downside of this approach is if the user tries to place the anchor, as the person brings the phone closer to the target and then brings the phone to its average height, the virtual camera inside the experience will be much higher than intended, giving an

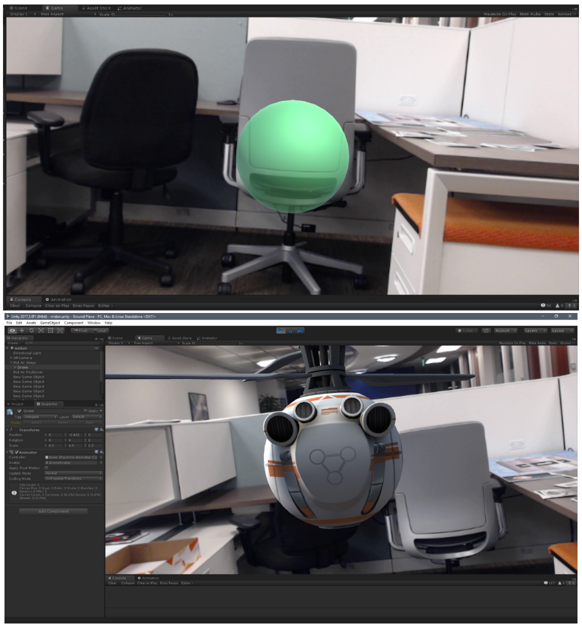

Figure 4.8: Mid-air anchor example. Source: [38]

impression that we are bigger than we should.

Both Ground Plane and Mid Air Anchor features provide customization for the placeholder, where the virtual scene will take place, for the former's default representation is a square representing the detected plane. The latter's default representation is a green sphere, representing where the object/scene will be placed, as seen in the figure 4.9.

Hybrid tracking: a marker-based and markerless tracking approach

To have a similar experience between the users of the experience, there was a need to place the virtual content at the exact location and rotation, thus ensuring a consistent experience across all instances.

At first, if you only used the Ground Plane feature, the monument would rotate differently. Due to this setback, we shifted our focus towards marker-based tracking to provide support.

So we resorted to a hybrid approach, using both marker-based and markerless based tracking, using an image to begin the experience, and the markerless anchor to ensure the user can navigate in the virtual world.

We need an image to serve as a target to use marker-based tracking. Vuforia provides a range of factors that define how well it tracks [36], such as:

- Richness in detail, such as Street scenes, groups of people, collages, and mixtures of items.
- Good Contrast: Images with bright and dark regions and well-lit areas work well.
- No repetitive Patterns: Employing unique features and distinct graphics covering as

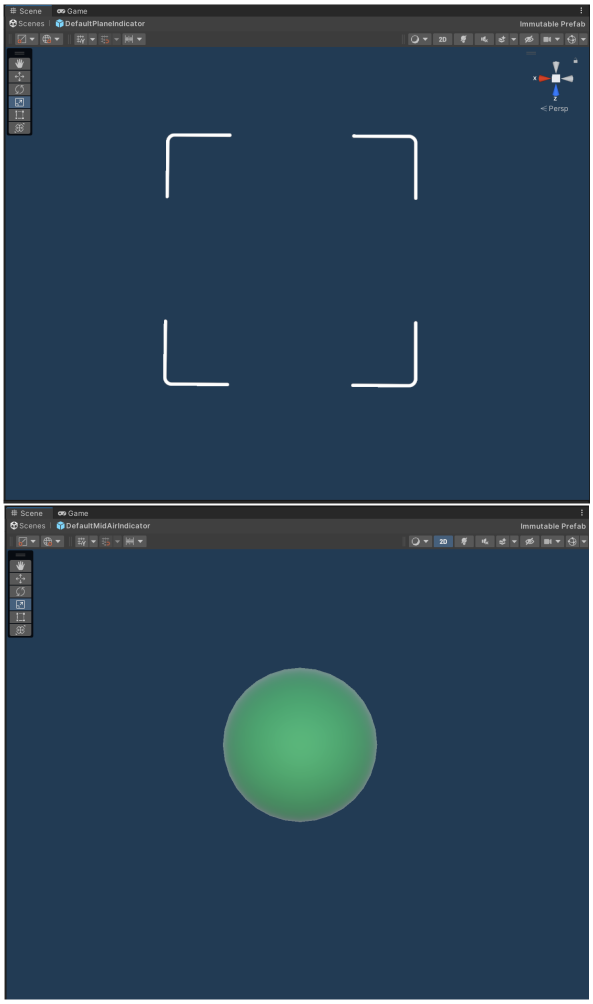

Figure 4.9: Ground Plane and Mid Air Anchor default placeholders

much of the target as possible to avoid symmetry, repeated patterns, and feature-less areas.

- Format: 8- or 24-bit PNG and JPG formats; less than 2 MB in size; JPGs must be RGB or grayscale

Taking these considerations into account, the artist designed the app's logo (figure 4.10) to serve as the designated tracking target.

By employing an image as the tracking target, we aligned the virtual world's orientation with that of the image, ensuring a consistent user experience.

Another benefit of using the image as the anchor location is the user's simplified recovery process from tracking loss, as they only need to reorient the camera toward the image. Occasionally, this procedure may not yield the desired results, requiring the user to reposition the anchor on the image.

For a more effortless user experience, we used the application logo as the placeholder for the Mid Air Anchor, so the user would instinctively try to position the placeholder on

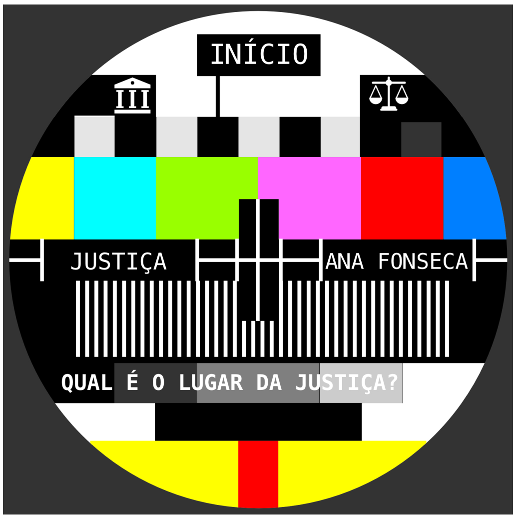

Figure 4.10: Application logo made by the artist

top of the real world image.

As mentioned, one issue with this approach is the user trying to overlap the anchor placeholder with the actual image, where there is no need to.

Instant tracking

While the hybrid approach allows for a robust and complex experience development, the user can go around the real space without many restrictions if he stays near the anchor. However, as stated earlier, only some devices allow for this approach. For that reason, there was a need to implement a tracking technique available for everyone, and that is when we opted for instant tracking.

In the early attempts of implementing instant tracking, we would turn off the Vuforia engine's tracking behaviour, use the gyroscope to control the camera movement and position the content in front of the camera, overlapping the initial image.

When using a gyroscope to control where the camera faces in Unity, the yaw and pitch axis are reversed. This is because Unity and the gyroscope use different coordinate systems. Unity uses a left-handed coordinate system, while the gyroscope uses a right-handed coordinate system (figure 4.11). This means that the rotation values obtained from the gyroscope have a different orientation compared to Unity's expectations [73].

To fix this problem, we initially tried to correct the camera movement and the object's initial rotation, but that solution only worked with one object. We need to calculate each object correction matrix when working with multiple instances.

So we searched for another solution and found one that fixed the problem [22]: after inverting the 'Z' and 'W' components in the quaternion representation, we introduced a separate quaternion. This new quaternion facilitated the application of a 90-degree rotation around the X-axis to align the camera with the desired orientation. We then combined this transformation with the previously inverted rotation quaternion, ensuring

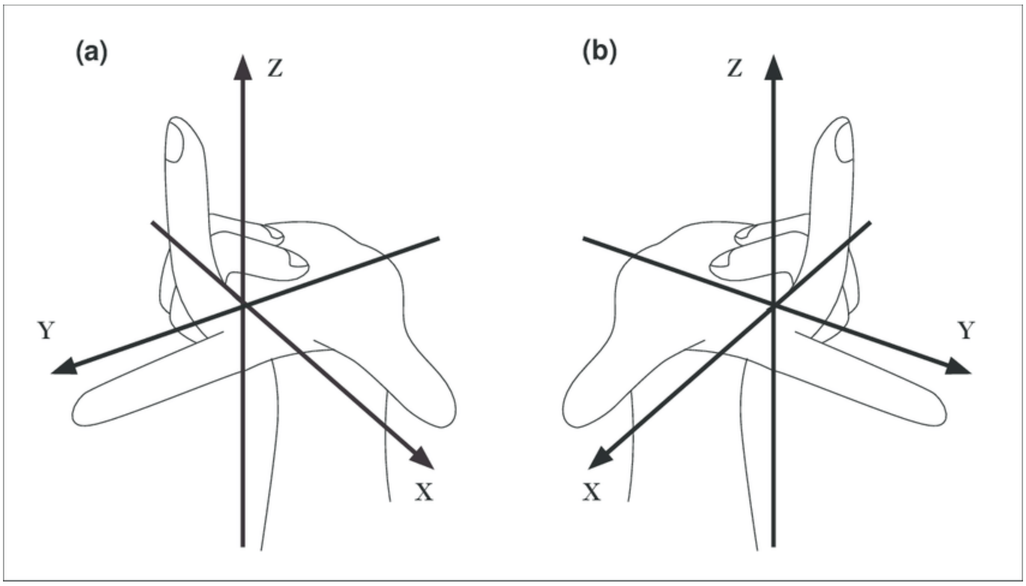

Figure 4.11: The left-handed and right-handed coordinate systems. Source: [34]

the camera was correctly oriented while considering the required adjustments.

The mobile device's gyroscope values vary with each passing tick, resulting in noticeable fluctuations and jitter in the monument's position. To address this issue, we implemented a solution that involved establishing a minimum threshold for changes in the gyroscope axis values to be considered movement. This helped create a smoother and more stable experience for users. However, even when the Vuforia engine's video quality settings are lowered, or the solution is tested on a higher-end device, the experience is not smoother than the markerless one because of the low frame rate of the produced solution. This might occur because the Vuforia engine was intended for use in a different manner.

4.2 Interacting with the Virtual Environment

To have an immersive experience, the user must be able to interact with the virtual world. In this subsection, we will discuss ways the user can interact with the world, given the restrictions of each experience.

4.2.1 Markerless experience

Considering the immersive nature of a markerless experience, users can explore the environment just as they would in real life. Therefore, it is logical that the interaction within this context mirrors real-world interactions.

We drew inspiration from first-person interactive adventure and storytelling games to recreate such interactions. These game genres provided valuable insights into creating immersive experiences where players can engage with and manipulate their surroundings, mirroring the tangible actions and interactions found in the physical world. These games include the Half-Life Series, Firewatch and the Amnesia Series (figure 4.12) [18, 68, 26].

We focused on the essential gameplay mechanics of this genre, which is often centred around physical manipulation. Players can pick up, examine, and utilize objects within the virtual environment, facilitating exploration, puzzle-solving, and narrative progression.

In this application, we have introduced features that enable users to interact with objects by clicking on them. This interaction includes moving objects (figure 4.13) and selecting/examining them, providing additional textual information.

To implement the features, there was a need to use Unity's physics engine, which is responsible for managing the physics behaviour of objects when they are being interacted with by the user. In the upcoming chapter, we will delve into the challenges encountered while integrating Unity's physics engine with Vuforia's engine, exploring the complications that arose during this process.

4.2.2 Instant tracking experiences

In instant tracking experiences, user mobility is restricted, limiting their actions to observation and interaction within the environment. To address this, we provided simplified interaction methods for a more accessible experience.

The lack of mobility makes environmental engagement harder, since bringing an object closer or further away from the user is challenging and makes the experience not pleasant. Therefore, we focused on observing the surroundings and utilizing UI components to manipulate the virtual world, as we will see next.

We can leverage the stationary nature of the user to incorporate green screen videos with transparent backgrounds. This allows us to seamlessly integrate animated content into the app, enhancing the overall visual experience without the effort of having to animate virtual objects, only needing to control the position and rotation of said videos to give the illusion of movement.

4.3 Chapter Summary

This chapter outlined the development and design choices of the "ARJustiça" application, focusing on Augmented Reality (AR) techniques to enhance visual arts experiences using Vuforia and Unity3D tools.

4.3.1 Technical Decisions and Implementation:

1. **AR Tracking Techniques:**

    - Initially focused on marker-based and markerless tracking techniques, we later integrated a hybrid technique, using both marker and markerless based tracking for a uniform experience.

Figure 4.12: Gaming images illustrating an interaction involving the movement of objects. Source: [83, 20, 27]

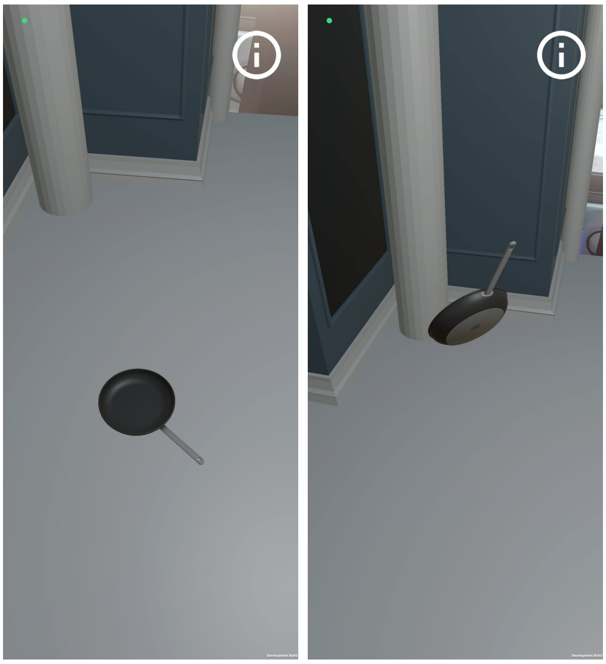

Figure 4.13: Frying pan, initially positioned on the ground and then lifted

- Then we focused on instant tracking to accommodate devices lacking advanced AR support. This approach allows the application to initiate AR experiences without prior calibration or markers, providing a seamless start and enhancing user accessibility. Instant tracking facilitates digital content placement on the real space with minimal restrictions, crucial for engaging and interactive AR applications.

2. **User-AR Interaction:**

   - Designed interactions to be intuitive, allowing users to explore AR content freely with dynamic adjustment of content placement for a consistent and adaptive experience.

Chapter 5

Implementation

This chapter will provide a comprehensive overview of the individual experiences forming the narrative. It will delve into the UI/UX design, exploring how to create an interface that enhances the usability of AR and complements the storytelling aspects of the narrative.

Two types of experiences were developed: stationary and virtual navigation. The stationary experience utilizes instant tracking techniques, where the user remains stationary and is able to look around. On the other hand, virtual navigation employs a hybrid technique which uses marker-based and markerless tracking, as described in the previous chapter.

This project was developed in two separate applications, one for stationary experiences and another for the virtual navigation experience, since the virtual navigation has hardware requirements and much older devices could not run the experience, and to ensure the apps ran smoothly without overloading any device with excessive data.

5.1 Development of the AR experience

In this phase, we introduced three distinct experiences, each serving a unique purpose within the app's framework: the ”Monument Showcase,” ”Justice Guess,” and ”Virtual Navigation”. The flagship experience (Virtual Navigation) comprises a series of sub-experiences, including the ”Scale of Justice,” ”Protesting,” ”The Exhibition,” ”The Choice,” and ”The End,” where users interact with dynamic elements and navigate through different scenes. On the other hand, the stationary group, comprising ”Monument Showcase” and ”Justice Guess” experiences, involves interactions within a fixed environment without the option to move around, and was optimized for less powerful devices.

5.1.1 Virtual navigation experience

The application was designed, so the user would think about his view on justice. To achieve that, we created a composite experience of five smaller experiences, where the user has to perform various justice-related actions, fitting the overall theme.

The nature of this experience requires the delivery of context. Hence, the user can interact with the virtual world within the device without having any previous contact.

The app aims to make the user reflect more about the sense of justice and its place in society. To achieve that purpose, the user is led to find the scales of justice, make a protest, select which kind of justice is correct according to the user's values, combine justice-related objects and celebrate justice. However, to prompt users to reflect on this subject deeply, it was essential to incorporate thought-provoking textual content to stimulate their contemplation.

First component: scale of justice

At first, the episode was supposed to begin outside the monument, having the user look at the building from outside, walking through checkpoints to end up in front of the first door open.

After much experimentation, we discovered that the experience would inevitably be disrupted by the loss of tracking, making the user frustrated by not being able to continue and going back to the initial mark many times, making this approach unworkable. Therefore, the experience was later changed to begin inside the monument.

This experience is intended for the user to understand he can walk and watch his surroundings, so the user is prompted to search for the scale of justice and touch it. This scale was in a working metronome, hidden behind a sphinx with a text for the user to read (figure 5.1)

To help the users understand that they can move around, explore the environment and click on objects to see which is interactable, they are prompted to walk around and search for the scale of justice. To hint at this fact, a yellow stripe outlines the scales.

Figure 5.1: Initial view and the scale of justice on top of the sphinx.

Second component: protesting

In the second component, the user is presented with a megaphone and is asked to grab it, move towards the objective, a waypoint ring, and go through all six objectives (figure 5.2).

We added a waypoint that would show the objective's position, so the user would always know where to go, which is the megaphone when it is on the ground. When holding the object, the next waypoint is that the user is given additional guidance, such as the number of waypoints cleared and a ”bling” sound when arriving at a new waypoint. To involve the user, protesting sounds emerge from the megaphone when held.

This was one of the most challenging part of the project to implement due to having objects affected by Unity's physics engine. Ensuring they stayed in the intended environment was a challenge throughout the project. Tracking losses would result in the monument disappearing and not said objects, thus making it fall into the infinite void, losing altitude until the experience stopped. Many attempts to mitigate this problem were made, such as imposing a lower height limit. If passed, the object would come to the initial position or return to its initial position when the tracking was lost. But none of these solutions worked. The only working solution was using a collision object to detect if the megaphone went under the monument, and returning the object to its initial position when the tracking was lost, the megaphone stayed on the ground.

In this app section, users encounter moving objects for the first time. The interface serves as a guide, instructing users to touch the objects and navigate through all the objectives. As mentioned earlier, the interface displays the number of completed objectives and those remaining, offering additional feedback. Additionally, a sound is triggered when a user successfully passes through an objective.

A waypoint indicator is provided to ensure that the user knows what to do, pointing towards the current objective, either the megaphone or the next objective.

Figure 5.2: Protest experience

Third component: the exhibition

This segment starts with an indication to observe the artworks around the user and choose the objects with descriptions that match the user's sense of justice. Each time the user clicks on an object, a textual description appears with the option to choose it or close the interface window.

Figure 5.3: Objects from the exhibition experience

The idea of the exhibition started with the user-facing many objects related to justice, such as a colonial hat, a pigeon and Napoleon's statue (figure 5.3). A message would appear stating that the user needs to choose which of the three objects are more correlated with his sense of justice. Said objects would have a good, neutral or lousy connotation of justice, but it would be revealed to him immediately, but was changed. The only thing presented was the object's description when clicked on, so the person reading could guess if it were relatable (figure 5.4). It was later changed from indicating whether the selection represents a positive or negative sense of justice, because the artist thought the user could dislike being said that their sense of justice is ”bad”, so the judgment part was replaced with a tag system, where the person would see in the end which tags corresponded to the objects.

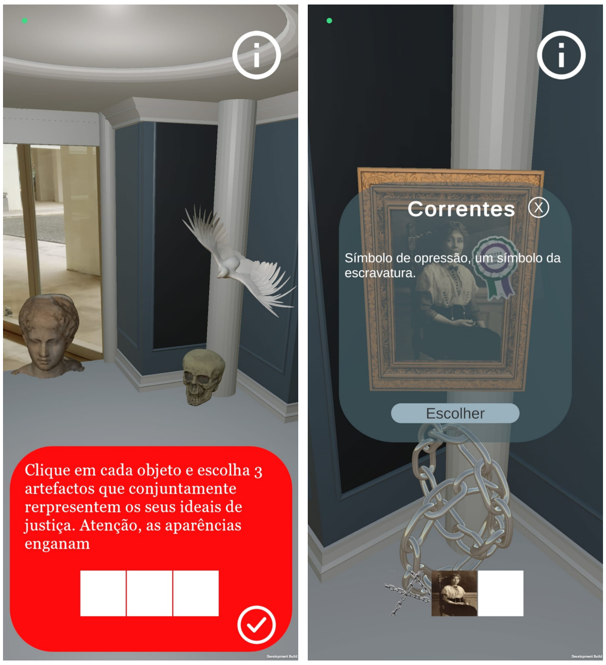

Figure 5.4: Exhibition experience

When chosen, the object's image appears square out of three at the bottom of the interface, providing visual feedback to the users about their options. When at least three objects are picked, a button under the images appears to let the user end the selection. If users change their minds and want to swap objects, they can choose another object similarly. Thus, a window asks what object to exchange with (left figure 5.5).

Figure 5.5: Exchange interface and selected objects on top of the pedestal

Once the selection is completed, the scene will transform into a pedestal featuring the three selected objects (right figure 5.5). The words in Latin are displayed in front of the podium for a brief period. Subsequently, they were replaced by Portuguese translations for some time. Following this brief pause, the user can proceed with the overall experience or reconsider their decision. If the former is chosen, the associated tags related to the selection are revealed (figure 5.6).

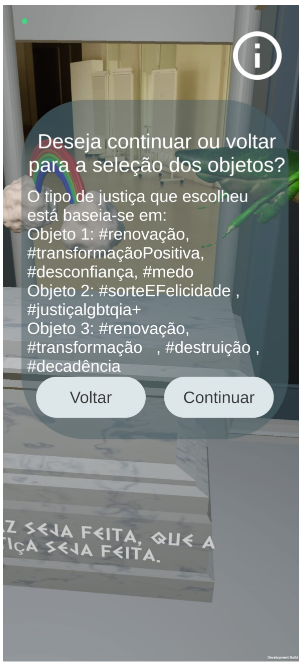

Figure 5.6: Tags related to the chosen objects

Fourth component: the choice

The last interactive part initiates with the recommendation to ”bring something home,” offering users the option to either combine two out of three objects or place one inside the box: a frying pan, seeds, and a vase. Each possible action has a text that would appear after performing it (figure 5.7), such as that bringing seeds provides food to the people, or suppose the seeds are placed on the vase. In that case, they disappear, and a plant grows, displaying a message about both items (figure 5.7), and so on.

It uses the same interaction technique as in the second experience to move objects around, and once the objects are combined, a window asks if the users are sure of the decision or want to repeat the interaction. If they go back, everything is back where it started from, meaning the objects returned to their initial positions/rotations. At first, there was an attempt to have a vector of fixed positions to where the objects would return. Still, this solution did not work, so an attempt worked by setting each object's initial rotation and position when the scene was loaded.

Figure 5.7: Choosing the objects and the resulting text

Fifth component: the end

To conclude the experience, users transition directly to a dance stage, the camera changes colours with a disco ball to simulate a little party for the completion of the whole experience, which then fades, revealing a red background with a central scale expressing a message of thanks at the end saying 'thank you.' (figure 5.8).

Figure 5.8: Ending of the virtual navigation experience

5.1.2 Stationary experiences

As discussed, this project aimed to develop an app allowing every user to experience it. Since the Ground Plane feature is limited to a list of devices, we searched for another solution to deliver low-end devices an experience that would run smoothly, which was an instant tracking-based experience due to its low computation demand, simplicity, and the delivery of content it can deliver to the users if they do not move.

The object to align the phone with was supposed to be a door frame made out of wood. However, since there was no financing for the project, we needed to opt for a budget-friendly option, which allowed us to move the said object around, so the experience would not be available to only one physical location. A styrofoam column would work better than a door frame due to its mobility, cost, and ease of assembly. The styrofoam column was only used in the high school, so in order to test the application with users outside the high school, we used buildings' columns.

Upon loading the scene, the user initiates the experience by aligning the semi-transparent column with the actual column and then pressing the "align" button, triggering the appearance of the experience, beginning with the monument inside or outside the building (figure 5.9). Different types of columns were utilized in various locations, such as a styrofoam column in a high school and a university building's column.

In this type of experience, the environment is better off manipulated by using user interface elements than interacting directly with touch, given the limited mobility of the setting.

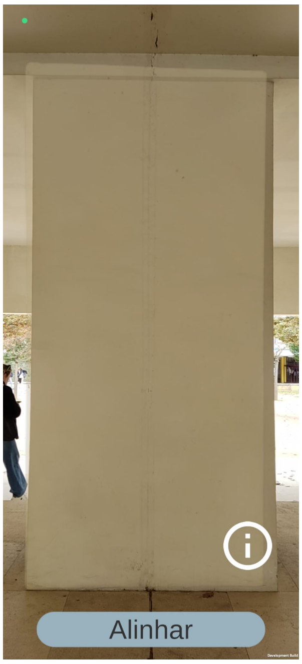

Figure 5.9: Start of the stationary experiences, using a pillar

Monument showcase

Since the primary experience revolved around completing tasks inside the monument, which was supposed to be viewed from outside at the beginning of said part of the app, the artist opted to create an experience where the user could observe the building from outside.

Two sliders were added to make the experience interactive, allowing the monument to rotate and move closer or even step inside. After the user completes the alignment, the user is outside the monument, being able to observe it from every angle (figure 5.10).

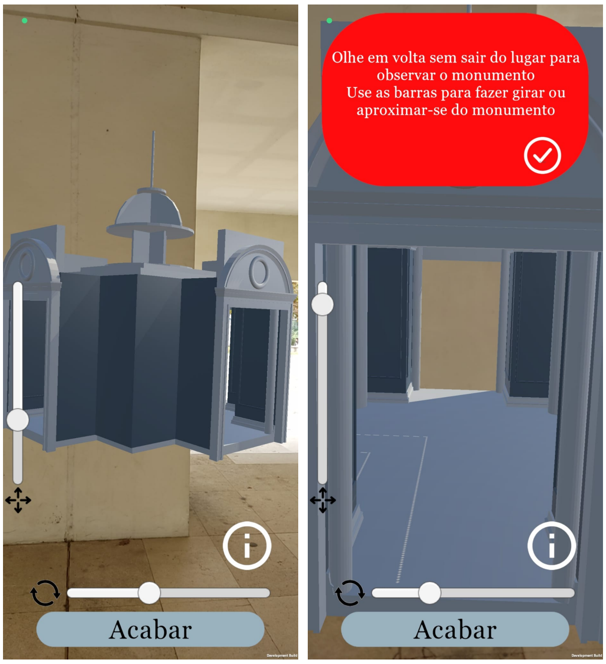

Figure 5.10: Stationary experience: watching the monument from outside

Justice guess

To take advantage of the green screen video's ease of implementation and good performance on AR experiences, the artist designed an experience in the centre of the monument, where the users can observe its surroundings, making them notice the videos behind each door (figure 5.11).

Each door is numbered in Roman numerals from one to four, with videos of the artist using props or movements related to the concept of justice. At the beginning of the experience, the user is shown the four concepts and is prompted to guess which concept relates to what door. When he is done, the solution is shown.

Figure 5.11: Stationary experience: guess the virtues

5.2 User Interface of ARJustiça App

All the application menus were designed from the ground up using Unity. The initial step for each scene in the app involves creating a ”Canvas” that acts as the foundation for each menu, with each UI (User Interface) element being directly linked to the canvas.

There is a need for the menus to appear correctly on various devices, given the diversity of screen sizes on Android devices. We opted to establish the canvas size based on the dimensions of the testing device, enabling menus to dynamically scale and maintain a uniform user experience across diverse devices using Unity's ”UI Scale Mode”, which allows choosing between a fixed pixel size or the current device's size.

5.2.1 Color Selection

There was a need to choose a pallet of colours for the different menus and UI elements. For the menus, a dark greyish-green tone was chosen, with the hex code of #476067, which gives an excellent contrast to the white buttons, and a red tone with the hex code of #FE0B0D for the initial menu.

We utilized a similar dark greyish colour, with a transparency level 57%, to present messages, menu choices, and information within the AR experience. This level of transparency was chosen to ensure that users could still glimpse the content behind the menu, enhancing their overall interaction with the augmented reality environment.

The buttons within the interface share a harmonious colour scheme. They feature a light blue #DDE7E9 shade, complementing the overall design. This light colour provides contrast against the dark background. Additionally, certain buttons maintain the same dark greyish tone as the background to maintain a cohesive look. To ensure readability, the text on these buttons is presented in white, making it clear and easily readable.

5.2.2 Initial Menu

The ”cover” of the app (Figure 5.12) features the theme, ”Monumento à Justiça” which sets the visual tone and narrative foundation for the entire experience. Under the title, the initial mark of the primary experience, which contains the name of the artist, Ana Fonseca, and a question about justice: ”qual é o lugar da justiça?”. To continue, the user must click an arrow button ”>” leading to the main menu.

Figure 5.12: Cover of both apps

5.2.3 Main Menu

The main menu offers users a simple choice: explore more information about the project or dive into our interactive AR experiences. The main version only showcases the virtual navigation experience called ”Explorar a justiça”. In contrast, the ”lite” version features both experiences ”justiça e virtudes” and ”explorar monumento”. That is the only difference between the two versions of the app (figure 5.14).

Figure 5.13: Initial menu

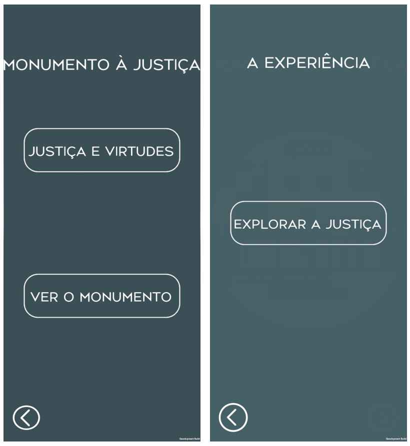

Figure 5.14: Experience menus from both apps

The information menu informs the user about who the artist is, what the monument is about and the partnership with Faculdade de Ciências da Universidade de Lisboa, showcasing the developers and the supervisors.

5.2.4 Information delivery

Before resorting to a text box to instruct the user on what to do, there was an attempt to show the instructions in a less intrusive manner by displaying information in a white fading text format for a few seconds, where the user could recheck it by pressing an information button (white circle with an 'i' inside). However, this proved impractical since it would only be visible in some settings; the user would also have to press the button many times before understanding what to do. A more fitting approach would involve presenting the information with the option to dismiss the instruction.

We came up with the instruction dialogue option. This little window shows the user what to do at the beginning of each experience. Its initial design featured a small purple box with black text. However, this design posed issues with low contrast and readability. To address this, we opted for a larger red container (the same colour tone as the main menu) with white text, ensuring better visibility and legibility. The information button persisted in the interface, as it worked seamlessly with this approach, allowing the user to recall what needed to be done at any time, as seen in the figure 5.10.

5.2.5 Stationary Experiences' Interface

Monument Showcase

The simplicity of this experience's mechanics is evident in its user interface, which features only two sliders for interaction with the monument, to rotate and set the distance from the user. It is accompanied by a button that allows users to conclude the experience and return to the main menu, as seen in the figure 5.10.

Justice Guess

In this experience, we positioned the dialogue container at the top, prompting players to identify the video corresponding to Courage, Prudence, Temperance, or Peace. The top placement allowed users to quickly close the dialogue, ensuring an unobstructed view of the content before them, while positioning the "end" button at the bottom.

Once the user is confident in their response and clicks the "end" button, the solution to the "riddle" is revealed, and they can then return to the main menu.

5.2.6 Virtual Navigation Experience Interface

To guide users in understanding the interactions, actions, and reflections within the environment, we chose to split the textual content into two components: CTAs (Calls to Action) providing clear instructions on user actions, delivered through dialogue boxes at the start of each experience, and detailed narratives featuring thought-provoking questions and historical quotes. The narratives are presented using "separators", encouraging users to contemplate and establish context for the upcoming or preceding experiences. For instance, after the first experience, the app shows an eye with a scale inside its pupil. This is also done purposefully to transition to another scene since suddenly changing the inside of the monument would not feel natural.

Initially, we considered incorporating a 3D model of a scale throughout the experiences, allowing users to click on it to reveal detailed narratives. However, we opted for alternative solutions, recognizing the potential for users to overlook this experience and the risk of overcrowding the monument's interior with interactive objects.

To solve the problem, we decided to include separators between each experience (figure 5.15), resulting in a more fluid play-through and ensuring f would not miss every part of the app.

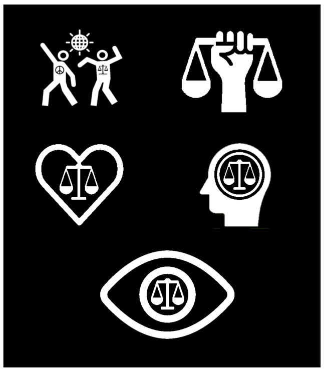

Figure 5.15: The five separators

5.3 Conclusion

We designed an interface to present it in the most straightforward manner possible, ensuring easy usability for every user. Additionally, we explored various methods to convey information in an AR setting.

In the upcoming chapter, we will evaluate the app by engaging users without prior experience with it. Our focus will be assessing their ability to navigate and utilize the app seamlessly, specifically evaluating their completion of each sub-experience. Through this research, we aim to gain valuable insights into the user experience and identify potential challenges or improvement areas.

Chapter 6

Testing and Evaluation

This chapter provides a detailed description of the user tests conducted and their outcomes. Two types of tests were carried out—one focusing on the virtual navigation part of the application and the other on stationary experiences. Only one survey was designed for both tests and was administered in the exact location, involving varying numbers of volunteers.

6.1 Questionnaires

In the usability test of the application, the experiences created for the narrative were evaluated, including augmented reality, virtual navigation, and interaction with the virtual world. There was no script since every instruction was present in each experience.

After completing the three experiences, volunteers are encouraged to fill out a questionnaire about the tested tools, where they can express their opinions and provide additional comments they wish to include. The questionnaire includes various demographic questions about the volunteers (age, gender, and experience with AR/VR applications), 6 questions with responses on a Likert scale from 1 to 5 to measure if the use of the employed techniques meets the volunteer's expectations, 3 questions to check if the user completed certain tasks, 7 questions to receive feedback on each sub-experience, and a form on the system's usability (System Usability Scale), translated to Portuguese using an official form [52]. The utilized questionnaire is included in Annex .1.

The System Usability Scale (SUS) is a widely used questionnaire-based method for assessing the perceived usability of a system. It is designed to be a quick and simple way to gather subjective feedback from users about the usability of a system or product [14]. The SUS questionnaire consists of ten statements that users respond to using a five-point Likert scale, ranging from "Strongly Disagree" to "Strongly Agree." The statements are designed to cover various aspects of usability, including learnability, efficiency, and user satisfaction. After collecting responses, a formula is applied to convert the individual scores into a single usability score, which can range from 0 to 100.

6.2 Testing Sessions

The tests were conducted in person with users at different locations, there was no time limit for these tests, but they all took around 10 minutes. After completing the test, volunteers, if desired, could navigate through the application or repeat some experiences.

The first session took place at Escola Secundária Rainha Dona Leonor, during an afternoon with the school's teachers and students. However, the students were unable to complete the entire session as they had to leave early. In this session, the styrofoam column was used for the stationary experiences (figure 6.1). The rest of the sessions were held in the Faculdade de Ciências da Universidade de Lisboa over weeks with students, friends, and Family. In these sessions, it was used a column of a building for the stationary experiences.

The participants were asked to follow the main application's instructions and then switch to the application where the stationary experiences are located. Only when completing both application tests was the user asked to complete the questionnaire on their phones. The device used for testing was the same across every test: a Xiaomi phone, Poco X3 Pro, with the "Android 13" operating system, 8Gb of RAM, and the app "ARJustiça" already installed and opened. All participants participated voluntarily, and the sessions unfolded as follows:

1. Introduction to the justice-themed app and what the project is about.
2. Completion of the virtual navigation experience.
3. Completion of the stationary experiences.
4. Completing the online form.

During the tests, the interviewer accompanied the user.

6.3 Participants

The first step was identifying the type of volunteer needed for the App. Since the App is supposed to work on everyone, there was no restriction on the volunteers who tested it. Therefore, anyone willing to participate could partake in the testing.

Thirty participants were experimenting with the AR technology, ranging from different work areas, with the most common being IT, with 15 participants. The age ranges of the volunteers were as follows: 21 participants aged between 19 and 25, 3 participants aged between 26 and 40, and 6 participants aged above 40.(figure 6.2). Only 13 participants had contact with Virtual Reality and Augmented Reality. Games had seven responses for VR Apps, two for VRChat, and one for Temple Run. Pokémon GO is the most used AR app/game, with five responses. Invizimals have two responses, and games have three.

Figure 6.1: Testing session in the Escola Rainha Dona Leonor

6.4 Test results

The tables 6.1, 6.2, 6.3, 6.4, and figure 6.3 present the result's completion rate, frequency, and SUS score.

6.4.1 Task Accomplishments and SUS test results

When the user starts the experience, he is asked to look for the scale of justice, which requires looking around for the first time and clicking on it. After completing the task, as mentioned before, the scene changes to a megaphone with six objectives after picking it up (touching the megaphone).

The table 6.1 shows the vast majority accomplished both tasks, which is positive. However, many users had trouble finding the megaphone, which was on the ground beneath them, and on top of that, there was a UI element stating what they should do, not letting them see the object, so they were hinted that the UI element should be closed. If they kept having trouble, which happened to some participants, they were told there was an icon saying objective with a distance to it. We must explore effective ways of placing objects to ensure users can intuitively locate them. Additionally, the organization of the UI should seamlessly fit within the experience screen.

Following the initial two experiences, users are prompted to select the objects that align most closely with their sense of justice. This involves reading about each object after clicking on it.

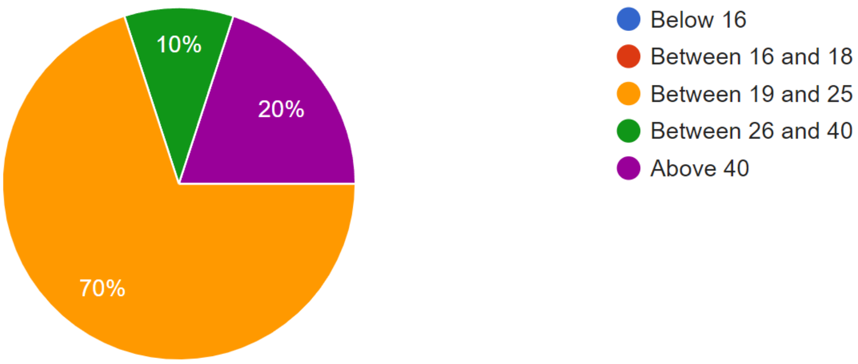

Figure 6.2: Age range of participants

Experience	Completed (%)	Not Completed (%)
Finding the Scale of Justice	96.7	3.3
Go through all the objectives with the megaphone	96.7	3.3

Table 6.1: The percentage of completion of the scale of justice and protesting experiences (question 11 and 12)

Question 13 (table 6.2) is related to the rest of the experiences and is divided into three. Question 13.1 asked the opinion of the participant about the text that describes each object (”In the selection of the three justice-related objects, the text describing each object is elucidating.”) Question 13.2 concerns the execution of the final experience (”In the final experience of combining two objects, there were no difficulties encountered,”) and Question 13.3 relates to achieving the objective of the experience (”The experiences made me reflect on justice.”)

The results of question 13.1 show that most participants understood what each object represented, meaning users can easily understand what is being conveyed when inspecting the object. Some participants had to have help, so they understood that they needed to click the objects to obtain more information.

The results of question 13.2 show that the majority comprehended combining two objects in the choice experience (the fourth one). However, this also implies that certain participants encountered task challenges. Consequently, it suggests exploring alternative instructions beyond textual guidance for a more effective experience.

The results of question 13.3 show that most participants reflected on justice, except for four people. This can be true about a shallow sense of justice. Still, while testing, the vast majority of participants did not show deep signs of interest in justice, opening an area to explore further how to create Augmented Reality content on a deeper level of education or entertainment for the user, perhaps by creating a better narrative through the use of storytelling [81].

The experience ”Justice Guess” has the user looking at 4 videos and answering which virtue corresponds to which video.

Frequency	Q13.1	Q13.2	Q13.3
1	1	3	4
2	2	4	0
3	6	4	9
4	12	12	9
5	9	7	8

Table 6.2: Frequency of the responses from the question 13

Frequency	Q21.1	Q21.2	Q21.3
1	0	0	0
2	1	1	1
3	1	2	2
4	5	3	14
5	23	24	13

Table 6.3: Frequency of the responses from the question 21

As depicted in the figure 6.3, most users got at least one of the allegories right, which implies this type of experience works well, given the technology restrictions mentioned before, but a better representation of each allegory could result in better results and consequently an overall better experience for the user.

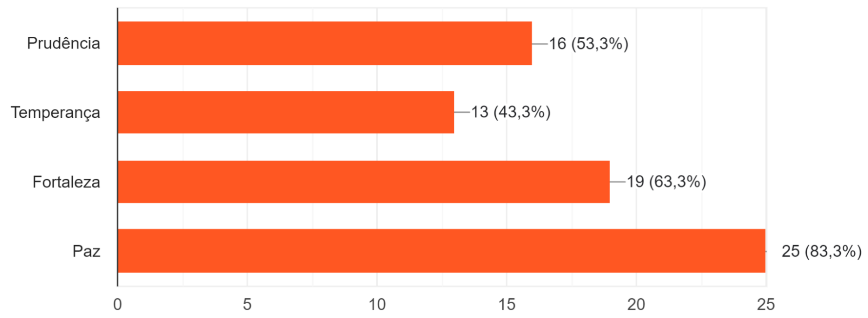

Figure 6.3: Frequency of the virtues guessed

Table 6.3 shows the responses from the users about question 21 regarding the visualization of the outside of the monument; similar to question 13, it is structured into three distinct sub-questions. Question 21.1 asked the participant, ”It was easy to rotate the monument.” question 21.2 asked, ”It was easy to move the monument apart and bring it closer.” and question 21.3 asked, ”In all experiences, the help cues provided the necessary information.”

The responses’ values are almost all ”Agree” or ”Strongly Agree,” meaning that the UI and the stationary type of experience make up for an intuitive experience and that in every experience, there was enough information to understand what to do.

Table 6.4 presents the results of SUS tests, offering a snapshot of user perceptions and

Number of tests conducted	Average SUS score
30	68,75

Table 6.4: Average value assigned by users in the SUS.

experiences regarding the system's usability.

6.4.2 Open-ended Questions

Since this type of technology has not been researched a lot in art, there was a need to ask open-ended questions to assess our strengths and weaknesses comprehensively. Questions 14 to 17 ask participants about commentary on experiences 1 to 4 of the virtual navigation, respectively, while question 18 asks about commentary concerning experiences overall.

In terms of improvements and future work, these were the most frequently mentioned implementation suggestions:

- Find a better solution to make clickable objects more intuitive to interact with.
- Enhance user understanding of object types, interactability, and interaction methods.
- Identify an improved resolution to make users understand each experience's meaning.
- Enhance the user interface to guide users more effectively in understanding available actions and choices.
- Address the bug related to movable objects falling through the floor due to interaction of the physics engine from Unity, specifically focusing on scenarios that were not completely resolved.
- Enhance the user experience by resolving the challenge of locating interactable objects in scenarios where they may be positioned in a way that makes them difficult for users to find and interact with.
- Improve overall experiences by crafting a cohesive narrative where messages unfold through user actions, avoiding reliance on pre-experience text. This ensures a more engaging and impactful user journey, steering away from disconnected mini-experiences.

6.5 Conclusion

The results obtained in the several tests were positive. Users generally found the app easy to use but encountered challenges at specific points, which is visible in the mean score of 68,75 from the SUS tests, an "OK" result according to Bangor [12]. However, there are still numerous challenges to using the app intuitively without any external help, such as improving clickable objects' usability, clarifying user understanding, resolving falling object issues due to physics engine implementation, enhancing the overall user experience by crafting a cohesive narrative, and improving interface guidance.

The upcoming chapter will give a brief overview of the results presented, accompanied by considerations for potential future implementations. These insights are drawn from the feedback received during testing and the unresolved issues identified throughout this project.

Chapter 7

Conclusion

This project aimed to develop an app that allowed users to experience art more interactively, so that they experience a narrative while interacting with the virtual world, for a more profound and impacting experience. To achieve this, it was researched the best way to align the virtual content with the real world, many development tools were tested, and various experiences were created.

An operational application was developed and tested with volunteers who were unaware of the experiences they would encounter beforehand. Users who engaged with the application provided positive feedback, expressing enthusiasm for observing art-related content through interactive experiences. Although the majority of participants seemed confused about the overall narrative and the meaning of each experience, they viewed each interaction as a separate action to complete rather than understanding the broader concept the app was trying to convey.

In this last chapter, it is described the acquired skills, challenges found during the development of the project, and finally future work.

7.1 Acquired skills

The project work resulted in the acquisition of skills across various tools and applications:

- Engaging in software development, analyzing problems, collecting requirements, and putting design and implementation into practice have provided valuable experience and learning opportunities that will significantly contribute to one's professional career.

- Acquiring expertise in augmented reality technology, the development tools needed to produce experiences, various techniques used, and development engines. Various tools have been implemented on the Android operating system.

  - In Unity, basic features such as creating scenes, importing models, and setting up the interface for the app, but also specifying which operating system the app is going to take, which packages to use, and setting the minimum version for Android.

- In Vuforia, essential functionalities such as placing an object on the ground or air to more advanced use of the API, such as using Unity's physics engine to make an environment where people can interact with objects by picking them up, or to manipulate the tracking during the experience.

- The growth and learning gained while working on an extensive project, involving only one artist. This experience enhanced communication skills, due to the collaboration needed for a person without an IT background, to develop experiences about art. It underscored the potential impact our opinions can have on decision-making processes.

7.2 Challenges found

One of the significant challenges encountered in this project involved collaboration with an artist who was not familiar with application development and IT-related tasks. At the project's start, it was necessary to clarify the possibilities and limitations within an AR setting, taking into account technological constraints. The artist presented her ideas, and subsequent discussions centered on their feasibility and potential user appeal. This collaborative process proved pivotal, specially when presenting ideas to the artist that would align with the artist's ideas, which proved the potential of this kind of technology in the creative process.

Furthermore, the organization and creation of all the content for the narrative and experiences, including images, videos, and audio files, proved to be challenging.

In particular, the most challenging part of the creation of AR experiences was the objects' placement, considering that the capability to manipulate objects was developed entirely from scratch. In addition, using the Unity engine in the context of augmented reality also proved challenging due to certain issues inherent to its use in this AR setting, which the engine does not address or anticipate, for instance, objects falling off to infinity due to gravity, when tracking was lost and users placing the objects under the floor making them fall as well. Beyond manipulating objects, dynamically placing them presented a challenge, as they would manifest in varying locations between each tracking session.

Coming up with a solution to implement image-based tracking using the gyroscope proved to be a big challenge when testing and developing tracking solutions since it took a lot of trial and error with distance values and camera correction, due to the difference of coordinate systems, as stated before.

7.3 Future work

Vuforia was the SDK chosen given the cross-platform requirement and has a lot of features that were not explored in this project due to its scope, which was projected to be used firstly in gardens that had brightness issues of outdoor environments, and then it was switched to be used in indoor environments. Such features and other SDKs such as ARCore could make the experiences more interactive or make the experiences work in other settings. Examples of these features are:

- Vuforia's Area Targets, which allow creating experiences tied to specific physical locations or objects, to seamlessly integrate AR content with specific physical spaces, such as walls, floors, or tables.

- Vuforia's Model Targets that allow the recognition and tracking of three-dimensional objects as targets

- ARCore Depth API, which is designed to enable more realistic occlusion in augmented reality (AR) experiences using a single camera, makes for a realistic experience.

- ARCore and ARKit Light Estimation, allow developers to adjust virtual content to match the real-world lighting for a more seamless integration.

Another important issue that was not covered is the ability to make the user understand how to interact with the AR world, even if the application's UI is intuitive, many users may not be able to complete the app's tasks, due to the high percentage of people that have not had any experience with AR. Such tasks are:

- Marker Recognition: Begin the experience by placing the content, either by looking at the marker, aligning with the semi-transparent image, or any other means of tracking placement.

- Interaction: Interacting with different types of objects (movable, fixed, clickable).

- Understanding what the current objective is, and how to complete it.

- Spatial Understanding: some users have a hard time understanding when they can move in the real world, or when they can not.

- Application's specific content: AR applications with complex features or interactions may have a steeper learning curve, depending on what content they have.

A possible way to tackle that problem is to implement dynamic tutorials, that require the user to interact with bits of the application, so later on they fully understand what they have to perform. This may be a better solution, other than tutorials where the user has to watch a video or read text, since during tests, users tended to skip instructions and informative texts.

Once the optimal method of guiding the user is identified, it is equally crucial to explore the effective communication of that message, specifically concerning the placement of the user interface (UI), due to the limited screen size of the device for both the experience and the instructions at the same time. One potential approach involves presenting instructions overlaid on the objects within the scene. This strategy aims to enhance the user experience by ensuring a more seamless interaction, considering users are likely to explore the surroundings and may overlook UI text.

Users did not show much interest in the application's narrative or were confused by it; therefore, a better understanding of how to develop a coherent narrative that engages the audience should be looked into. This means crafting a cohesive storyline within an AR application, involving constructing a narrative that not only guides the user but also entertains and captivates their attention. The challenge lies in striking a balance between delivering information and providing an engaging experience. An effective narrative should feel immersive, making users feel like active participants in the story. Incorporating elements of entertainment ensures that the user remains invested and intrigued, enhancing the overall experience. Moreover, considering replayability value adds an extra layer of depth to the narrative, encouraging users to revisit the application, discover new aspects, and enjoy a fresh experience with each interaction.

While the outcome of instant tracking aligned with our initial vision, it came with its own set of challenges. During the development of a solution for implementing image-based tracking through the device's gyroscope, numerous instances required the manual adjustment of object and camera positions through a trial-and-error process. Even after the tracking system was implemented, the camera's position underwent similar modifications to precisely align the real object with its virtual counterpart. This adjustment was crucial for users to seamlessly align and view both objects in an overlaid manner. To reduce the development time for instant tracking apps, it is advisable to explore improved solutions for positioning the camera and objects.

The development of the instant tracking feature involved deactivating Vuforia's tracking engine and utilizing the device's gyroscope to adjust the camera's rotation values. While this approach appeared effective, it came at the expense of a reduced frame rate. This decrease was not affected by the scene's geometry complexity, as the objects had a low vertex count, nor was it influenced by the engine's render quality, as switching to a performance mode did not yield any improvement. For the development of future apps incorporating image-based tracking, it is essential to employ alternative tools to ensure a more seamless experience.

In the third and fourth experiences within the virtual navigation section of the app, users experienced confusion regarding the next steps, particularly when finding themselves positioned directly above the object they intended to observe or interact with. Conducting research on effective object placement within a scene is crucial to enhance the app's intuitiveness.

Employing various AR tools, we successfully developed an app that allows users to engage with a virtual world through movement and interaction with the virtual scene. Although initially conceived as an Augmented Reality application, the outcome leaned towards Augmented Virtuality. Exploring additional functionalities of different AR SDK tools could offer techniques to incorporate real-world objects more significantly within the app, thereby reinstating its status as Augmented Reality rather than Augmented Virtuality.

Bibliography

[1] Acute art. https://acuteart.com/, 2022. [Online - Accessed on 13-12-2022].

[2] Appleinsder. https://appleinsider.com/inside/arkit, 2022. [Online - Accessed on 11-12-2022].

[3] Durga Prasad Acharya. 9 best augmented reality sdks to build creative apps. https://geekflare.com/best-augmented-reality-sdk/, 2023. [Online - Accessed on 16-10-2023].

[4] Alex David Morales Acosta, Sergio Antonio Sánchez Hernández, Héctor Urzola Berrio, Julio Álvarez Month, Miriam Consuelo Martín León, and Julián Garib Barrera González. Augmented and virtual reality for the strengthening of education in the marina museum park. *Migration Letters*, 21(S1):994–1002, 2024.

[5] Dhiraj Amin and Sharvari Govilkar. Comparative study of augmented reality sdks. *International Journal on Computational Science & Applications*, 5(1):11–26, 2015.

[6] José Gabriel Andrade and Patrícia Dias. A phygital approach to cultural heritage: augmented reality at regaleira. *Virtual Archaeology Review*, 11(22):15–25, 2020.

[7] Apple. Arkit documentation. https://developer.apple.com/documentation/arkit, 2022. [Online - Accessed on 11-12-2022].

[8] Apple. Arkit documentation. https://developer.apple.com/documentation/arkit, 2023. [Online - Accessed on 17-10-2023].

[9] Ronald Azuma, Jong Weon Lee, Bolan Jiang, Jun Park, Suya You, and Ulrich Neumann. Tracking in unprepared environments for augmented reality systems. *Computers & Graphics*, 23(6):787–793, 1999.

[10] Ronald T Azuma. A survey of augmented reality. *Presence: teleoperators & virtual environments*, 6(4):355–385, 1997.

[11] Ronald T Azuma et al. The challenge of making augmented reality work outdoors. *Mixed reality: Merging real and virtual worlds*, 1:379–390, 1999.

[12] Aaron Bangor, Philip Kortum, and James Miller. Determining what individual sus scores mean: Adding an adjective rating scale. *Journal of usability studies*, 4(3):114–123, 2009.

[13] Mafkereseb Kassahun Bekele, Roberto Pierdicca, Emanuele Frontoni, Eva Savina Malinverni, and James Gain. A survey of augmented, virtual, and mixed reality for cultural heritage. *Journal on Computing and Cultural Heritage (JOCCH)*, 11(2):1–36, 2018.

[14] John Brooke. Sus: a “quick and dirty’usability. *Usability evaluation in industry*, 189(3):189–194, 1996.

[15] byAR<. byar. `https://www.byar.pt/`, 2022. [Online - Accessed on 21-12-2022].

[16] Demetra-Bianca Chirica and Adrian Iftene. Enhancing the visit of the botanical garden of iasi with the help of smart devices and augmented reality. In *Proceedings of the Conference on Mathematical Foundations of Informatics MFOI2020, Kyiv, Ukraine*, pages 78–87, 2021.

[17] Adam Conway. Google arcore: Everything you need to know about the augmented reality platform. `https://www.xda-developers.com/arcore/`, 2023. [Online - Accessed on 28-11-2023].

[18] Valve Corporation. Half-life. `https://store.steampowered.com/franchise/Half-Life`, 2024. [Online - Accessed on 10-04-2024].

[19] Eleanor E Cranmer, M Claudia tom Dieck, and Paraskevi Fountoulaki. Exploring the value of augmented reality for tourism. *Tourism Management Perspectives*, 35:100672, 2020.

[20] Game UI Database. Firewatch. `https://www.gameuidatabase.com/gameData.php?id=238`, 2023. [Online - Accessed on 04-12-2023].

[21] Ankit Dave. Why choose unity 3d for your next game development project? `https://www.mindinventory.com/blog/unity-3d-game-development/`, 2023. [Online - Accessed on 18-10-2023].

[22] Stack Exchange Game Development. Unity gyroscope orientation (attitude) ”wrong”. `https://gamedev.stackexchange.com/questions/174107/unity-gyroscope-orientation-attitude-wrong`, 2019. [Online - Accessed on 10-04-2024].

[23] EnhanceXR. Ar compatibility: Everything you need to know about it. `https://www.ienhance.co/insights/ar-compatibility-everything-you-need-to-know-about-it`, 2023. [Online - Accessed on 28-11-2023].

[24] Alexander José Pereira Fernandes. *Soluções para alinhamento em realidade aumentada móvel.* Master dissertation, Faculdade de Ciências da Universidade de Lisboa, 2018.

[25] Source Forge. Wikitude reviews and pricing 2023. https://sourceforge.net/software/product/Wikitude/, 2023. [Online - Accessed on 16-10-2023].

[26] Frictional Games. Amnesia re-collection. https://store.steampowered.com/bundle/20170/Amnesia_Recollection/, 2024. [Online - Accessed on 10-04-2024].

[27] Gamespot. Unreleased half-life episodic game featured a magnet gun. https://www.gamespot.com/articles/unreleased-half-life-episodic-game-featured-a-magn/1100-6426877/, 2023. [Online - Accessed on 04-12-2023].

[28] Google. Arcore. https://developers.google.com/ar, 2022. [Online - Accessed on 11-12-2022].

[29] Google. Artvive. https://artivive.com/, 2022. [Online - Accessed on 11-12-2022].

[30] Google. Google arts & culture. https://artsandculture.google.com/, 2022. [Online - Accessed on 11-12-2022].

[31] Francisco Guimarães, Mauro Figueiredo, and José Rodrigues. Augmented reality and storytelling in heritage application in public gardens: Caloust gulbenkian foundation garden. In *2015 Digital Heritage*, volume 1, pages 317–320. IEEE, 2015.

[32] Zeya He, Laurie Wu, and Xiang Robert Li. When art meets tech: The role of augmented reality in enhancing museum experiences and purchase intentions. *Tourism Management*, 68:127–139, 2018.

[33] Software Testing Help. Top 14 augmented reality companies. https://www.softwaretestinghelp.com/augmented-reality-companies/, 2023. [Online - Accessed on 03-10-2023].

[34] Tsuneo Ichiguchi. the left-handed and right-handed coordinate systems. https://www.researchgate.net/figure/athe-left-handed-and-b-right-handed-coordinate-systems_fig1_45935344, 2023. [Online - Accessed on 30-10-2023].

[35] PTC Inc. Vuforia acquisition. https://investor.ptc.com/resources/news/news-details/2015/PTC-Completes-Acquisition-of-Vuforia/default.aspx, 2015. [Online - Accessed on 16-10-2023].

[36] PTC Inc. Best practices for designing and developing image-based targets. https://library.vuforia.com/objects/

best-practices-designing-and-developing-image-based-targets, 2023. [Online - Accessed on 30-10-2023].

[37] PTC Inc. Ground plane | vuforia library. https://library.vuforia.com/environments/ground-plane, 2023. [Online - Accessed on 27-10-2023].

[38] PTC Inc. Ground plane in unity | vuforia library. https://developer.vuforia.com/library/ground-plane/introduction-ground-plane-unity, 2023. [Online - Accessed on 30-11-2023].

[39] PTC Inc. Vuforia device tracking. https://library.vuforia.com/environments/device-tracking, 2023. [Online - Accessed on 26-10-2023].

[40] PTC Inc. Vuforia engine overview. https://library.vuforia.com/getting-started/vuforia-features, 2023. [Online - Accessed on 16-10-2023].

[41] PTC Inc. Vuforia engine pricing. https://www.ptc.com/en/products/vuforia/vuforia-engine/pricing, 2023. [Online - Accessed on 16-10-2023].

[42] PTC Inc. Vuforia fusion|vuforia library. https://library.vuforia.com/environments/vuforia-fusion, 2023. [Online - Accessed on 27-10-2023].

[43] PTC Inc. Vuforia library overview. https://library.vuforia.com/, 2023. [Online - Accessed on 16-10-2023].

[44] PTC Inc. Vuforia recommended devices. https://library.vuforia.com/platform-support/recommended-devices, 2023. [Online - Accessed on 16-10-2023].

[45] Ace infoway. 7 most powerful ar sdks and frameworks for app development. https://www.aceinfoway.com/blog/ar-sdk-and-frameworks, 2023. [Online - Accessed on 16-10-2023].

[46] Josh Jaffe. Comparing arkit vs arcore vs vuforia: The best augmented reality toolkit. https://bluewhaleapps.com/blog/comparing-arkit-vs-arcore-vs-vuforia-the-best-augmented-reality-toolkit, 2022. [Online - Accessed on 12-12-2022].

[47] Timothy Jung, M Dieck, Hyunae Lee, and Namho Chung. Effects of virtual reality and augmented reality on visitor experiences in museum. In *Information and communication technologies in tourism 2016*, pages 621–635. Springer, 2016.

[48] Ashwini KB, Preethi N Patil, et al. Tracking methods in augmented reality–explore the usage of marker-based tracking. In *Proceedings of the 2nd International Conference on IoT, Social, Mobile, Analytics & Cloud in Computational Vision & Bio-Engineering (ISMAC-CVB 2020)*, 2020.

[49] Soo Kyun Kim, Shin-Jin Kang, Yoo-Joo Choi, Min-Hyung Choi, and Min Hong. Augmented-reality survey: from concept to application. *KSII Transactions on Internet and Information Systems (TIIS)*, 11(2):982–1004, 2017.

[50] Kiyoshi Kiyokawa. Trends and vision of head mounted display in augmented reality. In *2012 International Symposium on Ubiquitous Virtual Reality*, pages 14–17, 2012.

[51] Diana Marques. Skin bones augmented reality app. https://dianamarques.com/portfolio-museum-exhibits/augmented-reality-app-skin-bones, 2022. [Online - Accessed on 11-12-2022].

[52] Ana Isabel Martins, Ana Filipa Rosa, Alexandra Queirós, Anabela Silva, and Nelson Pacheco Rocha. European portuguese validation of the system usability scale (sus). *Procedia computer science*, 67:293–300, 2015.

[53] Meta. Spark ar. https://www.facebook.com/business/tools/spark-ar-studio, 2022. [Online - Accessed on 11-12-2022].

[54] Paul Milgram and Fumio Kishino. A taxonomy of mixed reality visual displays. *IEICE TRANSACTIONS on Information and Systems*, 77(12):1321–1329, 1994.

[55] Paul Milgram, Haruo Takemura, Akira Utsumi, and Fumio Kishino. Augmented reality: A class of displays on the reality-virtuality continuum. In *Telemanipulator and telepresence technologies*, volume 2351, pages 282–292. Spie, 1995.

[56] Moiseum. Daily art. https://www.getdailyart.com/, 2023. [Online - Accessed on 27-09-2023].

[57] Claudete Oliveira Moreira. Portugal as a tourism destination. paths and trends. *Méditerranée. Revue géographique des pays méditerranéens/Journal of Mediterranean geography*, (130), 2018.

[58] Barbara Neuhofer, Dimitrios Buhalis, and Adele Ladkin. A typology of technology-enhanced tourism experiences. *International journal of tourism research*, 16(4):340–350, 2014.

[59] Smithsonian's National Museum of Natural History. Smithsonian brings historic specimens to life in free “skin and bones” mobile app. https://www.si.edu/newsdesk/releases/smithsonian-brings-historic-specimens-life-free-skin-and-bones-mobile-app, 2022. [Online - Accessed on 11-12-2022].

[60] orange media group. orange media group exhibit. https://orangemedia.me/services-digital.html#all-6, 2023. [Online - Accessed on 28-11-2023].

[61] Mauro Pichiliani. Rastreamento de objetos em realidade virtual e realidade aumentada. In *Anais Estendidos do XXII Simpósio de Realidade Virtual e Aumentada*, pages 59–60, Porto Alegre, RS, Brasil, 2020. SBC.

[62] PNGITEM. 6 dof. https://www.pngitem.com/middle/hRhbhm_kinect-joint-rotation-pitch-yaw-roll-unity-hd/, 2024. [Online - Accessed on 09-04-2024].

[63] Xiuquan Qiao, Pei Ren, Schahram Dustdar, Ling Liu, Huadong Ma, and Junliang Chen. Web ar: A promising future for mobile augmented reality—state of the art, challenges, and insights. *Proceedings of the IEEE*, 107(4):651–666, 2019.

[64] Xiuquan Qiao, Pei Ren, Guoshun Nan, Ling Liu, Schahram Dustdar, and Junliang Chen. Mobile web augmented reality in 5g and beyond: Challenges, opportunities, and future directions. *China Communications*, 16(9):141–154, 2019.

[65] Qualcomm. Wikitude. https://www.wikitude.com/, 2022. [Online - Accessed on 11-12-2022].

[66] Ihsan Rabbi and Sehat Ullah. A survey on augmented reality challenges and tracking. *Acta graphica: znanstveni časopis za tiskarstvo i grafičke komunikacije*, 24(1-2):29–46, 2013.

[67] Jannick P Rolland, Richard L Holloway, and Henry Fuchs. Comparison of optical and video see-through, head-mounted displays. In *Telemanipulator and Telepresence Technologies*, volume 2351, pages 293–307. SPIE, 1995.

[68] Campo Santo. Firewatch. https://www.firewatchgame.com/, 2024. [Online - Accessed on 10-04-2024].

[69] Sothebys. Sothebys. https://www.sothebys.com/en/about/sothebys-apps, 2023. [Online - Accessed on 27-09-2023].

[70] Maximilian Speicher, Brian D Hall, and Michael Nebeling. What is mixed reality? In *Proceedings of the 2019 CHI conference on human factors in computing systems*, pages 1–15, 2019.

[71] Jakob Kudsk Steensen. The deep listener - serpentine augmented architecture. https://experiments.withgoogle.com/augmentedarchitecture, 2022. [Online - Accessed on 11-12-2022].

[72] Ivan E Sutherland. A head-mounted three dimensional display. In *Proceedings of the December 9-11, 1968, fall joint computer conference, part I*, pages 757–764, 1968.

[73] Unity Technologies. Unity - scripting api: Gyroscope. https://docs.unity3d.com/ScriptReference/Gyroscope.html, 2023. [Online - Accessed on 30-10-2023].

[74] Unity Technologies. Unity software de desenvolvimento de realidade aumentada. https://unity.com/pt/unity/features/ar, 2023. [Online - Accessed on 28-11-2023].

[75] Unity Technologies. Welcome to unity. https://unity.com/our-company, 2023. [Online - Accessed on 18-10-2023].

[76] Bárbara Pires Teixeira. *Realidade Aumentada aplicada às Artes Plásticas.* Master dissertation, Faculdade de Ciências da Universidade de Lisboa, Started in 2021.

[77] Impossible Things. Reblink. https://www.impossiblethings.co/project/reblink/, 2022. [Online - Accessed on 11-12-2022].

[78] M Claudia tom Dieck and Timothy Hyungsoo Jung. Value of augmented reality at cultural heritage sites: A stakeholder approach. *Journal of Destination Marketing & Management*, 6(2):110–117, 2017.

[79] Rafael Rosado Torres. *Experiências de Realidade Aumentada Móvel para o Jardim Botânico Tropical.* Master dissertation, Faculdade de Ciências da Universidade de Lisboa, 2020.

[80] Stavroula Tzima, Georgios Styliaras, and Athanasios Bassounas. Augmented reality in outdoor settings: Evaluation of a hybrid image recognition technique. *Journal on Computing and Cultural Heritage (JOCCH)*, 14(3):1–17, 2021.

[81] Marcelo M Valença and Ana Paula Balthazar Tostes. O storytelling como ferramenta de aprendizado ativo. *Carta Internacional*, 14(2), 2019.

[82] Xiangyu Wang, Soh K Ong, and Andrew YC Nee. A comprehensive survey of augmented reality assembly research. *Advances in Manufacturing*, 4(1):1–22, 2016.

[83] WhatCulture. 10 video game moments so scary you stopped playing. https://whatculture.com/gaming/10-video-game-moments-so-scary-you-stopped-playing-2?page=9, 2023. [Online - Accessed on 04-12-2023].

[84] Wikipedia. Levada. https://pt.wikipedia.org/wiki/Levada, 2022. [Online - Accessed on 19-12-2022].

[85] Wikitude. 3d tracking for large-scale scenes. https://www.wikitude.com/blog-wikitude-large-scale-3d-tracking/, 2023. [Online - Accessed on 17-10-2023].

[86] Wikitude. Wikitude documentation - expert edition. https://www.wikitude.com/external/doc/expertedition/, 2023. [Online - Accessed on 17-10-2023].

[87] Wikitude. Wikitude product and services end-of-life announcement. `https://www.wikitude.com/blog-product-and-services-sunset/`, 2023. [Online - Accessed on 17-10-2023].

[88] Feng Zhou, Henry Been-Lirn Duh, and Mark Billinghurst. Trends in augmented reality tracking, interaction and display: A review of ten years of ismar. In *2008 7th IEEE/ACM International Symposium on Mixed and Augmented Reality*, pages 193–202. IEEE, 2008.

.1 Apendix A: Questionnaire

Formulário RA aplicada às Artes Plásticas

Este formulário serve para avaliar a aplicação e perceber eventuais problemas para serem resolvidos no futuro

* Indica uma pergunta obrigatória

Consentimento Informado

1. Concordo em participar nesta pesquisa. Entendo que minha participação é voluntária e que tenho total liberdade para desistir do estudo a qualquer momento, sem a necessidade de fornecer explicações e sem sofrer quaisquer consequências *

Marcar apenas uma oval.

- Sim
- Não

2. Entendo que os dados recolhidos durante o estudo possam ser acessados pelos membros da equipa de pesquisa, conforme necessário para o andamento do estudo. Dou minha permissão para que os membros da equipa tenham acesso a esses dados. *

Marcar apenas uma oval.

- Sim
- Não

3. Entendo que, caso esta pesquisa seja publicada, todos os dados serão mantidos de forma anónima e nenhuma informação será identificável como sendo minha. *

Marcar apenas uma oval.

- Sim
- Não

4. Dou a minha permissão para que as minhas respostas possam ser citadas de forma anónima *

Marcar apenas uma oval.

- Sim
- Não

Questionário Demográfico

5. Idade: *

Marcar apenas uma oval.

- Menor de 16
- Entre 16-18
- Entre 19 e 25
- Entre 26 e 40
- Maior de 40

6. Área principal de trabalho/estudo: *

Marcar apenas uma oval.

- Ciências e Tecnologia
- Ciências Socioeconómicas
- Línguas e Humanidades.
- Artes Visuais.
- Informática
- Outra: ______________________

7. Já utilizou aplicações com realidade virtual? *

Marcar apenas uma oval.

- Sim
- Não

8. Se utilizou aplicações de realidade virtual, quais foram?

____

9. Já utilizou aplicações com realidade aumentada? *

Marcar apenas uma oval.

- Sim
- Não

10. Se utilizou aplicações de realidade aumentada, quais foram?

____

Opção "Explorar a Justiça"

11. Consegui encontrar a balança da justiça *

Marcar apenas uma oval.

- [ ] Sim
- [ ] Não

12. Consegui percorrer todos os objetivos com o megafone *

Marcar apenas uma oval.

- [ ] Sim
- [ ] Não

13. *

Marcar apenas uma oval por linha.

	discordo totalmente	discordo	neutro	concordo	concordo totalmente
Na escolha dos 3 objetos relativos à justiça, o texto que descreve cada objeto é elucidativo.	◯	◯	◯	◯	◯
Na experiência final de juntar dois objetos não tive dificuldade.	◯	◯	◯	◯	◯
As experiências fizeram-me refletir sobre a justiça	◯	◯	◯	◯	◯

14. Comentários sobre a experiência da balança

15. Comentários sobre a experiência do megafone

16. Comentários sobre a experiência da escolha dos objetos

17. Comentários sobre a experiência de juntar 2 objetos

18. Comentários e sugestões sobre as experiências apresentadas

Opção "Justiça e Virtudes"

19. Consegui identificar as seguintes alegorias *

Marcar tudo o que for aplicável.

- [ ] Prudência
- [ ] Temperança
- [ ] Fortaleza
- [ ] Paz

20. Comentários sobre a experiência "Justiça e Virtudes"

Opção "Ver o monumento"

21. *

Marcar apenas uma oval por linha.

	discordo totalmente	discordo	neutro	concordo	concordo totalmente
Foi fácil rodar o monumento	◯	◯	◯	◯	◯
Foi fácil afastar e aproximar o monumento	◯	◯	◯	◯	◯
Em todas as experiências as indicações de ajuda forneceram a informação necessária.	◯	◯	◯	◯	◯

22. Comentários sobre a experiência "Ver o monumento"

____

____

____

____

____

Questionário "System Usability Scale" para avaliar a usabilidade da aplicação

Responda

23. *

Marcar apenas uma oval por linha.

	discordo totalmente	discordo	neutro	concordo	concordo totalmente
Acho que gostaria de utilizar a aplicação com frequência.					
Considerei a aplicação mais complexo do que necessário.					
Achei a aplicação fácil de utilizar.					
Acho que necessitaria de ajuda de um técnico para conseguir utilizar esta aplicação					
Considerei que as várias funcionalidades desta aplicação estavam bem integradas.					
Achei que esta aplicação tinha muitas inconsistências.					
Suponho que a maioria das pessoas aprenderia a utilizar rapidamente esta aplicação					

rapidamente esta aplicação.					
Considerei a aplicação muito complicado de utilizar.					
Senti-me muito confiante a utilizar esta aplicação					
Tive que aprender muito antes de conseguir lidar com esta aplicação					