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Kayıp Tarihi Eserler İçin Mobil Artırılmış Gerçeklik Uygulaması Geliştirilmesi

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Öz

Birçok kültürel miras alanı yıllar içinde gerçekleşen depremler ve diğer sebeplerden dolayı tahrip olmuştur. Turistler bu alanları ziyaret etmek istemekte fakat yıkıntılardan ve küçük bilgi levhalarından başka bir şey bulamamaktadır. Bazı eserler ise korunma amacıyla müzelere götürülmüştür. Yeni teknolojiler, bu kalıntıları gerçek ortamda görmek isteyen turistlere bir çözüm sunmaktadır. Turistler, mobil uygulamalar aracılığıyla mobil cihazlarını kullanarak kalıntıların ve var olmayan tarihi yerleri görebilme imkanına sahip olmaktadır. Bu araştırma, Dünya'nın yedi harikasından biri olan Halikarnas Mozolesinin Artırılmış Gerçeklik (AG) teknolojisi ile model geliştirmeyi amaçlamaktadır. Eğitim, eğlence ve turizm alanlarındaki uygulamaları kapsayan AG'in artan popülaritesi, tarihi bölgeyi ziyaret edenlere sürükleyici ve eğitici bir deneyim sunmak üzere tasarlanmış bir mobil uygulamanın geliştirilmesinde katalizör görevi görmektedir. Bilgisayar görüşü ve makine öğrenimi algoritmalarından yararlanan uygulama, kullanıcının konumunu ve hareketlerini algılayıp takip ederek, eserlerin sanal 3 boyutlu modellerini cihazın kamerası tarafından yakalanan gerçek dünya ortamına yerleştirilmesi ile gerçekleşmektedir. Bu çalışma, tahrip edilen diğer tarihi alanlar veya eserler için Artırılmış Gerçeklik modelleri oluşturmakta 3D modeller ile Unity üzerinden Vuforia API ile geliştirilen modeli sunmaktadır. AR, dijital içeriği fiziksel dünyayla kusursuz bir şekilde harmanlayarak tarihsel bilgilerin sunulmasına ve eksik eserlerin yeniden yaratılmasına yeni bir yaklaşım sunmaktadır. Halikarnas mozolesi geliştirilmesi en zor dijital objelerden biri olmaktadır. Mozolonin şekli en son gören kişinin tasvirleri doğrultusunda oluşturulmuştur. Araştırma sonucunda tamamen yok olmuş bir tarihi eserin yeniden canlandırılması ve AR kullanarak istenilen noktada görülebilmesi sağlanmaktadır. Bu ilk aşamada geliştirilen modelin ilerleyen zamanda çok daha gelişmiş versiyonlarının üzerinde çalışılması önerilmektedir.

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Developing a Mobile AR Application for Destroyed Historical Sites

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Abstract

Many cultural heritage sites have been destroyed due to earthquakes and other reasons over the years. Tourists want to visit these areas but find nothing but ruins and small information signs. Some works were taken to museums for preservation. New technologies offer a solution to tourists who want to see these ruins in a real environment. Tourists have the opportunity to see ruins and non-existent historical places using their mobile devices through mobile applications. This research aims to develop a model of the Mausoleum of Halicarnassus, one of the seven wonders of the world, with Augmented Reality (AR) technology. The growing popularity of AR, which encompasses applications in education, entertainment and tourism, is a catalyst for the development of a mobile application designed to provide an immersive and educational experience for visitors to the historic site. Using computer vision and machine learning algorithms, the application detects and tracks the user's location and movements, placing virtual 3D models of the works in the real-world environment captured by the device's camera. This study creates Augmented Reality models for other destroyed historical sites or artefacts and presents the 3D models and the model developed with Vuforia API via Unity. AR offers a new approach to presenting historical information and recreating missing artifacts by seamlessly blending digital content with the physical world. The Halicarnassus mausoleum is one of the most difficult digital objects to develop. The shape of the mausoleum was created according to the descriptions of the person who saw it last. As a result of the research, a completely destroyed historical artifact can be revived and viewed at any point using AR. It is recommended to work on much more advanced versions of the model developed in this first stage in the future.

Keywords

AR, Heritage, Artefacts, Mobile Application

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Introduction

The popularity of Augmented Reality (AR) technology has grown significantly in recent years, finding numerous applications in fields such as education, entertainment, and tourism (Petrelli et al., 2021; Beneyto and Alcaniz, 2022. The application will rely on computer vision and machine learning algorithms to detect and track the user's location and movements, then overlay virtual 3D models of the artefacts onto the real-world environment captured by the device's camera. Additionally, the application will include a database of historical information and multimedia content, including images, videos, and audio recordings, to provide an immersive learning experience for users. Tourists read, see, and learn about heritage sites before they visit (Paynta, 2021). When they visit the site, they want to see all the artefacts and feel what these monuments were like in earlier times (Voitik and Maslov, 2019). The engagement and interaction of tourists with the site and the destination can be increased using mobile devices and AR technology (Sadek, 2020). AR can be a solution to satisfy tourists who want to see the artefacts in a real environment (Marzouk et al., 2019).

The AR industry is rapidly expanding and changing how people interact with the world (Bottani and Vignali, 2019). This is especially true with the increasing use of AR games and apps (Parekh et al., 2020). With the right design and use of AR software, developers can create experiences that are not just "normal," but urban-like things that are now possible (Florescu and Nistor, 2020). This is where any industry can make a real impact. With the right ingredients and a little creativity, developers can create features that are both unique and in line with known trends in the real world. AR has enormous potential, and it is currently altering how people engage with their environment. In a variety of industries, AR is utilized to improve the user experience and create more interactive and engaging experiences (Hunsucker, 2018). As technology continues to evolve, the possibilities are endless. AR has the potential to fundamentally alter how users connect with their immediate environments and create entirely new and exciting experiences.

Developing an AR app model for a heritage interpretation is important for several reasons. Firstly, an AR app can provide a more engaging and immersive experience for visitors compared to traditional forms of interpretation. By overlaying digital information on the real-world environment, an AR app can bring historical events and artefacts to life, making them more tangible and memorable for visitors. Secondly, an AR app can help to enhance the accessibility of heritage sites, making them more inclusive and accommodating for visitors with disabilities or language barriers. For example, an AR app could include audio descriptions, sign language interpretation, or translations in multiple languages, making the interpretation more accessible to a wider range of visitors. Thirdly, an AR app can provide a platform for innovative storytelling and interpretation techniques. By combining different forms of media such as text, images, audio, and video, an AR app can create a more interactive and dynamic interpretation of a heritage site. An AR app

could provide a virtual tour of the Mausoleum, allowing visitors to explore and learn about the site from anywhere in the world. Overall, developing an AR app model for heritage interpretation, specifically for Mausoleum, can provide an innovative, engaging, and accessible way for visitors to learn about and appreciate these important historical sites.

Tourism is a rapidly growing industry that has been exploring new ways to enhance tourist experience and engagement. AR and Gamification are two technologies that have shown promising potential to improve tourist experiences (Petrovych et al., 2023). Hidayat et al. (2019) conducted a study on the implementation of AR and gamification in tourism, with a focus on mobile applications. The authors found that these technologies can improve tourists' engagement and satisfaction, as well as their learning outcomes. The study also highlights the importance of considering user experience design when developing AR and gamification applications for tourism. Similarly, Tay et al. (2023) developed a gamified AR mobile application for tourism in Kuching, Malaysia. Their study found that the application improved tourists' engagement, learning outcomes, and satisfaction. The authors emphasize the potential of gamification and AR in promoting tourism destinations and enhancing visitors' experiences. Other studies have also explored the use of AR and gamification in specific tourism contexts, such as cultural heritage sites (Grisolia et al., 2020) and nature tourism (Chen et al., 2020). These studies found that these technologies can improve visitors' engagement, emotional connection, and learning outcomes.

Turkey has more than 120 cultural heritage sites. These heritage sites are an important attraction for tourists visiting Turkey. Most of these sites have been destroyed over the years by earthquakes and other reasons. The sites are constantly being restored and archaeologically studied. However, archaeologists mainly focus on finding out how people lived at that time, rather than what the site looks like. Even though many artefacts are on display at the site, the most valuable artefacts are usually taken to the museum for protection and security reasons. One of the seven wonders of the ancient world is the mausoleum at Halicarnassus in Turkey. This remarkable monument has been destroyed by continuous earthquakes, and the remaining parts of the mausoleum are being displayed at the British Museum. When a tourist visits the mausoleum at the Halicarnassus site, they only see some of the monument's remaining stones.

In this study, the research aims to develop a mobile application that will provide visitors to the Halicarnassus Mausoleum with an AR experience that includes historical information. Despite the growing interest in the applications of disruptive technologies such as AR in the tourism sector, there is limited academic research on this topic. The AR application model was developed for the mausoleum at Halicarnassus. The AR application can be used both on and off-site at the ruins. Tourists will be able to see the mausoleum at Halicarnassus in real-time and in a real environment. This research will also be an example of utilizing AR models for other destroyed sites or artefacts. Therefore, this study is expected to make a significant contribution to the field by creating a reconstruction of the Halicarnassus Mausoleum using augmented technology, which has not been encountered

in the literature review. To achieve this, the reconstruction of the Halicarnassus Mausoleum will be created using a knowledge model and marker-based AR for mobile application development. As Favro (2006) suggests, knowledge models are used to obtain visual representations of destroyed works by interpreting available resources, such as ruins, old books, and writings.

1. AR

AR is an increasingly popular technology used to merge real and digital experiences. It does this by overlaying digital content on top of the physical world in real-time (Serravalle et al., 2019a). AR is used in a variety of scenarios, from games to tourism and museum applications (Parekh et al., 2020). In gaming, AR can be used to create immersive and interactive experiences (Rovithis et al., 2019). Players can use their physical environment to interact with digital elements in the game, allowing them to explore and experience the game in a more realistic way (Montero et al., 2019). AR is a disruptive technology that overlays digital information into the real world, enhancing our perception of reality in real-time (Wang and Dunston, 2017). AR has the potential to recreate or enhance real-world environments and objects, enabling visitors to experience historical sites and other locations in a more immersive and interactive way (Serravalle et al., 2019b). Additionally, AR can overcome language barriers by providing real-time translation or interpretation of text or audio in different languages, making information more accessible to a wider audience (Chen et al., 2020).

AR has the potential to offer visitors a range of experiences that were previously impossible. This technology can provide visitors with a deeper and more engaging experience by contextualizing information, creating interactive exhibits, and simulating historical events (Knutov et al., 2019). AR can be used in museums to create virtual exhibits, providing visitors with access to a wealth of information, 3D models, animations, and simulations overlaid onto the real-world environment. In tourism, AR can be used to provide virtual tours of historical sites, overlaying information, and animations onto the real-world environment, allowing visitors to explore and learn about the site in a more immersive and interactive way (Serravalle et al., 2019b). Overall, AR can provide visitors with a new level of engagement and interactivity with their surroundings, offering a more enriching and memorable experience.

AR can be used in many different fields, from education to tourism to the creative industries (Hidayat et al., 2019). It's a great tool to teach people about different topics while putting them into context, such as what a real object looks and feels like (Romano et al., 2021). For example, a museum could superimpose virtual models of artefacts to help visitors understand the significance of these objects in the real world (Marino et al., 2021). Grzegorczyk et al. (2019) suggested that with the right software and hardware, AR can create a learning experience that could be truly interactive, engaging, and fun. Marker-based AR is a popular technology that enables the overlay of digital information on physical

objects using markers as reference points. This technology has been used in various domains, including education, marketing, entertainment, and cultural heritage (Schall et al., 2018). Marker-based AR is an AR technology that uses a physical object, called a marker or target, to trigger digital content and overlay in the user's field of view (Fiala, 2005; Gherghina et al., 2013). This technology works by using a camera or scanner to detect the marker and then aligning the digital content with it, creating the illusion of the virtual object being in the same space as the physical object (Reddy, 2022). One of the key advantages of marker-based AR technology is its ability to enhance learning and educational experiences. Marker-based AR has been widely used for outdoor applications such as navigation and gaming. Schall et al. (2018) conducted a survey of marker-based AR for outdoor applications and found that marker-based AR can provide accurate and reliable location-based information and enhance user experiences in outdoor settings. AR virtual reality is not just about moving the user to another virtual place but rather about bringing digital information, such as a museum's collection or a map with information about a nearby landmark, into the physical world (Kyriakou and Hermon, 2019a; Gong et al., 2022a). It's more like having a digital assistant sit next to a user while the user explores the world.

2. AR Use In Tourısm And Historical Sites

Tourism is a rapidly growing industry, and technology has played a vital role in improving the overall visitor experience. One such technology is AR, which overlays digital information onto the physical environment, providing an immersive experience for tourists (Jung et al., 2019). AR technology enhances the physical world by overlaying digital information, thus providing an immersive experience for tourists (Serravalle et al., 2019a). AR is becoming increasingly popular in the tourism industry, as it provides tourists with a more interactive and personalized experience. According to a study by Buhalis and Amaranggana (2015), AR can enhance the tourism experience by providing real-time information, interactive navigation, and 3D visualization of tourist attractions. The study also suggests that AR can significantly influence tourists' behaviour, such as increasing their willingness to visit a destination and spending more money. Jung et al. (2019) outlined an overview of the current state of research on the use of AR in the tourism industry. The authors explore the potential benefits of AR, including its ability to enhance visitor experiences, create new revenue streams for businesses, and provide opportunities for destination marketing.

AR technology is being used across various sectors of the tourism industry to enhance the visitor experience. The hospitality industry is also using AR to improve the visitor experience. Hotels are using AR to provide visitors with virtual tours of their facilities, allowing them to explore the hotel before booking their stay (Lee et al., 2018). Restaurants are using AR to enhance the dining experience by providing digital menus, which can be customized to meet the dietary needs and preferences of customers (Kim and Lee, 2018; Hunsucker et al., 2018; Trunfio et al., 2022). Museums, national parks, theme parks, and the

hospitality industry are all using AR to provide visitors with a more immersive and interactive experience. Studies have shown that the use of AR has a positive impact on visitor engagement, learning, satisfaction, and likelihood of repeat visits. As technology continues to advance, it is likely that we will see further integration of AR in the tourism industry to enhance the visitor experience. Truong et al. (2020) found that the AR app was found to be effective in enhancing visitors' understanding of the park's geology, history, and cultural significance. Theme parks are also using AR to enhance their attractions and provide visitors with a more immersive experience. For example, Disney's "Play Disney Parks" app allows visitors to interact with the park's environment and characters using AR technology (Hsieh et al., 2020).

AR has been increasingly used in museums, cultural heritage, tourism, and art galleries. Several studies have explored the effectiveness of AR technology in enhancing visitor experiences in these contexts (Billinghurst and Duenser, 2012; Hsu and Huang, 2013; Liarokapis et al., 2016; Lee and Kim, 2018; Lopez et al., 2019; Li et al., 2021; Ozkaramanli and Karakus, 2021; Petrelli et al., 2021; Tosun and Ustundag, 2021; Beneyto and Alcaniz, 2022). Billinghurst and Duenser (2012) investigated the use of AR in museums and found that AR applications can increase visitor engagement and promote interactive learning. Hsu and Huang (2013) examined factors affecting museum visitors' behavioural intentions to use AR technologies and identified perceived usefulness and ease of use as important determinants. Lee and Kim (2018) studied the impact of AR on consumers' experiences in an art museum and found that AR technology can increase visitors' emotional response and satisfaction with the exhibit. Liarokapis et al. (2016) evaluated the effectiveness of mobile AR applications in museums and found that they can enhance visitor engagement and facilitate learning. More recent studies have continued to explore the potential of AR technology in museums, cultural heritage, and tourism. Beneyto and Alcaniz (2022) conducted an empirical study and found that AR technology can significantly improve visitors' experience and increase their intention to revisit the museum. Li et al. (2021) examined the influence of AR on visitors' perceived value, satisfaction, and loyalty in the Palace Museum in Beijing and found that AR can enhance visitors' emotional and cognitive experiences. Ozkaramanli and Karakus (2021) investigated the impact of AR applications on tourists' satisfaction and behavioural intentions and found that AR can increase tourists' satisfaction with the tourist destination and their intention to revisit. Petrelli et al., (2021) examined visitors' engagement with mixed reality exhibitions in heritage sites and found that the use of AR can increase visitors' curiosity and encourage them to explore more. Tosun and Ustundag (2021) explored the role of AR in enhancing museum visitors' emotional and cognitive experiences and found that AR technology can enhance visitors' emotional and cognitive responses to exhibits.

Museums are a great place to use AR because visitors can experience the museum without being taken out of their own world (Kyriakou, Hermon, 2019b); Gong et al., 2022b). Many museums, for example, have models of their collections that visitors can walk

through (Kaghat et al., 2020; Khan et al., 2021). However, traditional models are static (Wang and Zhu, 2022). Museums are working on using AR to let visitors walk through these models while experiencing the museum in 3D, like in a video game where the player can walk through the museum while immersed in the models (Kaghat et al., 2020). AR can help preserve cultural heritage by providing a more immersive and interactive experience for tourists (Kounavis et al., 2019). This AR experience could be especially useful for museums with large collections like the Louvre Museum or the British Museum (Papaioannou, 2019). These museums have so many objects that it might be difficult for visitors to see them all in one visit. Gong et al. (2022b) found that AR technology can trigger users' engagement, learning, meaningful experiences, and emotional connection. Trunfio et al. (2022) suggested that the use of AR in museums and art galleries has a positive impact on visitor engagement, learning, and satisfaction. The Louvre Museum in Paris is an excellent example of how AR is used to bring exhibits to life. The "Louvre AR" app allows visitors to explore the galleries and view digital reconstructions of ancient statues and artefacts (Trunfio et al., 2022). He et al. (2018), incorporating dynamic verbal cues in an AR-facilitated museum experience can significantly increase visitors' willingness to pay more for the experience. Dynamic cues refer to the use of audio or verbal prompts that change or adapt based on the visitor's location or actions within the AR experience. For example, in an AR museum exhibit, a dynamic cue could be triggered when the visitor approaches a specific artefact, providing them with relevant information or context. AR could help visitors see more of the collections, artefacts, and original appearance that were destroyed or demolished.

3. The Mausoleum at Halicarnassus

Bodrum is the most popular destination for domestic and foreign tourists in Turkey. It is situated at the peninsula's tip in southwestern Turkey and borders the country of Kos, which is situated in the northern part of the beginning Gulf of Gokova. Bodrum is located at the coordinates 37° 20' N, 27° 25' E. The ancient name of Bodrum is "Halicarnassus," and it is an important trading port with perfect urbanization between "Knidos" and "Miletos" (Koca and Akça, 2017). The importance of the region stems from its port and trading centre (Corso, 2019). The foundations of the Mausoleum of Halicarnassus, one of the Seven Wonders of the World, are in Bodrum. The important elements that make the Mausoleum of Halicarnassus one of the Seven Wonders of the Ancient World include the reason for its construction, its architecture, the techniques used in its construction, and the sculptors who worked there. Very few sites among the seven wonders of the world have survived modern conditions. Among the features that make Bodrum and the Mausoleum of Halicarnassus so important is that although it was built in 353 BC, some of the ruins have been found in this region without major damage, and some of the stones used in the construction of the mausoleum were used in the construction of the Bodrum Castle, so it is a place that can still be visited today.

The Mausoleum of Halicarnassus is a monumental tomb. The Mausoleum of Halicarnassus belongs to the Carian satrap Mausolos Mylasa (Göğebakan, 2017). The Mausoleum of Halicarnassus was built by Artemisia after the death of the Carian satrap Mausolos in 353 BC (Corsa, 2019). Artemisia was both the sister and wife of King Mausolos, and his ashes were placed in the mausoleum after he died 2 years after the mausoleum was built (Rowland and Howe, 2001). After the mausoleum was built, it led to the proliferation of mausoleums due to their magnificence, glory, and unique architecture, and the monumental tombs built with the same architecture were called "mausoleums" (Göğebakan, 2017). Göğebakan (2017: 112) states that the technical structure of the mausoleum is "about 41 meters high, covered with a 21-tiered pyramidal roof on a 60x80 m stepped base on 36 Ionic-style columns." Accordingly, the mausoleum was included in the classification of the "Seven Wonders of the World" as the most magnificent structure of the time. The pyramid, one of the wonders of the world, is 147 meters high, as are the statue of Zeus at 12 meters, the temple of Artemis at 55 meters, the lighthouse of Alexandria at 100 meters, the statue of Rhodes at 33 meters, and the mausoleum at 55 meters. Although the mausoleum stood like a medium-sized structure among other works, its geographical location made it a magnificent sight. Ancient sources tell us that the mausoleum, which is 32.5 meters wide and 38.8 meters high and whose base is almost square, is a structure that takes the form of a pyramid towards the top and is decorated with reliefs depicting figures, soldiers, and Amazon wars (Corsa, 2019).

Descriptions of the first state of the Halicarnassus mausoleum were made by the famous Roman architect and engineer Marcus Vitruvius Pollio (Rowland and Howe, 2001). The architect of the mausoleum is thought to be "Pytheos" or "Satyros" because Vitruvius points to the source of his writings on the Halicarnassus mausoleum as the works of these architects (Öncü, 2018). It is assumed that Vitruvius has a copy of the written records about the mausoleum, which include the architectural analytical descriptions, technical details, budget, and information about the employees of the architects who made the mausoleum in the period of Vitruvius, and in this way, such detailed information has survived from these written documents (Corso, 2019). In light of this information, one of the details that make the mausoleum important is the fact that four famous sculptors worked simultaneously in the mausoleum in the 4th century BC, when it was built. These famous sculptors are known as Skopas, Leokhares, Bryaksis, and Timotheos, respectively. It was written by Vitruvius that the eastern side of the mausoleum is the work of Skopas, the west side is the work of Leokhares, the north is the work of Bryaksis, and the south is the work of Timotheos (Koca and Akça, 2017). While Skopas, Leokhares, and Timotheos were sculptors from Greece, Bryaksis was a Carian sculptor (Corso, 2019). There are very important details about the Halicarnassus mausoleum.

The mausoleum structure is divided into four parts. The first section is located on the pedestal, also known as the high podium. The pedestal section is decorated with friezes at the top and bottom. The battles of the Greeks and the lapiti of the attors against the

Amazons, a race of warrior women, were depicted in the scenes. One above and the second part: There were a total of 36 Ioan columns, 11 on the long sides and 9 on the short sides, and there were sculptures in the spaces. In the third section, behind the pillars was a solid, cell-like block that carried the weight of the tomb's huge roof. This roof, which is the same height as the columns, consists of 24 steps in a pyramid shape. The last and fourth parts are the most important features of the pedestal and the mausoleum, and they also include four big horses pulling the carriage with the 6-meter-high statues of the Carian Satrap Mausolus and his wife Artemisia, known as the "Quadriga," a very important symbol throughout history. This quadriga is thought to be a work by "Pytheos" (Göğebakan, 2017; Corsa, 2019). It is thought that the last person to see the Halicarnassus mausoleum was Bishop Eustathios, and this was in the 12th century AD (Wypustek, 2013). Thus, it is understood that the monument has been a wonder of the world for many years. However, since Mugla is in the earthquake zone, there have been severe earthquakes throughout history, and these earthquakes have destroyed many buildings. It is thought that the Halicarnassus mausoleum was destroyed in these earthquakes.

The stones of the mausoleum, which were damaged because of natural disasters such as earthquakes, were dismantled by the Saint Jean knights who came to Bodrum in 1402 and used in the construction of the Bodrum Castle (Günay, 2017). As a result, the original stones have survived to this day, with the Bodrum Castle bearing its current name. It is known that many French travellers and archaeologists traveled around Anatolia in the 19th century and described what they found in their works (Amygdalau, 2017). The Bodrum region was visited by Charles Texier (Description de l'Asie Mineure, 1837) in 1826 and Leon de Laborde (Voyage de l'Asie Mineure, 1856) by French travelers in 1935, and the travelers mentioned the Mausoleum of Halicarnassus in their books (Amygdalau, 2017). What makes the Halicarnassus mausoleum more important is that the ruins, which were found after its destruction, disappearance, and later re-found, were taken to England and displayed in the museum (Uygur vd., 2015).

The British archaeologist and diplomat Charles Newton played a major role in the initiation of the excavations of the Halicarnassus mausoleum. The first excavations were carried out in the Halicarnassus Mausoleum in 1857–1858 by the British archaeologist Charles Newton with the permission of the Ottoman government (Jenkins, 2010). The sculptures of Mausolus and Artemisia, four-horse carriages, reliefs, and other sculptures, which were found because of excavations, were taken to the British Museum in England by Charles Newton (Göğebakan, 2017). In the British Museum, 22 pieces of the Halicarnassus Mausoleum are on display (The British Museum, 2021). The area where the foundation of the Halicarnassus mausoleum is located is included in the list of archaeological sites maintained by the Ministry of Culture and Tourism. The foundation and some of the remains of the Halicarnassus Mausoleum are exhibited in the Halicarnassus Mausoleum Open Air Museum.

4. Method

This research is designed based on model development. Favro (2006) refers to the models obtained through such research as "knowledge models." In this model, restructuring is carried out using available resources. Reconstruction is not a visual representation of an original historical artefact but rather a visualization of existing knowledge of the building. In other words, it is obtained based on the interpretation of existing sources. The research aim is to develop a mobile application for the Halicarnassus Mausoleum with an AR experience that includes historical information. There are two parts to developing an application. The first method is to do a literature search to find a visual representation of the destroyed artefact. There is no visual representation of destroyed works. Information is obtained from the ruins, old books, and writings. Sources for some historical artefacts were made according to the description of the last person who saw them. The reconstruction of Halicarnassus Mausoleum was created to use a knowledge model and marker-based AR for mobile application development for this study. The research question is set as “How to develop an augmented reality model for ancient ruins of the Halicarnassus Mausoleum?”.

The second part of the method is to design and implement a mobile AR (MAR) application for Android devices that provides 3D visualization of the Halicarnassus Mausoleum. The mobile AR model made with the method proposed in this study will provide the opportunity to interact with the reality of completely disappeared or destroyed remains. A marker-based AR application will provide the opportunity to see the Halicarnassus Mausoleum in 3D form via a marker on mobile devices. The model is developed by using the Vuforia-integrated Unity game engine for application generation and 3DS Max for the 3D objects. In the next section, the application creation method will be explained in more detail.

4.1. The Method of Developing a Mobile AR Application of The Mausoleum at Halicarnassus

Marker-based AR is a popular and prominent technology that enhances the user experience successfully. Nowadays, AR application developments have gained speed due to the accessibility and integrability of external tools and APIs, e.g., Unity (Unity, 2020) and Vuforia (Vuforia, 2020). In this model, the Vuforia-integrated Unity game engine is used for the application generation and to model 3D objects using 3DS Max. 3D modelling contains various algorithms and techniques that range from point cloud reconstruction (Berger et al., 2014) and image-based techniques (Remondino et al., 2006) to procedural techniques. Procedural modelling is used to refer to many rule-based computer graphics techniques that are used for production, e.g., fractals (Dudgeon and Gopalakrishnan, 1996), GML, etc. The problem with point cloud generation from the Mausoleum is that there are no standing blocks at the site or at any museum (see Fig. 1(a)).

(a) **(b)** **(c)**

Figure 1- (a): The ruins of the Mausoleum ancient site in Bodrum city centre (photo taken by the second author). (b): Model of the Mausoleum at Halicarnassus, at the Bodrum Museum of Underwater Archaeology. (c): 3D view of the Mausoleum on the marker modelled by the second author.

In this case, it is impossible to generate a point cloud with respect to surface reconstruction. Many artists still use ancient descriptive information for digital or real-life modelling (see Fig. 1(b)). Britannica (2020) describes the monument as "the monument was almost square, with a total periphery of 411 feet (125 meters). It was bounded by 36 columns, and the top formed a 24-step pyramid surmounted by a four-horse marble chariot". The 3D monument shape is modelled and utilized by 3DS Max. Step-by-step model generation, and the final result can be seen in Fig. 2. Surface reconstruction refers to the process of creating a 3D model of a real-world object or scene from captured data. In the case of the Halicarnassus Mausoleum, surface reconstruction could be used to create a 3D model of the ancient Greek tomb. The process of surface reconstruction typically involves capturing data from the physical object or scene using techniques such as photogrammetry, lidar, or structured light. This data is then processed to create a 3D model, which can be viewed and interacted with on a computer or other device. The accuracy of the reconstruction depends on the quality and quantity of the captured data, as well as the algorithms and techniques used to process it.

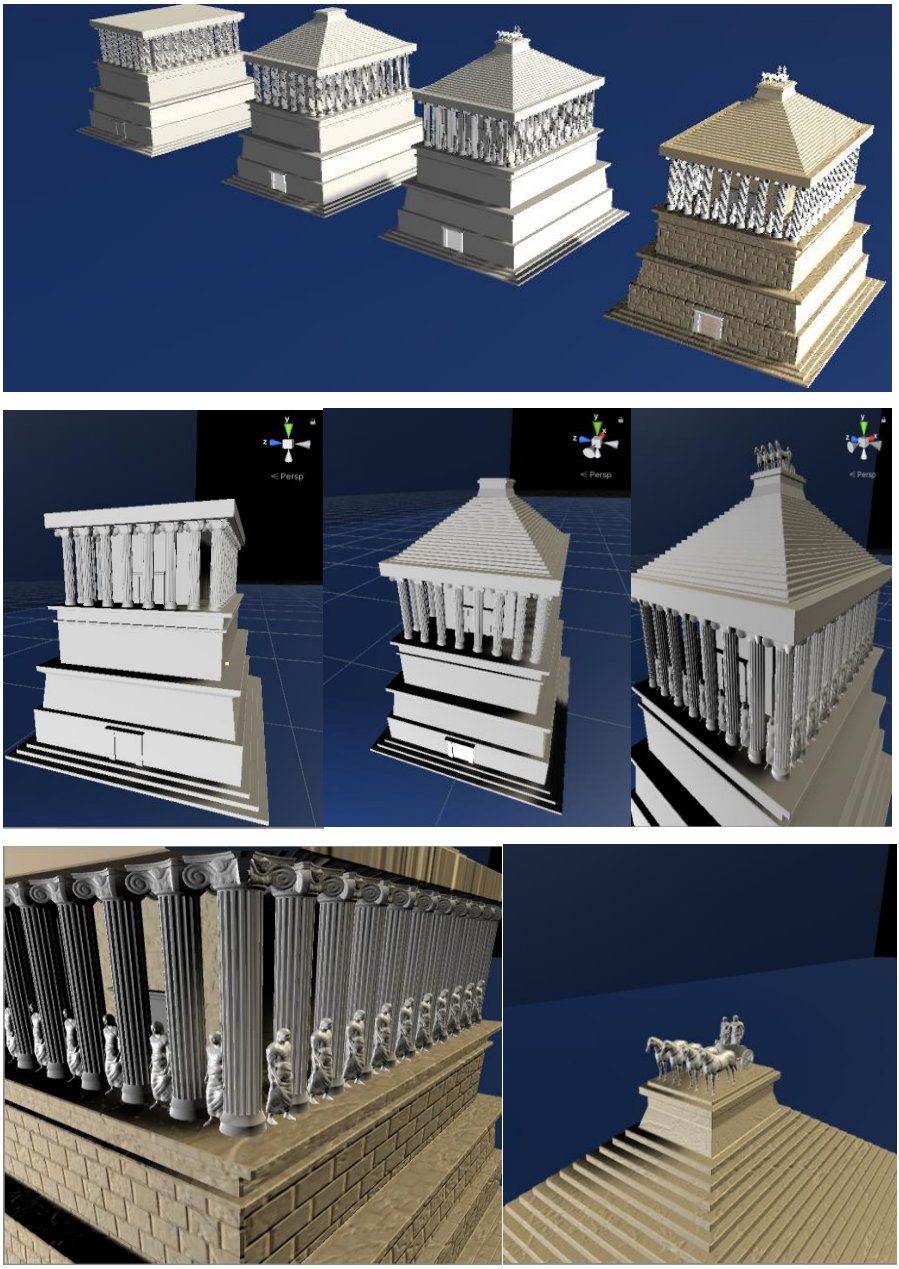

Figure 2: 3DS MAX for 3D modelling for Halicarnassus mausoleum

Figure 2 shows details of 3D modelling for the Halicarnassus mausoleum. The last known Halicarnassus mausoleum with a mosaic base with pyramids and doors, male statues and a horse carriage with Artemisia and the King at the top, and the final textures are shown from left to right. The close-up views can be seen in the second and third rows. In the application development part, a complete mobile application was developed by using Unity, which provides 4 main parts (Fig. 3). The mobile application allows the user to reach AR in a 3D model, Text-Based description of the ancient site, images and quiz game.

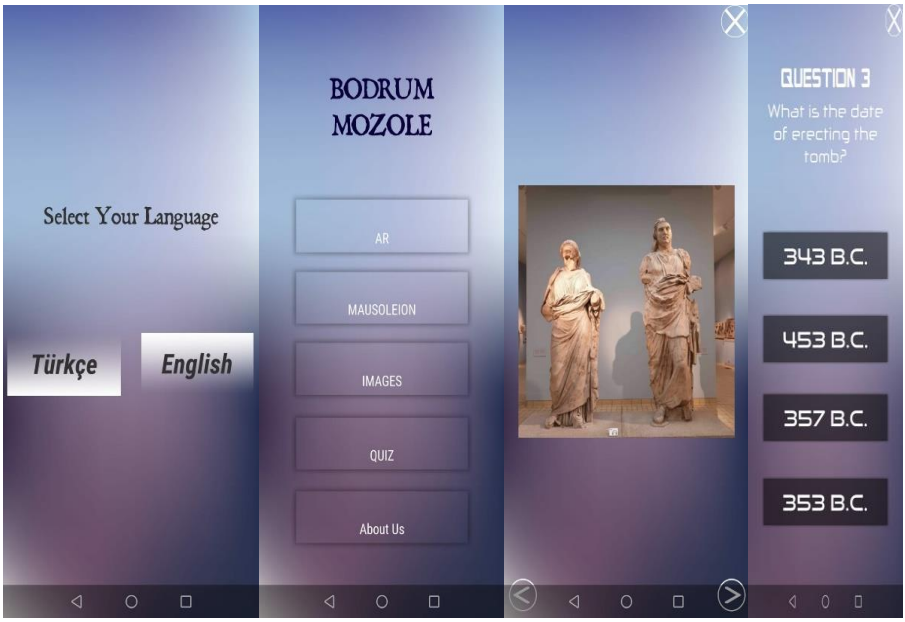

Figure 3: Pages of the developed application where you can start by selecting the language, choosing an option from the menu, selecting AR and accessing the above-shared model by using the tracker, seeing site-related images or continuing with the quiz to measure your knowledge about the ancient site.

A historical description of ancient sites (Part 2) and the images of ruins or in-museum artefacts (Part 3) are quite important for the user to grasp the information that the application offers them. The system using AR-based and quiz-based gamification is crucial since gamification is one of the most widely used learning methods in various areas. As AR helps the user visualize the original monument, the quiz-based gamification system helps to fill in the gaps in knowledge. All other three parts except AR were developed using pure Unity Game Components: Unity UI Text, Unity UI Image Support, Unity UI Button, and Event Triggering Systems. The AR part is developed using Vuforia support. In marker-based AR applications, accurate tracking of markers is crucial to triggering the event. This accuracy depends on the contrast-based features of the target that are visible to the camera and the number of feature points. Vuforia includes a target star rating mechanism to help

you assess the quality of your target and optimize target detection and tracking stability. According to the target start rating, the image should be rich in detail, have good contrast, and have no repetitive patterns.

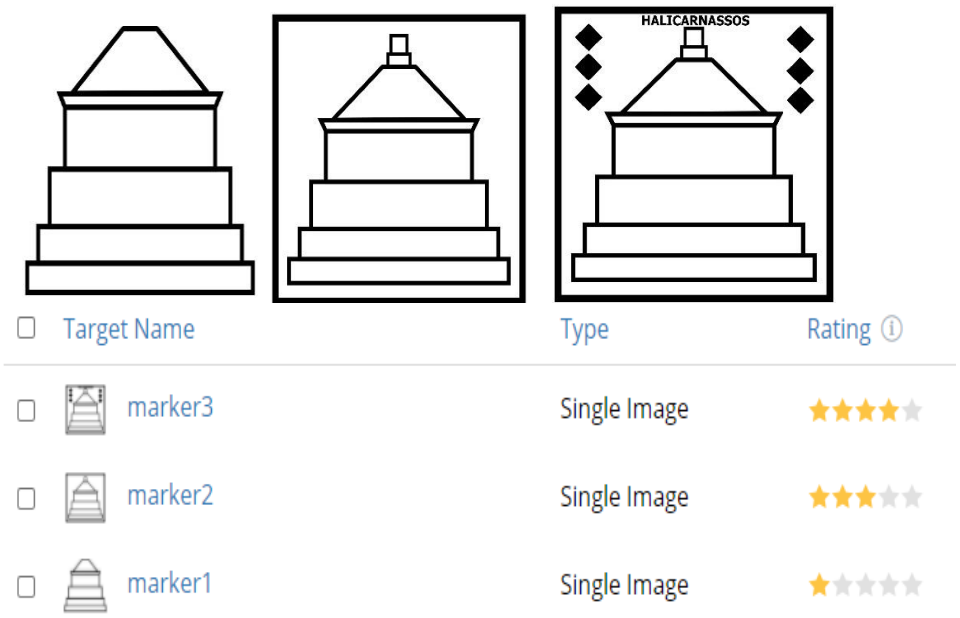

Figure 4. (a)-(c): Different image targets AR tracking and (d) their corresponding ratings.

Figure 4 shows different image targets for AR tracking and their corresponding ratings. 3 different image targets were tried as marker 1, marker 2, and marker 3, where each of them has different ratings according to the Target Star Rating (Fig. 4). The app utilizes marker 3 for this study. Once the marker is decided, it can now track and connect with the model in Unity using the Vuforia API. At this point, it is crucial that virtual models are rendered and aligned in the scene appropriately. This problem is solved using pose estimation or, equivalently, a camera localization process (Marchand et al., 2016). Figure 5 shows the whole process from the camera detecting the marker to the rendering image from the virtual model database. The user can only access market activation by using a downloadable API that is available via a link.

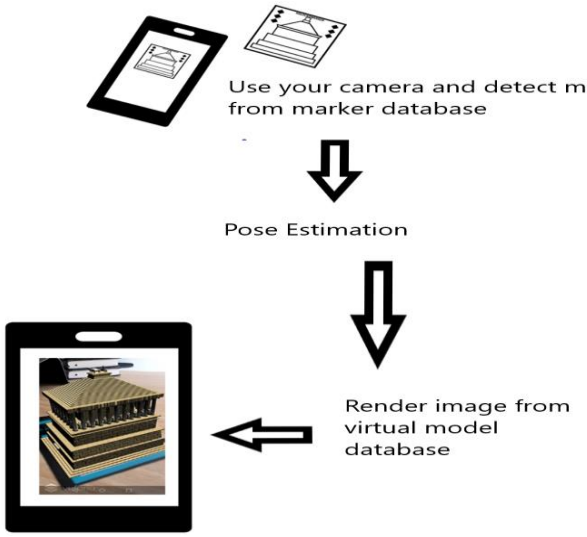

Figure 5. Stages of AR tracking and rendering

Figure 5 shows the stages of AR tracking and rendering, which can be broken down into the following steps: Step 1 is detection. This stage involves identifying the physical objects and surfaces in the real world that will be used as the basis for the AR experience. This can be done using various technologies, such as computer vision, structured light, and marker-based tracking. Step 2 is tracking. This stage involves determining the location and orientation of the physical objects and surfaces in real-time. This information is used to update the digital content in real-time so that it appears to be a part of the physical environment. Step 3 is calibration. This stage involves aligning the virtual content with the physical environment. This is done by adjusting the position, orientation, and scale of the virtual objects so that they match the physical environment. Step 4 is rendering. This stage involves generating the final AR experience by combining virtual and real-world content. This can be done using various techniques, such as real-time rendering and pre-computed rendering. Step 5 is interaction. This stage involves allowing the user to interact with the virtual content. This can be done using various input methods, such as touch, gesture, voice, and gaze. These stages are performed in real-time to create an immersive and interactive AR experience for the user. The quality of the AR experience is dependent on the accuracy and efficiency of each of these stages. The marker is captured by the camera in this model. It renders images from the virtual model database.

5. Conclusion

AR is a technology that blends real and virtual worlds by overlaying digital content onto

the physical world. It is used in various applications, including gaming, medical and military, education, tourism, and creative industries. AR systems use sensors to collect data about the user and environment to create an accurate 3D model that can be interacted with. AR is the next step from virtual reality, which transports users to a virtual world, whereas AR brings digital information into the physical world. Museums are a great place for AR implementation, as it can create a more interactive and immersive experience for visitors. AR can trigger user engagement, learning, meaningful experience, and emotional connection, and dynamic verbal cues can increase willingness to pay more for an AR-facilitated museum experience. AR also helps visitors see more of the collections, artefacts, and original appearances that may have been destroyed or demolished. The primary objective of this study is to enhance the visitors' experience of the Halicarnassus Mausoleum by using AR technology to improve their perception of reality.

The use of AR applications in historical sites has several implications for various stakeholders, including researchers, practitioners, and society (Serravalle et al., 2019a). For researchers, AR applications offer an opportunity to study and understand historical sites in a more interactive and dynamic way. By creating AR applications that provide additional historical information and visualizations, researchers can enhance their understanding of historical sites and provide new insights into their cultural and historical significance. In the case of the Halicarnassus Mausoleum, surface reconstruction could be used to create a complete and accurate model of the structure. This could help researchers and tourists gain a better understanding of the monument, including its size, shape, and details that may not be visible in photographs or other two-dimensional representations. The model could also be used to create virtual tours, allowing visitors to explore the mausoleum using their own computers or mobile devices.

The integration of AR into the realm of cultural heritage, as evidenced by the studies discussed, represents a dynamic and transformative shift in how historical sites are preserved, presented, and experienced. The versatility of AR technology is evident in Čejka, Zsíros, and Liarokapis's (2020) exploration of underwater cultural heritage sites, showcasing its adaptability to challenging environments. Graziano and Privitera's (2020) insights from Italy highlight the symbiotic relationship between cultural heritage, tourist attractiveness, and AR, emphasizing the technology's potential to enhance not only educational aspects but also the overall appeal of historical sites for tourists. Hincapié et al. (2021) contribute to this discourse by emphasizing the role of AR mobile apps in the reactivation of cultural heritage, positioning technology as a catalyst for revitalization. Finally, Andrade and Dias's (2020) phygital approach at Regaleira underscores how AR seamlessly blends with physical spaces, offering visitors immersive and layered experiences. Collectively, these studies illuminate the transformative impact of AR in preserving and reinvigorating cultural heritage, hinting at a future where technology becomes an integral part of our exploration and understanding of the past.

The diverse studies discussed collectively shed light on the broad spectrum of applications and implications of AR in the domain of cultural heritage. Litvak and Kuflik's (2020) exploration of augmented-reality smart glasses as tools to enhance outdoor cultural heritage experiences underlines the potential for immersive and interactive engagement with historical sites. Barrado-Timón and Hidalgo-Giralt's (2019) examination of augmented and virtual reality's impact on the transmission and perception of historic cities signifies a paradigm shift in how urban cultural heritage is understood and utilized in contemporary contexts. Meanwhile, Gonzalez Vargas et al. (2020) provide valuable insights into the educational realm, emphasizing the use of AR to improve learning motivation in cultural heritage studies. Their survey-based approach adds empirical evidence to the growing understanding of the positive influence of AR on educational experiences related to cultural heritage. Additionally, Boboc et al.'s (2019) focus on mobile augmented reality for cultural heritage further extends the geographical reach of AR applications, allowing users to trace the footsteps of historical figures across diverse European locations. Collectively, these studies highlight the multifaceted contributions of augmented reality, ranging from enhancing on-site experiences to revolutionizing educational approaches, and underscore the technology's potential to redefine our relationship with cultural heritage in the modern era.

For practitioners, AR applications can be used to improve the visitor experience and attract more tourists to historical sites. AR applications can offer a more immersive and engaging experience for visitors, providing them with additional information about the site and allowing them to explore its features in a more interactive way. This can help to increase the overall satisfaction of visitors and encourage them to revisit the site or recommend it to others. For society, AR applications can have significant implications for education and cultural preservation. By creating AR applications for historical sites, educators can provide students with a more engaging and interactive way to learn about history and culture. Furthermore, AR applications can help preserve cultural heritage by providing digital representations of historical sites that can be accessed by people all over the world.

Many tourists come to see the ruins every year. When they see the mausoleum of Halicarnassus built next to the ruins with the help of technology, it will enhance their perception and feelings. Future studies can use the Halicarnassus mausoleum application to investigate whether users have an increased sense of reality, whether their perceptions change, and whether it makes them want to come back. In addition, the method proposed in this study contributes to students' learning in the classroom. AR technology has the potential to significantly improve students' learning by providing them with a more interactive and engaging way to learn about historical sites and events. One specific recommendation for using AR in historical education is to simulate ceremonies and events held at historical sites, such as the ceremonies held at the Mausoleum. By using AR

technology to simulate historical ceremonies, students can gain a deeper understanding of the cultural significance of these events and how they were conducted. These apps, created with AR technology, can allow tourists to connect more with the historical places they visit. There may even be a reason for the visits. The use of new technologies can play an important role in increasing the number of tourists. Historical sites that have disappeared over the years are being redesigned using AR technologies to enhance the cultural and tourist experience. These apps, created with AR technology, can allow tourists to connect more closely with the historical sites they visit. There may even be a reason for the visits.

The use of new technologies can play an important role in increasing tourist numbers. Historical sites that have disappeared over the years are reconstructed using AR technologies to enhance the cultural and tourist experience. AR is an exciting new tool that will change the way we communicate and interact with the world. AR offers a range of new experiences that were previously impossible. AR also makes it easier to share information and contextualize experiences, providing opportunities for more people to connect with each other. With AR, businesses can better connect with their customers and explore innovative ways to engage their fans. Given these potential benefits, AR is likely to remain an important tool for enhancing visitor experiences, especially in museums. It will be exciting to see how AR continues to evolve and improve over time, potentially transforming the way people engage with cultural and historical sites.,

Future studies in the realm of AR applications for cultural heritage sites can explore several avenues to enhance user experiences and contribute to the broader field of heritage preservation. Firstly, conducting thorough user experience and satisfaction analyses will provide valuable insights into the effectiveness of AR applications, allowing researchers to refine and optimize these tools based on user feedback. Comparative studies between traditional informational signs and AR applications can offer a nuanced understanding of the impact on engagement and knowledge retention. Exploring the integration of advanced technologies, such as virtual or mixed reality, may further elevate the immersive qualities of these experiences. Researchers should also delve into cultural and ethical considerations to ensure responsible and respectful use of technology in historical locations. Scalability and generalization studies could extend the proposed AR model to other historical sites, fostering adaptability across diverse cultural and geographical contexts. Long-term impact studies tracking visitor numbers and preservation efforts will shed light on the sustained benefits of AR in heritage tourism. Collaboration with cultural institutions, archaeologists, and historians is essential to validate the accuracy of information presented through AR applications. Finally, keeping pace with technological advancements will enable researchers to leverage emerging technologies for more realistic and advanced AR experiences. Addressing these avenues will contribute to a comprehensive understanding of AR's potential in cultural heritage and facilitate the development of sustainable and enriching experiences for tourists at historical monuments.

This article is of paramount importance within the realm of cultural heritage and tourism due to its innovative approach to mitigating the challenges posed by the destruction of historical sites. Focused on the Mausoleum of Halicarnassus, a prominent historical landmark, the study leverages AR technology to offer visitors a unique and immersive experience. By developing a mobile app that overlays computer-generated objects onto the real environment captured by the camera, the research not only addresses the specific case of the Mausoleum but also introduces a replicable model for other historical sites grappling with similar issues. This signifies a significant contribution to the field by demonstrating the adaptability of AR to diverse cultural and historical contexts, paving the way for the preservation and presentation of heritage in a technologically advanced manner. The article's emphasis on sustainability, user engagement, and ethical considerations further underscores its relevance in shaping the future of cultural tourism. As a result, the study not only provides a tangible solution for tourists to experience missing artefacts in a real environment but also opens avenues for future research and advancements in the intersection of technology and cultural heritage preservation.

In the realm of engineering and technology development, a strategic focus on AR applications for cultural heritage can significantly elevate the user experience and impact of such technologies. To begin, the development of more sophisticated AR hardware, including improved smart glasses and wearables, holds the potential to enhance visual fidelity and expand the field of view, ensuring a more immersive encounter with historical sites. Additionally, exploring the integration of AR with emerging technologies such as artificial intelligence, machine learning, and computer vision can empower these applications to provide personalized and context-aware experiences for users. Real-time 3D reconstruction techniques could be pursued to create detailed virtual models of historical artefacts and sites, while the integration of haptic feedback technology offers the opportunity to simulate the tactile sensations associated with interacting with these artefacts. Optimizing mobile applications for AR experiences ensures widespread accessibility and collaborative AR experiences can foster shared learning and community engagement.

The study faced several constraints throughout its execution, presenting challenges across various dimensions of the research process. Access limitations to the physical site, the Mausoleum of Halicarnassus, posed initial hurdles in acquiring detailed and accurate data essential for developing the AR application. Technical challenges emerged during the application's implementation, encompassing issues related to AR overlay precision, historical information integration, and the optimization of the mobile app for diverse devices. Resource constraints, including limitations in time and funding, influenced the study's scope and depth, impacting the comprehensive development and application of the AR model. Navigating these constraints required a holistic and adaptive approach, underscoring the importance of flexibility and responsiveness in addressing the

multifaceted challenges inherent in the development of AR applications for cultural heritage sites.

In summary, the use of AR technology can enhance the experience of tourists visiting cultural heritage sites in Turkey. By using AR, tourists can see the monuments in a real-time and immersive environment, satisfying their desire to see and feel the artefacts. AR can also increase engagement and interaction with the site and destination. The AR industry is growing rapidly and changing the way we interact with the world, with the potential to revolutionize the way we experience our physical surroundings. Furthermore, the development of robust AR content management systems ensures the accuracy and relevance of historical information over time. By addressing these aspects, engineers and technologists can make substantial contributions to the advancement of AR applications in cultural heritage, enriching the exploration and understanding of historical sites for tourists.

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