



Augmented Reality for Tourist Routes

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Junho de 2024

Augmented Reality for Tourist Routes

A path to an Immersive Exploration

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**Dissertation to obtain a Master's Degree in
Informatics Engineering, Area of Specialization in
Games, Graphics and Interactive Systems**

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Declaration of Integrity

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I have not plagiarized or applied any form of misuse of information or falsification of results throughout the process that led to its elaboration.

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Dedication

I dedicate this dissertation to my dear mother, who always believed in me, even when I didn't.

Abstract

In the constantly evolving landscape of global tourism, improving the tourist experience through innovative technologies has become fundamental. The tourism sector, a significant contributor to the global economy, continually seeks innovative ways to create unique and engaging experiences for tourists through advanced technological synergy, like augmented reality (AR) applications. However, current tourist AR solutions face the problem of overwhelming tourists with excessive and poorly personalized information, thus compromising the overall experience. This dissertation aims to address this issue by designing and implementing an AR solution that enables tourists to explore routes in a more effective, immersive, and contextually way.

The project seeks to address several key issues, including facilitating easier exploration and navigation, reducing the overload of information, promoting local tourism, and enriching the route experience by making it more educational. By offering personalized information about historical monuments, points of interest, and cultural landmarks, the AR application aims to provide a deeper and meaningful understanding of each location.

The primary objective is to establish a mutual relationship between technology and tourism, where AR serves as a powerful tool to create personalized and enriching experiences. By focusing on location-based AR technology, this study develops a system that dynamically adapts to the user's movements, enhancing exploration and navigation. Two historic routes, one in the city of Porto and the other in the city of Chaves, were created to test the solution, selected for their rich cultural and personal significance for the author. This approach not only tested the applicability of the solution across different environments but also allowed for a comprehensive analysis of user experiences in multiple locations and itineraries.

Ultimately, this dissertation presents conclusions derived from experimentation and statistical data analysis, confirming the successful achievement of its objectives. It also validates the research hypothesis that the implementation of AR technology in tourist routes significantly enhances the efficiency, immersion, and contextualization in the exploration of these itineraries.

Keywords: Augmented Reality, Tourism, Tourist Routes, Tourism Innovation, Tourist Experience.

Resumo

No cenário em constante evolução do turismo global, melhorar a experiência turística através de tecnologias inovadoras tornou-se fundamental. O setor do turismo, um contribuidor significativo para a economia global, procura continuamente formas inovadoras de criar experiências únicas e envolventes para os turistas através de sinergias tecnológicas avançadas, como aplicações de realidade aumentada (AR). No entanto, as atuais soluções turísticas de AR enfrentam o problema de sobrecarregar os turistas com informações excessivas e pouco personalizadas, comprometendo assim a experiência geral. Esta dissertação pretende abordar esta questão através da conceção e implementação de uma solução de AR que permita aos turistas explorar rotas de uma forma mais eficaz, imersiva e contextualizada.

O projeto procura abordar várias questões importantes, incluindo facilitar a exploração e navegação, reduzir a sobrecarga de informação, promover o turismo local, e enriquecer a experiência da rota, tornando-a mais educativa. Ao oferecer informações personalizadas sobre monumentos históricos, pontos de interesse e marcos culturais, a aplicação AR visa proporcionar uma compreensão mais profunda e significativa de cada local.

O objetivo principal é estabelecer uma relação mútua entre tecnologia e turismo, onde AR serve como uma ferramenta poderosa para criar experiências personalizadas e enriquecedoras. Ao focar na tecnologia AR baseada em localização, este estudo desenvolve um sistema que se adapta dinamicamente aos movimentos do utilizador, potencializando a exploração e navegação. Duas rotas históricas, uma na cidade do Porto e outra na cidade de Chaves, foram criadas para testar a solução, selecionadas pelo seu rico significado cultural e pessoal para o autor. Esta abordagem não apenas testou a aplicabilidade da solução em diferentes ambientes, mas também permitiu uma análise abrangente das experiências do utilizador em vários locais e itinerários.

Em última análise, esta dissertação apresenta conclusões derivadas da experimentação e da análise de dados estatísticos, afirmando o sucesso na concretização dos seus objetivos. Também valida a hipótese de pesquisa de que a implementação da tecnologia AR em rotas turísticas aumenta significativamente a eficiência, imersão e contextualização na exploração desses itinerários.

Palavras-chave: Realidade Aumentada, Turismo, Rotas Turísticas, Inovação no Turismo, Experiência do Turista.

Acknowledgements

To my advisor, Dr. Carlos Vaz de Carvalho, for all the guidance and help provided throughout this dissertation.

To my close friends, colleagues, and family, for the friendship, companionship and support they offered me throughout this journey. Whether it was helping to clarify doubts about the dissertation itself, assisting with the experimentation of the project, or providing emotional support. Thank you!

To my mother, who is the person who helped me the most, not only in this dissertation, but throughout my entire life and academic path.

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Acronyms

AHP	Analytical Hierarchical Process
API	Application Programming Interface
AR	Augmented Reality
AV	Augmented Virtuality
CI	Consistency Index
CR	Consistency Ratio
FFE	fuzzy front end
GDP	Gross Domestic Product
GPS	Global Positioning System
HOQ	House of Quality
MR	Mixed Reality
NCD	New Concept Development
NPD	New Product Development
POI	Point of Interest
QFD	Quality Function Deployment
RI	Random Index
RTPS	Real-time Positioning Systems
SUS	System Usability Scale
SWOT	Strengths, Weaknesses, Opportunities, Threats
TSG	Technology Stage-Gate
UI	User Interface
UX	User Experience
VC	Virtual Continuum
VR	Virtual Reality

1 Introduction

In the current tourism context, the search for unique and personalized experiences has become crucial for contemporary travelers. The essence of discovering unexplored places, the history of cities and exploring hidden treasures are great desires that drives tourists' curiosity.

This chapter will provide a brief contextualization of tourism and its tourist routes, detailing the challenges that they face along their journeys. Furthermore, it will describe the objectives of this research, which aim to integrate Augmented Reality (AR) as a solution to enhance the tourist experience, offering a more efficient, personalized, and enriching approach for contemporary travelers.

1.1 Initial Context

A tourist route is an itinerary purposely designed to attract tourists due to its points of interest (POI), whether natural, cultural, historical, or other types. These itineraries are notable for their relevance in offering access to locations, encouraging travelers to explore and discover these points of interest.

These routes play a crucial role in promoting a location, highlighting its natural, cultural, and historical riches to attract tourists from all over the world. They not only boost tourism, generating revenue and local employment opportunities, but also play a significant role in preserving cultural and environmental patrimony.

By promoting and directing tourists to specific locations, the routes encourage the conservation and maintenance of these places, ensuring the protection of their historical and environmental value. Furthermore, by increasing the visibility of a location's attractions, they contribute to improving the image of the location, encouraging the development of new cultural and educational projects to further enrich the tourists' experience (Equipe editorial de Conceito, 2016).

An example of a famous route is the Camino de Santiago, a famous pilgrimage route in Europe that is made up of several paths, each starting at different points throughout Europe, whose final destination is Santiago de Compostela, as it is possible to see in Figure 1.

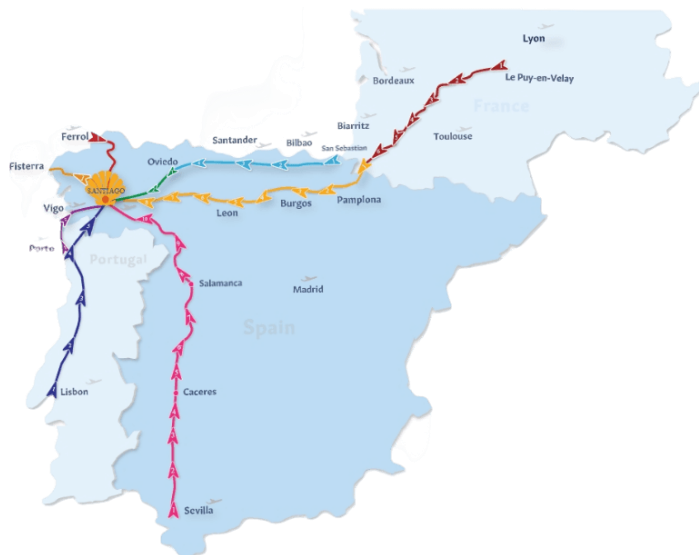


Figure 1 - Camino de Santiago (followthecamino, 2023)

The second most popular route on the Camino de Santiago passes through Portuguese territory and is called the Camino Portugués, which covers several cities in Portugal, such as Lisbon or Porto. From these cities, tourists can discover the best of Portugal and Spain with diverse landscapes, historic cities, and beautiful coastal stretches (followthecamino, 2023).

1.2 Problem

Tourists frequently have challenges when attempting to locate specific and detailed information about the attractions and POIs along their intended routes when visiting new locations. While conventional tour guides provide valuable information, they are not always able to customize their tours to the specific needs of each tourist. This gap becomes evident when a tourist has particular interests, such as exploring medieval areas of the locality, visiting monuments linked to specific historical events or any interested location. Finding detailed information about these aspects can be challenging.

This challenge presents a significant problem for tourists, as they often miss opportunities to explore a specific route in a deeper and contextualized way. Consequently, a lack of detailed information can lead to less satisfactory tourist experiences, leaving the feeling that important aspects were missed during the trip.

Thus, the lack of access to detailed information adapted to tourists' individual preferences can significantly impact the quality of the tourist experience. The absence of specific information can not only limit the traveler's potential to immerse themselves in the history and culture of

the location but also the ability to fully understand the meaning and importance of specific POIs along the route.

Overcoming this barrier becomes essential to improve tourists' journeys, allowing them to explore routes in a more personalized way, pursuing their interests and ensuring a more profound and meaningful understanding of the locations they visit.

1.3 Objectives

The aim of this project is to design and develop an augmented reality application to provide a more personalized and contextualized tourist experience. With this, the solution should solve several problems related to the tourist experience when exploring a tourist route, namely:

- **Facilitate the exploration around the tourist route:** contribute to improving tourist experiences, making them more efficient and immersive, thus reducing the time spent searching for information by tourists and making the time dedicated to exploring their destination more productive.
- **Reduce excess of unnecessary information:** ensure that the experience is relevant and contextual, avoiding overloading tourists with too much information that is unnecessary for the route they want to explore.
- **Promote local tourism:** promote local tourism by encouraging tourists to explore and learn more about destinations, history, and culture.
- **Enhance the educational experience:** incorporate educational elements to enrich the tourist experience with important information about the history, culture and significance of the destinations visited.
- **Improve the personalization and contextualization of the tourist experience:** Helping tourists to choose and follow specific routes will result in an immersive and more contextualized experience.
- **Ensure applicability across multiple touristic routes:** demonstrate the flexibility and effectiveness of the solution by creating and testing routes in different locations, to ensure it can solve problems across multiple tourist contexts.
- **Integrate immersive technologies into tourist exploration:** using augmented reality technology so that tourists have a more immersive and engaging experience.

1.4 Motivation and Hypothesis

The motivation to follow this idea came by my experience during the summer vacation of 2023. During a road trip through several cities in Spain, I had the goal of exploring the main medieval tourist attractions in each location. However, when trying to dive into the medieval history of these cities, I faced difficulties finding detailed and specific information about my specific POIs. This gap in the availability of relevant and contextualized information for the intended route was the main motivation to seek an innovative solution that would enhance the tourist experience for tourists with specific interests in exploring locations.

Consequently, my curiosity about the problem of exploring tourist routes raised useful **research questions** for the solution, such as the follows:

- “Are there studies on the use of augmented reality in tourism that help tourists to explore more efficiently specific tourist routes?”
- “How does an augmented reality solution on specific tourist routes affect the exploration efficiency of tourists?”
- “What impact does an augmented reality-based solution have on tourists' immersive experience when exploring tourist routes?”
- “How does an augmented reality solution improve ease of navigation for tourists when following personalized tourist routes?”
- “What are the challenges and opportunities in implementing an augmented reality solution on tourist routes and how do they affect the tourist experience?”

Therefore, after carrying out brief research into the potential of using augmented reality in tourism, a crucial point was discovered that separates this solution from several other existing ones, which is the use of this technology on tourist routes, so that they are more personalized and contextualized for the tourist.

Given this, the **hypothesis of research** of this solution is to confirm that:

- By implementing augmented reality technology on tourist routes, the exploration of these routes becomes more efficient, immersive, and contextualized.

From the understanding of the gap in the availability of detailed and contextualized information in the exploration of tourist itineraries, the hypothesis arises that the implementation of augmented reality technology in these itineraries can fill this identified need. The central idea is that this technological approach provides a more direct, engaging, and adapted tourist experience, allowing a deeper and more meaningful understanding of the places visited.

The expectation lies in the idea that augmented reality can revolutionize tourists' interaction with information along their routes, providing a richer and more engaging immersion. Therefore, the hypothesis suggests that this technology has the potential to considerably enrich the tourist experience, making the exploration of specific routes more personal and informative.

1.5 Work Plan and Design

In order to better understand the scope of the project, a **mind map** was created with the main characteristics to be analyzed for the design and construction of the solution, which serves as a visual representation to organize information, ideas, and their interconnections. Therefore, the visual representation discussed is presented in Figure 2.

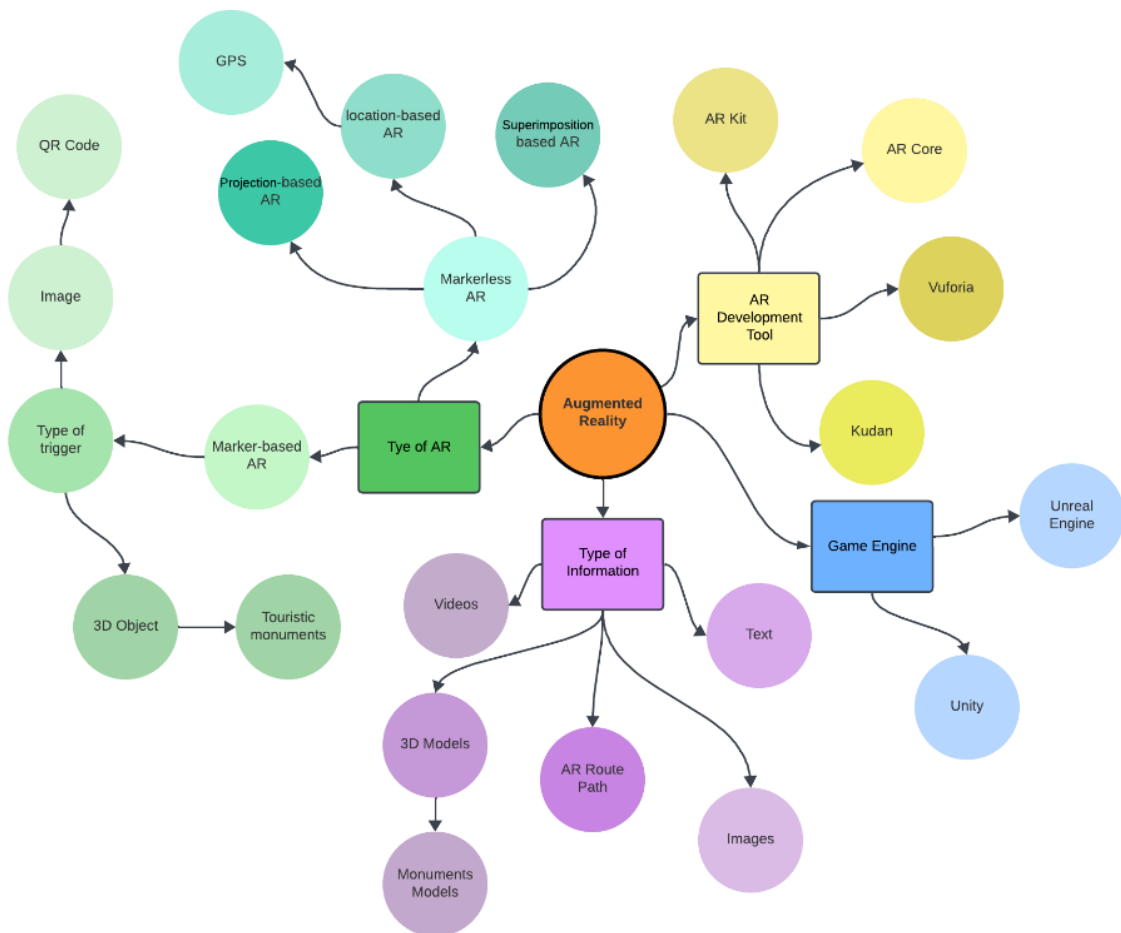


Figure 2 - AR Design Mental Map

When creating a mind map for this project, it is essential to have **augmented reality** technology as a central point. AR is the epicenter from which diverse existing technology techniques, information to be shown, game engines and frameworks for AR diverge to build the desired solution.

With this, the presented mind map expanded from the center point of the AR to cover four main points: type of **AR technique**, types of **AR development tools**, types of **AR engines**, and types of **AR information**. By going deeper into each of these points, it is possible to create an extensive mind map that covers the main considerations when designing an augmented reality application. This improves the understanding of the solution scope and establishes a solid foundation for the following planning phases, ensuring a well-informed and strategic approach to the development of the AR solution.

After the brainstorming phase, it is essential to establish tools that assist in the project planning, and one of these fundamental resources is the **Gantt chart**. The Gantt chart designed for this project has two main milestones: delivery of the document for the Dissertation Preparation curricular unit and final delivery of the dissertation in the Dissertation curricular unit.

Therefore, Figure 3 presents the Gantt chart with the main tasks to be conducted throughout the dissertation.

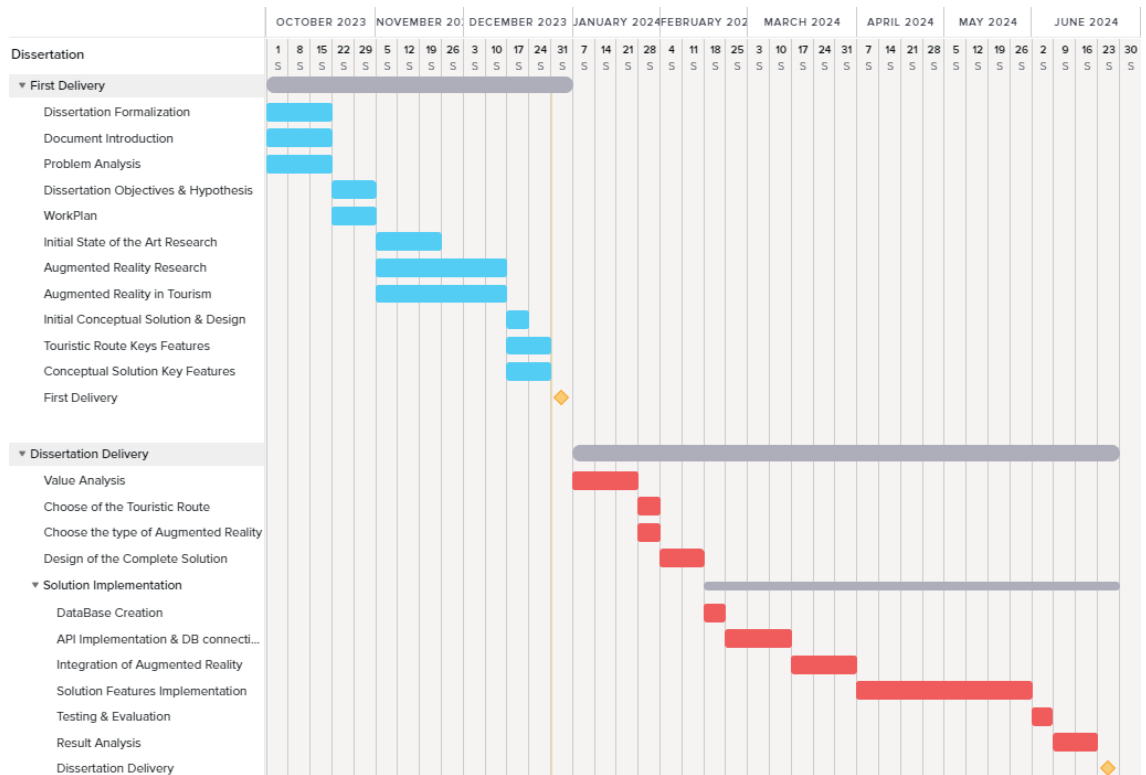


Figure 3 - Dissertation Gantt Chart

2 State of Art

2.1 Importance and Impact of the Tourism Sector in the World

The tourism sector plays a crucial role in the global economy, representing around 7.6% of global Gross Domestic Product (GDP) (World Travel & Tourism Council, 2023), which has economic consequences that extend across multiple industries. It is one of the primary drivers of economic growth worldwide, bringing tourists from all over the world to a variety of destinations, increasing the local economy and culture, protecting the historical and natural heritage, and promoting diversity.

In this context it is crucial that the tourism industry continues to evolve and adapt to changes in tourist preferences and emerging technologies.

2.2 Technologies in Tourism

During the pandemic, tourism was one of the sectors that suffered the most impact. But, in the same way that health advances after a pandemic, the same happened with technology.

There was a need to adapt to the modern times and new immersive technologies appeared to attend them, contributing to the industry's development over the years, improving it by providing tourists with innovative and engaging experiences while driving innovation in business models (Iva Cibilić, 2021). Millennials¹ and Generation Z² also significantly contributed to this paradigm shift. They are passionate about innovative technology, particularly smartphones, and use it in their daily lives.

¹ millennial is a person born between the early 1980s and the late 1990s; a member of Generation Y (wikipedia, 2009).

² Generation Z the generation of people born in the late 1990s and early 2000s (wekipedia, 2008)

According to a TripAdvisor Study, "42 percent of travelers around the world are Connected Travelers, having used a smartphone to plan or book a trip" (TripAdvisor, 2015). Table 1 shows some conclusions from this same study.

Table 1 - How Mobile is Used on Vacation (TripAdvisor, 2015)

How Mobile is Used on Vacation	Connected Travelers ³	All Travelers
Navigation help through maps	81%	67%
Looking for restaurants	72%	56%
Looking for things to do	67%	51%
Reading reviews	64%	47%
Looking for hotels	50%	36%
Making restaurant reservations	46%	36%

With the increasing tendency to travel, it makes sense that tourism technology trends would be driven by the preferences and behaviors of these generations. In this way, some emerging technologies in tourism evolved from the daily basis technologies. The technological advance in this sector can have a significant impact on the tourist experience, saving time and money, automating processes, and improving travel efficiency (Revfine, 2023).

2.3 Augmented Reality

In 1963, Ivan Sutherland created Sketchpad, the first AR application. The development of augmented reality over the last 60 years is shown in Figure 4, taken from a study (Toqeer Ali Syed, 2022).

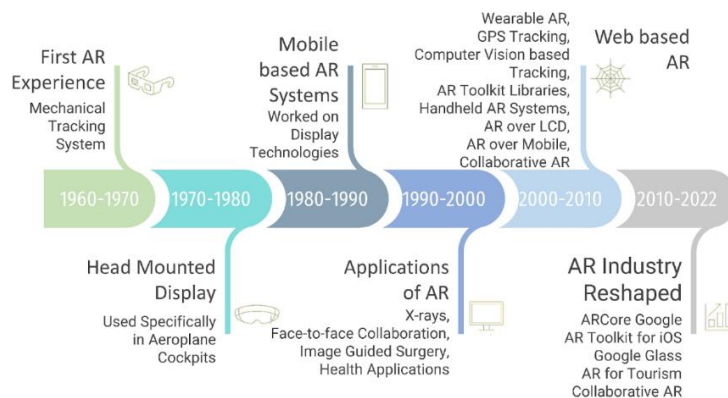


Figure 4 - Development of Augmented Reality over the last 60 years (Toqeer Ali Syed, 2022)

³ The term "Connected Travelers" is used in the report to refer to people who have used a smartphone to plan or book a trip

Many researchers, like Bottani and Sereno, have surveyed the literature on augmented reality and looked at how it intersects with collaborative work enabled by computers. In the same study, a general overview of AR is presented, including application areas, development tools, and tracking technologies. This overview is shown in Figure 5.

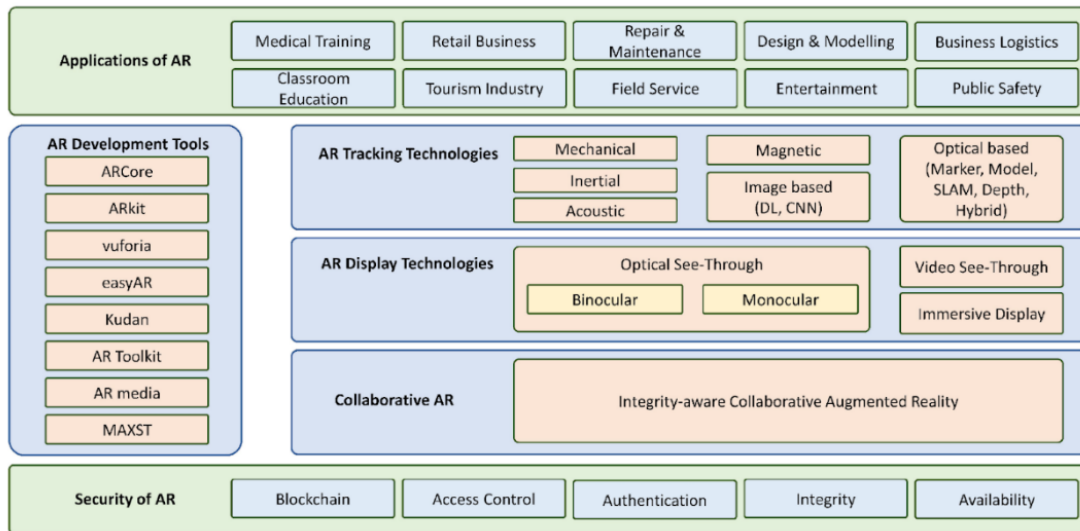


Figure 5 - AR Overview (Toqeer Ali Syed, 2022)

Among the several researchers involved in the field of augmented reality over the decades, Azuma's definition in 1997 stands out as one of the earliest definitions of this technology, that defines AR following 3 main characteristics (Azuma, 1997):

- combines real and the virtual,
- interactive in real-time,
- registered in 3D.

This definition is more in line with what is commonly referred to as marker-based AR today, where specific images are needed to record the position of 3D objects in the real environment. However, given how quickly technology has advanced, this description today seems outdated and does not cover Markerless AR. These two variations of AR will be explained in more detail in the following chapters.

AR today can be described as an interactive and immersive technology that uses multiple techniques and mixes the real world with digital components like audio, images, objects, text, and video. It utilizes tracking systems to place virtual objects in the actual world and then presents these components to the user.

Regarding hardware capable of supporting augmented reality, this technology can be achieved through wearable and non-wearable devices. Wearable devices include headsets and helmets,

and non-wearable devices include mobile devices and stationary devices (TVs, PCs, etc.) (Peddie, 2017). A visual demonstration of devices capable of using augmented reality is presented in Figure 6.

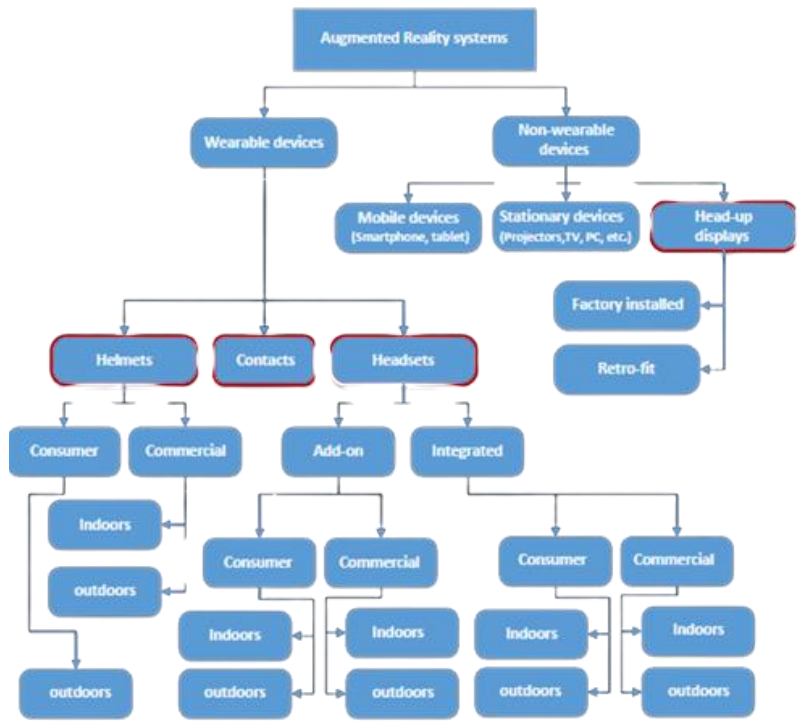


Figure 6 - Taxonomy of AR (Peddie, 2017)

While display technologies provide virtual content to the viewer's eyes, tracking systems follows a real-world pattern.

To obtain a deeper understanding of AR, it is essential to be familiar with the fundamental concepts and terminology frequently used in this technology (Butchart, 2011):

- **Reality View:** refers to the real-time video stream from a smartphone camera that an AR application enhances by adding virtual objects, providing an augmented experience for the user.
- **Registration and Tracking:** describes the techniques available for aligning a virtual object with a three-dimensional point in the view of reality.
- **POI:** refers to a data point often linked to a specific physical location (longitude, latitude, altitude) or a visual pattern (marker, book cover, etc.) that the AR application can display.
- **Virtual Object:** is a type of digital media that the AR application renders and overlays on the real-world scene. Typical content consists of text, icons, 2D photos, and 3D models.

- **Channels, Layers and Worlds:** references to published collections of connected POIs and linked virtual objects.

In terms of architecture, according to the study (Dan Li, 2019), AR apps involve several steps, such as capturing and tracking the real world, building a virtual world, rendering, analyzing the scene and interacting with virtual objects to create immersive experiences. Figure 7 is a representation of this architecture.

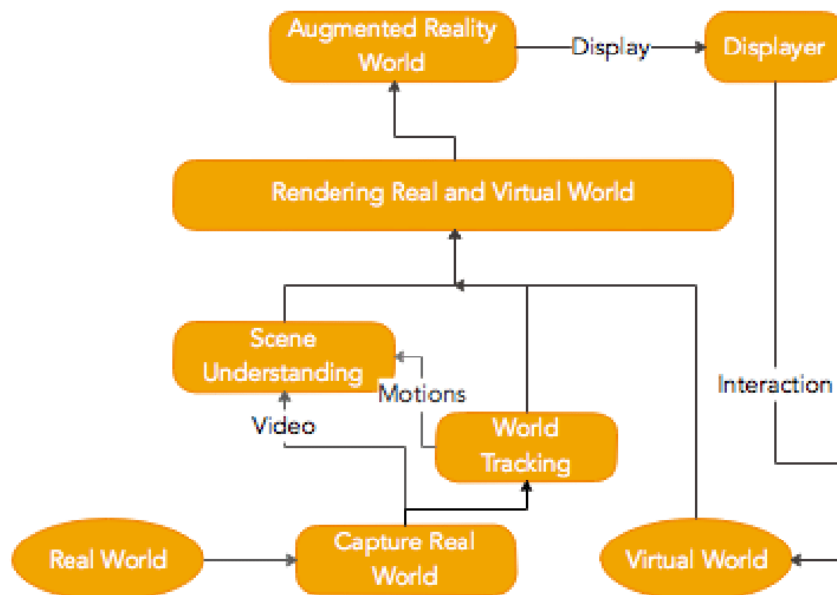


Figure 7 - AR Architecture (Dan Li, 2019)

Building upon the previous introduction to AR, it's possible to delve deeper into the immersive technology landscape, understanding its place within. The virtuality continuum (VC) can be explained as being on a line between reality and virtuality, with a real world at one end and a computer-generated virtual environment at the other, as shown in Figure 8.

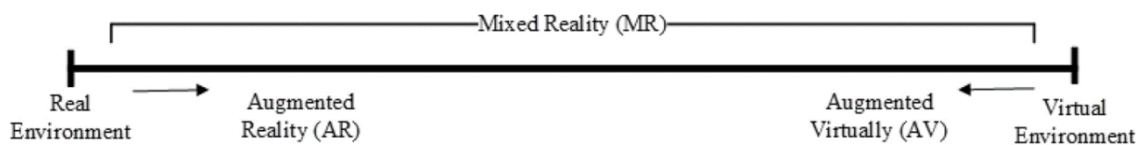


Figure 8 - Spectrum of the Virtuality Continuum (Pratisto, 2022)

In addition to AR, already mentioned, other technology within this spectrum includes Augmented Virtuality (AV), both of which are categorized under the term Mixed Reality (MR). As an additional option, there is Virtual Reality (VR), which is an entirely virtual environment (Pratisto, 2022).

2.3.1 Growth of Augmented Reality & Ethical Considerations

The constant technological advancement, especially in accessibility through mobile devices, has driven the adoption and expansion of the Augmented Reality market, which reached a value of \$31.9 billion in 2022 and is estimated that by 2024 the number of users of AR on mobile devices will reach 1.73 billion, with 86% of people having their first AR experience through smartphones.

Some optimistic projections even point out that AR revenue is expected to reach \$340 billion by 2028, with its main users belonging to the 16 to 34 age group (Wardini, 2023).

Figure 9, taken from a study (Supriya Bhosale, 2022), demonstrates the notable projected growth that Augmented Reality will have over this decade.

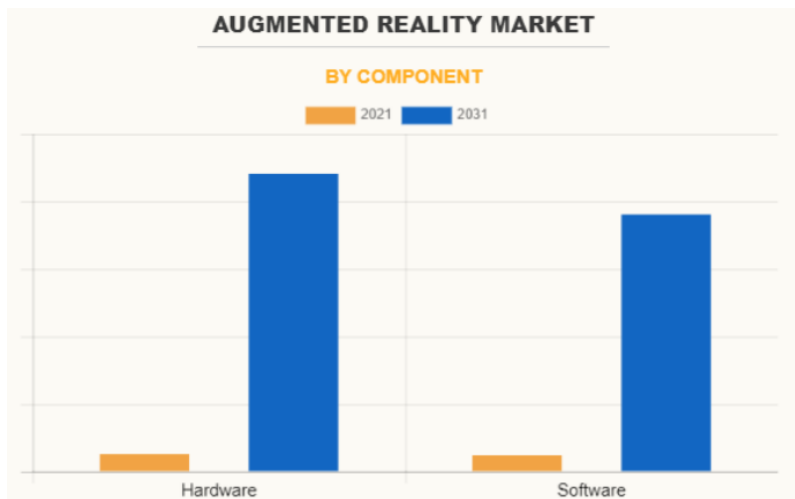


Figure 9 - Augmented Reality Market by Component (Supriya Bhosale, 2022)

However, it is necessary to mention ethical issues that this technology raises. Facial recognition raises concerns about privacy, with examples such as Amazon's controversial technology. While some defend its benefits in locating missing people, there are fears of abuse and real-time tracking. Furthermore, the potential influence of AR on mental health is discussed, with debates surrounding its role in depersonalization and increased cases of depression.

The possibility of unrealistic expectations also begins to raise concerns, especially among children, due to the distortion caused by reality. By causing difficulty in distinguishing the virtual from the real, the potential for manipulation is created, especially in environments controlled by developers.

The lack of regulation also presents risks of manipulation and crime, as the lack of legal infrastructure leaves users vulnerable to deceptive practices by companies, inducing unjustified purchases. Misuse of facial recognition can lead to false accusations and unfair incarceration (Blum, 2023).

Despite the rapid growth of augmented reality, it is essential to establish regulatory measures to control the ethical challenges that accompany this expansion. Lack of adequate supervision can result in questionable practices and potential abuses, highlighting the need for ethical and legal considerations to guide the development and responsible use of this constantly evolving technology.

2.3.2 Marker-based Augmented Reality

Marker-based AR is a technology where the AR content is placed on objects in the real world, which can be either paper-based or physical objects, that serve as markers or triggers. The marker, which needs to be unique, is recognized by the AR system when the user scans with their mobile device (Bhaur, 2023).

As a result of the mobile scan, and based on the marker's position, the additional content that was previously created will then be displayed on top of the marker, as it is shown in Figure 10. In essence, these marks act as a link between the real world and the digital one.

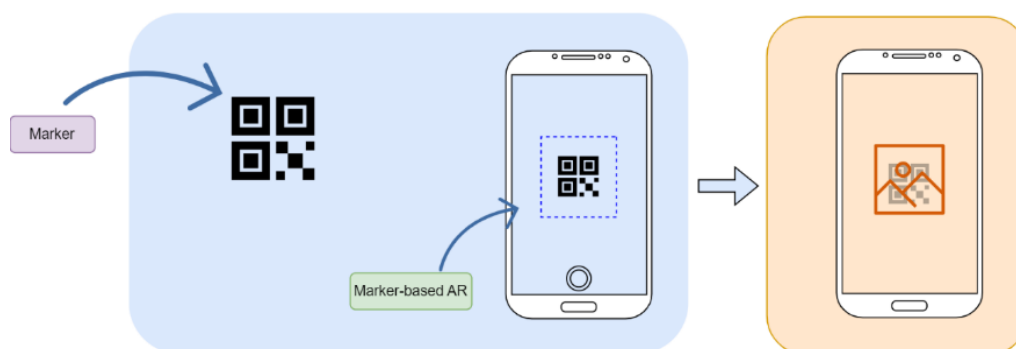


Figure 10 - Example of Marker-based AR (Bhaur, 2023)

2.3.3 Markerless Augmented Reality

Differing from marker-based, markerless AR doesn't depend on specific markers to determine where a virtual object should appear. "Markerless AR functionality allows developers to create digital applications that overlay interactive augmentations on physical surfaces, without the need for a marker" (Stenina, 2022).

There are several AR technologies that fall into the markerless AR category, with the most used being:

- Location-based AR
- Projection-based AR
- Superimposition-based AR

2.3.3.1 Location-based Augmented Reality

Location-based services use a variety of positioning tracking technologies to collect real-time location data, for instance the Global Positioning System (GPS) satellites (Froehlich, 2022).

For location-based services to operate its needed, namely:

- an app that uses location-based services.
- a positioning mechanism to collect geodata.
- a mobile network to transmit or receive data.
- analytics software running on an external server to provide to the user pertinent data based on their location.

Location-based AR utilizes technologies like GPS, accelerometers, digital compasses, and other sensor systems to accurately determine the phone's location and orientation. These sensors are available in smartphones, which means that augmented reality is very accessible for the users.

These applications rely on real-time positioning systems (RTLS), thereby obtaining information from sensors about the user's current location and movements. By connecting the gathered data with points of interest (POI), the technology also establishes the specific position and method in which virtual data is integrated into the physical environment (Evgeniy Altynpara, 2023). By doing so, the augmented reality content overlays the camera view if the user is close enough to the point of interest, as shown in Figure 11.

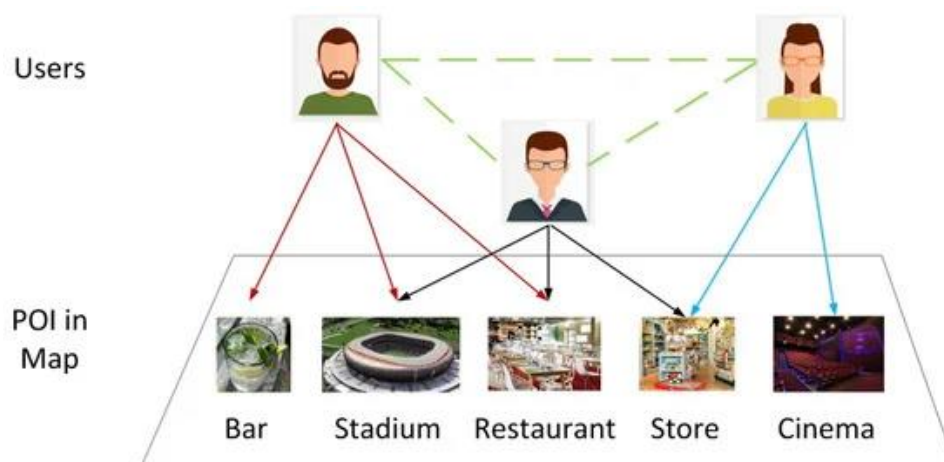


Figure 11 - Examples of POI (Yang, 2019)

To illustrate the practical application of location-based AR, a notable example is the popular game Pokémon GO, released in 2016. By using GPS, Google Maps and the mobile device's camera, Pokémon GO allows players to explore the environment around them in search of

virtual creatures called Pokémon, through their real location. This creates a unique experience in which players must physically move around to find and capture Pokémon, encouraging real-world exploration (Shock, 2018). With this, Pokémon GO demonstrates the viability and potential positive impact of location-based services using augmented reality on the user's daily life. For a more concrete visualization, Figure 12 presents the game Pokémon GO.



Figure 12 - Pokémon Go (Kozlowski, 2017)

2.3.3.2 Projection-based Augmented Reality

Projection-based is often used to generate illusions about the depth, location, and orientation of an object. This technology provides digital information in a static environment, and the main goal is to render virtual things on or within a user's real physical space, where light is projected into a surface. The interaction occurs by physically touching the projected surface (White, 2018).

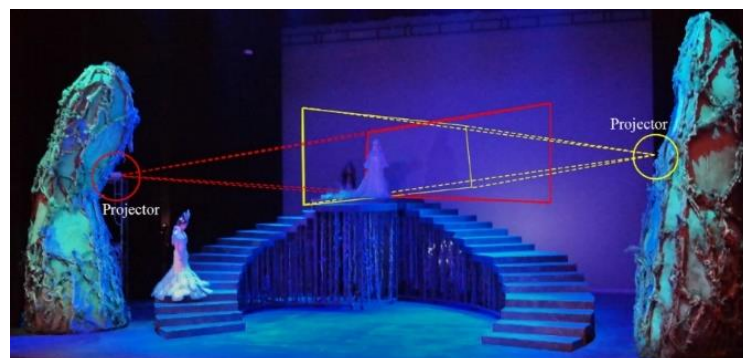


Figure 13 - Example of Projection-based AR (Jaewoon Lee, 2015)

Users and the target items can move around the environment within the specified zone, in which both the fixed projector and supporting camera for tracking are positioned, as shown in Figure 13.

2.3.3.3 Superimposition-based Augmented Reality

Superimposition-based AR, also known as Spatial AR, is a technology where virtual objects or information are overlapped on the physical world. In order to create a hybrid experience that improves the user's view of reality, computer-generated content is required to be integrated into the user's view of the physical world (Poghosyan, 2019).



Figure 14 - Example of Superimposition-based AR (Poghosyan, 2019)

With the help of this technology, it is possible by instance to make an historical exploration around the city while learning about the characteristics of old buildings, as shown in Figure 14.

2.3.4 Markerless Augmented Reality VS Marker-based Augmented Reality

Marker-based and Markerless are the two most common technologies used in AR. With different goals to different contexts, it's important to choose carefully which one is better to use.

Marker-based systems are easy to use as markers can be placed in real locations and detected by a camera. This allows users to point their devices at the markers and view relevant digital content. It's a great way to promote products or services, like using QR codes on a website to provide additional information.

On the other hand, markerless systems are the most advanced form of augmented reality. They use computer vision to recognize objects in the real world and display relevant information about them, without the need for special steps on the part of the user. These systems are

considered more futuristic as they can be detected by a camera and a computer vision system, making the experience of viewing digital content more intuitive (Queppelin, 2022).

A comparison between these two technologies is presented in the Figure 15, taken from an study (Jack C. P. Cheng, 2017).

Comparison Aspects		Marker-based AR	Markerless AR
Methods	Relative position/angle	Depends on markers	Depends on localization technology and gyroscope
	AR Software Development Kit (SDK)	Commonly used	Rarely used
Position accuracy	High/low	Relatively higher	Relatively lower
	Influence factors	Brightness	Localization technology
Stability	High/low	Relatively lower	Relatively higher
	Influence factors	Markers and SDKs	Localization technology and gyroscopes
Hardware support	Desktop	Supported	Usually not supported
	Mobile	supported	Supported

Figure 15 - Marker-Based vs Markerless AR (Jack C. P. Cheng, 2017)

2.3.5 Augmented Reality: Conclusions

Augmented reality technology is still at an early stage, yet its potential is rapidly growing, with applications in various fields such as engineering, medicine, entertainment, or tourism. AR serves as a bridge between the physical and digital realms, offering an infinite number of possibilities.

The two main types of this technology, marker-based and markerless, present distinct approaches to overlaying virtual content onto the real world. While marker-based AR requires specific visual identifiers to position content, markerless AR eliminates this need, allowing overlay on multiple physical surfaces.

Within the markerless AR category, three main approaches stand out:

- location-based AR, which uses real-time positioning systems, such as GPS, to overlay contextualized information on the user's location.
- projection-based AR, which creates illusions of depth and orientation of objects projected onto physical surfaces.
- superimposition-based AR, which integrates digital content with the view of the physical world, offering a hybrid experience.

These diverse types of AR demonstrate the transformative potential of technology, whether in offering interactive experiences to users, optimizing processes, or developing new business models. Despite increasing accessibility of AR, the general adoption and everyday use are still at an early stage, and augmented reality companies face significant ethical and security challenges to address and mitigate potential criminal concerns.

However, this technology is recognized as one of the most important and revolutionary innovations, it is possible that augmented reality will develop into the technology of the future.

2.4 Augmented Reality in Tourism

AR has helped and continues to help the growth of the tourism industry economy. The most notorious years were especially during Covid-19, as physical interactions were not allowed and new ways of carrying out tourism had to be created.

Most of the AR uses in tourism involves marker-based and location-based technologies. These solutions must consider users' needs and experiences and have the potential to improve the tourist experience by providing relevant information about the attraction or location the tourist wants to visit, while also providing entertainment. It acts as a travel guide that helps tourists explore destinations, navigate through cities, and identify POIs (Morozova, 2015).

On tourism it can usually be seen on a mobile or wearable device, as seen in Table 2, taken from a study (Pratisto, 2022). As a result, it is less expensive for the customer than most headsets or other equipment that support augmented reality.

Table 2 - Devices used in AR (Pratisto, 2022)

Devices used in AR study	Number of studies	Percentage (%)
Mobile device	35	59.3%
Wearable device	10	16.9%
Other	2	3.4%
Not mentioned	12	20.3%
Total	59	100%

Furthermore, the accessibility of augmented reality technologies on mobile devices doesn't represent a significant obstacle for tourists, given their use of smartphones during travels.

Adopting experiences based on AR becomes simpler by the simple integration of mobile devices into the tourist experience, which works naturally with their daily routines.

The same study also reveals that most of the AR triggers used are location-based (37.3%), as shown in Table 3.

Table 3 - AR triggers (Pratisto, 2022)

Trigger type	Number of studies	(%)
Location-based	22	37.3%
Markerless	13	22%
Marker-based	7	11.9%
Spatial marking	4	6.8%
Combination of marker-based and location-based	3	5.1%
Combination of markerless and location-based	1	1.7%
Not mentioned	9	15.3%
Total	59	100%

Although Table 3 has separated markerless from location-based and spatial marking, in fact, as explained in the last chapter, these two technologies can be placed in the markerless category. Since they have no markers, they are indeed markerless.

2.4.1 Advantages and Disadvantages of Augmented Reality in Tourism

AR is a technology that has been making significant advances into the tourism industry, enriching the travel experience for tourists in many ways. From improving navigation to providing contextualized information and reinvigorating tourist destinations, augmented reality has the potential to transform the way tourists explore the world and engage with their surroundings during.

Some of the advantages that AR brings to tourists are:

- **Better navigation:** rather than just presenting a map, through the display of the directions in AR, the tourist navigation is improved and facilitated.
- **Contextualized information:** AR can show contextualized information about attractions along the tourist exploration.

- **Promotion and Marketing:** by integrating AR features into travel services, it is possible to create a distinct and engaging marketing approach that captures the attention of potential tourists.
- **Customer Engagement:** AR apps for tourism have the power to impress and engage users. When tourists that use an app have a positive experience, they are more likely to tell their friends about it, post about it on social media, and generate discussion about it.
- **Popularizing tourist destinations:** AR can help promote tourist destinations by offering interactive, entertaining presentations of local attractions. Travelers are more inclined to visit these destinations when they've had an engaging experience.
- **Reviving experiences:** AR can add excitement and new life to experiences that were already experienced, like visiting museums or old buildings.

Taking all this into consideration, it becomes evident that this AR offers numerous advantages to the touristic industry. The touristic exploration becomes more immersive and enjoyable, with information in a centralized space with easy accessibility.

However, the merging of AR with the real world has brought some disadvantages and concerns due to its heavy reliance on creating and sharing information and user feedback. These concerns cover different areas including (Ivankov, 2019):

- **Privacy issues:** legal issues are caused by some AR devices that record the environment continuously. Additionally, user data is collected by AR systems, including biometric and geographic data. This emphasizes the need to adhere to data usage standards, particularly in compliance with stringent laws like the GDPR of the European Union.
- **Boundaries between the real and the virtual:** the potential for AR to confuse the boundary between the real world and the digital world raises safety concerns. For instance, the Pokémon Go game caused controversy because users' lack of caution when using digital elements that are superimposed on the real world resulted in accidents and even fatalities.
- **Technical Requirements:** implementing AR-based solutions is expensive and technically challenging. This can put smaller organizations at a disadvantage due to resource constraints. Furthermore, the effectiveness of AR depends on advanced technologies and powerful devices like smartphones to run smoothly.
- **Information overload:** with the small display of the smartphone, sometimes the user can feel overloaded with the AR information. "Make it simple, but significant." - Don Draper.

2.4.2 Use Cases of Augmented Reality in Tourism

The goals in AR for tourism are diverse, depending on the context in which the app will be inserted. In doing so, these apps help to revolutionize the relationship between tourists and tourist destinations, enabling a deeper, more immersive, contextualized, and individualized appreciation of the world around them.

The next chapters will delve deeper into the most common practices adopted that improve the tourist experience. These include navigation, tour guides, cultural attractions such as museums, zoos, oceanariums and educational tourism.

2.4.2.1 Navigation using Augmented Reality

Maps have always been present as tools used to explore roads, cities, countries, and even the cosmos. The development of mapping, from early hand-drawn maps to sophisticated digital maps, thanks to technological advances, is evidence of humanity's continuous attempt to understand and navigate its surroundings.

One of the technological advances is in Augmented Reality. The integration of this technology into navigation apps has revolutionized the way tourists interact with digital maps. Beyond the traditional advantages of digital maps, AR brings an immersive layer to the user experience, making the experience more accessibility, personalized, and, of course, with an economy of physical space.

By using AR for location assistance, it becomes easy to locate and navigate through locations like streets, museums, parks, etc. For efficient navigation, AR makes path coordination and visual orienting easier.

AR navigation apps use a wide range of inputs, including the GPS location of the user, an initial camera measurement, and object location. They maintain records of how things move. This data is gathered by sensors and connected to the inertial measurement units (IMUs⁴) of the moving objects. And, considering the user's movement in real time, the data is used to create and overlay components (Karla Leiva, 2021).

Numerous businesses have begun utilizing AR to enhance their navigational offerings, and a famous example is Google Live View. When Google published its Web mapping service in 2005, the Google Maps, it was the first free service providing a global coverage of satellite map views, offering customers the capacity to explore, in 2D and 3D, topographical maps and street maps (Schauland, 2023).

⁴ "An inertial measurement unit (IMU) is an electronic device that measures and reports a body's specific force, angular rate, and sometimes the orientation of the body" (Wikipedia, 2023)

Along with the technology advances, Google added into Google Maps an AR feature for navigation: Google Maps Live View. This feature assists users with location determination and navigation, by showing in the mobile display, with location-based AR technology, landmarks in AR of the directions the tourist needs to travel to reach a certain location (Warren, 2023).

An example of using AR in Google Maps Live View is as presented in Figure 16 and Figure 17.



Figure 16 - AR in Live View (Kavafian, 2019)



Figure 17 - AR Destination (Awards, 2021)

A research on the use of Augmented Reality for navigation in tourism is presented in an article (Pranoto, 2023), which focuses on the initiative to develop a navigation application to promote tourism at the local historical attraction "Lawang Sewu". This initiative started as a result of the covid-19 pandemic that had a devastating impact on the tourism industry in Indonesia. The methodology covered analysis, development, implementation, and evaluation, with the choice of AR as a delivery method, given its popularity and innovation in the tourism market. The application's implementation involved using technologies such as Unity, Vuforia, and Maya. Positive results from user acceptance testing indicated that 66.6% of participants enjoyed the application during the exploration of the state attraction, suggesting that the use of the application enhanced the user experience when interacting with Lawang Sewu and, consequently, improving the local tourism.

2.4.2.2 Augmented Reality in Tour Guide

Tourists frequently seek the guidance of an experienced guide to improve their understanding of the destination before embarking on their journeys. Beyond aiding navigation, these guides enhance the overall travel experience by offering helpful information on attractions, restaurants, or any kind of POI.

In this context, augmented reality has revolutionized the way tourists explore and learn about new destinations by tour guides in AR, that serves as an advanced tool that goes beyond conventional guidebooks or tour guides. The traditional role of a tour guide is enhanced and transformed through the integration of AR technology, providing an immersive and interactive experience for travelers.

The primary function of an AR tour guide is to offer real-time information about POI as travelers navigate through city streets. By utilizing their mobile devices, tourists can gain instant access to a wealth of knowledge about the historical significance, cultural context, and other relevant details of the places they encounter. This not only enriches their understanding of the destination but also adds layers of engagement to their overall travel experience (Onirix, 2022).

Zumoko AR Tourist Guide is an example of a tour guide app, that aims to improve tourists' experience while exploring locations through augmented reality technology. This solution uses location and time as markers for augmented reality technology, like objects or images. It delivers informative or specific content in the chosen format to the tourist's smartphone based on specific times or locations.



Figure 18 - Zumoko AR Tourist Guide (Zumoko, 2023)

Figure 18 shows an example of how this app works, where the user can see POIs of restaurants and other locations, as contextualized information about a church. Zumoko AR Tourist Guide is an ideal solution for (Zumoko, 2023):

- creating more informative and interactive specific POI
- visually rich search mechanism for relevant data
- travel planning
- navigation and maps
- accommodation possibilities
- transportation options
- restaurant tips and reviews

A research on the use of augmented reality applications for tour guides in tourism is illustrated in the article (Byung-Kuk Seo, 2010), detailing an AR Tour Guide conducted at the iconic Gyeongbokgung, a cultural heritage site in Korea. The approach uses AR to virtually bring the past to life by overlaying animated 3D characters into historical sites. Additionally, contextual information such as tourist location and profiles are integrated to provide personalized guides. The prototype was successfully tested at Gyeongbokgung, highlighting the effectiveness of this innovative approach and its potential to enhance the tourist experience.

2.4.2.3 Augmented Reality in Cultural Experiences

AR is revolutionizing the arts and entertainment industry by providing immersive, interactive experiences, including captivating encounters in museums, zoos, and oceanariums.

Within AR cultural experiences, museums stand out as the most common and readily accessible application. It simplifies the process of enhancing museum visits by providing informative explanations for the displayed artifacts. Therefore, when viewing exhibitions using AR, tourists can discover more about what they are observing. It also might potentially be used by museums to show artists' digital representations next to their creations.

Many museums all around the world have already embraced augmented reality programs, altered the museum experience, and increased audience participation. By bridging the gap between history and innovative technology, these creative projects bring new life into the existing collections and grab the attention of tourists with engaging interactions. In essence AR transforms museums into dynamic settings where the past and present meld together to provide a richer, more comprehensive examination of cultural, historical, and artistic achievements (Coates, 2023).

An example of the use of AR in cultural experiences is The Augmented Gallery, that provides, through an AR app, a free innovative public art experience, showing, by scanning a QR, paintings from London's best institutions in augmented reality.

“The Augmented Gallery is a mile long public art trail which begins at The National Gallery and ends at Fortnum & Mason”. The app was designed during the pandemic, with the goal of having socially distanced, yet interactive ways to increase public access to art galleries and museums in a responsible and secure way (Tegan, 2021).



Figure 19 - National Gallery Museum (Tegan, 2021)

In Figure 19 it is possible to observe a user pointing to a picture of the National Gallery Museum, in order to see details of the painting, thanks to the help of AR.

A research found of the use of AR in museums is presented in the article (Zhe Gong, 2022), which is focused on an AR prototype for information visualization based on a renowned Chinese artwork named "Along the River During the Qingming Festival". With 58 evaluators participating, the results show that AR technology can trigger visitor engagement, facilitate learning, promote meaningful experiences, and establish emotional connections.

2.4.2.4 Augmented Reality in Educational Tourism

The education and tourism sectors have increased in importance over the past few decades, and this has given rise to a convergence of these two industries, with education facilitating mobility and learning becoming an integral part of the tourist experience. This convergence has occurred on both an economic and social level. Nowadays, education is a common component of tourism activities, however, there is little research on educational tourism and the connections between tourism and education (Ritchie, 2003).

According to the previously mentioned book, an educational tourist is defined as a person who travels outside their city or country, where education and learning is important or even the main reason for the trip. Excursionists are defined as people involved in educational activities

or excursions, where education is seen as a relevant form of leisure. Therefore, educational tourism involves trips where education is an essential or secondary part of the experience. This includes various forms of tourism, such as standard educational tourism, adult educational tours, study trips and exchange programs, and can be organized independently or formally, in natural or built environments.

Based on the growing importance of educational tourism, an innovative study (Kleftodimos, 2023) has developed a solution that incorporates MR technologies such as AR and VR to boost the mountainous areas of Western Macedonia, Greece. This Greek region faces socioeconomic challenges, including high unemployment rates, and could benefit significantly from increased tourism. The implementation of these innovative technologies not only enhances the region's educational attractions, but also aims to attract more tourists, promoting local economic development. Figure 20 illustrates part of this solution, where it shows the user, through AR, a laboratory (a red dot), a local store (the yellow dot) and their own GPS location (the blue dot).

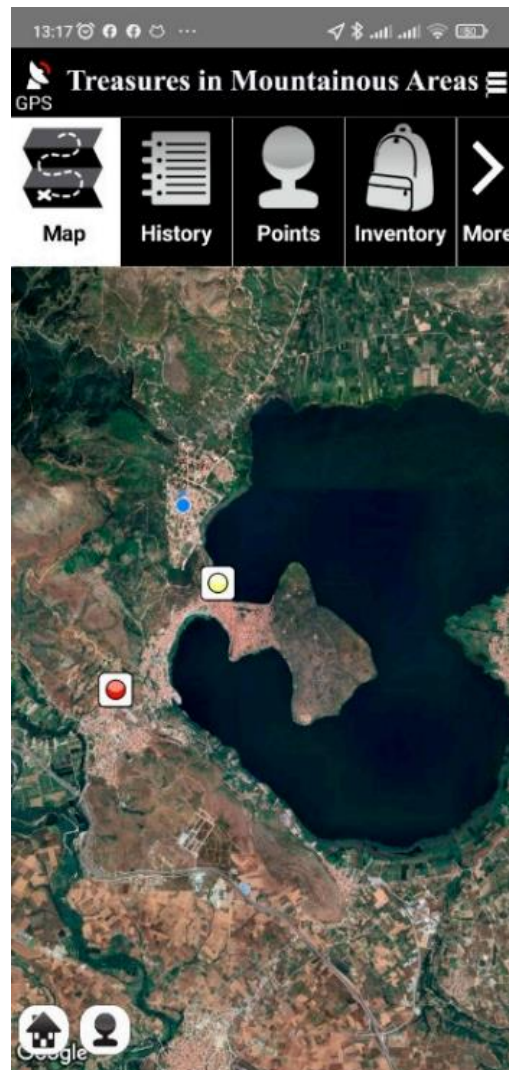


Figure 20 - Solution Based on MR in Western Macedonia (Kleftodimos, 2023)

2.4.3 Limitations of Augmented Reality in Tourism

Nothing is perfect, and just like any other technology, AR has some limitations. Some of the limitations of Augmented Reality in tourism are the follows:

- **Internet access:** AR applications need to have constant access to the internet, and some countries don't have touristic zones covered with free wi-fi. Nevertheless, many tourists still do not have access to their own mobile data, preventing them from being able to positively use AR.
- **Authenticity:** there is a challenge of finding a balance between integrating AR technology and preserving the authenticity of historical and cultural sites. Some stakeholders are concerned that technology and mobile devices could potentially compromise the integrity of their content (King, 2023).
- **Hardware:** despite using a mobile device is easy, sometimes holding up a device to view AR can be exhausting, especially over an extended period of time.
- **Battery Power:** the 3D objects and the virtual world of AR can significantly drain the device's battery life.
- **Spatial Recognition Precision:** Despite technological developments, the alignment of 3D objects when utilizing cellphones may still have small errors.

3 Solution Conception and Design

This chapter focuses on conceptualizing and designing the proposed solution to address the challenges caused by the identified problem, outlining the tourist route and the key considerations and features for developing the augmented reality application.

3.1 Tourist Route

As stated in the introduction chapter, a tourist route is an itinerary designed to attract tourists, standing out for offering access to notable points of interest, encouraging travellers to explore and discover these attractions.

A well-designed tourist route must include several elements to provide an attractive and organized experience for tourists, such as the follows:

- **POI:** highlighting the inclusion of significant tourist attractions, such as natural, cultural, historical, architectural, and recreational attractions.
- **Information:** Providing relevant information about the history, culture and context of the places visited, enriching the tourist experience.
- **Markers:** efficient signs or markers along the route to guide the tourists along it.
- **Logical Itinerary:** logical organization of points of interest to optimize tourists' time and facilitate the path between them.

3.2 Solution Main Features

This chapter aims to highlight the key features and use cases that the solution must have, to enhance the tourist experience along a touristic route.

3.2.1 Register & Login

Any application needs a secure authentication process. Users must be able to create a new account with an email and password and then log in to the application with these credentials.

3.2.2 Incorporation of Augmented Reality Technology

The main component of the solution is AR, which improves the tourist experience by fusing the digital and real world along the touristic route.

In the state of the art chapter, several technologies and approaches in the field of Augmented Reality were discussed, each presenting advantages and disadvantages. The decision of the approach that will be used on the final solution will be discussed later in the value analysis chapter.

3.2.3 Incorporation of Tourist Routes

The flexibility of choosing any tourist itinerary opens the door to an infinite number of possibilities, allowing the solution to meet different interests and locations. Therefore, one of the main strengths of the proposed solution lies in its adaptability to a wide range of tourist routes. Whether exploring historic buildings, cultural and architectural POI's, or natural spaces, incorporating different routes ensures a customizable and engaging experience for a broad spectrum of tourists.

In order to create routes to the solution it is important to consider factors such as the history and cultural richness of the locality, and geographic diversity. Routes with deep historical significance provide a more enriching experience for tourists, as by providing information about the history and culture of the locations, the educational value of the journey is increased. Additionally, customizing routes allows tourists to adapt their journey to individual interests, ensuring a focus on aspects that align with their preferences.

3.2.4 Choose & Create a Tourist Route

Users should be able to create a personalized itinerary based on their preferences by selecting desired POIs available in the solution. Additionally, the solution must provide access to a list of available routes, including the personalized ones they have created, with detailed information about each one. Finally, users should be able to select and explore these itineraries.

3.2.5 Efficient Navigation

In an effort to improve the exploration process, the navigation through the route will be improved with the help of GPS and AR, by adding virtual markers on the screen, reducing the possibility of confusion and increasing the efficiency of their exploration.

Intuitive AR visual markers will guide tourists from one POI to another, providing a clear path to follow. The AR navigation system will adjust in real-time based on the tourist's location, ensuring that they can easily follow and navigate the route.

3.2.6 Relevant and Contextualized Information

To address the challenge of information overload, the solution needs to ensure that tourists receive contextualized and relevant details to enhance their understanding of each POI. This prevents unnecessary content that do not belong to the route itself, allowing users to concentrate on the most significant aspects of their exploration. As tourists explore the route, AR information will dynamically appear on their screens, providing a rich overview about each POI. This content ensures that users receive detailed insights into the historical context, architectural features, and cultural significance of each location. With this, the solution must have the following details:

- **Historical Information:** by highlighting the historical context and significance of each POI, and some influential persons that played influential roles in the history of each point of interest.
- **Architectural Details:** by providing architectural insights, revealing the unique characteristics that contribute to a more complete experience.
- **Social Impact:** by showing information to the tourists about the value and importance of each POI culture, exploring the traditions, behaviours, and social influences.
- **Incorporating Local Narratives and Stories:** by incorporating local narratives and stories related to each point of interest, it enriches the tourist experience with authentic and captivating narratives.

3.2.7 Enrich Tourist Education

It is important to incorporate educational elements into the solution to enhance the overall tourist experience. By integrating educational information, the solution can provide tourists with a deeper understanding and appreciation of the places they visit. One effective way to deliver this educational content, besides the AR content in the exploration, is through quizzes. The solution will include a Tourist Quiz feature, offering users a fun and engaging way to learn more about the history and culture of points of interest.

3.2.8 Community Interaction

The solution will enable users to share their experiences by capturing and sharing photos. Users will be able to take and save their own photos during explorations in a private gallery and access a public gallery to view and like photos shared by the community. This feature promotes the creation of a community, allowing users to connect with others, share moments, and seek inspiration for their own adventures.

3.2.9 Statistics

Providing personal statistics to users improves their engagement and overall experience within the app. By offering insights into their progress and activities, users can track the number of POIs visited, photos taken, and quiz scores accumulated. These statistics not only motivate users to explore more but also provide a sense of accomplishment and progression.

3.2.10 Accessibility Features

In order to ensure a comprehensive and inclusive experience, the solution will be incorporated with some essential accessibility features, such as multilingual support and audiobooks. These features play a crucial role in accommodating diverse users, acknowledging the importance of making the exploration of the tourist route accessible to a broad spectrum of tourists.

3.3 Software Support Design

This section outlines the conceptual software design, using UML diagrams to visually represent the key components and their interactions.

3.3.1 Component Diagram

The following component diagram illustrates the structure of the proposed solution, detailing interconnections between components, providing a clear overview of the system's design.

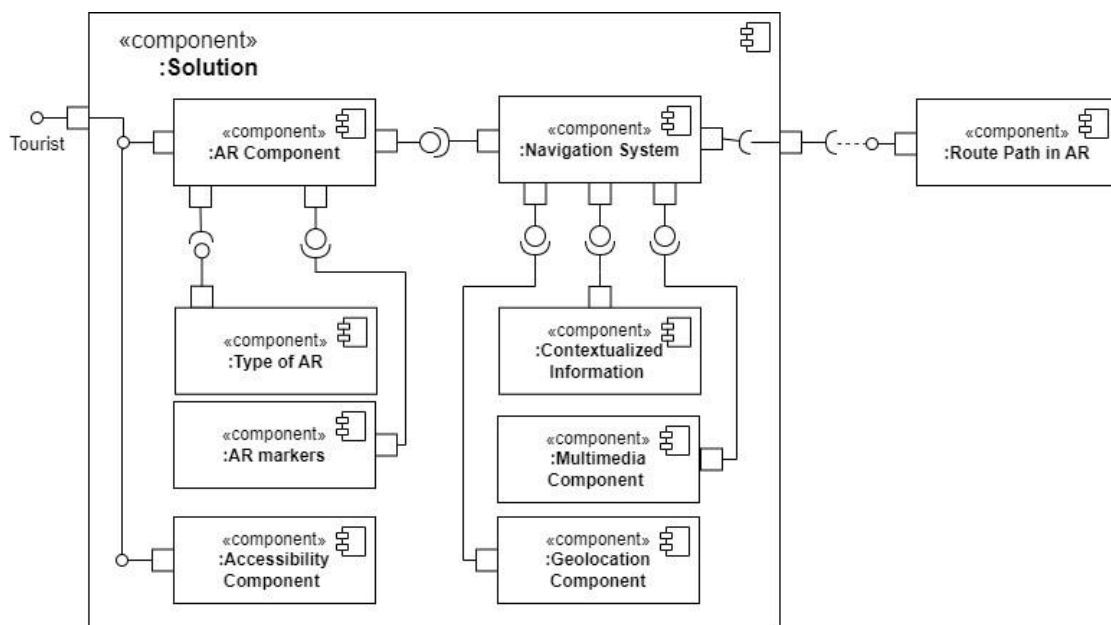


Figure 21 - Component Diagram of the Solution

3.3.2 Use Case Diagram

This section includes a Use Case diagram that visually represents the functionalities previously described in the conceptual solution. The diagram illustrates the interactions and relationships between users and the system, providing a clear overview of the application's core use cases.

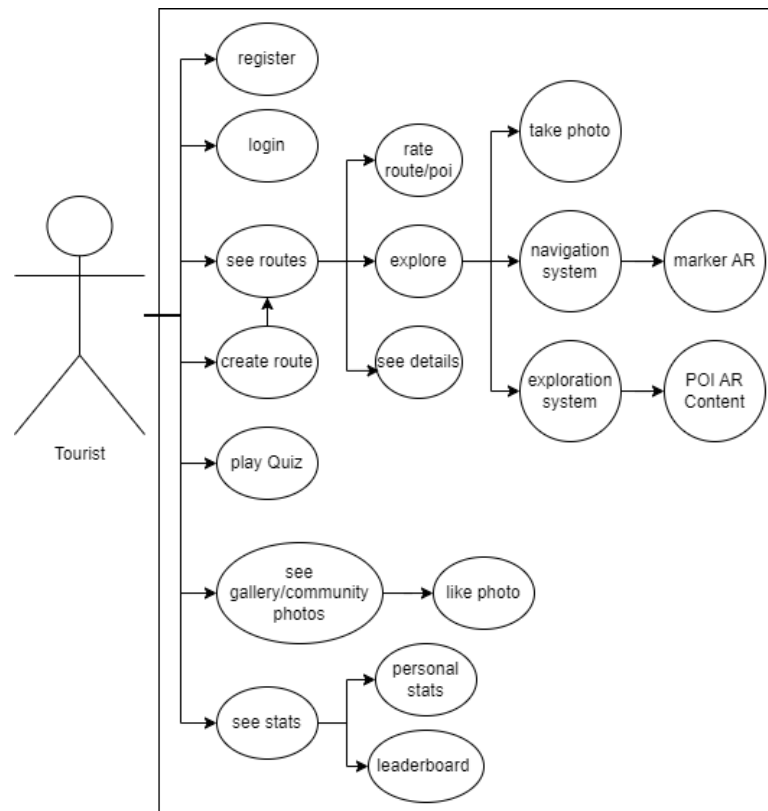


Figure 22 - Main Use Cases of the Solution

3.4 Conclusions of the Conceptual Solution

The conceptual solution in this chapter takes advantage of augmented reality technology to enhance the tourist experience along a tourist route. The choice of the type of AR technology that will be used will be explored further in the upcoming value analysis chapter, weighing the advantages and challenges associated with each approach. It prioritizes personalized itineraries, efficient navigation through GPS and AR, and educational engagement via informative content and quizzes. In addition, community interaction through photo sharing and inclusive features like multilingual support further enriches user engagement.

With these significant features, the solution offers a perfect combination of technology, navigation, contextualized information, and accessibility throughout the exploration of a tourist route, promising to revolutionize the tourist experience along these itineraries.

4 Value Analysis

In this chapter it will be presented the value analysis of the proposed solution, in order to evaluate and select the most appropriate approach for the final solution. In the previous chapter was designed the conceptual solution, however, some questions were left open to be resolved in this chapter. A crucial decision that still needs to be made is the choice of the specific AR technology to be used.

Value analysis is a systematic and organized process that is used on product designs in order evaluate the functionalities that the product must have in order to satisfy the needs of the user.

There are some key points and elements of Value Analysis, such as (Rich, 2000):

- **Value Analysis (and Value Engineering):** is a methodical, structured, and formal process of analysis and evaluation.
- **Product Analysis:** understanding the features of the product and how they align with the needs of the user.
- **Understanding the use of the Product:** understanding how a product is used indicates that requirements can be created to evaluate how effectively the product fits the needs of the user and the value that the user receives.
- **Consistent Meeting of Specifications:** for the formal management process to be successful, it must consistently meet functional specifications and performance criteria.
- **Design Improvements for Cost Reduction:** the final goal of Value Analysis is to generate design improvements that reduce production costs while maintaining the product's value through its functions.

In summary, value analysis presents a multitude of advantages for companies, including significant cost reduction, maintaining standards, adopting new technologies, stimulating innovation, among others. The adoption of value analysis turns into a strategic contribute for businesses, promoting efficiency, competition, and long-term success in the market.

4.1 Innovation Process

The initial phase of the innovation process establishes the basis for future product development activities, since the decisions made in this initial phase determine the innovation options available for later development and commercialization.

The innovation process can be separated into three sections: the fuzzy front end (FFE), the new product development process (NPD process), and commercialization (A.Koen, 2004).

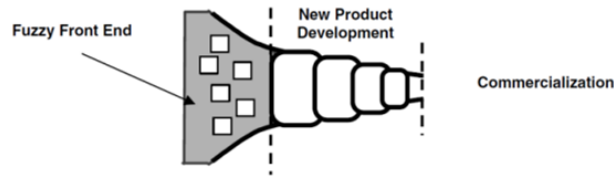


Figure 23- Innovation Process (A.Koen, 2004)

Following the research of Peter A. Koen and his collaborators, was created a new model called New Concept Development (NCD). The model has a circular shape to represent the continuous flow, circulation and iteration of ideas between the elements.

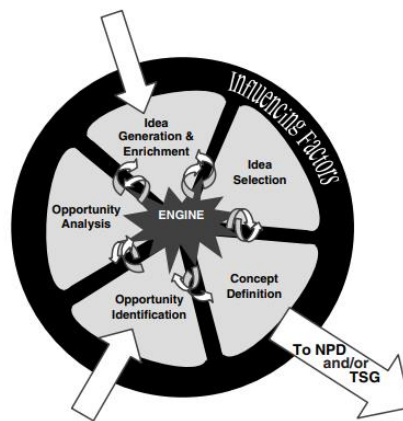


Figure 24 - New Concept Development Modal (A.Koen, 2004)

This model consists of three main parts:

- The **engine**, which is the central part of the model, provides power to the front-end process such as the organization's leadership, culture, and business strategy, which drives the five key elements controllable by the corporation.
- The **internal part** of the model contains the five activity elements: Opportunity Identification, Opportunity Analysis, Idea Generation & Enrichment, Idea Selection, and Concept Definition.
- Finally, the third part of the NCD model consists of the external environmental factors that influence the previously mentioned parts (the engine and the five elements).

Furthermore, the arrows pointing into the model represent the starting points of the projects, which can begin with the Opportunity Identification activity or the Idea Generation & Enrichment activity. On the other hand, the arrows pointing out of the model represent projects that leave the front-end process, thus entering the NPD or Technology Stage-Gate (TSG) process (A.Koen, 2004).

4.1.1 Opportunity Identification & Analysis

An opportunity can be seen as a discovery by a person or company of a gap between the current situation and an ideal situation in the field of business or technology. This difference is identified in order to achieve an advantage in competition, deal with a threat, solve a problem, or overcome a challenge (A.Koen, 2004).

In this sense, there are many gaps that are increasingly being explored in AR. As shown in the state of the art chapter, the use and evolution of this technology is and will continue to grow exponentially, which bring a lot of advantageous things to users in their daily lives. But what about in specific situations? When people go on vacation, they don't bring their closet on their backs, but only the essential clothes.

Sometimes, the important is not how easy it is for someone to have different things at their disposal, but rather how easy it is to have something useful for a specific need, without other distractions. Sometimes a tourist prefers a simple map that focuses on what they want to explore, rather than an extensive map of everything that is available. And that is precisely where the opportunity for this solution lies. To evaluate the opportunity, it is important to do a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis of internal and external factors. This technique helps management build solid strengths, minimize weaknesses, identify opportunities, and mitigate threats. Figure 25 shows the SWOT analysis of the solution.

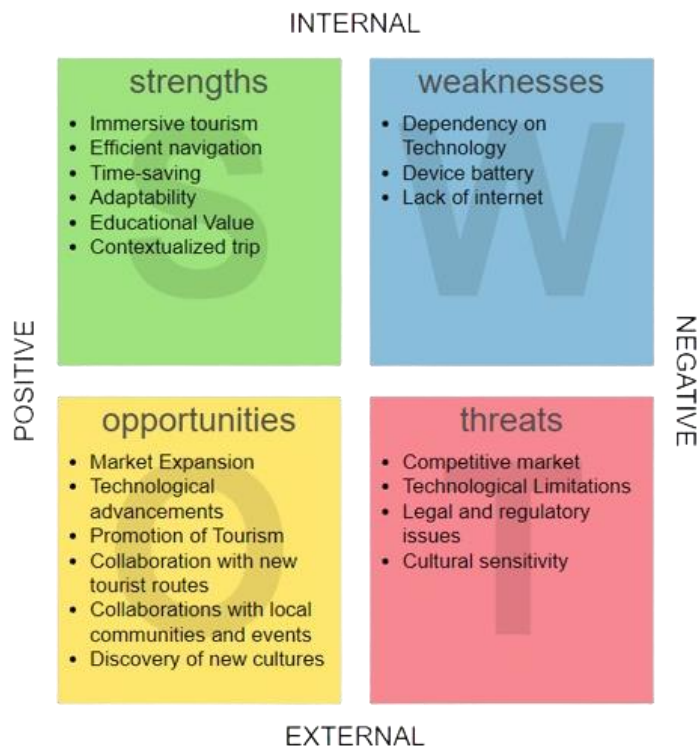


Figure 25 - SWOT Analysis

The main topics of that analysis can be described as follows:

Strengths:

- **Immersive tourism:** the incorporating AR technology offers a more engaging and immersive tourist exploration.
- **Efficient navigation:** the integration of GPS and AR ensures a more efficient navigation through virtual markers, reducing confusion and enhancing the exploration process.
- **Time saving:** the solution saves time for tourists, making the search for information more efficient and allowing the time dedicated to exploration to be more productive
- **Adaptability:** the flexibility of the solution in meeting a wide variety of tourist itineraries, meeting different interests and preferences.
- **Educational Value:** the inclusion of historical, cultural and architectural information enriches the tourist experience, increasing the educational value of the places visited.
- **Contextualized trip:** The solution's ability to offer contextualized information enriches the journey by providing only relevant details about each point of interest of the route.

Weaknesses:

- **Dependency on Technology:** the solution depends heavily on the availability and functionality of AR technology, which can have challenges in areas with limited technological infrastructure.
- **Device battery:** the continued use of location services for AR can lead to increased battery consumption, affecting app usability throughout the entire exploration journey.
- **Lack of internet:** the solution is dependent on internet connectivity, which could harm tourists without online access or in areas with limited internet.

Opportunities:

- **Market Expansion:** the growing search for ways to integrate technologies into the tourism sector, along with the need for unique and personalized tourist experiences, presents an opportunity for the solution to explore a market that is constantly growing.
- **Technological advancements:** technological evolution offers opportunities to improve the solution, incorporating new functionalities and ensuring continued relevance in the digital tourism sector.
- **Promotion of Tourism:** the solution can help promote tourism, encouraging more tourists to explore specific destinations.

- **Collaboration with new tourist routes:** collaboration with new tourist routes offers opportunities to attract tourists to little known or previously unexplored destinations.
- **Collaborations with local communities and events:** collaborations with local communities and events provide an opportunity to highlight unique cultural aspects along tourist routes.
- **Discovery of new cultures:** the discovery of new cultures through the solution helps attract tourists looking for authentic and diverse experiences.

Threats:

- **Competitive market:** with a competitive market in which there are increasingly AR-based solutions, the emergence of similar tourism solutions could represent a threat.
- **Technological Limitations:** technological restrictions or limitations may affect the effectiveness and innovativeness of the solution.
- **Legal and regulatory issues:** challenges related to legal and regulatory issues, such as restrictions on the use of AR technology in certain areas or privacy requirements, can impact the implementation and operation of the solution.
- **Cultural sensitivity:** failure to consider cultural sensitivity in the information provided by the solution may result in misunderstanding, offense, or resistance from local users or tourists.

As can be seen in the SWOT analysis, despite challenges such as technological dependence and the competitive market, the strengths outweigh the weaknesses, consolidating it as a promising opportunity in the digital tourism.

4.1.2 Idea Generation and Enrichment

Idea generation and enrichment involve the continuous evolution, development, and improvement of specific ideas. This dynamic process is influenced by customer interaction, interconnected cooperation, and external partnerships, and occurs in both formal and informal ways. It shapes innovation possibilities for the following development and commercialization operations while helping in the non-linear evolution of concepts within the NCD model (A.Koen, 2004).

With the value of the identified opportunity determined, the focus shifts to creating ideas that can evolve into a final solution based on the conceptual solution. Based on the AR technologies analyzed in the state of the art chapter, the four possible solutions are:

- Solution 1: Location-based AR

- Solution 2: Marker-based AR
- Solution 3: Projection-based AR
- Solution 4: Superposition-based AR

4.1.3 Idea Selection

Often, the biggest challenge is not the lack of original ideas, but rather the complexity companies face in choosing which ideas are best to maximize business value. In the selection process, it is important and crucial to support and improve ideas rather than simply eliminate them. After identifying promising ideas, the next step is to prioritize them and choose the most viable ones, considering that companies generally have more ideas than available resources (A.Koen, 2004).

4.1.3.1 Decision of the Most Valuable Idea

To determine the most valuable idea, a multi-criteria decision method was used, specifically the Analytical Hierarchical Process (AHP), which divides the decision problem into hierarchical levels, composed by the Objective, Criteria, and the Alternatives. This method evaluates the relative importance between the criteria, followed by comparing the alternatives in each specific criterion. With this, the overall classification is determined.

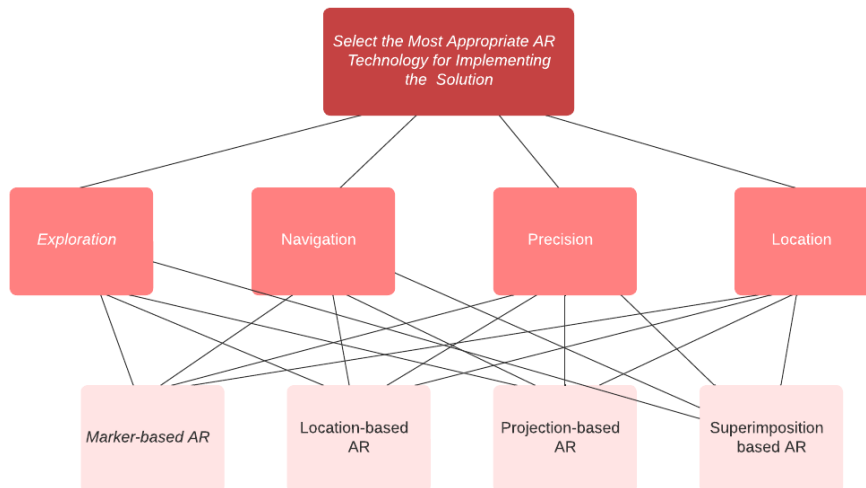


Figure 26 - The Hierarchy Decision Tree

As it is possible to see in Figure 26 , the main objective of this AHP is to choose which type of AR technology is better to use for the solution.

In order to build the best solution, the criteria chosen were the efficiency and flexibility of exploration, the ease of navigation, the accuracy of the technology triggers, and the accuracy of the user's location along the tourist route. Finally, the alternatives are Marker-based AR, location-based AR, projection-based AR and Superimposition-based AR.

With the objective, criteria and alternatives defined, the next step is to determine the relative importance of the different criteria in relation to each other. These levels of importance are described in Figure 27 , taken from the study (Taherdoost, 2017).

Importance Scale	Definition of Importance Scale
1	Equally Important Preferred
2	Equally to Moderately Important Preferred
3	Moderately Important Preferred
4	Moderately to Strongly Important Preferred
5	Strongly Important Preferred
6	Strongly to Very Strongly Important Preferred
7	Very Strongly Important Preferred
8	Very Strongly to Extremely Important Preferred
9	Extremely Important Preferred

Figure 27 - Scores for the Importance of Variable (Taherdoost, 2017)

With the importance levels established, was created a second-level comparison matrix.

Table 4 - Second-level Criteria Comparison Matrix

	Exploration	Navigation	Precision	Location
Exploration	1	3	5	2
Navigation	1/3	1	3	1/3
Precision	1/5	1/3	1	1/3
Location	1/2	3	3	1
Sum	51/20 (2.55)	22/3	23	11/3

With the matrix created, the next step is to normalize it, dividing the values in each column by the sum of that column.

Table 5 - Second-level Criteria Normalized Matrix

	Exploration	Navigation	Precision	Location
Exploration	20/51	9/22	5/23	6/11
Navigation	20/153	3/22	3/23	1/11
Precision	4/51	1/22	1/23	1/11
Location	10/51	9/22	3/23	3/11

Now it's time to get the criteria weights, presented in Table 6. This can be done by determining the average of each row. Note that the values of each weight have been rounded to two decimal places.

Table 6 - Criteria Weights calculation

	Exploration	Navigation	Precision	Location	Criteria Weights
Exploration	20/51	9/22	5/23	6/11	0.39
Navigation	20/153	3/22	3/23	1/11	0.12
Precision	4/51	1/22	1/23	1/11	0.06
Location	10/51	9/22	3/23	3/11	0.25

The outcome results from table 4.4 is:

- Exploration: 0.39
- Navigation: 0.12
- Precision: 0.06
- Location: 0.25

In the next step, the Consistency Ratio (CR) is calculated to validate the AHP results, using the following formula:

$$CR = \frac{CI}{RI} \tag{1}$$

Where:

- CR = Consistency Ratio
- CI = Consistency Index
- RI = Random Index

In order to calculate the CR, it is necessary to first calculate the CI and RI. Starting by calculating the CI, first it is necessary to multiply the normalized matrix (N) by the criteria weights (W):

$$N \times W = \begin{bmatrix} 20/51 & 9/22 & 5/23 & 6/11 \\ 20/153 & 3/22 & 3/23 & 1/11 \\ 4/51 & 1/22 & 1/23 & 1/11 \\ 10/51 & 9/22 & 3/23 & 3/11 \end{bmatrix} \times \begin{bmatrix} 0.39 \\ 0.12 \\ 0.06 \\ 0.25 \end{bmatrix} \approx \begin{bmatrix} 0.35 \\ 0.10 \\ 0.06 \\ 0.20 \end{bmatrix} \tag{2}$$

Then, it is necessary to determine the λ_{max} , by averaging NW with weights vector (W):

$$\lambda_{max} = \frac{\left(\frac{0.35}{0.39} + \frac{0.10}{0.12} + \frac{0.06}{0.06} + \frac{0.20}{0.25}\right)}{4} \approx 0.80 \tag{3}$$

With the λ max determined, it is then possible to calculate the CI, following the formula:

$$CI = \frac{\lambda \max - n}{n - 1} = \frac{(0.80 - 4)}{4 - 1} = -1.07 \quad (4)$$

Then, the next step that remains is to calculate the Random index. The RI is constant and can be obtained in Figure 28, where “Matrix Size” is the number of criteria. in the case of this solution, n = 4, so the RI = 0.90.

Matrix size	Random consistency index (RI)
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

Figure 28 - Random Index (Saaty, 1980)

With the IC and RI calculated, it is now possible to finally calculate the CR.

$$CR = \frac{CI}{RI} = \frac{-1.07}{0.90} \approx -1.19 \quad (5)$$

As the CR is -1.19, which is < 0.1, the result can be considered consistent. The next step involves the construction of a matrix to compare parity within each criteria, simultaneously considering all the alternatives.

Table 7- Parity Comparison Matrix for Exploration

	Marker-based AR	Location-based AR	Projection-based AR	Superimposition-based AR
Marker-based AR	1	1/3	9	1/3
Location-based AR	3	1	9	5
Projection-based AR	1/9	1/9	1	1/3
Superimposition-based AR	3	1/5	3	1
Sum	64/9	74/45	22	20/3

Table 8 - Parity Comparison Matrix for Navigation

	Marker-based AR	Location-based AR	Projection-based AR	Superimposition-based AR
Marker-based AR	1	1/5	9	5
Location-based AR	5	1	9	5
Projection-based AR	1/9	1/9	1	1/3
Superimposition-based AR	1/5	1/5	3	1
Sum	284/45	68/45	22	34/3

Table 9 - Parity Comparison Matrix for Precision

	Marker-based AR	Location-based AR	Projection-based AR	Superimposition-based AR
Marker-based AR	1	3	5	5
Location-based AR	1/3	1	3	3
Projection-based AR	1/5	1/3	1	3
Superimposition-based AR	1/5	1/3	1/3	1
Sum	26/15	14/3	28/3	12

Table 10 - Parity Comparison Matrix for Location

	Marker-based AR	Location-based AR	Projection-based AR	Superimposition-based AR
Marker-based AR	1	1/9	1/5	1/5
Location-based AR	9	1	3	3
Projection-based AR	5	1/3	1	1/2
Superimposition-based AR	5	1/3	2	1
Sum	20	16/9	31/5	47/10

With the parity comparison matrices made, the next step is to normalize each of these matrices and obtain the criteria weigh for each one. It is important to note that the “Criteria Weights” values were, again, rounded to two decimal places.

Table 11 - Weight Vector for Exploration

	Marker-based AR	Location-based AR	Projection-based AR	Superimposition-based AR	Criteria Weights
Marker-based AR	9/64	15/74	9/22	1/20	0.20
Location-based AR	27/64	45/74	9/22	3/4	0.55
Projection-based AR	1/64	5/74	1/22	1/20	0.04
Superimposition-based AR	27/64	9/74	3/22	3/20	0.21

Table 12 - Weight Vector for Navigation

	Marker-based AR	Location-based AR	Projection-based AR	Superimposition-based AR	Criteria Weights
Marker-based AR	45/284	9/68	9/22	15/34	0.29
Location-based AR	225/284	45/68	9/22	15/34	0.58
Projection-based AR	5/284	5/68	1/22	1/34	0.04
Superimposition-based AR	9/284	9/68	3/22	3/34	0.10

Table 13- Weight Vector for Precision

	Marker-based AR	Location-based AR	Projection-based AR	Superimposition-based AR	Criteria Weights
Marker-based AR	15/26	9/14	15/28	5/12	0.54
Location-based AR	5/26	3/14	9/28	1/4	0.24
Projection-based AR	3/26	1/14	3/28	1/4	0.14
Superimposition-based AR	3/26	1/14	1/28	1/12	0.12

Table 14- Weight Vector for Location

	Marker-based AR	Location-based AR	Projection-based AR	Superimposition-based AR	Criteria Weights
Marker-based AR	1/20	1/16	1/31	2/47	0.05
Location-based AR	9/20	9/16	15/31	30/47	0.53
Projection-based AR	1/4	3/16	5/31	5/47	0.18
Superimposition-based AR	1/4	3/16	10/31	10/47	0.14

Once the various criteria weights have been done for each criteria, it is now necessary to multiply each value of criteria weight vector obtained by the one obtained at the beginning of the method, thus giving the final weight of each criteria.

$$Exploration = \begin{bmatrix} 0.20 \\ 0.55 \\ 0.04 \\ 0.21 \end{bmatrix} \times \begin{bmatrix} 0.39 \\ 0.12 \\ 0.06 \\ 0.25 \end{bmatrix} \approx 0.20 \quad (6)$$

$$Navigation = \begin{bmatrix} 0.29 \\ 0.58 \\ 0.04 \\ 0.10 \end{bmatrix} \times \begin{bmatrix} 0.39 \\ 0.12 \\ 0.06 \\ 0.25 \end{bmatrix} \approx 0.21 \quad (7)$$

$$Precision = \begin{bmatrix} 0.54 \\ 0.24 \\ 0.14 \\ 0.12 \end{bmatrix} \times \begin{bmatrix} 0.39 \\ 0.12 \\ 0.06 \\ 0.25 \end{bmatrix} \approx 0.28 \quad (8)$$

$$Location = \begin{bmatrix} 0.05 \\ 0.53 \\ 0.18 \\ 0.14 \end{bmatrix} \times \begin{bmatrix} 0.39 \\ 0.12 \\ 0.06 \\ 0.25 \end{bmatrix} \approx 0.13 \quad (9)$$

In the final phase, the combined priorities of the alternatives are finally determined by multiplying the priority matrix (which includes all relative priorities for each criterion) by the corresponding weights of each criterion.

$$\begin{bmatrix} 0.20 & 0.29 & 0.54 & 0.05 \\ 0.55 & 0.58 & 0.24 & 0.53 \\ 0.04 & 0.04 & 0.14 & 0.18 \\ 0.21 & 0.10 & 0.12 & 0.14 \end{bmatrix} \times \begin{bmatrix} 0.20 \\ 0.21 \\ 0.28 \\ 0.13 \end{bmatrix} \approx \begin{bmatrix} 0.26 \\ 0.37 \\ 0.01 \\ 0.11 \end{bmatrix} \quad (10)$$

A higher importance number means that it would be important to choose this solution over others, as defined in Saaty's Fundamental Scale. Based on this, the established criteria and their significance, the **location-based AR** Solution would be the most favorable to follow, as it received the highest weight of 0.37. The next option to follow would be the Marker-based AR Solution, with a weight of 0.27.

4.1.4 Concept Definition

The last step of the new concept development model is to define the concept itself. The innovator needs to convince those responsible to invest in the idea to move forward. This is known as "declaring victory." The result is usually a business plan or a project proposal, which allows you to improve the concept (A.Koen, 2004).

The concept defined for this AR tourism solution aims to solve the challenges tourists face when exploring specific routes, transforming the way these routes are explored. Leveraging augmented reality technology, the solution provides a more efficient, personalized and enriching experience. By addressing issues of accessibility and personalization of information, it seeks to improve the quality of tourist experiences and promote local tourism initiatives.

4.2 Consumer Value and Perceived Value

Creating value is vital in business. It's about offering goods or services, tangible or intangible, and ensuring that customers or clients recognize their importance and are willing to pay for them. This recognition can happen within the company, among partners, or with external customers (Nicola, 12).

The word and meaning of "value" often get tied to money. But for customers, it's way more than that. It's not just about what they pay, it's about what they're willing to sacrifice. Morris Holbrook describes consumer value as an "interactive relativistic preference experience." (Holbrook, 1998). He explains the meaning of consumer value in three points, namely, "Consumer value is interactive", "Consumer value is relativistic" and "Consumer value is preferential". This implies that value is established through the interaction between the customer and the product (interactive), and its perception varies depending on the moment and context of use (relativistic). Customers make preference judgments based on their likes and dislikes, positive or negative feelings, and whether the product meets their desires, ultimately shaping their opinions on its pros and cons (preference). Additionally, there's the idea that all

products serve to satisfy wants and needs, contributing to the overall consumer experience. This book measures the value produced in eight ways:

- **Efficiency:** refers to the effectiveness with which a product or service uses resources to achieve desired results, often measured by the proportion between products and inputs, with time being a critical factor.
- **Excellence:** refers to a user's satisfaction with a product or service fulfilling its intended purpose or providing a valuable experience.
- **Status:** this is achieved when consumers adjust their consumption patterns to influence others, signaling their social position or prestige through their choices.
- **Esteem:** somewhat related to status, esteem value arises when a consumer appreciates his or her own consumption or lifestyle choices without actively seeking to influence others. It is about personal satisfaction and self-esteem derived from possessions or lifestyle choices.
- **Play:** play value refers to the pleasure and fun derived from the use of a product or service, being very focused on the user experience.
- **Aesthetics:** this relates to the intrinsic beauty or appeal of a product, which is appreciated for its own sake and not for any utilitarian purpose. It is the pleasure derived from its design or appearance.
- **Ethics:** ethics concerns the moral consequences of using a product or service on others and how these actions can affect their well-being
- **Spirituality:** involves admiration for supernatural or transcendent qualities, often seen as a counterpart to ethics.

Based on the outlined consumer value principles, this project fits into them in many ways. Firstly, in relation to efficiency, the solution aims to improve the tourist experience by providing relevant information in real time along the route, saving time. Furthermore, by offering a tourist experience through personalized and contextualized information about each point of interest, it is possible to achieve excellence.

Additionally, tourists obtain personal satisfaction and esteem through exploring tourist routes enriched by the application of augmented reality. AR technology adds a playful and immersive element to the tourist experience, increasing fun and engagement. Furthermore, the solution improves the aesthetic appeal of the tourist experience by replacing printed maps and guides with more visually appealing AR elements, enriching the overall visual experience for tourists.

Finally, ethical considerations are important when implementing the solution, especially in relation to environmental and cultural impact. Ensuring that technology is used responsibly,

and that the information provided is accurate and respectful of local culture and the environment is fundamental to an ethical and sustainable tourism experience. However, since customers often see different values in the same products or services, the idea of perceived value becomes a new important key in value. Perceived value means how much value a customer sees based on what they gain versus what they give up (University, 2023). This concept is an important element to understand how customers view the value of what's offered and finding ways to make them loyal.

The following table shows the benefits and sacrifices of the solution, in order to help to understand better its customer value.

Table 15 - Customer Value: benefits and sacrifices

Benefits	Sacrifices
Improved tourist experience	Initial learning curve
Personalized exploration	Dependence on technology
Contextualized exploration	Battery & internet consumption
Efficient navigation	Privacy Concerns
Enriched cultural understanding	Potential distraction
More fun and engaging exploration	
Time saving	

4.2.1 Value Proposition

The Value Proposition Canvas, created by Dr. Alexander Osterwalder, is a framework designed to ensure that a product and its market are in alignment. It takes into account the customer groups and Business Model value propositions and describes them in two distinct diagrams (B2B International, 2024). Figure 29 demonstrates the Value Proposition Canvas for this solution.

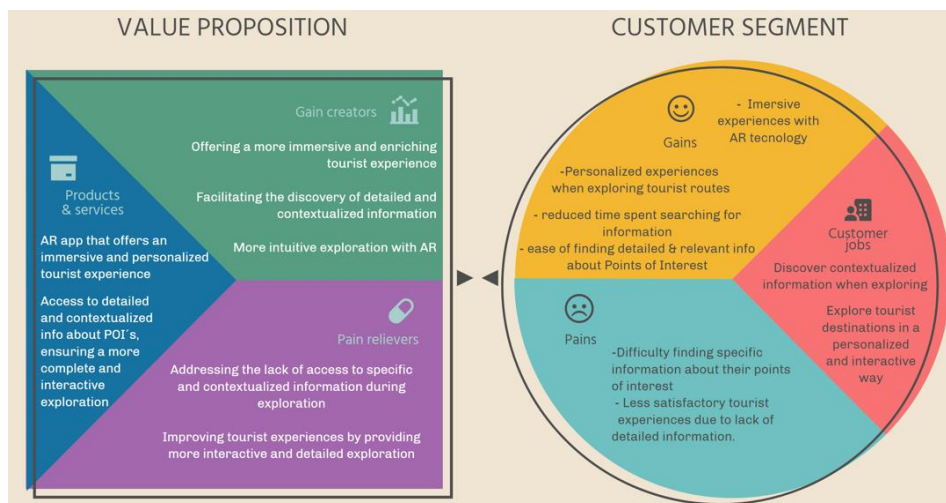


Figure 29 - Value Proposition Canvas

4.2.2 Business Model

A more detailed and complex way to explain how a company can generate, provide, or obtain value is through the elaboration of a business model. This model aims to capture value for the organization and distribute it to relevant stakeholders, emphasizing the essential strategic components of a company (Ebinum, 2016). It includes:

- **Customer segments:** who it's for.
 - In this solution, this represents the tourists and possible travel agencies/tours operators that want to increase their services to their users.
- **Customer relationships:** how the team will support and work with its customer base.
 - In this solution, this represents the custom support to create AR content for tourists' POIs, and community engagement through photos shared by tourists on their explorations.
- **Channels:** how the organization will market and sell it.
 - In this solution, this represents the mobile app.
- **Value propositions:** what the product does and promises.
 - In this solution, this represents immersive exploration of tourist routes through AR, access to detailed and contextualized information about POI's along them, and personalized routes based on individual interests and preferences.
- **Revenue streams:** how the product will make money.
 - In this solution, this represents premium service with more features through subscription and revenue sharing with partners.
- **Key activities:** the steps the team must complete to make it successful:
 - In this solution, this represents develop and maintain the app, update content about tourist routes and points of interest, update content about tourist routes and points of interest, marketing to attract tourists to unknown routes, and promote local tourism.
- **Key resources:** services, tools, and budget the team will have access to.
 - In this solution, this represents database & webserver, and services for AR, internet, and GPS & location.
- **Key partners:** how third parties will fit into the plan.

- In this solution, this represents AR technology providers for hardware and software support and partnerships with travel agencies & tour operators, Cultural heritage & museums, and localities to increase local tourism.

Cost structure: what it costs to build the product as well as how to sell and support it.

- In this solution, this represents hosting services like web server and database, web service, marketing, and app maintenance.

Figure 30 presents the business model canvas for the solution.

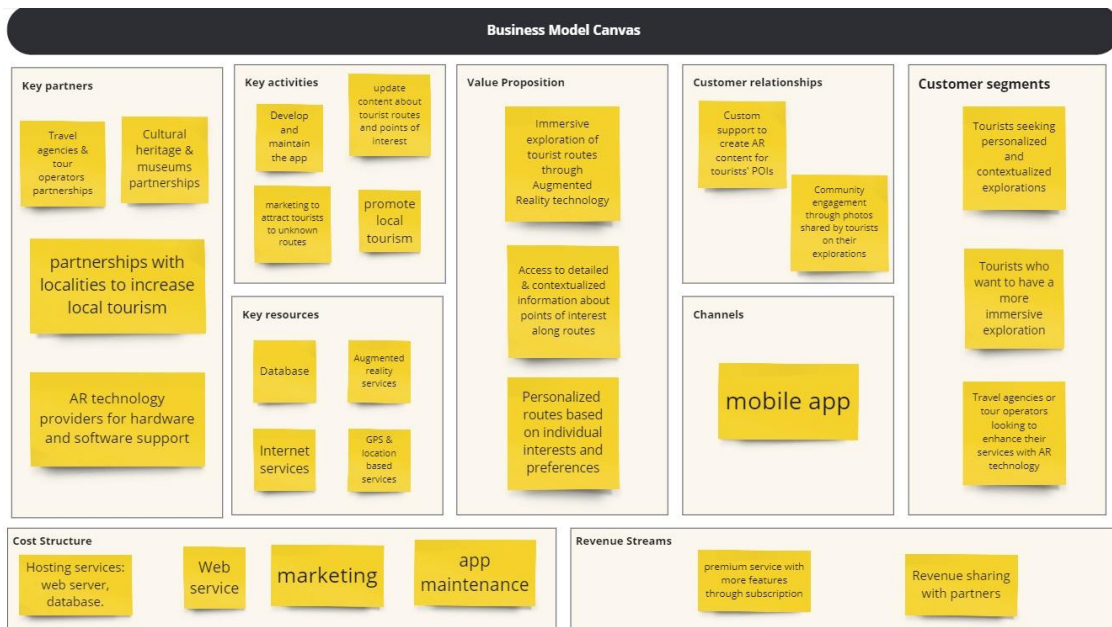


Figure 30 - Business Model Canvas

4.2.3 Quality Function Deployment

Quality Function Deployment (QFD) is a proactive approach used to ensure that customer needs and expectations are fully considered from the beginning of the design and production process. This means that instead of just dealing with problems after manufacturing, the idea was to anticipate customers' needs from the beginning. It is a more active way of dealing with quality, as it aims to prevent problems before they occur, rather than just fixing them later (Guevara, 2023).

The House of Quality (HoQ) is a fundamental stage of QFD, where every detail must be carefully considered, as this will determine the direction of the following QFD steps. HOQ is characterized by the Consumer Requirements, also known as "Whats", and by the Functional Requirements, also known as "Hows". The alignment of these requirements ensures that design and

production processes directly address customer needs, enhancing overall product quality and satisfaction.

The list below enumerates all the Consumer Requirements, as well as their importance:

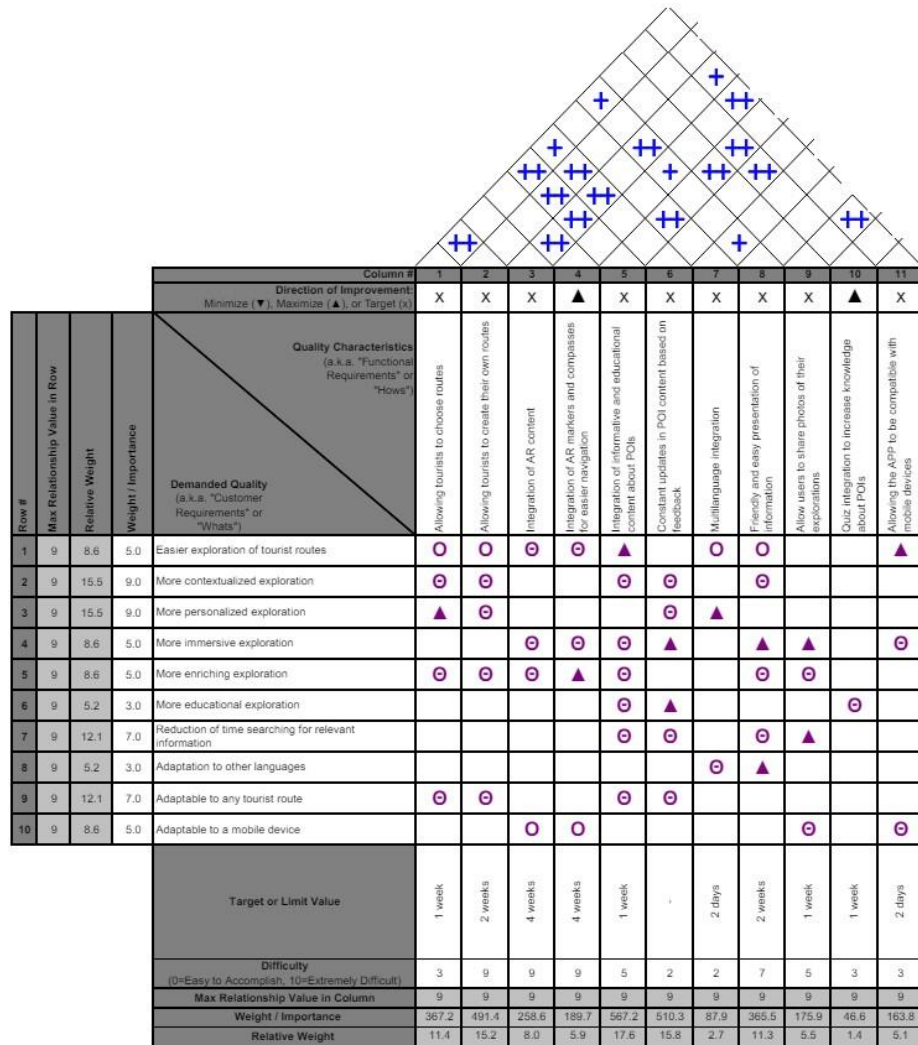
- Easier exploration of tourist routes (5)
- More contextualized exploration (9)
- More personalized exploration (9)
- More immersive exploration (5)
- More enriching exploration (5)
- More educational exploration (3)
- Reduction of time searching for relevant information (7)
- Adaptation to other languages (3)
- Adaptable to any tourist route (7)
- Adaptable to a mobile device (5)

Therefore, to meet the consumer's needs, the functional requirements are then presented, which detail how the expected additional value will be created:

- Allowing tourists to choose routes.
- Allowing tourists to create their own routes with their own POIs.
- Integration of AR content.
- Integration of AR markers and compasses for easier navigation.
- Integration of informative and educational content about POIs.
- Constant updates in POI content based on feedback.
- Multilanguage integration.
- Friendly and easy presentation of information
- Allow users to share photos of their explorations.
- Quiz integration to increase knowledge about POIs.

- Allowing the APP to be compatible with mobile devices

The following Figure 31 presents the House of Quality for this solution, illustrating the relationships between consumer requirements and the functional requirements.



Legend		
⊙	Strong Relationship	9
○	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
-	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
X	Objective Is To Hit Target	

Figure 31 - House of Quality

5 Development Process and Implementation

This chapter details the development process of the solution based on AR, building on the analysis, approaches, and conceptual design from previous chapters. It highlights the solution final design, development methodology and implementation details, providing a clear understanding of how the initial concept was transformed into a functional application.

5.1 Solution Final Design

In the Solution Conceptual and Design chapter the conceptual solution was designed, outlining the main and general features that the solution should have in its core. Now, based on the AR technology chosen in the Value Analysis chapter, the final design of the solution is presented.

5.1.1 Type of Augmented Reality Chosen

Following the value analysis in the previous chapter, **Location-based AR** was selected as the most suitable technology for the final solution. This choice ensures dynamic exploration by adapting to user movements, providing a personalized experience. Despite the small disadvantage in precision compared to marker-based AR, Location-based AR was chosen due to its advantages in exploration, navigation, and adaptability, which outweighed any limitations.

5.1.2 Routes Chosen

The solution aims to address the lack of contextualized information along tourist routes, enhancing the overall experience with relevant and engaging content. For the context of this dissertation, two historic routes were created in the cities of Porto and Chaves.

5.1.2.1 Porto Route

The Porto Route is composed of the following POI:

- **Lello Bookstore:** considered one of the most beautiful bookstores in the world, with a captivating atmosphere for book and architecture enthusiasts.
- **University of Porto:** founded in 1911, the University of Porto is one of the best universities in Portugal, with distinctions from UNESCO.

- **Clérigos Tower:** the Baroque Clérigos Tower offers panoramic views over the city of Porto from its tower.
- **Portuguese Photography Center:** Housed in a former prison, it shows the evolution of photography in Portugal, making it a fascinating destination for photography enthusiasts.
- **Puppet Museum:** This museum presents marionettes and offers a glimpse into the artistic and cultural legacy of this traditional form of entertainment through its varied collection.
- **Bolsa Palace:** a neoclassical building from the 19th century that housed the stock exchange, is recognized for its extravagant Arabian Room.
- **City Museum:** Infante's House is one of the oldest buildings in the city of Porto, being the birthplace of Infante D. Henrique, patron saint of Portuguese discoveries.
- **Ribeira:** the Ribeira area, close of the Douro River, is a very touristy area of Porto with a vibrant atmosphere.

Figure 32 shows the path of the presented tourist route.

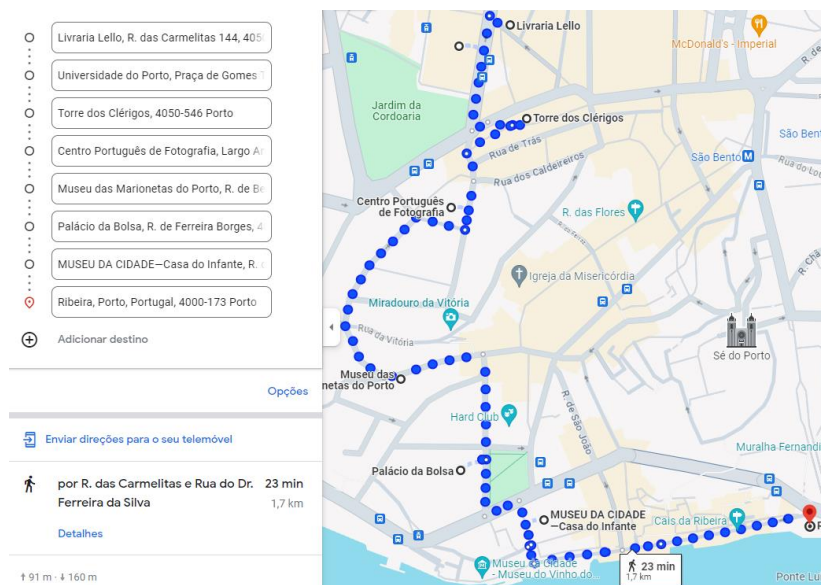


Figure 32 - Solution Tourist Route – Porto

5.1.2.2 Chaves Route

The Chaves Route is composed of the following POI:

- **Trajan's Bridge:** This roman bridge it is the oldest bridge in Portugal and one of the oldest in Europe, measuring around 150 meters long and with 12 visible arches.

- **Roman Thermal Baths:** is considered the largest Roman thermal bath on the Iberian Peninsula and one of the largest in the Roman Empire.
- **Mother Church of Santa Maria Maior:** The older church in Chaves, with the first references in 1259.
- **Chaves Castle:** With medieval characteristics and a rectangular plan, Chaves Castle, with its strategic location close to the border with Spain, was a crucial point of defense during the Middle Ages.
- **Fountain of the People:** The thermal waters were discovered by the Romans, even giving rise to the name of the city as Aquae Flaviae.

Figure 33 shows the path of the presented touristic route.

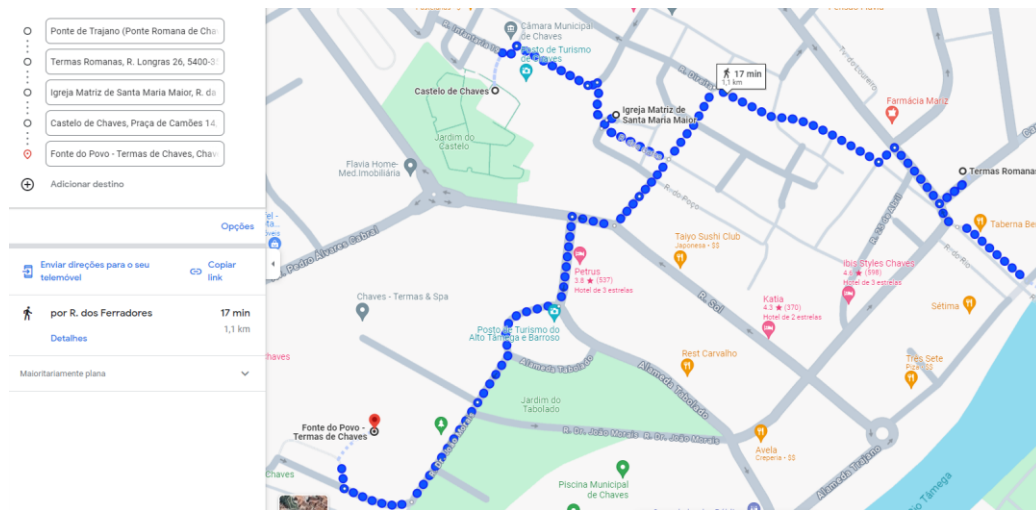


Figure 33 - Solution Tourist Route – Chaves

5.1.3 Augmented Reality Content Design

When developing the AR content for tourist route POIs, a consistent standard was created to ensure a cohesive and informative experience for users, composed of three main parts:

- **Central Part:** In the central part of the AR content of each POI is displayed its name along with a description about the location. This section serves as the focal point of the AR experience, providing users with an overview of what they can expect when exploring the POI.
- **Right Part:** users have access to detailed information about the history and meaning of the POI. Here, they can find details about the origin of the place, relevant historical events associated with it, and its cultural or historical importance. This section allows

users to delve deeper into the history of the POI, providing a more complete understanding of its context and relevance.

- **Left Part:** interesting facts and information related to the POI are displayed. This section offers users additional insights and fun facts that may not be directly related to the location's main story or description, but still contribute to a richer experience.

Some other secondary elements are incorporated in this standard, depending on the context of the POI in question, like images, opening hours and the official website. The color palette of the AR content also depends on the POI architectural style and historical context.

To illustrate, Figure 34 presents an example of a generic POI AR content with the described pattern: title and description in the central part, historical information on the right and curiosities on the left.



Figure 34 - Example of AR Content in a Generic POI

5.2 Development Methodology

The development of the solution follows an agile methodology to ensure flexibility, adaptability, and efficient progress throughout the project lifecycle. The development process involved dividing the project into sprints of two weeks.

Initially, the User Interface (UI) and User Experience (UX) were defined through mockups created in Figma. Features were then incrementally developed during each sprint, followed by regular testing and evaluation to assess progress. Based on testing results, continuous improvements were made to both UI and features. This iterative cycle of sprinting, developing, testing, and refining continued until the final solution was achieved.

5.3 Engine Chosen

For the development of the solution, Unity was selected for its versatility and powerful features, making it ideal for developing AR applications. Its dedicated AR tools simplify the integration of virtual elements like POIs, contextual information, and navigation guides. Additionally, Unity's community and documentation serve as great help and support for development and problem solving.

5.4 Augmented Reality Development Kit

To integrate AR into the solution, the chosen development kit was ARCore. Developed by Google, ARCore supports both Android and iOS, and it accurately detects device position and orientation in relation to the environment, enabling realistic placement of virtual objects.

5.5 Software Architecture

Microsoft SQL Server was chosen to be the database of the application. Additionally, the implementation of the Application Programming Interface (API) was developed in Node.js, enabling backend integration with Unity via HTTP requests. The following Figure 35 presents the detailed architecture of the solution.

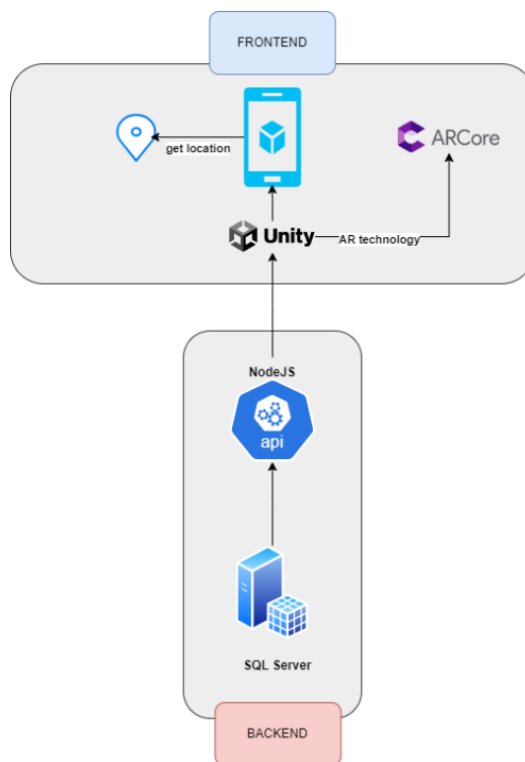


Figure 35 - Software Architecture

5.6 Database Architecture

The database architecture was designed to offer a comprehensive and integrated solution where tourists can not only explore and learn about tourist destinations, but also interact with each other and share their experiences, contributing to a more connected and engaging tourist community. Figure 36 presents the tourist in the center, then branching into three key components:

- **Exploration** (right side of the figure): Tourists can select and explore routes, access POI information, and use AR markers for navigation.
- **Quiz** (left side of the figure): Tourists can play quizzes about POIs, enhancing the educational and enjoyable experience.
- **Photo Gallery and Community** (top side of the figure): Tourists can share and view photos, promoting community interaction and inspiration.

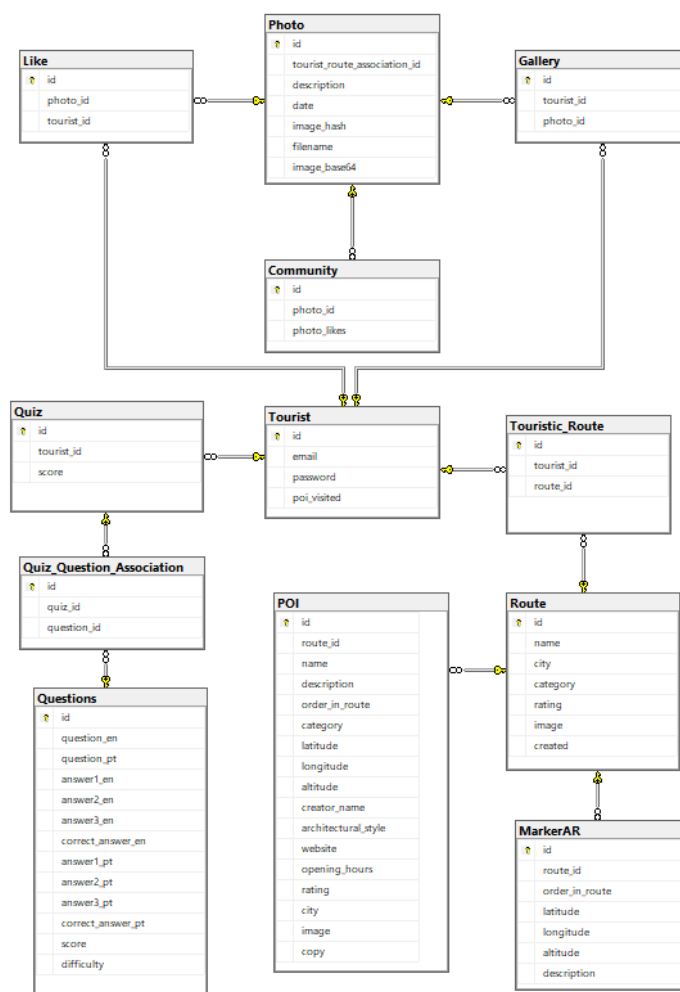


Figure 36 - Database Architecture

5.7 Augmented Reality Content Implementation

In the next subchapters, the content developed to be presented in AR at each POI will be presented, following the established pattern of three main parts: central part, right part, and left part. This content was created based on the unique characteristics of each POI, ensuring an informative, engaging, and contextualized experience for users.

5.7.1 Porto Route

5.7.1.1 Lello Bookstore

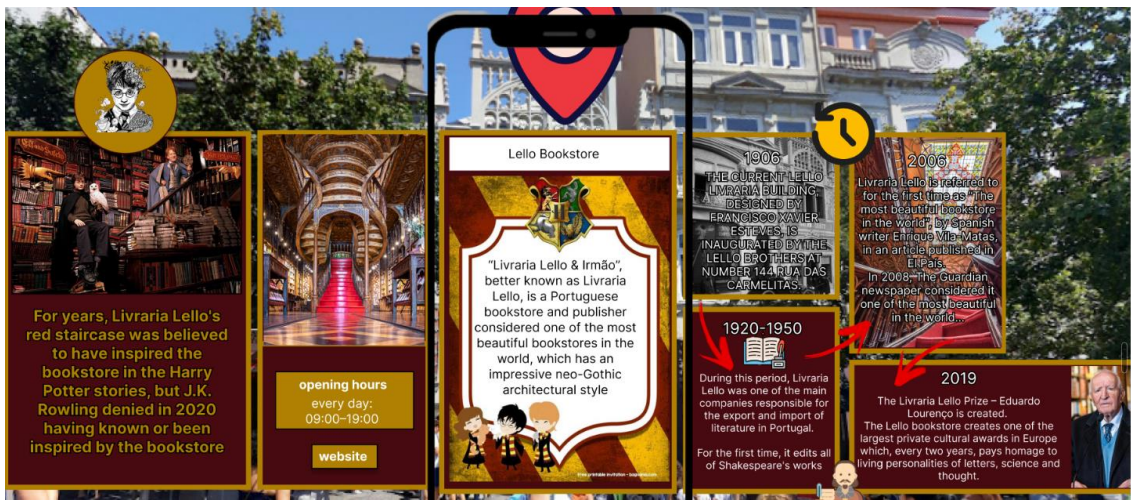


Figure 37 –Lello Bookstore AR Content

5.7.1.2 University of Porto



Figure 38 –University of Porto AR Content

5.7.1.3 Clerigos

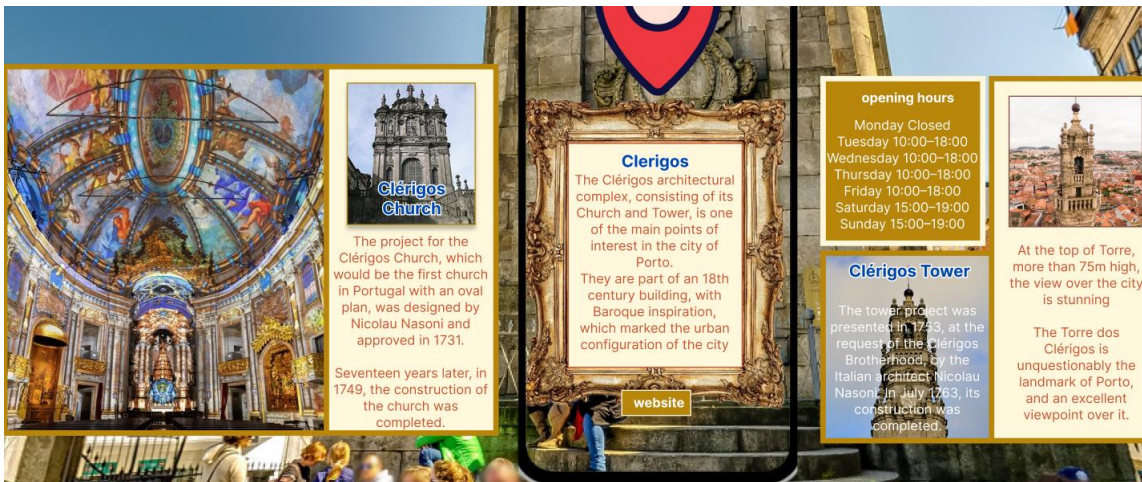


Figure 39 - Clerigos AR Content

5.7.1.4 Portuguese photography center



Figure 40 - Photography Center AR Content

5.7.1.5 Porto puppet museum



Figure 41 - Puppet Museum AR Content

5.7.1.6 Bolsa Palace



Figure 42 - Bolsa Palace AR Content

5.7.1.7 Infante House



Figure 43 –Infante House AR Content

5.7.1.8 Ribeira

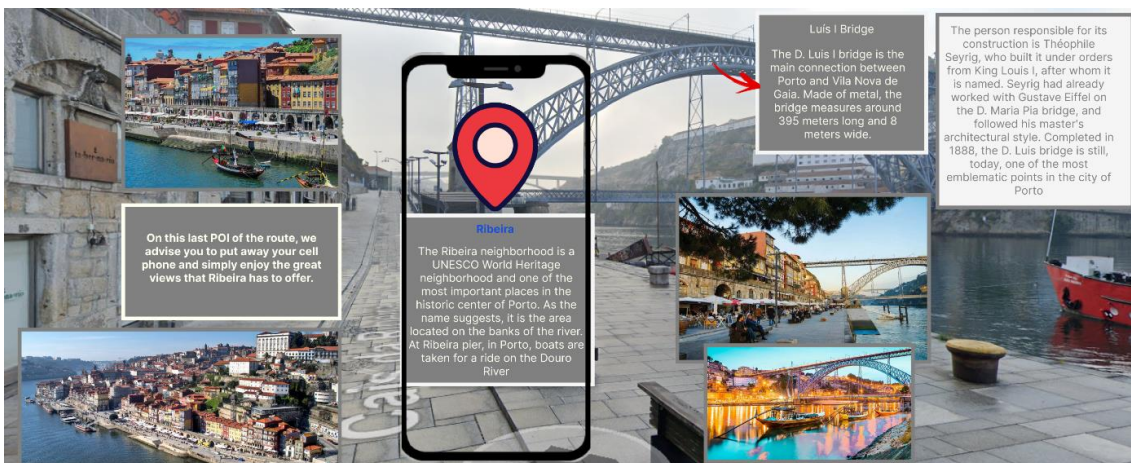


Figure 44 - Ribeira AR Content

5.7.2 Chaves Route

5.7.2.1 Trajan's Bridge



Figure 45 - Trajan's Bridge AR Content

5.7.2.2 Roman Thermal Baths



Figure 46 –Roman Thermal Baths AR Content

5.7.2.3 Church of Santa Maria Maior

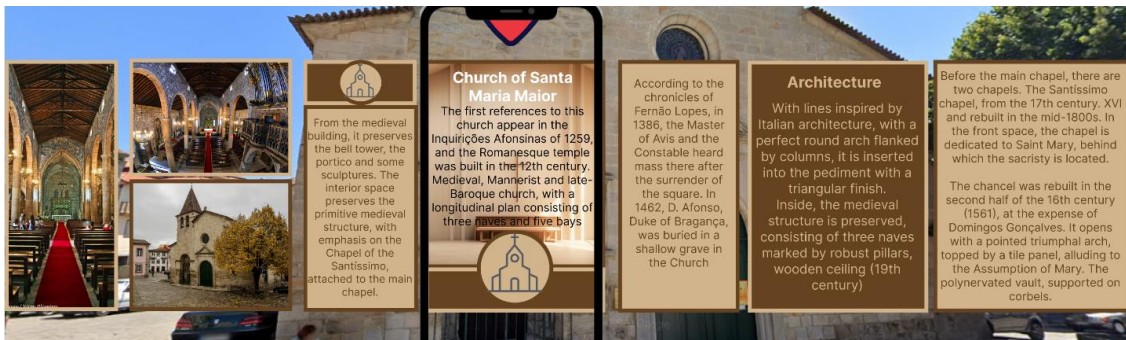


Figure 47 – Church of Santa Maria Maior AR Content

5.7.2.4 Chaves Castle



Figure 48 - Chaves Castle AR Content

5.7.2.5 Fountain of the People

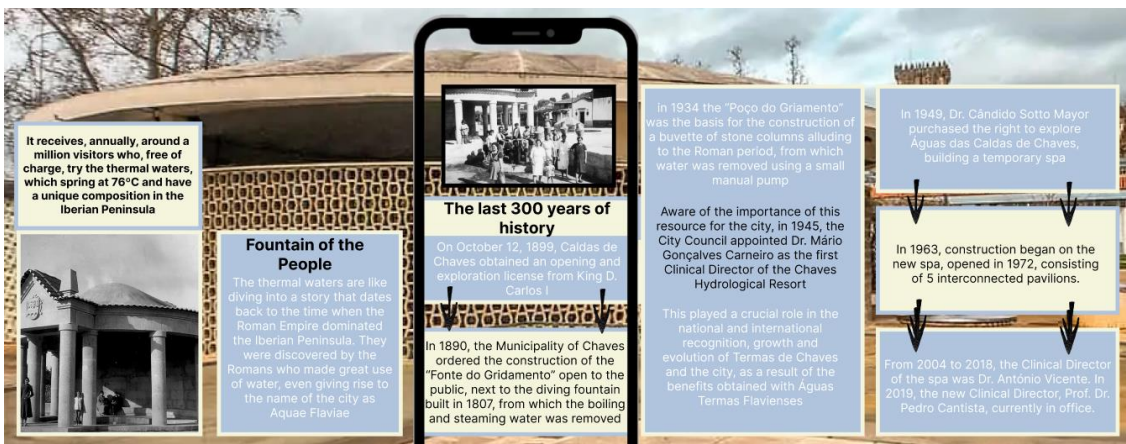


Figure 49 - Fountain of the People AR Content

5.8 User Interface

UI plays a crucial role in the success of any application, directly influencing user experience and satisfaction. The logo, shown in Figure 50, was created to reflect the essence and purpose of the solution. Focused on the idea of routes and paths, the logo evokes the feeling of movement and discovery, reinforcing the idea that the solution is oriented towards exploration. The logo's name, ARound Routes, is the name of the application, highlighting the two central aspects of the solution: AR and tourist routes.



Figure 50 – ARound Routes Logo

The app's color palette consists of 2 main colors: the background and text color has been set to #0D2535, while the buttons, navigation bar and other elements were set to the as #3CB371.

The main color evokes a feeling of depth and mystery. Furthermore, blue is associated with serenity, confidence, and even technology. The secondary color is often associated with nature and the outdoors. Green is also used to indicate positive actions, such as "go" or "forward", reinforcing the idea of progression and discovery in tourist exploration.

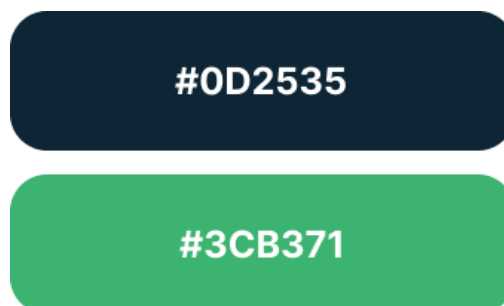


Figure 51 - ARound Routes Color Palette

5.9 Application Features Implementation

This chapter explores the technical development of the application, covering the implementation of key functionalities, the integration of technologies, and relevant code snippets and screenshots. It is possible to access the two public repositories on GitHub for a deeper and more detailed analysis of the solution's source code:

- **API repository:** <https://github.com/MiguelTomaz/tese-api>
- **Unity repository:** <https://github.com/MiguelTomaz/tese>

These repositories provide access to the complete API and frontend source code, enabling a more comprehensive understanding of the technical implementation behind the AROUND Routes app.

5.9.1 Register & Login

The registration and login process are fundamental in any application, providing users with secure access to the resources offered. The following Figure 52 and Figure 53 demonstrate the UI of the final product's registration and login functionality.



Figure 52 - App Registration Functionality



Figure 53 - App Login Functionality

5.9.2 Choose & Create a Tourist Route

Users can choose from existing tourist routes or create personalized ones based on the available list of POIs. In addition to the ability to explore the route, each itinerary offers options to view details and evaluate it and the POIs contained within it. Figure 54 and Figure 55 below show the final application interface during the route selection process.



Figure 54 -List of existing Routes in the App



Figure 55 - Route Details

Route creation, on the other hand, offers users the possibility of creating their own specific adventures. This process is divided into two steps:

- **Route Definition**, where users can choose a name, city and category.

```
async function addRouteFromTourist(name, city, category, created) {
  try {
    let pool = await sql.connect(config);
    let result = await pool.request()
      .input('name', sql.NVarChar(255), name)
      .input('city', sql.NVarChar(255), city)
      .input('category', sql.NVarChar(255), category)
      .input('created', sql.Int, created)
      .query(`INSERT INTO [Route] (name, city, category, created)
VALUES (@name, @city, @category, @created); SELECT SCOPE_IDENTITY() AS
RouteId`);
    (...)
  }
}
```

Code Snippet 1 - Implementation of Route Creation in the API

- **Selection of POI**, to select the POIs they want to include in their custom route.

```

async function addPoiToRoute(route_id, order_in_route, id) {
  try {
    let pool = await sql.connect(config);
    // Query to get the POI data with the given ID
    let queryResult = await pool.request()
      .input('id', sql.Int, id)
      .query('SELECT * FROM [POI] WHERE id = @id');

    (...)

    // Gets the data of the POI found
    const poiData = queryResult.recordset[0];

    // Update POI data to set the new route_id
    poiData.route_id = route_id;
    poiData.order_in_route = order_in_route;
    delete poiData.id;

    // Insert a new POI with updated data
    let insertResult = await pool.request()
      .input('route_id', sql.Int, poiData.route_id)
      .input('name', sql.NVarChar(255), poiData.name)
      (...)
      .query('INSERT INTO [POI] (route_id, name, (...)) ); SELECT
SCOPE_IDENTITY() AS NewPOIId');

    // Checks whether the insertion was successful
    if (insertResult.recordset && insertResult.recordset.length > 0) {
      const newPOIId = insertResult.recordset[0].NewPOIId;
      return { success: true, message: 'POI added to route
successfully.', newPOIId: newPOIId };
    }
    (...)
  }
}

```

Code Snippet 2 - Add POI to the Custom Route in the API

Figure 56 and Figure 57 below presents the final application interface during the route creation process. Once its created, it is added to the list and is visible only to the user who created it.

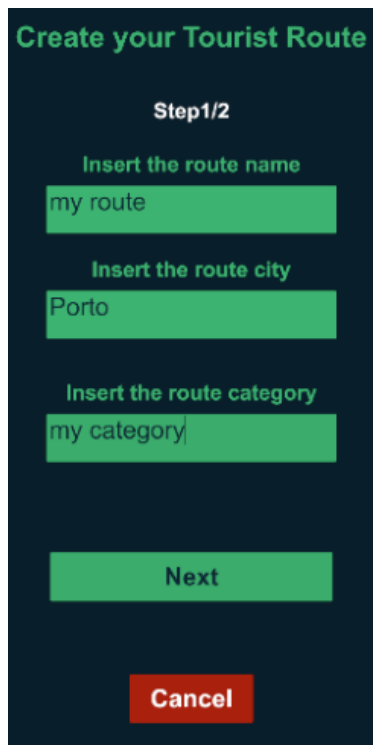


Figure 56 - Creating a Custom Route

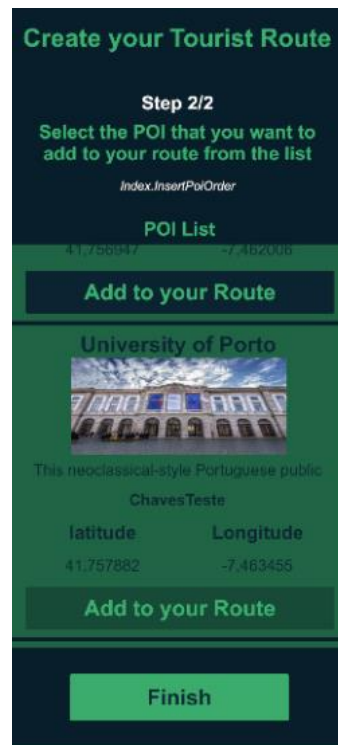


Figure 57 - add POIs to the Custom Route

5.9.3 Gallery & Community

During the tourist route exploration, users can take photos that will be stored in their private gallery and in the public community gallery, promoting sharing moments and inspiration for future journeys. Community members can interact with these photos through likes.

```

async function addPhoto(photo) {
  try {
    let pool = await sql.connect(config);
    let insertPhoto = await pool.request()
      .input('tourist_route_association_id', sql.Int,
photo.tourist_route_association_id)
      .input('description', sql.NVarChar, photo.description)
      .input('date', sql.DateTime, photo.date)
      .input('image_hash', sql.NVarChar, photo.image_hash)
      .input('filename', sql.NVarChar, photo.filename)
      .input('image_base64', sql.NVarChar, photo.image_base64)
      .query('INSERT INTO Photo (tourist_route_association_id,
description, date, image_hash, filename, image_base64) VALUES
(@tourist_route_association_id, @description, @date, @image_hash,
@filename, @image_base64); SELECT SCOPE_IDENTITY() AS id');
    (...)
    if (result.recordset && result.recordset.length > 0) {

```

```

touristId = result.recordset[0].tourist_id;

// Add to user gallery
await pool.request()
    .input('photo_id', sql.Int, insertedId)
    .input('tourist_id', sql.Int, touristId)
    .query('INSERT INTO Gallery (photo_id, tourist_id)
VALUES (@photo_id, @tourist_id)');

// Add to general community
await pool.request()
    .input('photo_id', sql.Int, insertedId)
    .query('INSERT INTO Community (photo_id, photo_likes)
VALUES (@photo_id, 0)');
(...)
}

```

Code Snippet 3: Add Photo to Gallery and Community in the API

The following Figure 58 shows some photos of the community, with their description, the user who took the photo, date, and number of likes. To like a photo, the user just needs to click on the heart at the bottom of each photo (the heart that is all red means that the user has already liked that photo).



Figure 58 – App Community

5.9.4 Tourist Quiz

The Tourist Quiz enhances user engagement and education by presenting 10 random questions with 3 difficulty types about POIs. The Quiz points earned by the user are added to their stats, thus competing in the leaderboard. Below is a snippet illustrating the quiz creation logic.

```
async function createQuiz(touristId) {
  try {
    // Create the quiz in the Quiz table with the tourist ID and
    initial score 0
    let pool = await sql.connect(config);
    let result = await pool.request()
      .input('touristId', sql.Int, touristId)
      .query('INSERT INTO Quiz (tourist_id, score) VALUES
(@touristId, 0); SELECT SCOPE_IDENTITY() AS QuizId;');
    const quizId = result.recordset[0].QuizId;
    // Get 10 random questions from the Questions table
    let questions = await pool.request()
      .query('SELECT TOP 10 * FROM Questions ORDER BY NEWID();');
    (...)
    return quizId;
  }
  (...)
}
```

Code Snippet 4: Create Quiz in the API

In the following Figure 59 it is also possible to observe the Quiz interface in the app. At the end of the Quiz, the final quiz score and the list of questions with the correct answer are presented.

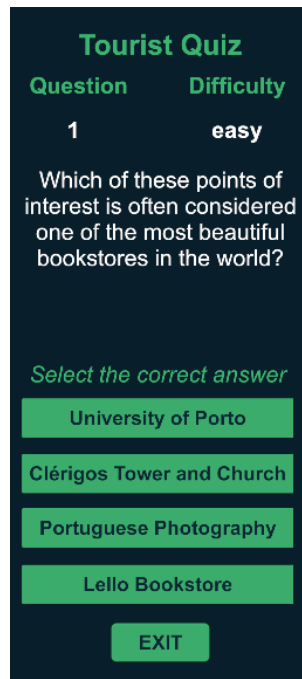


Figure 59 - Tourist Quiz

5.9.5 Route Exploration

Here, AR provides tourists with an immersive and interactive experience when exploring POIs along the way. It was necessary to design and implement the content for each POI, ensuring an accurate and engaging representation of tourist locations. The development of this component involved the integration of several technologies, namely ARCore services for AR technology, location services for tracking the user's position, and content positioning in AR.

5.9.5.1 POI Coordinates

Using platforms like Google Maps and Google Earth made it easy to determine the latitude and longitude of each POI. However, an additional challenge came up in determining the altitude of each POI. GeospatialAPI, an ARCore feature used to position AR elements, uses a reference system known as WGS84. This system assumes that the Earth is an Ellipsoid, that is, a mathematical model that represents the planet as a sphere slightly flattened at the poles and widened at the equator. On the other hand, Google Maps uses a more advanced reference system called EGM96, which employs a Geoid model to represent the Earth. A Geoid is an irregular surface that corresponds to mean sea level and is more accurate in describing the actual shape of the Earth, as can be seen in Figure 60.

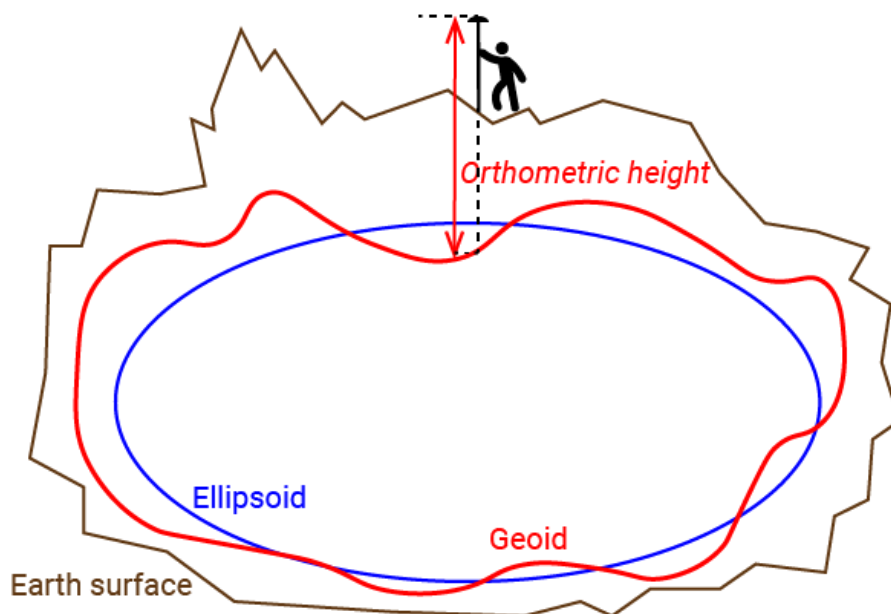


Figure 60 - Ellipsoid and Geoid Model (ArduSimple, 2021)

Due to the differences between these two reference systems, the altitude provided may vary in representing the altitude of a given point on the Earth's surface. Therefore, it was necessary to consider these differences to ensure an accurate and consistent representation of the AR content along the route.

To do this, firstly, was used the altitude provided by Google Earth for each POI, based on the latitude and longitude coordinates. Then, using the same coordinates, an external website ⁵ was used to obtain the corresponding altitude value in the EGM96 model.

Therefore, to represent the altitude of the POI in Unity, was added to the Google Earth altitude value, the EGM96 altitude value provided by the external website. Finally, so that the POI does not remain on the ground, 1.5 was added to the final value so that it remains 1.5 meters above the ground.

5.9.5.2 User Coordinates

The user's coordinates were obtained by collecting the coordinates of the user's own device. This was accomplished using the location features available on mobile devices, allowing the application to determine the user's current geographic position.

To ensure the app always has the user's most updated coordinates, these are updated every 5 seconds. Bellow, it is possible to observe a code snippet for obtaining the user's coordinates.

```
IEnumerator GPSUserLocation()
{
    if (!Permission.HasUserAuthorizedPermission(Permission.FineLocation))
    {
        Permission.RequestUserPermission(Permission.FineLocation);
        Permission.RequestUserPermission(Permission.CoarseLocation);
    }
    if (!Input.location.isEnabledByUser)
    {
        userLocationText.text = "location is not Enabled By User";
        yield break;
    }
    //start service
    Input.location.Start();
    if (Input.location.status == LocationServiceStatus.Running)
    {
        lon = Input.location.lastData.longitude;
        lat = Input.location.lastData.latitude;

        PlayerPrefs.SetString("UserLatitude", lat.ToString());
        PlayerPrefs.SetString("UserLongitude", lon.ToString());
        PlayerPrefs.Save();
    }
}
```

Code Snippet 5 - Get User Location in Unity

⁵ <https://geographiclib.sourceforge.io/cgi-bin/GeoidEval>

5.9.5.3 Vector Between the User and the POI

To determine the direction in which the POI is in relation to the user, providing visual guidance and facilitating navigation along the tourist route, it was necessary to calculate the vector between the user and the POI, its tangent and the respective angle.

The following code snippet demonstrates how this was done, taking into account that the user and POI coordinates have already been calculated.

```
string latitudeString = PlayerPrefs.GetString("UserLatitude");
string longitudeString = PlayerPrefs.GetString("UserLongitude");
var x1;
var y1;

if (!string.IsNullOrEmpty(longitudeString))
{
    x1 = double.Parse(longitudeString);
}

if (!string.IsNullOrEmpty(latitudeString))
{
    y1 = double.Parse(latitudeString);
}

var x2;
var y2;

if (currentPoiLongitude != 0)
{
    x2 = currentPoiLongitude;
}

if (currentPoiLatitude != 0)
{
    y2 = currentPoiLatitude;
}

double delta_x = x2 - x1;
double delta_y = y2 - y1;

double[] vector_AB = { delta_x, delta_y };

double angle_with_x_axis = Math.Atan2(delta_y, delta_x);

// Convert angle to degrees
double angle_degrees = angle_with_x_axis * (180 / Math.PI);
double angle_degrees_Y = 90 - angle_degrees;
```

Code Snippet 6 - Get angle between User and POI

It is important to highlight that the rotation of the compass that points to the POI with the calculated angle only works correctly in the ideal scenario, in which the user is pointing the

device to the north. However, if the user is not in that position, it was necessary to find the north and update the compass arrow rotation with the correct value. This was achieved by determining the north direction using the mobile device's orientation sensors.

```
// Gets the North direction
float trueNorthAarrowDirection = Input.compass.trueHeading;
```

Code Snippet 7 - Get North Direction

5.9.5.4 Augmented Reality Integration

ARCore services were used to bring AR to life in the app, using ARAnchorManager to create and manage anchors in the virtual environment. These anchors ensure stability and alignment with the real world, allowing POIs to be positioned in the virtual space and viewed through the AR camera. This integration combines POI information, user location data, vectors, and orientation calculations to provide an immersive and interactive navigation experience along the tourist route. Below are code snippets on the integration of ARCore into the solution.

```
private void VerifyGeospatialSupport()
{
    var result =
earthManager.IsGeospatialModeSupported(GeospatialMode.Enabled);
    switch (result)
    {
        case FeatureSupported.Supported:
            readyToUseText.text = "ready to use VPS";
            PlaceObjects();
            break;

        case FeatureSupported.Unknown:
            Invoke("VerifyGeospatialSupport", 5.0f);
            break;

        case FeatureSupported.Unsupported:
            readyToUseText.text = "vps unsupported";
            break;
    }
}

private void PlaceObjects()
{
    if (earthManager.EarthTrackingState == TrackingState.Tracking)
    {
        var geospatialPose = earthManager.CameraGeospatialPose;
        foreach (var obj in geospatialObjects)
        {
            var eartPosition = obj.earthPosition;
            var objAnchor =
ARAnchorManagerExtensions.AddAnchor(aRAnchorManager, eartPosition.latitude,
eartPosition.longitude, eartPosition.altitude, Quaternion.identity);
            Instantiate(obj.objectPrefab, objAnchor.transform);
            canStartExploration = true;
        }
    }
}
```

```

    }
  }
  else if (earthManager.EarthTrackingState == TrackingState.None)
  {
    Invoke("PlaceObjects", 5.0f);
  }
}

```

Code Snippet 8 - ARCore integration and position POIs in the Virtual World

Below are three images showing the exploring process in the app. It starts with Figure 61 (the left image), where the user can observe some general information about the status of the chosen itinerary, as well as an audiobook functionality about the current POI. To explore the route, the user just needs to click on the "Explore Route" button. Then, Figure 62 shows AR markers indicating the path, a compass pointing in the direction of the POI, the distance between the POI and the user, and information about the direction of the cardinal point towards which the user is directed. Finally, in the right image, Figure 63 shows the AR information of a specific POI. These images provide a visual overview of the navigation and exploration experience of a tourist route, highlighting the successful integration of AR into the app.

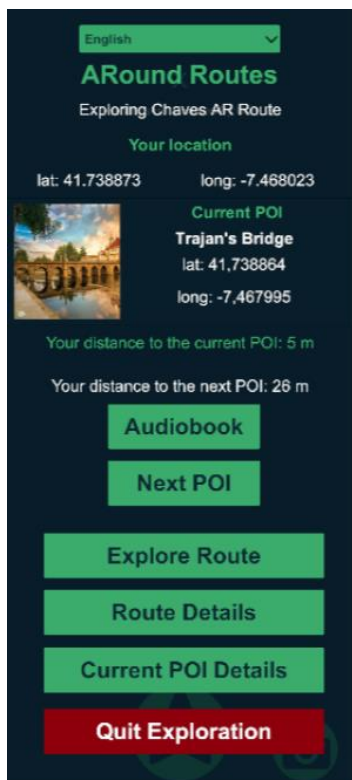


Figure 61 - Exploration Menu

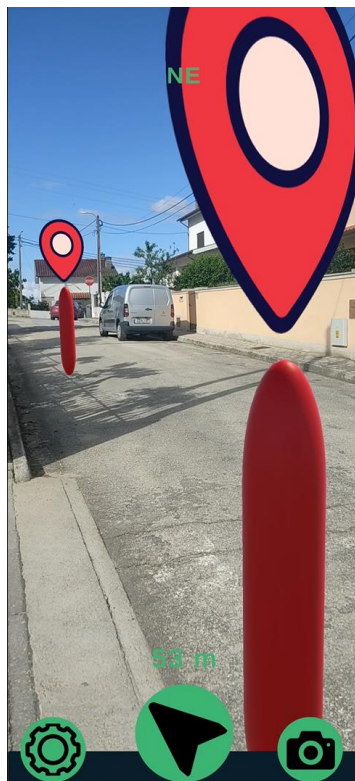


Figure 62 - AR Navigation



Figure 63 - AR POI Exploration

6 Experimentation and Evaluation

This chapter details the experimentation and evaluation process of the developed solution. Two questionnaires were conducted via Google Forms. The first focuses on usability tests using the System Usability Scale (SUS), and the second evaluates the app's impact on users and whether it meets the established objectives. The questionnaires can be accessed at the following links:

- Usability questionnaire: <https://forms.gle/niraucDNnfugJ9Zu5>
- Objectives questionnaire: <https://forms.gle/nrQa52XzF5d33gKD9>

The SUS is a widely used tool for evaluating the usability of applications, consisting of questions rated on a Likert scale from 1 to 5, where 1 represents "I completely disagree" and 5 represents "I completely agree" (Teixeira, 2015). To calculate the system usability percentage, the following recommended steps for the SUS were followed:

1. Convert into points for each user answer (from 1 to 5), according to the following rules:
 - a. subtract 1 from the point provided for questions where 5 corresponds to a positive result (points - 1).
 - b. Subtract 5 before the point provided for questions where 5 corresponds to a negative result (5 - points).
2. Then, add all points for each user to calculate their individual scores.
3. The score previously obtained is divided by the maximum total that can be obtained, and then multiplied by 100. This is the user's final score.
4. After the final scores of all users are calculated, the scores are then averaged to obtain the final SUS score.

The System Usability Score has an average of 68 points. If the final score of the solution is below this value, the application may have usability challenges (Teixeira, 2015). In addition, some open answer questions were created, where the participant can give feedback and suggestions for improvements.

6.1 Results Analysis

The following sections analyze and evaluate the data from the questionnaires answered by 31 participants.

Participants had all the following prerequisites:

- The participant had a smartphone (android).
- The participant had internet access.
- The participant allowed the use of location services on the smartphone.
- The participant was located either in the city of Chaves or in the city of Porto to explore the routes.

6.1.1 System Usability Scale

In the usability questionnaire of this solution, 59 questions were answered by all the 31 participants, chosen from both Chaves and Porto. Although the application is mainly aimed at young tourists due to the use of technology most appreciated by this group, the ages of the participants varied. This diversity was intentional to assess whether older people can use the app without difficulties.

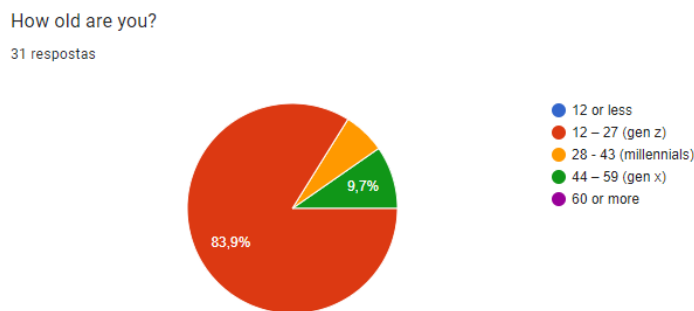


Figure 64 - Ages of Participants

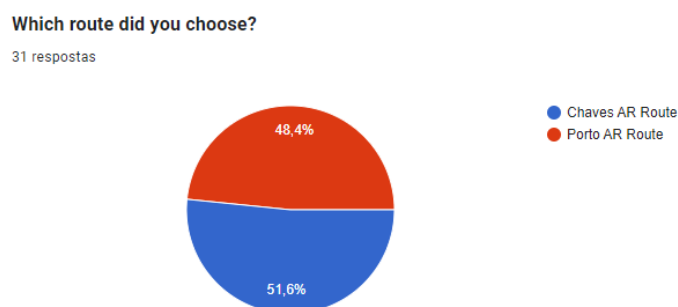


Figure 65 - Chosen Tourist Route

The SUS result was **86.7**, which indicates an excellent usability score. Usability was aspect highly focused throughout the development of the solution, as it is crucial in a tourism context for users to navigate routes without difficulty. Every feature was designed to be intuitive and user-friendly, and this high score confirms that this objective was successfully met.

The following images present some key results regarding the AR navigation and AR exploration system usability, which are central aspects of the app. For the navigation system, **77.4%** of participants agreed with the statement "How easy was it to identify the direction and distance to the next POI using the navigation system (compass and AR markers)?". Additionally, **61.3%** found the AR navigation effective in response to "How effective was the AR navigation system in guiding you towards the points of interest along the route?".

For the AR exploration system, all participants answered positively to the question "How satisfied were you with the overall immersive experience provided by the AR technology during the route exploration?", with **61.3%** expressing that they were very satisfied. These results highlight the strong usability of the app for exploring routes with augmented reality.

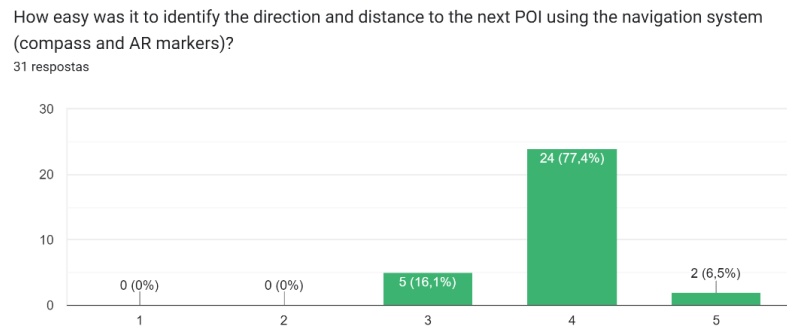


Figure 66 - User answer to AR Navigation Ease

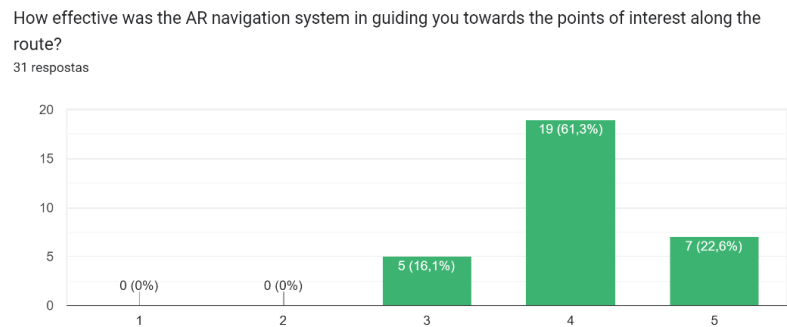


Figure 67 - User answer to AR Navigation Effectiveness

How satisfied were you with the overall immersive experience provided by the AR technology during the route exploration?

31 respuestas

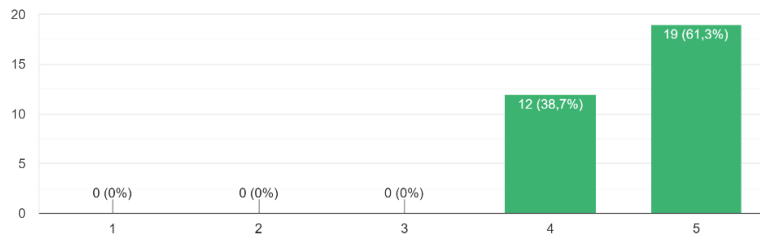


Figure 68 - User answer to AR Exploration Satisfaction

In the questionnaire, participants had the opportunity to provide open answers, highlighting aspects they found relevant. Some responses positively mentioned are the follows:

- **Audiobook Inclusion:** “I liked the audiobook. It made exploration more interesting as I was listening to a story while exploring the city” – participant feedback.
- **Community Interaction:** “I liked the small community that the app tries to create” - participant feedback.
- **Language Inclusion:** “I don't understand English well, I'm glad there is an option to change the language” - participant feedback.

Despite the positive feedback regarding the application's accessibility, some responses suggested areas for improvement. These included:

- **Error & Feedback Messages:** “Some error messages would be a good addition. I had written the password wrong but there was no message informing me of this” - participant feedback.
- **More POIs:** “The functionality to create a personalized route has a lot of potential, but there should be more destination points” - participant feedback.
- **Navigation Compass:** “The compass is always spinning like crazy.” - participant feedback.

6.1.2 Impact of the Solution and Objectives

After the initial usability tests through the SUS, a second questionnaire was carried out with the same participants, to analyze the impact that the developed application had on them and determine whether it successfully achieved the established objectives.

6.1.2.1 Customization of the Tourist Route

The customization of tourist routes brought benefits to the user, with **83.8%** of participants answering positively that the possibility of creating personalized routes allowed them to have a more unique travel experience adapted to their interests, as it's shown in Figure 69. However, the same figure also indicates that **67.7%** encountered some difficulties in finding customization options due to the limited number of available POIs in the application.

Did you feel that the ability to create personalized routes allowed you to have a more unique travel experience adapted to your interests?

31 respostas

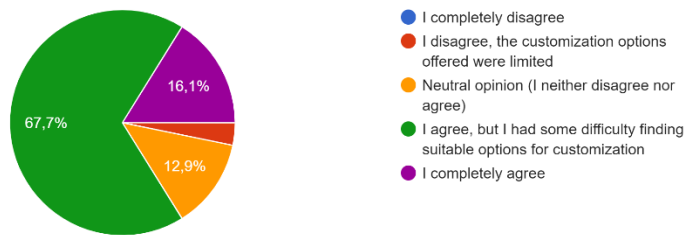


Figure 69 - Result of Creating a Personalized Route

Additionally, Figure 70 shows that **45.2%** of participants preferred using both predefined and customized routes for exploration, while **29%** opted solely for personalized routes and **25.8%** preferred the default route.

Did you prefer to follow the default tourist routes or create your own custom routes?

31 respostas

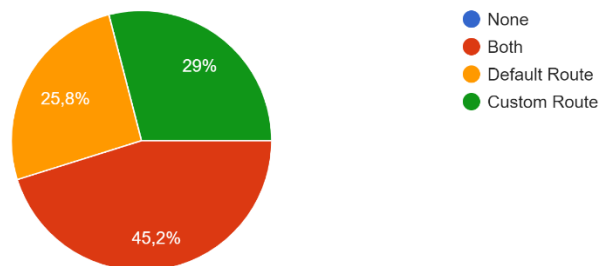


Figure 70 - Result of Choosing a Route to Explore

These results suggest that the goal of enhancing personalization and contextualization in the tourist experience was successfully achieved. Nevertheless, increasing the variety of available POIs is crucial to further enriching the user experience, providing users a wider range of options to choose.

6.1.2.2 Usefulness of Educational Elements

Regarding the educational elements available in the app, there was total approval from participants, with **54.8%** agreeing that they were useful for learning more about POIs, and the remaining **45.2%** considering them extremely useful.

Do you think the educational elements available in the application were useful in learning more about tourist destinations?
31 respuestas

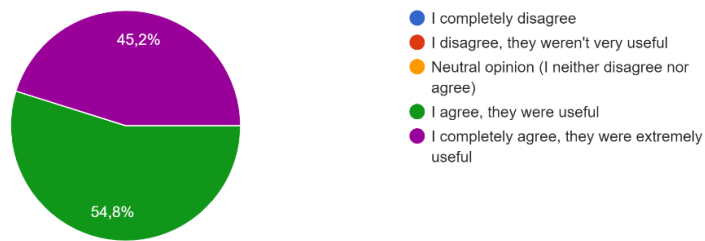


Figure 71 – Result of Usefulness of Educational Elements for Learning

Based on these results, it is possible to conclude that the objective of improving the educational experience was successfully achieved.

6.1.2.3 Augmented Reality Navigation

Regarding the exploration efficiency with AR navigation, Figure 72 shows that **52.2%** of the participants agreed that AR navigation enhances exploration efficiency, with an additional **41.9%** completely agreeing. This results in **87.1%** of participants expressing positive responses.

Do you think AR navigation has made your exploration more efficient?
31 respuestas

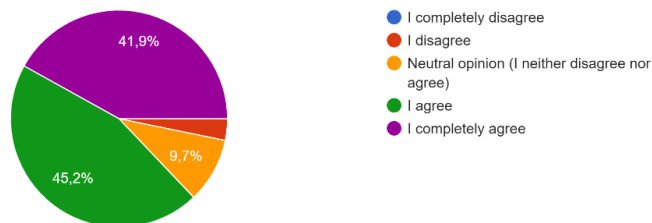


Figure 72 - Result of AR Navigation

Further analysis reveals:

- The mode of the answers falls into the "agree" category, with 14 participants selecting this option.

- The median response is positioned between "agree" and "completely agree". The average score, on a scale where 1 corresponds to "completely disagree" and 5 to "completely agree", is approximately 4.23, indicating a strong lean towards agreement.
- The standard deviation of 0.76 suggests that most participants opinions around the positive end of the scale.

These statistics shows a high level of satisfaction and perceived efficiency with AR navigation among participants during the exploration of tourist routes. This affirms that the objective of enhancing navigation through AR technology was successfully achieved.

6.1.2.4 Augmented Reality Exploration

In terms of efficiency in reducing unnecessary information, it is evident from Figure 73 that there was unanimous approval from the participants, with **22.6%** agreeing and **77.4%** completely agreeing. This indicates that the objective of reducing unnecessary information was successfully achieved.

Did the app effectively reduce the excess of unnecessary information, providing you with useful and relevant content during your exploration of the tourist route?
31 respuestas

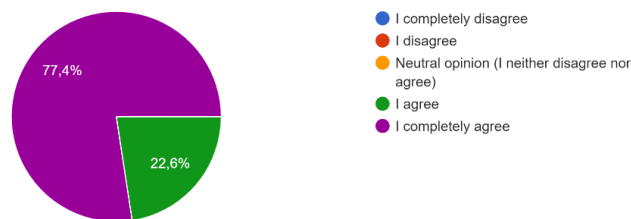


Figure 73 - Result of Effectiveness in reducing Unnecessary Information

Regarding the goal of promoting local tourism and encouraging tourists to explore and learn more about their destinations, history, and culture, it is also possible to conclude that this was successfully achieved. As shown in Figure 74, **67.7%** of participants agreed, **29%** completely agreed, and only **3.2%** (1 participant) had a neutral opinion.

Did the app succeed in promoting local tourism by encouraging you to explore and learn more about destinations, history, and culture?
31 respuestas

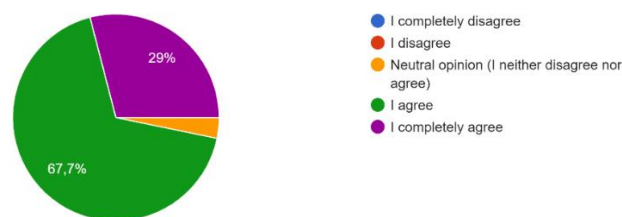


Figure 74 - Result of Promoting Local Tourism

Finally, as can be seen in Figure 75, **54.8%** of participants agreed that the use of AR in the application improved the route exploration experience, while **35.5%** completely agreed. Only **9.7%** (3 participants) expressed a neutral opinion.

Do you think that Augmented Reality in the app was useful in improving your experience when exploring tourist routes?
31 respostas

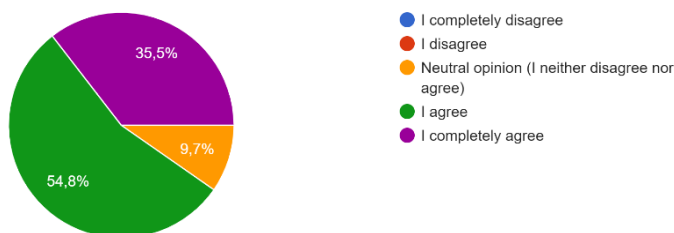


Figure 75 - Result of AR's Effectiveness in improving Route Exploration

Analyzing in more detail, the average response was 4.26 on a scale of 1 to 5, indicating a strong general agreement on the benefits of AR in route exploration. Furthermore, the median of 4 suggests that most participants agreed, at least partially, with the question. The relatively low standard deviation of approximately 0.62 indicates that participant opinions are closely aligned around this average, demonstrating a high level of agreement regarding the use of AR in the application.

These results demonstrate that the integration of augmented reality technology was well received by users, contributing positively to the experience of exploring tourist routes.

6.1.2.5 Applicability Across Multiple Touristic Routes – Chaves and Porto

In the questionnaire, some questions were divided into two distinct groups: those who tested the application in Chaves and those who tested it in Porto. The results of this data were then analysed, with the purpose of checking the consistency of the user experience between the two groups, as well as evaluating the success of creating an effective solution for multiple tourist routes in different locations.

The results obtained for the Chaves and Porto groups were predominantly positive, reflecting a favorable reception for the application in both locations. Although the following Figure 78 and Figure 79 demonstrate a significant similarity in the results of the question on promoting tourism in the two cities, a disparity was observed in the answers to the other questions.

Did you feel that the application provided an enriching tourist experience in Chaves?

16 respostas

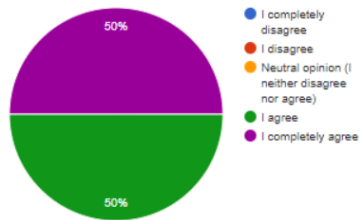


Figure 76 - Tourist Experience in Chaves

Did you feel that the application provided an enriching tourist experience in Porto?

15 respostas

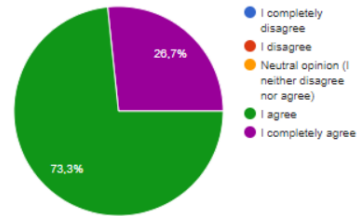


Figure 77 - Tourist Experience in Porto

Do you believe the application contributed to promoting local tourism in Chaves?

16 respostas

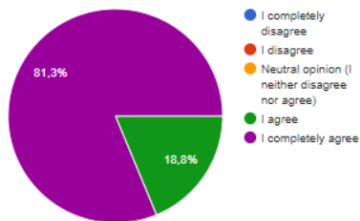


Figure 78 - Promoting Tourism in Chaves

Do you believe the application contributed to promoting local tourism in Porto?

15 respostas

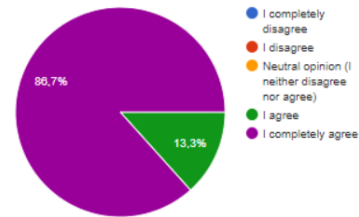


Figure 79 - Promoting Tourism in Porto

Did you feel the app provided a comprehensive overview of Chaves' history, culture and attractions?

16 respostas

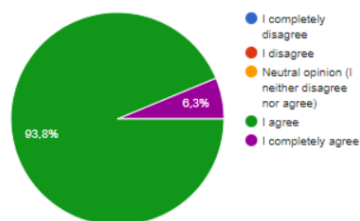


Figure 80 - Culture in Chaves

Did you feel the app provided a comprehensive overview of Porto history, culture and attractions?

15 respostas

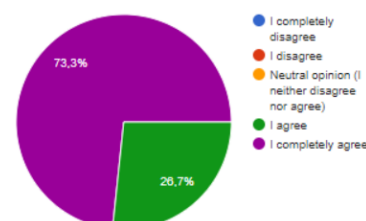


Figure 81 - Culture in Porto

Analyzing the results of the question about enriching the tourist experience, a significant difference stands out between the Chaves and Porto groups. In Figure 76, **50%** of participants from Chaves responded that they completely agree, contrasting with the results in Figure 77, where only **26.7%** of participants from Porto expressed the same level of agreement.

This difference may be due to the fact that Chaves is still a smaller and developing tourist destination, where even small improvements are seen as significant, while Porto's more established tourist sector sets higher expectations.

On the other hand, the discrepancy swaps between the cities in the question of whether the app provided a comprehensive overview of the city's history, culture, and attractions. While in Figure 81, for Porto, **73.3%** of participants responded that they completely agreed and the remaining **26.7%** that they agreed, in Figure 80, in Chaves, only **6.7%** totally agreed, with the remaining **93.8%** agreeing. This suggests that Porto's tourists may be less demanding about information quality due to the extensive existing tourism infrastructure, while Chaves' tourists may have higher expectations for detailed historical information.

Therefore, based on the results and analysis of participants' responses, **all solution objectives were successfully achieved**. The application made exploring and navigating routes more efficient and immersive, and proved to be effective on multiple routes in different locations, demonstrating its versatility. The integration of educational elements enriched the experience, providing valuable information about the history, culture, and significance of the destinations, improving the overall tourist experience. Furthermore, the promotion of local tourism has also been successfully achieved, encouraging tourists to explore and learn more about destinations, their history, and culture. Finally, the application effectively reduced unnecessary information, delivering contextualized content throughout tourist itineraries.

6.1.2.6 Solution Hypothesis

After analysing and verifying that all objectives have been successfully achieved, it is still necessary to analyse the core behind the creation of this solution: the research hypothesis.

To remember, the hypothesis of this research seeks to confirm that:

- By implementing augmented reality technology on tourist routes, the exploration of these routes becomes more efficient, immersive, and contextualized.

A final question was included in the questionnaire, in which participants were asked about their agreement with the following statement: *"This application, by using Augmented Reality technology on tourist routes, made the exploration of these routes more efficient, immersive and contextualized"*.

What do you think of the following statement: "this app, by using Augmented Reality technology on tourist routes, made the exploration of these routes more efficient, immersive and contextualized"?

31 respuestas

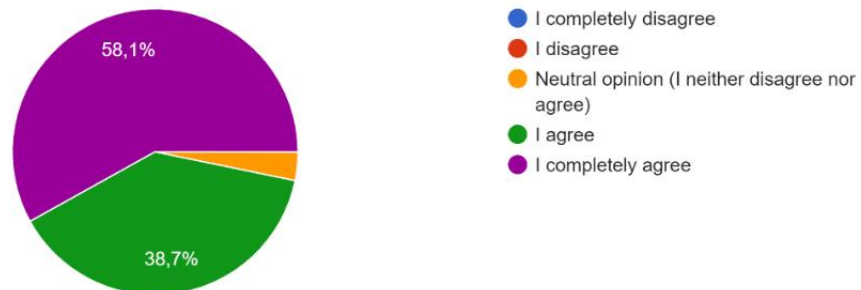


Figure 82 - Result of Solution Hypothesis Question

As can be seen in Figure 82, the results reveal an almost unanimous vote in favor, with **38.7%** agreeing and **58.1%** completely agreeing, totaling **96.8%** positive votes. Only **3.2%** (1 participant) expressed a neutral opinion.

After a more detailed analysis of the statistical data for this question, it is possible to observe the following:

- The average answer rate is **4.55**, indicating a very positive assessment of the effectiveness of augmented reality technology.
- The median of the data is **5**, reflecting that most participants completely agreed with the statement.
- The mode is **5**, meaning that the "*completely agree*" response was the most common, appearing 18 times.
- The standard deviation is **0.56**, suggesting a relatively low dispersion of the data around the mean.

However, to provide a robust validation of the observed data, a formal statistical test was performed. For this purpose, the utilization of the Wilcoxon test with one sample is justified, primarily due to the non-normal distribution of the dataset. With a p-value of 0.0000009313 at a significance level of 0.05, the data does not conform to a normal distribution.

Therefore, since the value of 4 is the minimum value for the hypothesis to be positive, a unilateral test on the left side was chosen:

- H0 (null hypothesis): the average is equal to 4.
- H1 (alternative hypothesis): The average is less than 4.

With this, the results are as it follows:

Table 16 – Analysis of Wilcoxon test

Answers	Skew	p-value	Normal Distribution	Test	Significance Level	p-value of the test
31	-0.74	0.0000009313	No	Wilcoxon 1 sample	0.05	0.99

With a p-value of the test being 0.99, which is significantly higher than the significance level of 0.05, the null hypothesis is not rejected. This suggests that there is no statistically significant evidence that the average score for the question is less than 4.

Based on the statistical results of this test, since 4 is the minimum positive value for the hypothesis to be valid, **it can be confirmed that the hypothesis of the dissertation has been validated**. This solution, using Augmented Reality technology in tourist routes, has proved that its exploration has become more efficient, immersive, and contextualized.

7 Conclusion

This dissertation was motivated by the desire to address the challenges tourists face when navigating unfamiliar routes. The journey began with a comprehensive analysis of the issues that affect conventional methods of tourist exploration. Along with the study of the state of the art, including the analysis of existing solutions and technologies in the tourism sector, the problem was analyzed and understood, in order to design a solution that could improve the way tourists explore routes.

The analysis revealed several key challenges. Traditional tour guides often overload users with too much information, making navigation and exploration difficult. They also lack specific information about the POIs and rarely provide personalized experiences suited to individual interests and preferences. With this, the goal was to design and develop a solution that would improve the exploration of tourist routes, encouraging engagement and delivering more contextual experiences about POIs. Through research, design and development, an application named ARound Routes was created to meet the initial objectives. This app takes advantage of Augmented Reality to provide users with an immersive experience by smoothly overlaying digital information into the physical world.

The research hypothesis of this dissertation, stating that the implementation of AR technology would increase the efficiency, immersion, and contextualization of tourist exploration, was validated through user testing and statistical analysis. The positive feedback and results obtained from participants confirmed the effectiveness of the solution in achieving the intended objectives.

Augmented Reality proved to be a good choice to solve the established problem, being well received even by the most traditional users. This was due to its ability to provide a more immersive and interactive experience, making exploration more captivating. Furthermore, the technology allowed for a better understanding and contextualization of POIs by directly integrating them into users' environment, creating a deeper sense of immersion.

The journey taken in this dissertation to design and implement an AR application for tourist routes exploration has proven to be highly successful. By addressing the challenges previously established, ARound Routes delivers tangible value to users. The application not only fulfilled the original objectives and the research hypothesis, but also created a new way of exploring tourist routes, providing an immersive and enriching experience through augmented reality.

Additionally, the research and development carried out during this dissertation led to the writing of a paper that was submitted and will be published in a scientific journal indexed in Clarivate JCR⁶. Details of this paper are provided in annex.

⁶ <https://clarivate.com>

7.1 Future Work

For future work, there are several areas in which this app can be further improved based on the feedback provided by participants in the questionnaires. One recurring suggestion was the implementation of some informative messages to provide feedback to users when they find issues, such as entering incorrect passwords, incorrect emails, among others. Adding these feedback messages will enhance the user experience and reduce frustration.

Another aspect highlighted for improvement is the functionality related to the compass navigation. Participants noted that the compass often showed erratic behavior, which impacted the overall navigation experience. Addressing this issue will contribute to smoother navigation, enhancing their overall satisfaction with the application.

Expanding the variety and quantity of POIs available within the application emerged as another key area for future development. By increasing the number of POIs, users will have access to a more diverse exploration, allowing them to discover a wider range of attractions and points of interest in their chosen destinations. Additionally, participants expressed interest in further developing the functionality for creating personalized routes. Enhancing this feature will unlock the full potential of the application, providing users with tailored experiences aligned with their specific interests and preferences.

Furthermore, recognizing the application's significant potential to support multiple tourist routes, future efforts will focus on expanding its availability to cover other cities and destinations. By expanding the reach of the app beyond its current scope, it will appeal to a wider audience of tourists looking for enriching and engaging experiences in diverse locations.

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Annex

Details of the Submitted Paper

	
<i>Article</i>	1
Enhancing Tourism Experience with Augmented Reality	2
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Abstract: In the evolving landscape of global tourism, integrating augmented reality (AR) technology into tourist routes is crucial for enhancing tourist experiences. The tourism sector, a major economic contributor, seeks innovative approaches to engage tourists, yet current AR applications often overwhelm users with excessive information. This study addresses the challenge of improving these experiences by designing an AR solution that increases the efficiency of exploring and navigating tourist routes, while minimizing information overload, placing only contextualized information about these itineraries. The solution was tested on two historic routes, one in Porto and the other in Chaves, both in Portugal, chosen for their cultural richness. The AR application delivers personalized details about historical monuments, points of interest (POIs), and cultural landmarks, enriching educational experiences and promoting local tourism. The study's conclusions, derived from experimentation and statistical analysis, confirm the AR technology's effectiveness in enhancing the efficiency, immersion, and contextualization of tourist routes. This research establishes AR as a powerful tool for creating personalized and enriching tourist experiences.	7-19
Keywords: Augmented Reality; Tourism; Tourist Routes; Tourism Innovation; Tourist Exploration	20-21
Introduction	22
In contemporary tourism, the demand for unique and personalized experiences has become crucial for tourists. Exploring unexplored places, delving into the history of cities, and discovering hidden treasures are key motivations driving tourists' curiosity. However, they often face challenges in finding specific and detailed information about attractions and Points of Interest (POIs) along their routes. This gap becomes evident when tourists have particular interests, such as exploring medieval areas or visiting monuments linked to specific historical events, leading to less satisfactory experiences due to the lack of contextual information.	23-30
Tourist routes, intentionally designed to attract visitors, play a significant role in promoting locations, generating revenue, and preserving cultural and environmental patrimony. Despite their importance, traditional tour guides often fail to provide customized tours tailored to individual preferences [1].	31-34
This research aims to integrate AR to enhance the tourist experience by offering more efficient, personalized, and enriching route explorations. The proposed solution aims to facilitate the exploration of tourist routes by reducing the time spent searching for information and providing relevant, contextual details without overwhelming tourists. Additionally, it seeks to promote local tourism by promoting deeper engagement with destinations, enhance the educational aspect of tourism through historical and cultural insights, improve the personalization and contextualization of tourist exploration, and demonstrate flexibility across diverse tourist routes. Finally, this study aims to confirm that AR can effectively enhance the tourist experience by addressing the need for detailed, contextual information, ultimately making exploration more engaging, contextualized, and immersive. Given this, the research hypothesis is to confirm that:	35-45
<small>Citation: To be added by editorial staff during production.</small>	
<small>Academic Editor: Firstname Last-name</small>	
<small>Received: date</small>	
<small>Revised: date</small>	
<small>Accepted: date</small>	
<small>Published: date</small>	
	
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<small>Information 2024, 15, x. https://doi.org/10.3390/xxxxx</small>	<small>www.mdpi.com/journal/information</small>

- By implementing augmented reality technology on tourist routes, the exploration of these routes becomes more efficient, immersive, and contextualized.

From the understanding of the gap in the availability of detailed and contextualized information in the exploration of tourist itineraries, the hypothesis arises that the implementation of AR technology in these itineraries can fill this identified need. The central idea is that this technological approach provides a more direct, engaging, and adapted tourist experience, allowing a deeper and more meaningful understanding of the places visited.

2. State of Art

The tourism sector plays a crucial role in the global economy, representing around 7.6% of global Gross Domestic Product (GDP) [2], which has economic consequences that extend across multiple industries. It is one of the primary drivers of economic growth worldwide, bringing tourists from all over the world to a variety of destinations, increasing the local economy and culture, protecting the historical and natural heritage, and promoting diversity. In this context it is crucial that the tourism industry continues to evolve and adapt to changes in tourist preferences and emerging technologies.

During the pandemic, tourism was one of the sectors that suffered the most impact. But, in the same way that health advances after a pandemic, the same happened with technology.

There was a need to adapt to the modern times and new immersive technologies appeared to attend them, contributing to the industry's development over the years, improving it by providing tourists with innovative and engaging experiences while driving innovation in business models [3]. Millennials¹ and Generation Z² also significantly contributed to this paradigm shift. They are passionate about innovative technology, particularly smartphones, and use it in their daily lives.

According to a TripAdvisor Study, "42 percent of travelers around the world are Connected Travelers, having used a smartphone to plan or book a trip" [4]. Table 1 shows some conclusions from this same study.

Table 1 - How Mobile is Used on Vacation [4]

How Mobile is Used on Vacation	Connected Travelers ³	All Travelers
Maps navigation	81%	67%
Looking for restaurants	72%	56%
Looking for things to do	67%	51%
Reading reviews	64%	47%
Looking for hotels	50%	36%
Restaurant reservations	46%	36%

With the increasing tendency to travel, it makes sense that tourism technology trends would be driven by the preferences and behaviors of these generations. In this way, some emerging technologies in tourism evolved from the daily basis technologies. The technological advance in this sector can have a significant impact on the tourist experience, saving time and money, automating processes, and improving travel efficiency [5].

¹ millennial is a person born between the early 1980s and the late 1990s.

² Generation Z the generation of people born in the late 1990s and early 2000s

³ The term "Connected Travelers" is used in the report to refer to people who have used a smartphone to plan or book a trip.

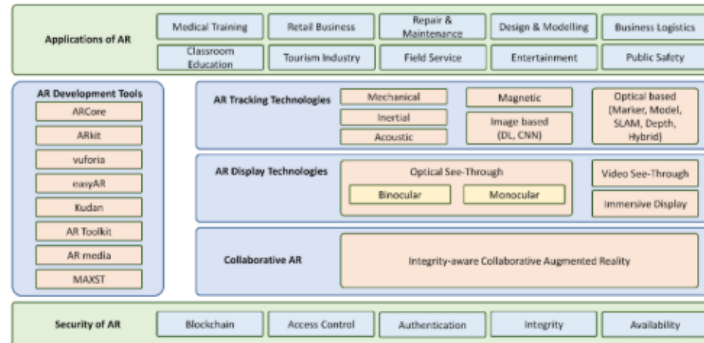


Figure 1 - AR overview [6]

AR today can be described as an interactive and immersive technology that uses multiple techniques and mixes the real world with digital components like audio, images, objects, text, and video. It utilizes tracking systems to place virtual objects in the real world and then presents these components to the user.

Regarding hardware capable of supporting augmented reality, this technology can be achieved through wearable and non-wearable devices. Wearable devices include headsets and helmets, and non-wearable devices include mobile devices and stationary devices like TVs, PCs, among others [7]. While display technologies provide virtual content to the viewer's eyes, tracking systems follows a real-world pattern. To obtain a deeper understanding of AR, it is essential to be familiar with the fundamental concepts and terminology frequently used in this technology [8]:

- **Reality View:** refers to the real-time video stream from a smartphone camera that an AR application enhances by adding virtual objects, providing an augmented experience for the user.
- **Registration and Tracking:** describes the techniques available for aligning a virtual object with a three-dimensional point in the view of reality.
- **POI:** refers to a data point often linked to a specific physical location (longitude, latitude, altitude) or a visual pattern (marker, book cover, etc.) that the AR application can display.
- **Virtual Object:** is a type of digital media that the AR application renders and overlays on the real-world scene. Typical content consists of text, icons, 2D photos, and 3D models.
- **Channels, Layers and Worlds:** references to published collections of connected POIs and linked virtual objects.

In terms of architecture, according to the study [9], AR apps involve several steps, such as capturing and tracking the real world, building a virtual world, rendering, analyzing the scene and interacting with virtual objects to create immersive experiences. Figure 2 is a representation of this architecture.

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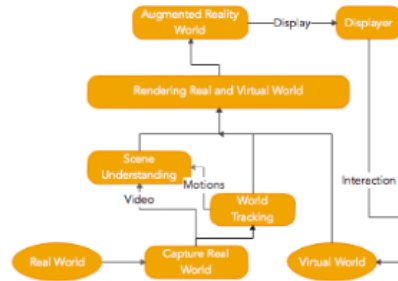
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Figure 2 - AR architecture [9]

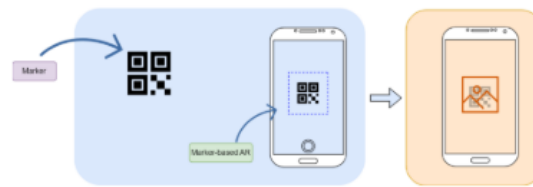
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2.3.1. Marker-based vs Markerless Augmented Reality

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Marker-based AR is a technology where the AR content is placed on objects in the real world, which can be either paper-based or physical objects, that serve as markers or triggers. The marker, which needs to be unique, is recognized by the AR system when the user scans with their mobile device [10]. As a result of the mobile scan, and based on the marker's position, the additional content that was previously created will then be displayed on top of the marker, as it is shown in figure 2. In essence, these marks act as a link between the real world and the digital one.

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Figure 3 - example of marker-based AR [10]

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Differing from marker-based, marker-less AR doesn't depend on specific markers to determine where a virtual object should appear. "Marker-less AR functionality allows developers to create digital applications that overlay interactive augmentations on physical surfaces, without the need for a marker" [11]. The most used types of this type of AR are:

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- **Location-Based AR:** uses technologies like Global Positioning System (GPS), accelerometers, digital compasses, and other sensor systems to accurately determine the phone's location and orientation. These sensors are available in smartphones, which means that AR is very accessible for the users. These applications rely on real-time positioning systems (RTLS), thereby obtaining information from sensors about the user's current location and movements. By connecting the gathered data with points of interest (POI), the technology also establishes the specific position and method in which virtual data is integrated into the physical environment [12].
- **Projection-based Augmented Reality:** is often used to generate illusions about the depth, location, and orientation of an object. This technology provides digital information in a static environment, and the main goal is to render virtual things on or within a user's real physical space, where light is projected into a surface. The interaction occurs by physically touching the projected surface [13].
- **Superimposition-based Augmented Reality:** also known as Spatial AR, is a technology where virtual objects or information are overlapped on the physical

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world (Figure 4). In order to create a hybrid experience that improves the user's view of reality, computer-generated content is required to be integrated into the user's view of the physical world [14].

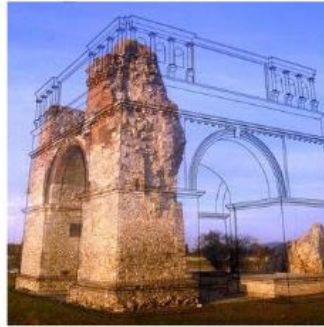


Figure 4 - example of Superimposition-base AR [14]

Marker-based and marker-less AR are the two primary AR technologies, each suitable for different contexts. Marker-based systems are straightforward to use as they involve placing markers in real locations, which a camera can detect. Users simply point their devices at these markers to view digital content, making this approach ideal for promoting products or services through mechanisms like QR codes. In contrast, marker-less AR represents a more advanced form of AR. It uses computer vision to recognize real-world objects and display relevant information about them without requiring special markers. This technology is considered a more current technology as it allows for a more intuitive user experience, with objects detected by a camera and computer vision system seamlessly integrating digital content into the real world. A comparison between these two technologies is presented in the figure 5, taken from a study [15].

Comparison Aspects		Marker-based AR	Markerless AR
Methods	Relative position/angle	Depends on markers	Depends on localization technology and gyroscope
	AR Software Development Kit (SDK)	Commonly used	Rarely used
Position accuracy	High/low	Relatively higher	Relatively lower
	Influence factors	Brightness	Localization technology
Stability	High/low	Relatively lower	Relatively higher
	Influence factors	Markers and SDKs	Localization technology and gyroscopes
Hardware support	Desktop	Supported	Usually not supported
	Mobile	supported	Supported

Figure 5 - Marker-Based vs Marker-less AR [15]

2.4. Augmented Reality in Tourism

AR has significantly contributed to the growth of the tourism industry, especially during the COVID-19 pandemic when physical interactions were limited. Most AR applications in tourism use marker-based and location-based technologies to enhance the tourist experience by providing relevant information and entertainment.

Typically, in this sector most of the AR uses in this sector involves travel guides, helping tourists explore destinations, navigate cities, and identify POIs [16]. Besides, this

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technology in tourism is accessed via mobile or wearable devices, making it affordable compared to other AR equipment, with 59.3% of AR studies involving mobile devices, 16.9% involve wearable devices, and the rest use other or unspecified devices. Most AR triggers in tourism are location-based (37.3%), followed by marker-less (22%) and marker-based (11.9%) triggers [17]. Some key advantages of using AR in tourism are:

- **Better Navigation:** It improves navigation by overlaying directions on the real-world view.
- **Contextualized Information:** It provides relevant information about attractions during exploration.
- **Promotion and Marketing:** It creates engaging marketing strategies that attract potential tourists.
- **Customer Engagement:** Positive experiences with AR apps lead to word-of-mouth promotion and social media sharing.
- **Popularizing Destinations:** Interactive AR presentations make tourist spots more appealing.
- **Reviving Experiences:** It adds excitement to revisits of museums and historic sites.

However, this technology also has some disadvantages and concerns [18]:

- **Privacy Issues:** Continuous recording by AR devices and collection of user data raise privacy concerns, requiring strict adherence to data usage laws like GDPR of the European Union.
- **Real vs. Virtual Boundaries:** The blending of real and digital worlds can cause safety issues.
- **Technical Requirements:** Implementing AR is expensive and requires advanced technology, challenging smaller organizations.
- **Information Overload:** with the small display of the smartphone, sometimes the user can feel overloaded with the AR information.

2.4.2. Use Cases of Augmented Reality in Tourism

The most common uses of AR in tourism relate to navigation, tour guides, cultural attractions, and educational tourism.

2.4.2.1. Navigation

Augmented Reality has revolutionized navigation, making it more accessible and personalized. By using GPS, cameras, and sensors, AR navigation apps help tourists easily locate and navigate through various locations, such as buildings, museums and streets. Google Maps Live View (Figures 6a and 6b) is a notable example, overlaying directions and landmarks on the user's view, making navigation intuitive and engaging [19].



Figure 6a - AR directions in Live View



Figure 6b - AR destination in Live View

A research on the use of Augmented Reality for navigation in tourism is presented in an article [20], which focuses on the initiative to develop a navigation app to promote tourism at the local historical attraction "Lawang Sewu". Positive results from user

acceptance testing indicated that 66.6% of participants enjoyed the application during the exploration of the state attraction, suggesting that the use of the application enhanced the user experience when interacting with Lawang Sewu and, consequently, improving the local tourism.

2.4.2.2. Tour Guides

AR tour guides provide real-time information about POIs as tourists explore new destinations. The primary function of an AR tour guide is to offer real-time information about POI as travelers navigate through city streets. By utilizing their mobile devices, tourists can gain instant access to a wealth of knowledge about the historical significance, cultural context, and other relevant details of the places they encounter. This not only enriches their understanding of the destination but also adds layers of engagement to their overall travel experience [21].

Apps like Zumoko AR Tourist Guide enhance the experience by delivering informative content based on location services. These apps offer interactive POIs, travel planning, and navigation assistance, enriching the travel experience [22].

A research on the use of augmented reality applications for tour guides in tourism is illustrated in the article [23], detailing an AR Tour Guide conducted at the iconic Gyeongbokgung, a cultural heritage site in Korea. The approach uses AR to virtually bring the past to life by overlaying animated 3D characters into historical sites. Additionally, contextual information such as tourist location and profiles are integrated to provide personalized guides. The prototype was successfully tested at Gyeongbokgung, highlighting the effectiveness of this innovative approach and its potential to enhance the tourist experience.

2.4.2.3. Cultural Experiences

AR improves cultural attractions like museums, zoos, and oceanariums by providing immersive, interactive experiences. The Augmented Gallery, for instance, allows users to view paintings from London's institutions in AR, enhancing public access to art during the pandemic [24].

A research found of the use of AR in museums is presented in the article [25], which is focused on an AR prototype for information visualization based on a renowned Chinese artwork named "Along the River During the Qingming Festival". With 58 evaluators participating, the results show that AR technology can trigger visitor engagement, facilitate learning, promote meaningful experiences, and establish emotional connections.

2.4.2.4. Educational Tourism

Educational tourism combines travel with learning experiences. AR enhances this by offering interactive educational content during trips. An innovative study in Western Macedonia, Greece, uses AR and VR to boost educational tourism, promoting local economic development by attracting more visitors to the region's educational attractions [26].

Based on the growing importance of educational tourism, an innovative study [27] has developed a solution that incorporates AR and VR to boost the areas of Western Macedonia, Greece. This Greek region faces socioeconomic challenges, including high unemployment rates, and could benefit significantly from increased tourism. The implementation of these innovative technologies not only enhances the region's educational attractions, but also aims to attract more tourists, promoting local economic development.

3. Solution Development

This chapter explores the technical development of the application, covering the solution design, implementation of key functionalities, and technology integration.

3.1. <i>Tourist Routes</i>	262
A well-designed tourist route must include several elements to provide an attractive and organized experience for tourists, such as the follows:	263
• POI: highlighting the inclusion of significant tourist attractions, such as natural, cultural, historical, architectural, and recreational attractions.	264
• Information: Providing relevant information about the history, culture and context of the places visited, enriching the tourist experience.	265
• Markers: efficient signs or markers along the route to guide the tourists along it.	266
• Logical Itinerary: logical organization of POIs to optimize tourists' time and facilitate the path between attractions.	267
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The solution aims to address the lack of contextualized and pertinent information along tourist routes, enhancing the overall experience with relevant and engaging content.	273
For the context of this solution, two historic routes were created in the Portuguese cities of Porto and Chaves.	274
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3.1.1. <i>Porto Route</i>	277
The Porto Route is composed of the following POI:	278
• Lello Bookstore: considered one of the most beautiful bookstores in the world, with a captivating atmosphere for book and architecture enthusiasts.	279
• University of Porto: founded in 1911, the University of Porto is one of the best universities in Portugal, with distinctions from UNESCO.	280
• Clérigos Tower: the Baroque Torre dos Clérigos offers panoramic views over the city of Porto from its tower.	281
• Portuguese Photography Center: Housed in a former prison, it shows the evolution of photography in Portugal, making it a fascinating destination for photography enthusiasts.	282
• Puppet Museum: This museum presents marionettes and offers a glimpse into the artistic and cultural legacy of this traditional form of entertainment through its varied collection.	283
• Bolsa Palace: a neoclassical building from the 19th century that housed the stock exchange, is recognized for its extravagant Arabian Room.	284
• City Museum: its one of the oldest buildings in the city of Porto, being the birthplace of Infante D. Henrique, patron saint of Portuguese discoveries.	285
• Ribeira: the Ribeira area, close of the Douro River, is a unique sensory experience with its vibrant atmosphere.	286
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Figure 7 shows the path of the presented tourist route.	298

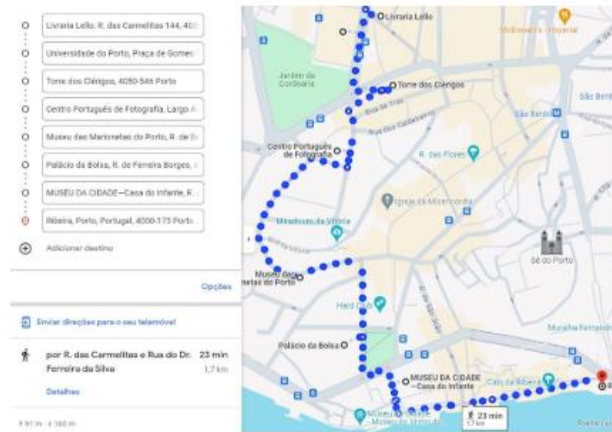


Figure 7 - Tourist route – Porto

3.1.2. Chaves Route

The Chaves Route is composed of the following POI:

- **Trajan's Bridge:** This roman bridge it is the oldest bridge in Portugal and one of the oldest in Europe, measuring around 150 meters long and with 12 visible arches.
- **Roman Thermal Baths:** is considered the largest Roman thermal bath on the Iberian Peninsula and one of the largest in the Roman Empire.
- **Church of Santa Maria Maior:** The older church in Chaves, with the first references in 1259.
- **Chaves Castle:** With medieval characteristics and a rectangular plan, Chaves Castle, with its strategic location close to the border with Spain, was a crucial point of defense during the Middle Ages.
- **Fountain of the People:** The thermal waters were discovered by the Romans, even giving rise to the name of the city as Aquae Flaviae.

Figure 8 shows the path of the presented touristic route.



Figure 8 - Tourist route – Chaves

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The logo, shown in figure 9, was created to reflect the essence and purpose of the solution. Centered on the idea of routes and paths, the logo evokes the feeling of movement and discovery, reinforcing the idea that the solution is oriented towards exploring tourist destinations. The app's name, ARound Routes, highlights the two central aspects of the solution: AR and tourist routes.



Figure 9 - ARound Routes logo

For the development of the solution, Unity was selected for its versatility and powerful features, making it ideal for developing AR applications. Its dedicated AR tools simplify the integration of virtual elements like POIs, contextual information, and navigation guides. Additionally, Unity's community and documentation serve as great help and support for development and problem solving.

3.2. Augmented Reality

Location-based AR was selected as the most suitable technology for the final solution. This choice ensures dynamic exploration by adapting to user movements, providing a personalized experience. Despite the small disadvantage in precision compared to marker-based AR, Location-based AR was chosen due to its advantages in exploration, navigation, and adaptability. To integrate AR into the solution, the chosen development kit was ARCore. Developed by Google, ARCore supports both Android and iOS, and it accurately detects device position and orientation in relation to the environment, enabling realistic placement of virtual objects.

When developing the AR content UI for tourist route POIs, a consistent standard was created to ensure a cohesive and informative experience for users, composed of three main parts:

- **Central Part:** Displays the POI's name and a description, serving as the focal point with an overview of what users can expect.
- **Right Part:** Provides detailed historical information, including history, relevant events, and cultural significance, allowing users to delve deeper into the POI's context.
- **Left Part:** Shows interesting facts and additional insights that enrich the user's experience.

Secondary elements like images, opening hours, and official websites may also be included. The color palette is tailored to the POI's architectural style and historical context.

Below is an example of a generic POI following this pattern, with the title and description in the center, historical information on the right, and curiosities on the left.



Figure 10 - solution AR Content in a generic POI

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3.5. Solution Main Features

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3.5.1. Register & Login

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Users are able to create a new account with an email and password and then log in to the application with these credentials. This way the app can record the individual preferences of the user.

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3.5.2. Choose & Create a Tourist Route

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Users can choose from existing tourist routes or create personalized ones based on the available list of POIs. Each route offers options to view details, rate the POIs, and select a route for exploration. Figure 11 below show the final application interface during the route selection process.

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Figure 11a - list of existing routes in the app

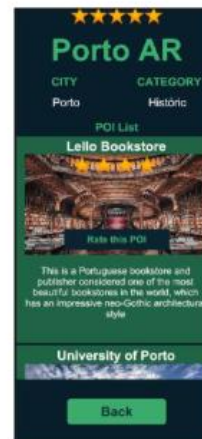


Figure 11b - route details in the app

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Route creation, on the other hand, offers users the possibility of creating their own specific adventures. This process is divided into two steps:	367
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• Route Definition, where users can choose a name, city and category.	369
• Selection of POI, to select the POIs they want to include in their custom route.	370
Once a custom route is created, it is added to the list and is visible only to the user who created it.	371
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3.5.3. Community Interaction	374
During the route exploration, users can take and store their own photos during explorations in a private gallery and access a public gallery to view and like photos shared by the community. This feature promotes the creation of a community, allowing users to connect with others, share moments, and seek inspiration for their own adventures.	375
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3.5.7. Enrich Touristic Education	380
It is important to incorporate educational elements into the solution to enhance the overall tourist experience. By integrating educational information, the solution can provide tourists with a deeper understanding and appreciation of the places they visit. One effective way to deliver this educational content is through quizzes.	381
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With this, the app includes a Tourist Quiz feature, offering users a fun and engaging way to learn more about the history and culture of points of interest.	385
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3.5.8. Route Exploration	388
To improve the exploration process, the navigation through the route was improved with the help of GPS and AR, by adding virtual markers on the screen, reducing the possibility of confusion and increasing the efficiency of their exploration. Intuitive AR visual markers guide tourists from one POI to another, providing a clear path. The AR navigation system also adjusts in real-time based on the tourist's location, ensuring that tourists can easily follow and navigate the route.	389
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To address the challenge of information overload, the solution ensures that tourists receive only relevant information about each POI along their route, enhancing their understanding without overwhelming them. As tourists explore, dynamic textual information appears on their screens, providing insights into historical context, architectural features, and cultural significance. This approach focuses on delivering meaningful content adapted to enrich the exploration experience.	395
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Overall, the AR route exploration feature provides an immersive and interactive journey for tourists. This development integrates ARCore for augmented reality functionality, location services for user tracking, and content positioning to enhance accuracy and engagement throughout the exploration process.	401
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3.5.8.1. POI Coordinates	406
Using platforms like Google Maps and Google Earth made it easy to determine the latitude and longitude of each POI. However, an additional challenge came up in determining the altitude of each POI. GeospatialAPI, an ARCore feature used to position AR elements, uses a reference system known as WGS84. This system assumes that the Earth is an Ellipsoid, that is, a mathematical model that represents the planet as a sphere slightly flattened at the poles and widened at the equator. On the other hand, Google Maps uses a more advanced reference system called EGM96, which employs a Geoid model to represent the Earth. A Geoid is an irregular surface that corresponds to mean sea level and is more accurate in describing the actual shape of the Earth.	407
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Due to the differences between these two reference systems, the altitude provided may vary in representing the altitude of a given point on the Earth's surface. Therefore, it was necessary to consider these differences to ensure an accurate and consistent	416
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representation of the AR content along the route. To do this, firstly, was used the altitude provided by Google Earth for each POI, based on the latitude and longitude coordinates. Then, using the same coordinates, an external website ⁴ was used to obtain the corresponding altitude value in the EGM96 model. Therefore, to represent the altitude of the POI in Unity, was added to the Google Earth altitude value, the EGM96 altitude value provided by the external website. Finally, so that the POI does not remain on the ground, 1.5 was added to the final value so that it remains 1.5 meters above the ground.

3.5.8.2. User Coordinates

The user's coordinates were obtained by collecting the coordinates of the user's own device. This was accomplished using the location features available on mobile devices, allowing the application to determine the user's current geographic position. To ensure the app always has the user's most updated coordinates, these are updated every 5 seconds.

3.5.8.3. Augmented Reality Exploration

ARCore services made AR implementation easier in the app, using ARAnchorManager for anchor content in the virtual environment. Anchors ensure stability and alignment with the real world, enabling accurate POI placement through the AR camera. This integration combines POI details, user location data, vectors, and orientation calculations for an immersive navigation experience.

Below, in figure 12, are three images illustrating the app's process of exploring a tourist route. The left image shows the route details and access to an audiobook for the current POI. Clicking "Explore Route" takes users to the center image, where AR markers guide the path, a compass pointing to the POI, and displays distance and cardinal direction. The right image presents AR details specific to a POI.

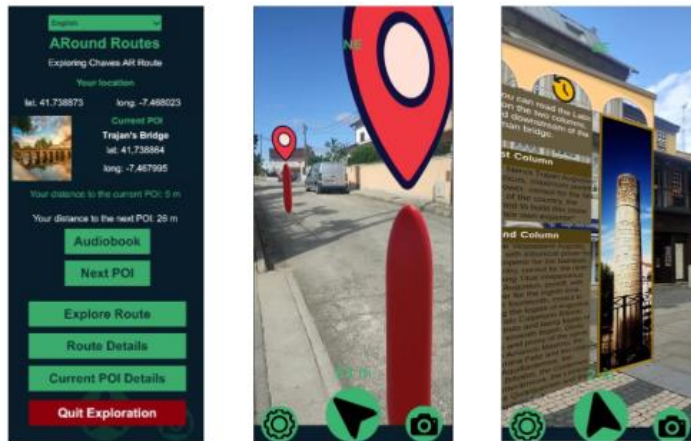


Figure 12a - exploration Menu

Figure 12b - AR navigation

Figure 12c - AR POI exploration

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⁴ <https://geographiclib.sourceforge.io/cgi-bin/GeoidEval>

4. Validation and discussion

This section outlines the validation process of the developed solution. 31 participants were involved in the study and they fulfilled all the following prerequisites:

- The participant had a smartphone (android).
- The participant had internet access.
- The participant allowed the use of location services on the smartphone.
- The participant was located either in the city of Chaves or in the city of Porto to explore the routes.

The participants were divided into two groups to cover both solution routes, which 16 of them tested the Chaves route, while 15 tested the Porto route. Two validation tools were applied: one for usability testing using the System Usability Scale (SUS) and another to evaluate the app's impact and whether it meets the established objectives.

4.1. Usability

The SUS is a widely used tool for assessing application usability, with questions rated on a Likert scale from 1 (strongly disagree) to 5 (strongly agree) [28]. The steps to calculate the system usability score are:

1. Convert each answer to points (1 to 5) using these rules:
 - a. Subtract 1 for questions where 5 is positive (points - 1).
 - b. Subtract from 5 for questions where 5 is negative (5 - points).
2. Add the points for each user to get individual scores.
3. Divide the total score by the maximum possible score, then multiply by 100 to get the final score.
4. Average the final scores of all users to obtain the final SUS score.

The System Usability Score has an average of 68 points. If the final score of the solution is below this value, the application may have usability challenges [28]. In addition, some open answer questions were created, where the participant can give feedback and suggestions for improvements.

The SUS result was **86.7**, which indicates an excellent usability score. Usability was aspect highly focused throughout the development of the solution, as it is crucial in a tourism context for users to navigate routes without difficulty. Every feature was designed to be intuitive and user-friendly, and this high score confirms that the objective was successfully met.

The following image presents the average responses from participants regarding the usability of the AR navigation and AR exploration systems, which are central aspects of the app. There were no negative responses and only **11%** of participants were neutral, while **59%** expressed a positive opinion and **30%** reported an extremely positive opinion. Based on this data, it is possible to conclude that most participants found the AR navigation and AR exploration experience very satisfactory, which reflects the application's effectiveness in providing efficient exploration and navigation.

■ I totally disagree ■ I disagree ■ Neutral ■ I agree ■ I completely agree

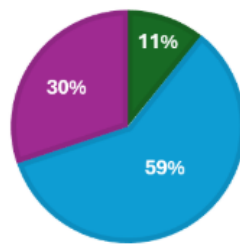


Figure 11 - Average Responses per Option in the Usability of Exploration and Navigation

4.2. Impact

After the initial usability tests using the SUS, a second questionnaire was conducted with the same participants to analyze the impact of the application and determine if it met its objectives. 59 questions were answered by all the 31 participants.

The results of the different objectives were consolidated in a single graph, as can be seen in the graph in following figure.

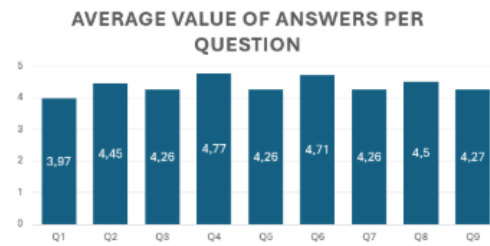


Figure 12 - Average Responses per Option in Solution Objectives

In the graph, the y-axis values correspond to the average value of the participant's responses per question, which can range from "I totally disagree" (value 1) to "I totally agree" (value 5). Each question is represented as follows:

- **Q1:** Did you feel that the ability to create personalized routes allowed you to have a more unique travel experience adapted to your interests?
- **Q2:** Do you think the educational elements available in the application were useful in learning more about tourist destinations?
- **Q3:** Do you think AR navigation has made your exploration more efficient?
- **Q4:** Did the app effectively reduce the excess of unnecessary information, providing you with useful and relevant content during your exploration of the tourist route?
- **Q5:** Did the app succeed in promoting local tourism by encouraging you to explore and learn more about destinations, history, and culture?
- **Q6:** Did the app enrich your experience in exploring a tourist route by providing useful and contextual information?
- **Q7:** Do you think that Augmented Reality in the app was useful in improving your experience when exploring tourist routes?
- **Q8:** Did you feel that the application provided an enriching tourist experience in Chaves?
- **Q9:** Did you feel that the application provided an enriching tourist experience in Porto?

This graph illustrates that across all main objectives, the average answers were consistently high, with the lowest being 3.97 for question Q1 and the highest at 4.77 for question Q4. These data reflect an extremely positive reception in achieving its objectives.

With this, based on the results obtained, it is possible to conclude that **the solution objectives were all successfully achieved**. The AR app provided a more personalized and contextualized tourist experience, facilitating the exploration of tourist routes and making them more efficient, easier, and immersive for tourists. Additionally, the integration of educational elements enriched the experience by providing important information about the history, culture, and significance of the destinations visited, further enhancing the app's applicability across multiple routes. The promotion of local tourism was also successfully accomplished, as evidenced by the encouragement of tourists to explore and learn more about destinations, their history, and culture. Finally, the app demonstrated effectiveness in reducing excess unnecessary information, providing useful, relevant, and

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contextualized content along tourist routes, thus solidifying its efficacy in catering to several tourist preferences and needs across different locations. 530

After analysing and verifying that all objectives have been successfully achieved, it is still necessary to analyse the core behind the creation of this solution: the research hypothesis. To remember, the hypothesis of this research seeks to confirm that: 531

- By implementing augmented reality technology on tourist routes, the exploration of these routes becomes more efficient, immersive, and contextualized. 532

A final question was included in the questionnaire, in which participants were asked about their agreement with the following statement: "This application, by using Augmented Reality technology on tourist routes, made the exploration of these routes more efficient, immersive and contextualized". 533

What do you think of the following statement: "this app, by using Augmented Reality technology on tourist routes, made the exploration of these routes more efficient, immersive and contextualized"? 534
31 responses



Figure 15 - result of solution hypothesis question 541

As it shows in Figure 15, the results reveal an almost unanimous vote in favor, with 38.7% agreeing and 58.1% completely agreeing, totaling 96.8% positive votes. Only 3.2% (1 participant) expressed a neutral opinion. After a more detailed analysis of the statistical data for this question, it is possible to observe the following: 542

- The average answer rate is 4.55, indicating a very positive assessment of the effectiveness of augmented reality technology. 543
- The median of the data is 5, reflecting that most participants completely agreed with the statement. 544
- The mode is 5, meaning that the "completely agree" response was the most common, appearing 18 times. 545
- The standard deviation is 0.56, suggesting a relatively low dispersion of the data around the mean. 546

However, to provide a robust validation of the observed data, a formal statistical test was performed. For this purpose, the utilization of the Wilcoxon test with one sample is justified, primarily due to the non-normal distribution of the dataset. With a p-value of 0.0000009313 at a significance level of 0.05, the data does not conform to a normal distribution. Therefore, since the value of 4 is the minimum value for the hypothesis to be positive, a unilateral test on the left side was chosen: 547

- H0 (null hypothesis): the average is equal to 4. 548
- H1 (alternative hypothesis): The average is less than 4. 549

With this, the results are as it follows: 550

Table 2 - Analysis of Wilcoxon test 551

Answers	Skek	p-value	Normal Distribution	Test	Significance Level	p-value of the test
31	-0.74	0.0000009313	No	Wilcoxon 1 sample	0.05	0.99

With a p-value of the test being 0.99, which is much higher than the significance level (0.05), the null hypothesis is not rejected. This suggests that there is no statistically significant evidence that the average for the question is less than 4.

Based on the statistical results of this test, since 4 is the minimum positive value for the hypothesis to be true, **it is possible to confirm that the hypothesis of the research has been validated.** This solution, using AR technology in tourist routes, has proven to improve the efficiency, immersion, and contextualization of the exploration of these itineraries.

5. Conclusion

This research was motivated by the desire to address the challenges tourists face when navigating unfamiliar routes. This journey began with a comprehensive analysis of the issues that affect conventional methods of tourist exploration. Along with the study of the state of the art, including the analysis of existing solutions and technologies in the tourism sector, the problem was analyzed and understood, in order to design a solution that could improve the way tourists explore tourist routes.

The analysis revealed several key challenges. Traditional tour guides often overload users with too much information, making navigation and exploration difficult. They also lack specific information about the POI and rarely provide personalized experiences suited to individual interests and preferences. With this, the goal was to design and develop a solution that would improve the exploration of tourist routes, encouraging engagement and delivering more contextual experiences about POIs. Through research, design and development, an application named ARound Routes was created to meet the initial objectives. This app takes advantage of Augmented Reality to provide users with an immersive experience by smoothly overlaying digital information into the physical world.

The research hypothesis, stating that the implementation of AR technology would increase the efficiency, immersion, and contextualization of tourist exploration, was validated through user testing and statistical analysis. The positive feedback and results obtained from participants confirmed the effectiveness of the solution in achieving the intended objectives. Augmented Reality proved to be a good choice to solve the established problem, being well received even by the most traditional users. This was due to its ability to provide a more immersive and interactive experience, making exploration more captivating. Furthermore, the technology allowed for a better understanding and contextualization of POIs by directly integrating them into users' environment, creating a deeper sense of immersion.

Author Contributions: Conceptualization, M.C. and C.V.; methodology, M.C. and C.V.; software, M.C.; validation, M.C. and C.V.; formal analysis, M.C.; investigation, M.C.; data curation, M.C.; writing—original draft preparation, M.C.; writing—review and editing, C.V.; supervision, C.V. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Ethical review and approval were waived for this study due to no sensitive individual data is published.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data supporting reported results is available following a request to the authors.

Conflicts of Interest: The authors declare no conflicts of interest.

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