Increasing Awareness and Preserving History of the Grotte des Pigeons

Rion Crear
Olivia Deckers
Soumaya El Mansouri
Lauren Eppinger
Matthew Resmini

INCREASING AWARENESS AND PRESERVING THE HISTORY OF THE GROTTE DES PIGEONS

An Interactive Qualifying Project Submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
In partial fulfillment of the requirements for the degree of Bachelor of Science

by
Rion Crear
Olivia Deckers
Soumaya El Mansouri
Lauren Eppinger
Matthew Resmini

Date:
5 May 2023

Rabat, Morocco Project Center Report

Submitted to:

Salma Azzouz
Abdelilah Mhattem
Association Passagers

Professors Bland Addison
Fabio Carrera
Joseph Doiron
Worcester Polytechnic Institute

Abstract

The Grotte des Pigeons, also known as Tafoughalt due to its proximity to the namesake village, is a cave located in the Berkane province of Morocco's Oriental Region. Decades of excavations have revealed the world's oldest known skull showing successful evidence of the medical procedure known as trepanation as well as revealing burial customs of the Iberomaurusian people dating from about 10,000 to 20,000 years ago. Although the cave and its surrounding area are rich in scientific and cultural significance, tourism to the region remains low because of its remote location and the lack of publicity about the cave. Working with our sponsor, *Association Passagers,* we made 3D models of artifacts and 360-degree images of the cave to be integrated into an interactive digital platform that will highlight the area's key attractions and encourage tourism to the region, ultimately boosting the local economy.

Table of Contents

Executive Summary

Our sponsor, *Association Passagers*, is a non-profit organization with members in Morocco, France, and Senegal. Since its founding in 2011, the *Association* has centered its mission around youth development through arts and entrepreneurship projects. As an organization, they believe that investment in young people will foster creative ideas to boost local economies.

Association Passagers is interested in the Grotte des Pigeons because of its untapped potential to attract tourists to the Oriental Region. Located in the town of Tafoughalt, the cave is recognized internationally amongst scientific communities as one the world's most important sites containing evidence of early human civilizations. The Grotte des Pigeons is seen as a symbol of cultural pride for the region because of its connection to ancient humans, but there is not much public knowledge about its specific excavations. The area around the cave also lacks the physical infrastructure to support tourists to the region.

Figure 1. Skyline of Oujda Morocco.

Increasing access to educational resources about the Grotte des Pigeons will not only help preserve the cave's cultural heritage but also encourage tourism to the area, boosting the local economy.

Project Goal

Our project's goal was to provide our sponsor with the necessary components to create a digital museum and virtual tour for the Grotte des Pigeons as part of their larger educational campaign, the Tafou Experience. With a focus of creating an educational yet entertaining digital museum, we developed interactive 3D renderings of artifacts excavated from the cave, 360-degree images of the cave's exterior, an informational guidebook, and a comprehensive repository of all the creations and research conducted. Our provided material was given to the *This Is* digital marketing agency to be used in their development of a virtual tour of the cave. The user-interactive virtual tour will be publicly available, aiming to increase tourist interest in the Tafoughalt area.

Methodology

The artifacts that we focused on for this project were located in the museum at Mohammed I University in Oujda, Morocco and accessed under the supervision of Professor Hassan Aouraghe. With Professor Aouraghe's advice, we selected seven artifacts for 3D

renderings. We used photogrammetry to create 3D models of these artifacts by taking several hundred 2D photographs of each artifact, capturing all sides using a rotating platform. These photos were then processed using the photogrammetry software Agisoft Metashape, creating an interactive 3D model. A catalog was then created for the artifacts imaged, which included each artifact's name, description, and other important information. Additionally, 360-degree images of the area surrounding the cave were captured using a GoPro MAX. These 360-degree photos will be used by *This Is* to create a virtual museum of the cave and surrounding area. A guidebook about the Grotte des Pigeons was also developed using information gathered both through scientific papers and expert interviews at Mohammed I University and the National Institute of Archaeology and Heritage in Rabat, Morocco. All of these creations, as well as research and interviews conducted, were put into a digital information repository.

Results and Analysis

We created 3D models of seven artifacts housed at the museum located at Mohammed I University. Over 4,000 pictures were taken and processed into high-quality models with Agisoft Metashape and Blender. All renderings are available under a creative commons license. Eleven images were taken along the path to and in front of the Grotte des Pigeons using a 360-degree camera. While we were unable to access the inside of the cave, most of it was easily within view, even from behind the protective fence.

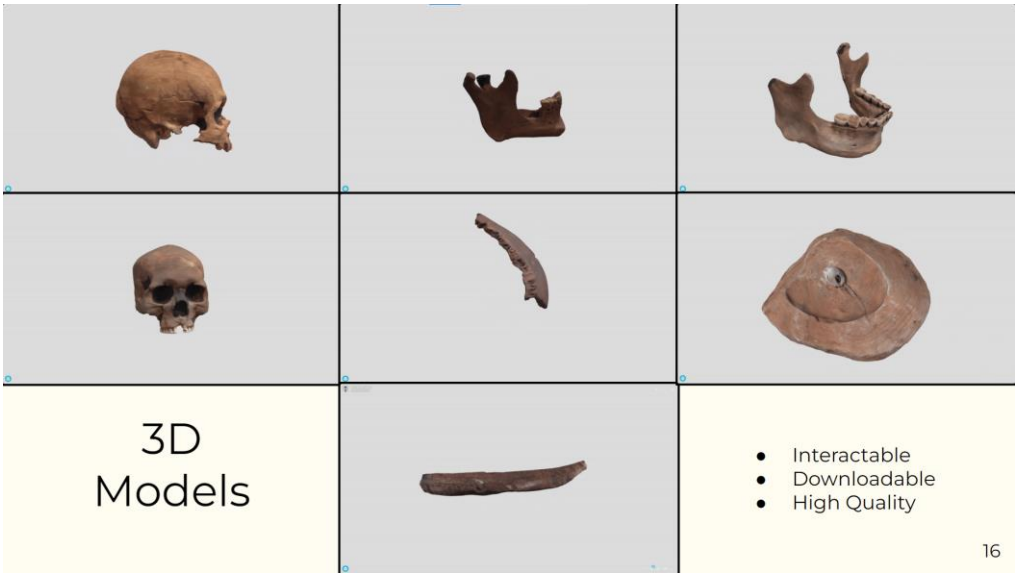


Figure 2. All Seven 3D Models.

We provided all the 360-degree images and 3D models through a Google drive to *This Is* to be made into the virtual museum and embedded into the sponsors final website. In addition to the models and images, we created an information repository, which we shared with *Association Passagers* via Google drive. It contains all the information we collected on the Grotte des Pigeons, including research articles, artifact descriptions, transcripts, and recordings of our expert interviews. The goal of the repository was to provide our sponsor with supplemental content for their platform.

Figure 3. All Eleven 360-Degree Images.

Conclusion

Through the completion of our project, it became abundantly clear that the Grotte des Pigeons is a unique yet undervalued site at the intersection of culture and science. We aimed to digitally preserve the cave and its artifacts to allow those who may never be able to visit Tafoughalt a chance to experience the beauty, history, and culture of the area. There currently exists no other 3D models of the cave's artifacts online, and our scans allow for a unique viewing experience for those hoping to learn more about the scientific and cultural importance of the area.

Figure 4. Pigeons in the Cave. The Origin of Its Name.

Acknowledgements

As a team, we would like to thank the following people for their assistance throughout our project:

- *Professors Bland Addison, Fabio Carrera,* and *Joseph Doiron*: We give great thanks to all of our advisors for their guidance from ID 2050 through the completion of our IQP.

- *Abdelilah Mhattem, Salma Azzouz,* and *Idriss El Fatih Hadef* of *Association Passagers:* We thank *Association Passagers* for their sponsorship of our project. Their support, encouragement, and mentorship allowed us to exceed all project expectations, and their extensive knowledge of the region was invaluable.

- *This Is Digital Marketing Agency:* We thank *This Is* for their help in formatting and creating the technical aspects of the project.

- *Professor. Hassan Aouraghe* of *Mohammed I University*: We thank Professor Hassan Aouraghe for his help in accessing university-held artifacts. His guidance was instrumental in creating artifact descriptions and learning about the scientific and cultural heritage of Tafoughalt.

- *Professor Abdeljalil Bouzouggar*, director of the *National Institute of Archeology and Heritage Science (INSAP)*: We thank Professor Abdeljalil Bouzouggar for sharing his knowledge and expertise about the history and cultural significance of Tafoughalt.

- *Lincoln Institute*: We thank Lincoln Institute for caring for us in Morocco, and for guidance and acting as our home-base.

- *Abdelali (Ali) El-Irari:* We thank Ali immensely for his assistance, guidance, and support throughout this project and in our time in Morocco as a whole.

Table of Figures

Authorship of Report

Section	Author	Reviewer
1. Intro	All Authors	All Authors
2. Background	RC, SE, LE, OD	SE, MR, LE, OD
3. Methodology	LE, MR, OD	SE, RC
4. Results and Analysis	MR, RC, SE	OD, RC
5. Conclusion and Recommendation	LE, MR	OD, SE, RC

Authors:

Rion Crear (RC), Olivia Deckers (OD), Soumaya El Mansouri (SE), Lauren Eppinger (LE), Matthew Resmini (MR)

1. Introduction

The Grotte des Pigeons is a cave in the Berkane province of northeastern Morocco. Its French name stems from the large number of pigeons found within it during excavations. Also known as Tafoughalt due to its proximity to the nearby village, the cave is broadly recognized as one of the oldest human burial sites in the world. Excavations have also revealed evidence dating back 12,000 years that show the successful completion of the surgical practice known as trepanning, which is an ancient form of brain surgery in which a small hole was scraped or sawed through the skull to relieve pressure buildup in the brain. Additional excavations have helped to uncover the diet, lifestyle, and mortuary history of the early humans, known as the Iberomaurusians, who inhabited the cave 10,000 to 20,000 years ago. Despite its immense significance, the cave remains largely unknown outside scientific circles, even among Moroccans. Many organizations who seek to publicize this remarkable historical achievement lack the resources necessary to bring proper recognition to the cave. Receiving recognition would bring greater economic growth and prosperity to the Tafoughalt region.

Our sponsor, *Association Passagers*, is a non-profit organization based an hour from the Grotte des Pigeons in Oujda, Morocco. Since its founding in 2011, its mission has been to serve youth in Morocco, Senegal, and France to ensure better local and national development in each locale. As an organization primarily composed of young people, *Association Passagers* believes that reaching out to Morocco's youth will garner ambitious minds armed with ideas to promote economic growth in their communities. The Association collaborates with numerous other non-profit organizations in North Africa and the Middle East, and their most recent projects include Takafship, a program that encourages cultural entrepreneurship.

Association Passagers is particularly interested in the Grotte des Pigeons because there is a lack of accessible educational information about its importance. The cave has untapped potential to become a tourist attraction for Tafoughalt. The Association hopes that tourism will boost the local economy and increase job opportunities for local youth while promoting awareness of this unique archeological site.

To accomplish this, *Association Passagers* is working with the digital marketing agency, *This Is*, to create Tafou Experience, which is a virtual platform to draw tourists to the many attractions of the Oriental Region of Morocco. They envision that the platform will highlight the region's key attractions, suggest places to stay, and include a virtual museum of the cave.

Our project produced digital materials to create the virtual museum that will publicize knowledge of Tafoughalt's history and culture, thus encouraging tourism to the area, and contributing to the region's economic development. We made 3D models of artifacts excavated from the cave and larger 360-degree images of the cave's interior and surroundings. Expert interviews informed the development of a guidebook to showcase the scientific and cultural importance of the cave and its contents. These digital materials were compiled into a repository, which was then given to our sponsor for integration into their larger platform.

2. Background

This chapter introduces the context of our project through descriptions of the Grotte des Pigeons, its excavations, colonial control, and habitation. We discuss the context of the larger region, illustrating the current economic status of the area as well as our sponsor's vision for future developments. Existing virtual museums are examined, recounting their proven history to spread awareness and pique the interests of their online audiences, as well as their influence on the design of our own project, and their influence on the design of our project is considered.

2.1 The Grotte des Pigeons

The Grotte des Pigeons stands 720 meters above sea level in the northeastern corner of Morocco (Figure 5). Located in the Oriental Region, the cave is situated nearly halfway between the urban areas of Oujda and Nador.

Figure 5. Location of the Grotte des Pigeons in Northeastern Morocco.

The mouth of the cave measures approximately 30 meters wide and 15 meters in height as shown in Figure 3, with its floor covering roughly 400 square feet (Hogue, 2014). The oldest excavated human remains are estimated to be 11,000 to 12,000 years old but determining the years in which the cave was inhabited is difficult due to damage from early excavations. Regardless, archeologists do not believe there was any extensive period when it was abandoned year-round (Reynolds, 2020).

Figure 6. Mouth of the Grotte des Pigeons.

2.1.1 Important Scientific Discoveries at the Grotte des Pigeons

Thousands of artifacts have been excavated from the Grotte des Pigeons since the 1950s, including roughly 500,000 pieces of jewelry, tools, and human remains. Initial estimates from 1962 put the number of individuals buried in the Grotte des Pigeons around 86 remains, yet recent research puts that number closer to 40 (Mariotti et al., 2009). These graves and excavations reveal information about Iberomaurusian culture, habits, and technology. They have been found in various depths of sediment, suggesting that cave habitation spanned thousands of years (Kharroubi, 2010).

Figure 7. Necklace excavated from Tafoughalt, 82,000 AP.

Unique markings of human bones, including traces of red ochre pigmentation and cut marks, provide archeologists with a look into ancient Iberomaurusian traditions. Experts suggest that the markings and treatment of remains indicate that the Grotte des Pigeons was a sacred place for ceremonies (Mariotti et al., 2009). Bones of adults were commonly found to be spread out among multiple graves, while those of children never moved and remained relatively untouched. Analysis of the bones also gives insight into the diets of cave inhabitants and even evidence of the world's first surgeries, including the oldest known evidence of successful cranial

trepanation, believed to have taken place roughly 11,000 to 12,000 years ago (Crubézy, 2001).

Figure 8. Replica of Skull excavated from Grotte des Pigeons showing evidence of successful trepanation.

Trepanning is the process of scrapping and sawing a hole into living person's skull while leaving the underlying soft tissue intact (Figure 5). This was done by using sharpened stone and is widely considered to be a sophisticated surgical technique that was believed to have been a therapy to remove pressure in the brain caused by physical trauma, headaches, or infections. Remarkably, the success rate of the procedure is estimated between 50% and 90%, inferred from scarring found around the trepanation hole (Faria, 2015).

2.1.2 The Grotte des Pigeons during French Colonial Period

20th-century French political control over Morocco created a practice of sloppy record keeping about French excavations of the cave, and ultimately has contributed to its lack of international recognition today. In 1907, France began its conquest of Morocco, resulting in the creation of the French protectorate in 1912 following the Treaty of Fez. Though Morocco legally remained sovereign, and the Sultan of Morocco remained on the throne, he had virtually no autonomy (Ḥizb al-Istiqlāl, 1953). During this period, France exploited the Moroccan people, politics, and economy, and this exploitation extended to scientific research and archeological excavations. As a result, the records of artifacts found at the Grotte des Pigeons are lost and disorganized, and the artifacts themselves are difficult to locate.

Figure 9. Remains of French Military Barracks in Tafoughalt.

The cave was first recognized internationally following French doctor Edouard Pinchon's written records of discovering the cave during his explorations of the Algerian Moroccan Border in 1908, but it is unclear if there were any excavations by Moroccans prior to this.

Figure 10. Top Layer of Lime Mortar on Cave Floor Filled During French Military Occupation.

Pinchon's writing marked the first mention of the cave in written literature in Europe. Under the protectorate, the French military used the Grotte des Pigeons in 1939 to shelter livestock and troops after artificially leveling the floor with lime mortar, a process which incidentally helped with the preservation of the sediment and artifacts below as shown in Figure 7 (Hogue, 2014).

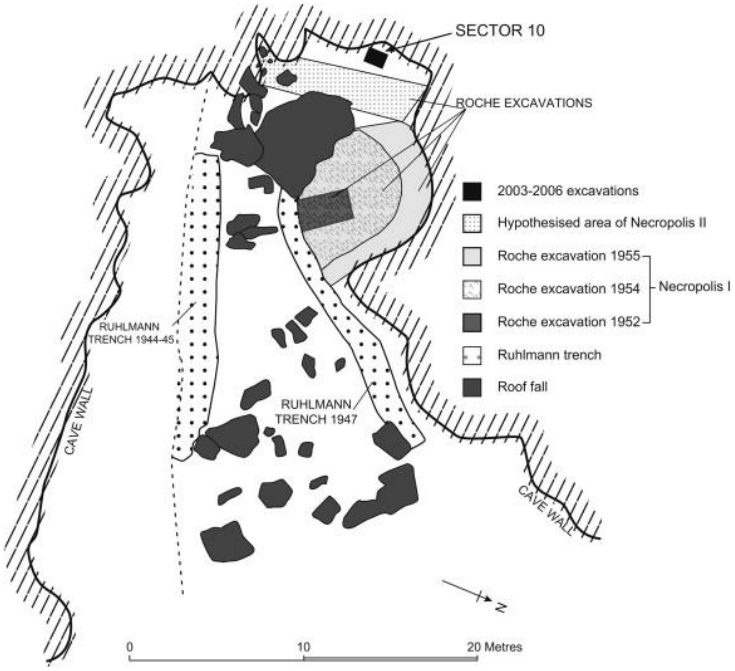


Figure 11. Location of the First Known Cave Excavations from 1944-1955.

The first major archeological excavations of the cave took place around 1951-1972 (Figure 8). These were led by Jean Roche, who is credited with many major discoveries in the Grotte des Pigeons (Bouzouggar et al, 2016). A few fresh trenches and a cave collapse revealed the first evidence of human burials. The archeologists used these trenches to classify sediment layers but neglected to provide any descriptions of the human remains they found (Hogue, 2014). It is these excavations that led to the discovery of evidence of trepanning.

Though Morocco gained its independence in 1956, remnants of the French occupation are still felt to this day. Like many other formerly French-occupied countries, Morocco only gained local control over its archeological records in the latter part of the twentieth century (Smith, 2020). A lack of consistent control over archaeological research as well as poor record keeping has resulted in disorganized and scattered records.

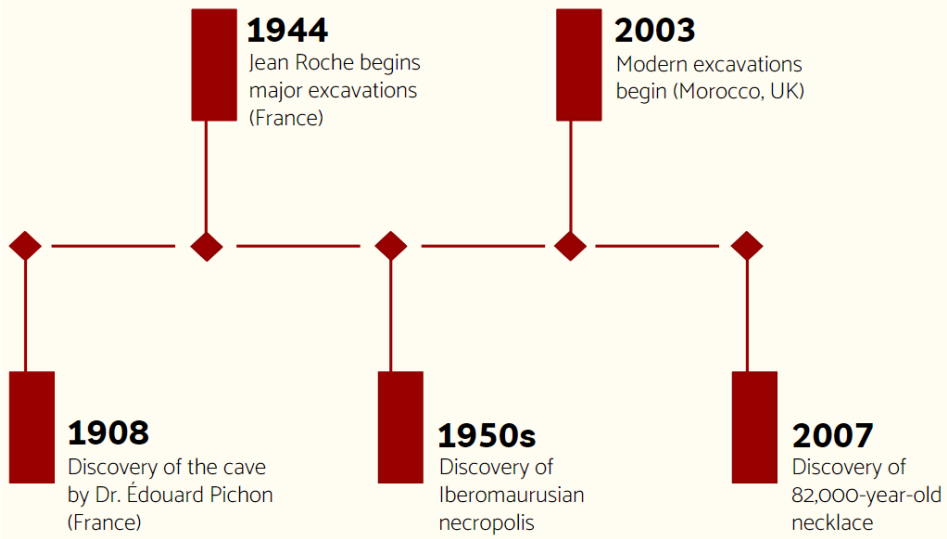


Figure 12. Timeline of Excavations at the Grotte des Pigeons.

Consequently, the Grotte des Pigeons has a small online presence, making it particularly difficult to find comprehensive information. Many articles provide only summaries of archaeological work. Determining the location of artifacts that have been removed from the cave remains challenging because artifacts have not been kept in the same place or even the same country, and there is no existing catalog of what has been removed from the cave. The lack of easily accessible information about the cave is detrimental to its cultural prominence. To correct for these inconsistencies, more recent excavations from 2003 to 2010 have split the cave into numbered sectors, focused on gathering new dating samples, and developed a solid record of the history of the site (Figure 9) (Hogue, 2014).

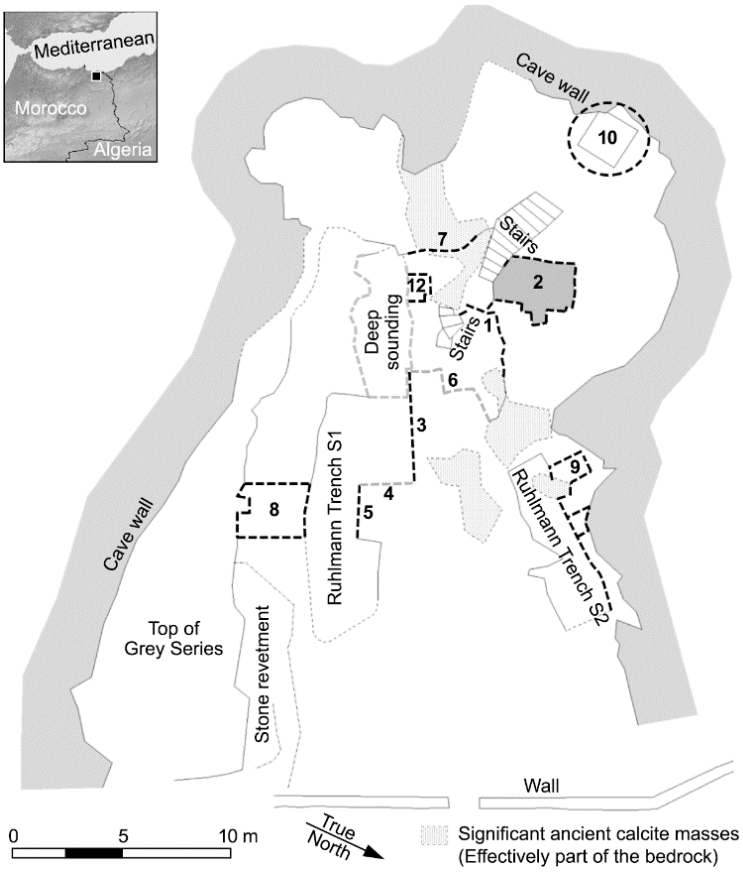


Figure 13. Diagram of the Modern Cave Sector Numbers.

2.2 Tourism in Morocco's Oriental Region

Tafoughalt and the Grotte des Pigeons are located in the Oriental region, within the Beni Snassen mountains, which take their name from the Amazigh tribal confederation living in the area (Figure 10) (E. B & Chaker, 1991). Famous for its citrus fruits, the region is highly dependent on agriculture as its primary source of income, comprising 15.2% of its total GDP (Direction Regionale de l'Oriental, 2021). The climate and geography of the Beni Snassen allow crops to flourish, especially at the mountains' summits. The climate of the Oriental region varies widely from north to south, allowing for various agricultural products to be produced (E. B & Chaker, 1991). The major cities in this region are Oujda and Berkane, both of which are within an hour of Tafoughalt.

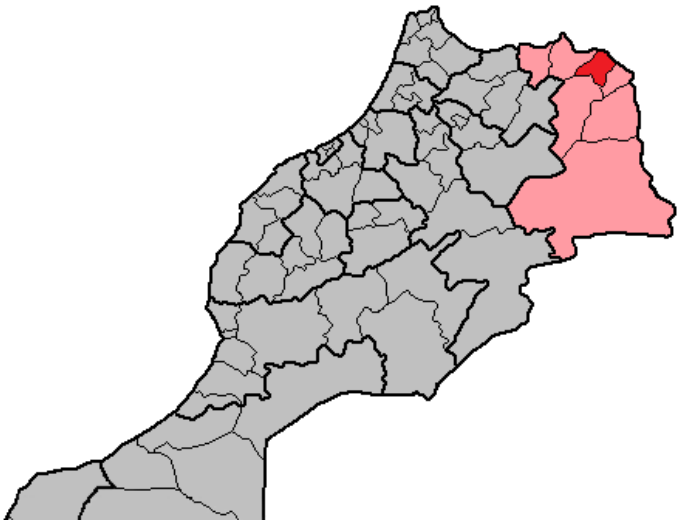


Figure 14. Location of the Grotte des Pigeons (Tafoughalt) in the Oriental Region.

Despite being agriculturally prominent, the region is economically weaker than other Moroccan regions. A 2012 United Nations investment guide on the region cited insufficient transportation infrastructure and unemployment as major factors limiting economic development. Although accessible transportation has improved in recent years, the remote location of the region has caused the area to suffer in the past from a lack of connections to major cities such as Rabat and Casablanca (UNCTAD-ICC, 2012).

Tafoughalt and the surrounding forests have great potential to attract tourism, yet they do not receive international recognition in part because of their remote location, resulting in a weak tourist industry. Currently, most tourists to the area are Moroccans visiting from other regions of the country (UNCTAD-ICC, 2012).

Figure 15. Beni Snassen Mountains in Tafoughalt.

There have been many efforts to increase tourism in the Oriental Region, yet tourism contributes little to the local economy (Direction Regionale de l'Oriental, 2021). Many regional initiatives have focused primarily on the Mediterranean coastline, featuring attractions such as the Marchica lagoon and beachside resorts in the nearby cities of Nador and Saidia as well as the Spanish exclave of Melilla.

Figure 17. Coastline of Melilla.

Improving accessibility to the region has been a top priority to increase traffic (UNCTAD-ICC, 2012). The Moroccan Ministry of Tourism's current policy, dubbed "Vision 2020", focuses on promoting regional tourism and sustainable development, particularly in Northern Morocco. This program includes publicizing the region's various tourist attractions by developing digital platforms. However, these efforts have not seen widespread success, nor do they include Tafoughalt or the Grotte des Pigeons (OECD, 2020). Because of the cave's significance, both scientifically and historically, it is uniquely positioned to attract tourists to the area.

Figure 16. Coastline of Saidia.

2.3 Virtual Museums

Virtual museums are online collections of images, files, and other recorded media which mimic the physical museum experience. They are used to complement and enhance traditional museums for a wider audience range. For decades, virtual museums have been proven to effectively increase recognition of the museum sites they portray and contribute to the transmission of culture to online audiences in an engaging way.

2.3.1 Virtual Museum Structure

The evolution of digital technology has created many tools for the design of virtual museums including virtual reality, augmented reality, and multimedia experiences. Virtual reality (VR) creates an entirely artificial 3D interactive environment for the user that is visualized on a screen or headset. Augmented reality (AR) overlaps virtual contents with digital components, and multimedia approaches make use of various images, videos, and sounds to create a collective experience of the physical museum.

Interactivity is a principal consideration in the experience design of all virtual museums. In a study performed including VR, AR, and multimedia museums, it was shown that users remembered only 30% of the content they viewed as images and videos but 90% of the content they experienced as a controllable simulation (Pietroni, 2019). For museums designed with multimedia content, consistent presentation, clear mappings of the relationships between exhibits, and an attractive user design were strong indicators of user satisfaction and time spent within the museum. It was acknowledged that many virtual museums trade user interactivity for control over a singular historical narrative but suggest that this trade is a necessity to make a virtual environment that is most engaging. These design principles will inform the creation of our multimedia virtual museum to ensure that users understand the cultural and scientific significance of the Grotte des Pigeons as well as its context to the surrounding Tafoughalt region.

2.3.2 Effectiveness of Virtual Museums

A popular virtual museum, known as the V-Museum, was implemented as an educational initiative about the history and culture of Fez, Morocco in 2020 (Kadri, et al., 2020). The museum implemented both augmented and virtual realities as well as 3D modeling, allowing users to interact dynamically with the platform. Although the project's scope was broad, the museum was intended to improve access to restricted monuments and encourage tourism to the area. Increasing tourism would, in turn, serve to develop the Fez economy (Kadri, et al., 2020). The design of the museum served to both enhance user experience through interactivity and ensure the sustainability of the museum for future developments.

A survey to evaluate the user experience of the virtual museum revealed that 96% of participants believed that the application would encourage tourists to visit Fez, suggesting that the use of the V-Museum gave tourists a general vision of the cultural heritage of this city and the desire to visit the area (Kadri, et al., 2020). The paper asserts that virtual museums are uniquely able to "drive human curiosity" about the places they display because of their ability to immerse users in otherwise restricted cultural heritage. They cite interactivity with museum objects as the main method for fostering user excitement (Kadri, et al., 2020).

Additionally, researchers in China evaluated the online museum, *Exhibition of Architecture of the Forbidden City*, focusing on areas for improvement from the perspective of visitors. It was noted that when developing virtual museums, the needs of the people using them must be paramount. This consideration means increasing the interactivity of the exhibit and ensuring sufficient information about each artifact to keep viewers' attention. In another key finding, the researchers found that having high-quality 3D models helped create a higher sense of reality (Li, et al., 2022).

2.3.3 Implementing Virtual Museums for Caves

Virtual museums of cave sites largely use multimedia approaches and are generally categorized into two distinct types. The first category displays a rotating catalog of images of the cave's artifacts, and the second type contains a 360-degree virtual tour of its interior.

The American Southwest Virtual Museum, which includes the Rampart Cave (located in Arizona, United States) exhibit, categorizes artifacts into a catalog, separated by type, showing 2D images and descriptions. These catalogs do not use 360-degree technology, have limited interactivity, and serve mostly as a record-keeping platform. The museum requires users to click through a collection of images in order to 'guide' the virtual visitors through the space.

The Lehman Caves (located in Nevada, United States) virtual museum, a 360-degree virtual tour of the space, was created by the National Park Service in 2021. The museum is a non-interactive video tour of the space in which the creator travels through the cave creating a recording so that the user gets a first-person experience of the location.

Cave Ledenika (located in the Balkan Mountains, Bulgaria) is another 360-degree tour in which the user is immersed in the cave's interior and can click on popup icons to move through the space. Unlike the Lehman Caves, the experience of this museum is controlled by the user. There is no time limit on the experience, and its interactivity allows for an enhanced interaction with the cave, allowing users to interact with the space by clicking to travel through it, zooming in, and zooming out to see detail or more widescale, respectively. This type of museum will serve as a model for our design because of its increased interactivity and strengthened narrative resulting from the descriptive popups.

2.3.4 Virtual Tour Platforms

In order for the general public to access virtual museums, they are typically hosted on a web platform. These platforms control how the space is viewed, and each one can serve to focus on a specific function. Some emphasize creating an interactive space, while others focus primarily on the cataloging of information.

An important requirement of the Grotte des Pigeons' virtual museum is a strong component of interactivity, so the platform must also have the ability to provide a tour. *This Is* had previously created a virtual museum formatting tool. Their tool hits all of the factors that we were hoping to find in the program we used for this platform. It allows for user interactivity with a 3D room tour including the possibility for narration, pop-up text, and images that the user can click on within the virtual space. Our work will provide *This Is* with the 360-degree photos taken within the cave, descriptive blurbs for the locations within the cave, and both 2D and 3D photographs of the artifacts. These components will then be loaded into their tool, creating a virtual museum of the cave.

2.3.5 Digital Storytelling

Digital storytelling is a multimedia presentation combining a variety of digital elements within a narrative structure. The media may include text, images, video, audio, social media, and interactive elements (de Jager et al., 2017). Digital storytelling has been recently recognized for its creative potential to share effective and engaging narratives. It has been proven to have therapeutic, educative, movement building, and research potentials (de Jager et al., 2017).

More interestingly, digital storytelling has become a common method for the preservation of cultural heritage. Some have equated digital storytelling with traditional oral storytelling because of their similarities in ability "to collect and store stories in community groups" (de Jager et al., 2017). Digital storytelling is able to capture the cultural, mythological, and historical fabric of daily life in a timeless manner while also encouraging new ways of thinking within communities. Digitalization provides a further level of engagement with traditional stories because they generally take a "person-centric" approach that is designed to prioritize the audience as consumers of the media (de Jager et al., 2017).

Rizvic et al. analyzed the abilities of novel storytelling methods to both educate and entertain users, including virtual reality, augmented reality, and multimedia stories. Researchers acknowledged the difficulty in assessing the balance between user autonomy with the historical accuracy of the story, but concluded that multimedia stories, such as the kind used for our project, led to the smallest risk of story distortion. It was instead concluded that the most compelling digital stories "provide meaningful context for understanding the story being told, use images to capture and/or expand upon emotions found in the narrative, employ music and other sound effects to reinforce ideas, and invite thoughtful reflection from their audience(s)" (Rizvic, 2020). Our digital platform will implement inciteful context from

key opinion leaders in the field, 2D and 3D images of cave artifacts, and an interactive tour to create an educational yet entertaining user experience.

2.3.6 Methods for Capturing 3D Imaging of Artifacts and Interiors

3D imaging is often a necessary part of virtual museums as it helps to increase the interactive nature of the exhibit. An increase in interactivity has been shown to increase the effectiveness of the virtual museum itself (Kadri, et al., 2020). There are currently three main ways to capture 3-dimensional (3D) images of objects: LIDAR, infrared, and photogrammetry. The most effective and high-resolution scans are procured using LIDAR, which stands for 'light radar' or 'light detecting and ranging. It creates highly accurate digital 3D representations of objects or spaces by emitting pulses of light and measuring the time it takes for the light to bounce off objects and return. While this is the most accurate method, it is also the most expensive, ruling it out for amateur use. The next technique utilizes infrared light to create a 'line of light,' which the device then uses to measure disturbances caused by the object. While this method is significantly cheaper than LIDAR, the price often limits the quality.

Perhaps the best technique for making high-quality, cheap 3D models of objects is a process called digital photogrammetry. Photogrammetry requires the user to take many photos from different angles of an object. Software then stitches these images together to create a 3D representation of the object. While it is the cheapest option equipment-wise as it will work with virtually any camera, higher-quality photos will result in more detailed models. Each method has its strengths and drawbacks and requires careful consideration by the user before selecting the method that is best for the chosen application (3D Scanning, n.d.).

3. Methodology

The goal of this project was to help *Association Passagers* preserve and disseminate information about the Grotte Des Pigeons and the Tafoughalt area by assisting in the creation of a virtual platform to house data of historic, scientific, and cultural significance, and any other information about the cave that could be found. To accomplish this, we set the following objectives:

1. Planning Virtual Tour Content
2. Creating Interactive Elements
3. Developing a Repository of Information

The following sections discuss in detail the individual steps we used to complete these objectives.

3.1 Planning Virtual Tour Content

Our first objective was to engage with local experts and project collaborators to plan the virtual tour and museum. Since our project is only one part of a larger campaign with other creators, our first objective was to engage with those collaborators. The discussions focused on how our work will further their goals and overarching project mission, as well as the more technical details surrounding the implementation of the project.

3.1.1 Planning Discussion with Collaborators

The two collaborators that we had to meet prior to beginning the technical work for the project were *Association Passagers* and *This Is*, the digital marketing agency hired by *Association Passagers* to create the platform. During our meetings with the collaborators, we asked questions revolving around goals and the scope of our project. These conversations helped narrow the project's focus as well as a guide to the important information for the museum tour. See Appendix B for discussion questions.

3.1.2 Conducting Expert Interviews

To ensure that we were providing accurate and meaningful information to *Association Passagers*' educational campaign, we conducted interviews with experts in the region. These interviews ensured that we were gathering critical information regarding both cultural and scientific significance. They also helped capture local sentiments regarding the cave, as the Grotte Des Pigeons is sparsely mentioned in academic literature. Cultural importance of the

cave and surrounding region is important when considering how to design and choose content for the digital platform and storytelling to best capture the interest of viewers.

These interviews were semi-structured in nature with the main lines of questioning outlined below.

1. Relevance of the Grotte des Pigeons to the public of the Oriental Region
2. The Grotte des Pigeon's current significance to the international scientific community
3. The symbol of Grotte des Pigeons as a site of cultural heritage for both the Oriental Region and Morocco

Figure 18. The Team with Professor Aouraghe.

The interview questions were sent in advance to each interviewee but were altered slightly during the interview, adapting to their responses. All interviews were conducted in the language of choice of the interviewee to encourage thorough and thoughtful answers. A translator was present to help ask and answer questions between interviewer and interviewee. The audio of these interviews was recorded and transcribed for analysis by the team. At the conclusion of each interview, the interviewee was asked to suggest potential candidates for additional interviews. This snowball sampling technique was found to be the most effective to identify quality interviewees due to there being few experts on the cave. See Appendix C and D for specific interview questions.

3.1.3 Selection of Artifacts

Looking at our virtual museum, it is clear that we did not create models of every artifact found within the Grotte des Pigeons. The Grotte des Pigeons housed an incredible collection of artifacts, some estimations placing the number in the thousands.

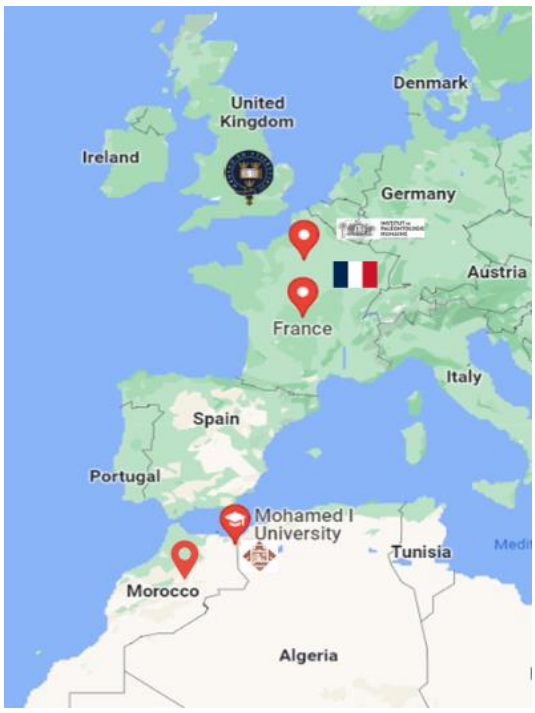


Figure 19. Map Showing Known Locations of Artifacts from the Grotte des Pigeons.

The first step was determining which artifacts we had access to. Excavations over the history of this cave were done by many different individuals, meaning that these artifacts are widespread, both in and out of Morocco. The artifacts found outside of Morocco are concentrated in the United Kingdom, specifically Oxford University, and France, specifically the Institut de Paléontologie Humaine. Because of this, we knew that we would not have access to all of them. Fortuitously, Professor Aouraghe managed the museum at Mohammed I University, which gave us a fantastic sampling selection of artifacts that we were assured access to. He gave the group a detailed tour of all artifacts present, highlighting those found in the Grotte Des Pigeons and more broadly in Tafoughalt.

Additionally, we were looking for visual interest. While we, of course, want to accurately portray this cave and the artifacts found within accurately, we also want to ensure that those using the platform find the experience interesting to encourage tourism to the area and spark interest in the cave. This means that the artifacts that we are including are also interesting to look at and learn about.

With this selection criteria we were able to identify seven artifacts of significance that we also had access to -- seven that were scanned for 3D rendering and 2D photos of a selection of bladelets that could not be removed from their case.

3.2 Creating Interactive Elements

To create an engaging and entertaining experience for those looking to learn more about the Grotte des Pigeons, our group decided to create 3D models of artifacts and capture 360-degree images of the cave. While these can be viewed alone, the interactive elements can also be used by *This Is* in the virtual tour assembly. These models and images are an essential part of our project and the methods to create and capture them are outlined in this section.

3.2.1.1 Creating 3D Models of Artifacts

We digitized a handful of the artifacts in the museum located at Mohammed I University by creating 3D models of the artifacts. The following section will outline the steps used to create these models using the process of digital photogrammetry.

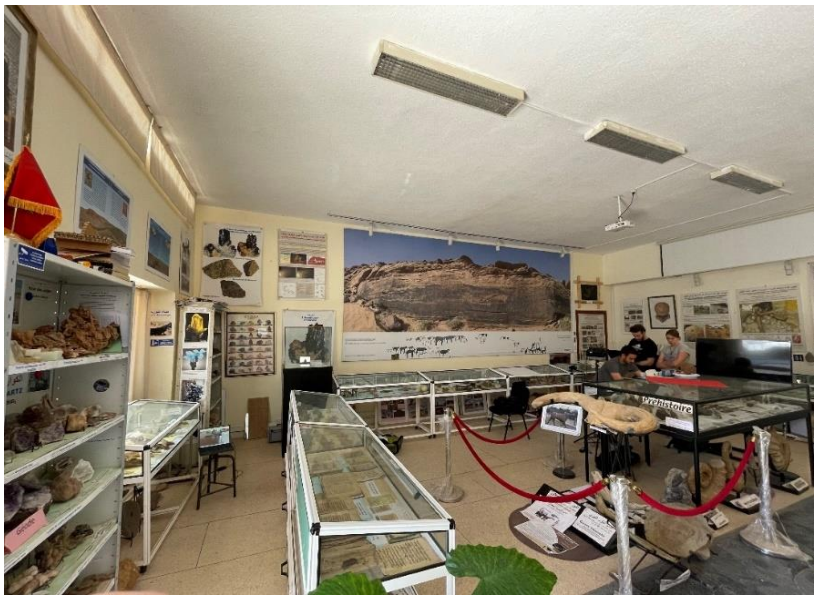


Figure 20. Archaeology and Paleontology Museum at Mohammed I University.

3.2.1.2 Capturing Images of Artifacts

To create a high-quality 3D model using digital photogrammetry, many high-resolution images from multiple different angles must be captured. The lighting must also be adequate to ensure no shadows are cast on the object in question. To accomplish this, our setup used two Genaray SP-E-500D SpectroLED lights, a Sony RX100 camera, a lazy-Susan to function as a turntable, and white poster board**.** The camera was mounted on a Magnus PV-7451M tripod. All technical equipment was sourced from the WPI Academic Technology Center (ATC). The setup of our equipment can be seen in Figure 15.

Figure 21. Setup for Photographing Artifacts.

The artifact was placed on the turntable, images were captured at regular angles by rotating the turntable by hand. After a full rotation, the angle of the camera was changed. Depending on the artifact, images were captured at angles of 0, 30, 45, and 70-degrees (all angles are approximations). Some artifacts were then turned on their side and captured at all angles to provide detailed images of the underside. Additionally, detailed images of important aspects of the artifacts were taken. All images were then stored in folders on an external hard drive.

3.2.1.3 Processing Images of Artifacts

The images collected were processed using the photogrammetry software Agisoft Metashape. The images were loaded into the software and were masked to remove the background and only allow the object of interest to be processed. The masked photos were aligned, and a dense point cloud was created. From this point cloud, a mesh was formed and then textured. The models were exported from the software as .glb files and imported into the 3D graphics software Blender for additional mesh and texture touch ups. Finally, the completed models were exported from Blender as .glb files and sent to *This Is* to be included in the digital museum platform. For more information regarding this process see appendix E.

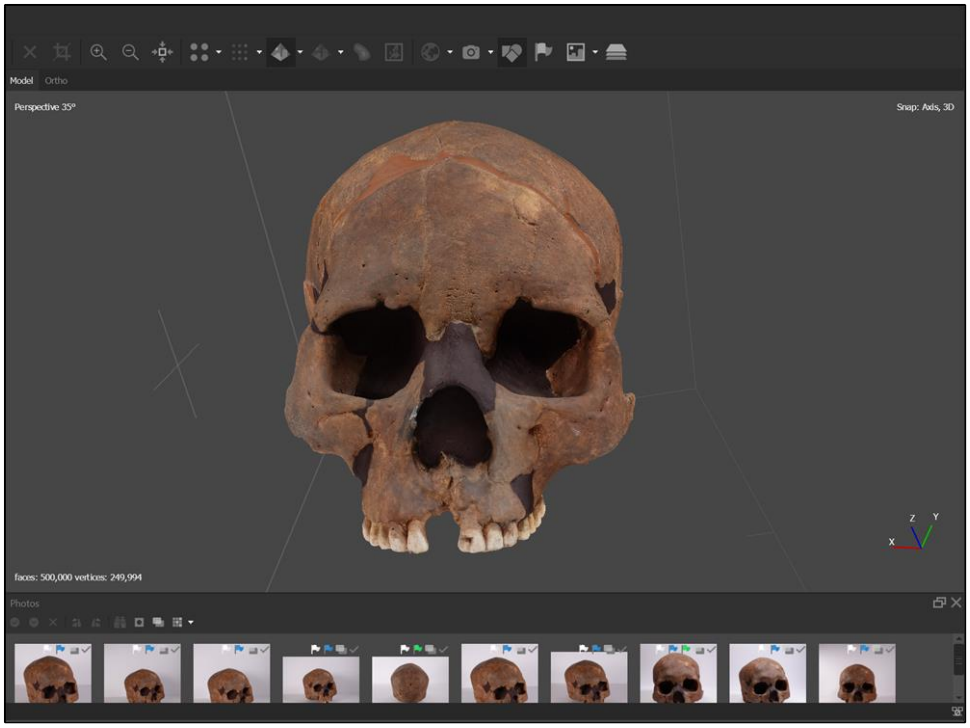


Figure 22. Model of a Skull in the Agisoft Metashape Workspace.

3.2.2.1 Capturing 360-Degree Images of the Grotte des Pigeons

In addition to the 3D models of the artifacts found in the Grotte des Pigeons, our team also decided to capture 360-degree images of the cave and the surrounding area. These images will then be stitched together by *This Is* to create a virtual tour. To capture these images, we traveled to the Grotte des Pigeons in the village of Tafoughalt with two 360-degree cameras – a Ricoh Theta V and a GoPro MAX. Images were then captured at regular intervals using both cameras and then uploaded to Google images to be viewed. It is worth noting, that we were unable to obtain the proper permit to enter the cave itself, so all images are from behind a restrictive fence as seen in Figure 24.

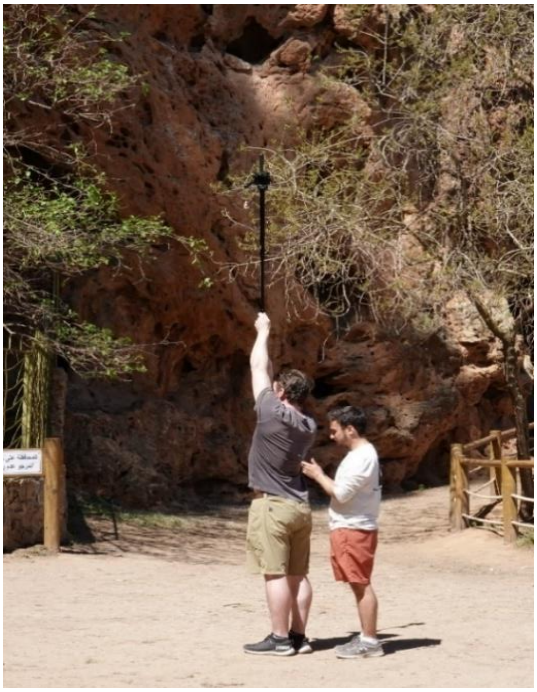


Figure 23. Capturing 360-degree Images Using Ricoh Theta Monopod.

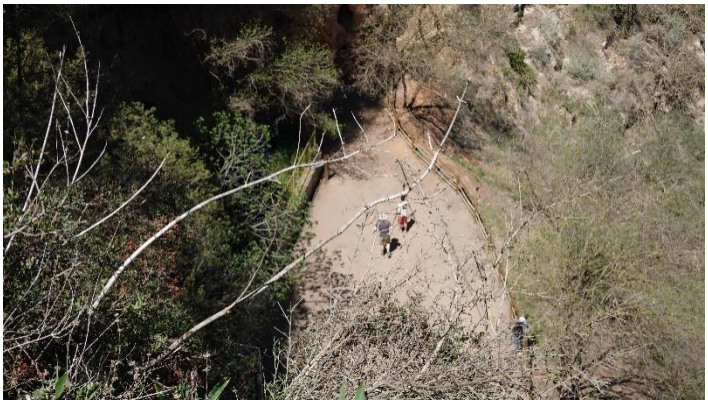


Figure 25. Capturing Various Locations Around the Cave Exterior.

Figure 24. Restrictive Fence Around the Cave.

All images were captured around noon on a sunny day to take advantage of the natural light. A common starting point was selected and then the 360-degree camera was mounted to the tripod. The tripod was then fully extended and leveled. The mobile apps *Theta* and *GoPro Quik* were used to remotely capture an image for the Ricoh Theta V and GoPro MAX respectively from a phone. The connection range from a phone to the cameras was only about ten feet so the person taking the pictures did so from underneath the tripod to be within range but not in the picture. Upon capturing the image, the tripod was moved to a location approximately fifteen feet further down the path and an additional image was captured.

Figure 26. The Grotte des Pigeons Exterior at the Time of Photography.

Once the entire path was imaged, special attention was paid to the cave itself by removing the monopod from the tripod and capturing two additional images of just the cave. This entire process was conducted for both the Ricoh Theta V and GoPro MAX.

Figure 27. Example Spherical Image from GoPro MAX.

3.2.2.2 Selecting the 360-Degree Images

Although we were unable to conduct an initial field test using the Ricoh Theta V and GoPro MAX, both cameras were brought to the cave and used to capture images. Because all the images were captured at around the same time and from the same place, this allowed us to compare images from each respective camera and select the set of images which appeared the best. Once all the images were uploaded to Google Photos, they could be viewed to determine which camera captured the highest quality images. It was found that the GoPro MAX captured images that were less grainy and had minimal glare compared to the Ricoh Theta V. Due to this, all the images captured by the GoPro MAX were shared with *This Is* to be turned into a virtual tour.

Figure 28. Sample Ricoh Theta Image Showing Heavy Glare and Blurriness.

Figure 29. Sample GoPro Max Image.

3.3 Compiling an Information Repository

In addition to creating 3D models and 360-degree images of the Grotte des Pigeons, we compiled a folder of resources about the cave gathered through our literature research, interviews, and work in the archaeological museum at Mohammed I University. The folder was shared with *This Is* as an informational resource for their virtual tour and platform. The folder included relevant academic articles, 3D models, high resolution 2D pictures, an artifact catalog, interview notes and recordings, and a guidebook summarizing important aspects of the cave**.**

3.3.1 Creating an Artifact Catalog

We created an artifact catalog as part of the repository to be used as an organizational tool to manage artifact scans, images, and descriptions. We included each artifact that had a 3D scan in the catalog. Each artifact was then assigned a number and compiled into a catalog using Microsoft Excel. Fields for each artifact are listed below. Unknown fields are left as blank cells in the catalog. Below are the eight pieces of information included in the catalog for each artifact:

1. Identification Number
2. Name
3. Material
4. Age
5. Date of Discovery
6. Scientific Significance
7. Cultural Significance
8. Miscellaneous Notes

Due to difficulties accessing other artifacts in the museum and well as artifact size, several high resolution 2D images were taken to supplement 3D renderings. These artifacts were not included in the catalog.

Figure 30. Museum Case Showing Artifact Descriptions.

3.3.2 Building an Educational Guidebook

To create a comprehensive summary of our literature review, interview results, and work in Tafoughalt, we created a summary guidebook composed primarily of images about the Grotte des Pigeons including both key scientific and cultural information. This guidebook will be used not only by *This Is* as an extensive and accessible source of information, but also by *Association Passagers* as an educational resource. Because the guidebook includes information about the broader Tafoughalt area, it can also be used to advertise the cave as a tourist destination. Because the cave does not have much signage, our virtual resource will be helpful as a source of background information when touring the area. The guidebook was made available in physical copies for *Association Passagers* as well as on our team website. Figure 31 shows the front cover and table of contents, but a complete collection of pages of the guidebook can be viewed in Appendix H.

Figure 31. Cover and Table of Contents of Guidebook.

4. Results and Analysis

4.1 Virtual Tour Content

By meeting with members of *Association Passagers* and the digital marketing company *This Is*, our group was able to better determine the scope and design of our project. Prior to these meetings, we were unsure about how our 360-degree images and 3D models would be integrated into our sponsor's website and Tafou Experience. However, after these meetings we were able to come up with a plan of action where we would provide all the 360-degree images and 3D models (including the 2D pictures used to make them) to *This Is*. *This Is* would then use their own software to create a virtual tour from all our 360-degree images. This allowed us to focus on capturing the best images possible without having to worry about this technical aspect. All images and models were shared via a google drive between our group and *This Is* to allow for easy access by all parties involved.

4.2 Interactive Elements

Creating interactive elements was something that we knew from the beginning we wanted to provide to increase the user experience. Through research we had determined that with an online platform, 3D renderings of the artifacts and 360-degree tours are very popular among users. These provide an opportunity for users to have an interactive and engaging learning experience.

4.2.1 3D Images of Artifacts

Throughout this process, we created models of seven artifacts housed at the museum located at Mohammed I University. Taking approximately 4,000 pictures, we were able to create high resolution 3D models of all seven artifacts to be used as part of our sponsor's larger education campaign and shared with *This Is*. It is important to note that the artifacts we selected represent a very small sample of the total artifacts taken from the Grotte des Pigeons. These models will be under a creative commons license so that our work is accessible to anyone who is seeking more information on this topic.

Figure 32. Screenshot of Completed 3D Model.

4.2.2 360-Degree Images of the Grotte des Pigeon

Eleven images were taken of the Grotte des Pigeons using a 360-degree camera. These images were captured along the path leading up to the cave as well as in front of the cave itself. All images were inspected for quality, taking into consideration glare and graininess of the images, before moving on to the next image. All the images were kept consistent by maintaining the same tripod height and level. This ensured that once everything was stictched together, the resulting virtual tour would be smooth and unbroken.While we were unable to access the cave, we believe that these images still provide an authenitic viewing experience as the cave is wide and shallow, therefore easily viewed even from behind the protective fence.

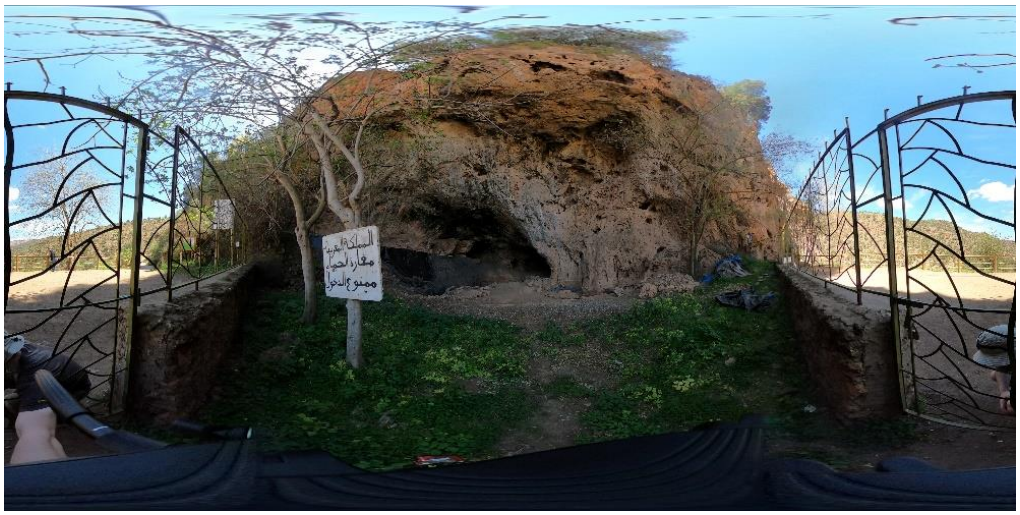


Figure 33. Image of cave taken with GoPro MAX.

4.3 Expert Interviews

Two expert interviews were conducted to better understand the Grotte des Pigeons from both a scientific and cultural perspective. Interviews with Professor Aouraghe and Professor Bouzouggar from Mohammed I University and INSAP respectively, provided key insight that our group used in the creation of our informational repository. Below is information from both interviews that our team found significant:

1. The most significant discovery from the Grotte des Pigeon, in terms of public perception, was the 82,000-year-old necklace, uncovered in 2007, rather than the discovery of trepanation in the 1950s. Professor Bouzouggar speculated that this was due to the lack of social media at the time of the trepanned skull discovery whereas Professor Aouraghe credited the necklace's connection to cultural heritage for its source of popularity.
2. Professor Bouzouggar divided the public perception into three parts:
    a. Little interest in the cave (largely during the French protectorate).
    b. Limited advertisement from local officials due to security and preservation concerns.
    c. Modern, increased interest following the discovery of the shell necklace in 2007. People of the Berkane province view the cave as a source of cultural identity and pride.
3. Tourism in Tafoughalt generally includes locals from the Oriental region who come to area for hiking and picnics.
4. King Mohammed VI's interest in the preservation of cultural heritage has greatly influenced public interest in conservation of the Grotte des Pigeons.

Voice recordings of all interviews were transcribed using Microsoft Word Transcribe. We found that recordings had large pockets of inaccuracy and incompleteness due to language changes between Darija and French to English, so we continued to manually amend broken portions of the transcriptions. Transcriptions were used to identify key themes such as the emphasis on the anthropologic significance of the cave.

The specific questions asked during these interviews can be found in Appendices C and D.

Figure 34. Photo from Interview with Professor Bouzouggar.

4.4 Information Repository

To best assist our sponsor, it was necessary to create an information repository. This repository contains all the information we have collected on the Grotte des Pigeons, including transcripts and recordings of our expert interviews. The goal of the repository is to assist *Association Passagers* in the development of a script to be used in an animated short showcasing the history and culture of the region. This repository is in the form of a google drive folder to allow for easy sharing. It is split up into four sub folders and two standalone documents as seen in Figure 35.

Figure 35. Repository Organization.

4.4.1 Summary Guidebook

To provide an easily accessible and digestible source of information regarding the Grotte des Pigeons and the region, our group created a digital summary guidebook. This guidebook is a twenty-four-page summary which contains the following sections:

1. Geography of the Region
2. Trepanation Discovery

3. Excavation Sequence
4. Cave Habitation
5. Grotte des Pigeons Today

This guidebook has the potential to serve as an information source for tourists visiting the region and to increase the information readily available online.

5. Conclusion and Recommendations

While completing this project, it has become clear to us that the Grotte des Pigeons is a site rich in scientific and cultural importance – not only for the Oriental region but for Morocco as a whole. While there is a museum located in Mohammed I University, there is no information readily available online about the Grotte des Pigeons and the artifacts found within. It became clear to us that we had a very special opportunity to showcase the significance of this cave to many people through this project. Our goal of **spreading awareness about the Grotte des Pigeons** was accomplished by the completion of three main objectives: planning content for a virtual tour, creating interactive elements, and developing a repository of information. Despite the work already done, we also have developed recommendations for how this project could be furthered in the future.

5.1 Project Outcomes

We first met with our sponsor, *Association Passagers*, and the digital marketing group, *This Is*, to better determine and understand the scope of our project. Through these open-ended conversations, we were able to conclude how we could best assist in our sponsor's larger education campaign about the region.

Having a better grasp on the scope of our project, we were able to begin the bulk of our data collection. We travelled to Mohammed I University in Oujda to visit a museum containing artifacts, and replicas of artifacts, excavated from the Grotte des Pigeons. Thousands of images of the seven artifacts that we selected were taken and compiled into 3D models using the process of digital photogrammetry.

To complete the visual aspect of our project, we traveled to Tafoughalt to visit the Grotte des Pigeons. We captured eleven images of the area leading up to, and including, the outside of the cave. These images were shared with our contacts at *This Is* and will make up the virtual tour aspect of the educational campaign.

To best assist our sponsor in their goals, our team created a repository of information that can be accessed and utilized at any time by stakeholders. This repository contains descriptions of all the artifacts that we scanned as well as all relevant information we found on the Grotte des Pigeons. It contains not only summaries of published material, but also the information gathered from the two expert interviews that we conducted. These interviews provide expert insight into the scientific and cultural significance of the cave and can best help our sponsor in creating a script for digital story telling. Lastly, we decided to create an information packet, or guidebook, which can be distributed to tourists. The guidebook is a standalone document that essentially summarizes all information relevant to this project in an easy to digest and visually appealing format.

5.2 Importance of Our Project

Our project combines the scientific and cultural significance of the Grotte des Pigeons. By combining the two, we were able to create a more complete and authentic showing of this cave and the Iberomaurusians who used to live within it. Our work also aims to preserve the cave and the artifacts found within. While the artifacts can be kept in a museum and properly preserved, the cave itself is subject to nature and changing weather patterns. The Grotte des Pigeons and the surrounding area were captured by 360-degree images showing exactly how it appears now, thus creating a record of any changes which may occur, natural or otherwise. Lastly, our virtual museum allows those who may never have the chance to visit the area a chance to experience the beauty, history, and culture of the region. There exist no other 3D models of the cave's artifacts online, and our scans allow for a unique viewing experience, not only for tourists, but also for those hoping to learn more about the scientific and cultural importance of the cave and region in which it resides.

5.3 Recommendations

In our completion of this project, we were able to create recommendations for the future development of this project. These recommendations are as follows:

1. Expand Artifact Selection
2. Utilize Augmented and Virtual Reality to Increase Cave Engagement
3. Combine Grotte des Pigeons with Other Nearby Attractions as a Day Trip

5.3.1 Expand Artifact Selection

At the start of this project, it was clear that we would only be able to scan a small portion of the many artifacts found within the Grotte des Pigeons. To continue expanding on this project, other groups would want to consider adding different objects to our artifact catalog. There are artifacts that remain in Mohammed I University in Oujda, but more importantly there remains artifacts at both Oxford University and in France. By creating new artifact descriptions and 3D models, even more information would be readily accessible to more people all over the globe, further raising awareness of the Grotte des Pigeons.

5.3.2 Utilize Augmented and Virtual Reality to Increase Cave Engagement

Due to the excavations, the Grotte des Pigeons no longer houses the artifacts highlighted in this paper. In addition, the inside of the cave is still restricted to the public. As such, there is not currently much to see within the cave itself. To increase engagement, we recommend utilizing augmented reality (AR) to view the 3D models of the artifacts. When

used, the viewer will be able to use their phone camera to view artifacts as if they were still in the cave. This would add a level of interactivity and provide visitors with a more immersive experience.

Figure 36. Example Graphic of Augmented Reality in the Cave.

While our 360-images are being used to create a virtual tour, there is currently no plan to make this tour accessible in VR. Adding this compatibility to the virtual tour will, again, allow for another level of engagement and improve the experience for users who cannot visit the cave in person. Ideally, this should contain popups and descriptions for the artifacts in the areas within the cave in which they were found.

5.3.3 Combine Grotte des Pigeons with Other Nearby Attractions as a Day Trip

The Grotte des Pigeons has an incredibly fortunate location for tourism. It is located just about centrally to Oujda and Nador, both of which have international airports which are often used by tourists. It is also located about an hour from the already developed tourist

Figure 37. Map of Sites and Cities Surrounding the Grotte des Pigeons.

areas of Saidia, Nador, and Melilla. These locations already have infrastructure built to accommodate tourists - such as resorts, hotels, and restaurants. As these three cities already have the infrastructure for tourists it can minimize the need to create new infrastructure in Tafoughalt itself. These starting points for a day trip aren't the only important thing that this area has to offer in terms of a tourist day trip. Once a visitor drives to the Tafoughalt area, there is much more to do beyond just visiting the Grotte des Pigeons. Three locations of interest nearby are the Grotte du Chameau (an underground cave carved by water), L'oued Zegzel (a river with a beautiful waterfall), and the Beni Snassen mountains (a common hiking and picnic area). Marketing these additional locations with the Grotte des Pigeons creates a compelling day of travel for tourists in which they will learn about the culture and scientific importance of the cave, while also taking in the breathtaking views of the area.

Bibliography

Belcastro, M. G., Condemi, S., & Mariotti, V. (2010). Funerary practices of the Iberomaurusian population of Taforalt (Tafoughalt, Morocco, 11–12,000 BP): The case of Grave XII. *Journal of Human Evolution*, *58*(6), 522–532. https://doi.org/10.1016/j.jhevol.2010.03.011

Crubézy, É., Bruzek, J., Guilaine, J., Cunha, E., Rougé, D., & Jelinek, J. (2001). The antiquity of cranial surgery in Europe and in the Mediterranean basin. *Comptes Rendus de l'Académie Des Sciences - Series IIA - Earth and Planetary Science*, *332*(6), 417–423. https://doi.org/10.1016/S1251-8050(01)01546-4

de Jager, A., Fogarty, A., Tewson, A., Lenette, C., & Boydell, K. M. (2017). Digital Storytelling in Research: A Systematic Review. *The Qualitative Report*, *22*(10), 2548-2582. https://doi.org/10.46743/2160-3715/2017.2970

Direction Régionale de l'Oriental. (2021). *Monographie de la région de l'Oriental*. Haut-Commissariat au Plan.

E. B, & Chaker, S. (1991). Beni Snassen / Beni iznasen (en berb.: At Iznasn). *Encyclopédie berbère*, *10*, Article 10. https://doi.org/10.4000/encyclopedieberbere.1685

Faria, M. A. (2015). Neolithic trepanation decoded- A unifying hypothesis: Has the mystery as to why primitive surgeons performed cranial surgery been solved? *Surgical Neurology International*, *6*, 72. https://doi.org/10.4103/2152-7806.156634

French Protectorate Established in Morocco. (1912). *The American Journal of International Law*, *6*(3), 699–702. https://doi.org/10.2307/2187068

Ḥizb al-Istiqlāl (Morocco). (1953). *Morocco under the Protectorate: Forty years of French administration. An analysis of the facts and figures.* The Istiqlal (Independence) Party of Morocco, Moroccan Office of Information and Documentation. https://catalog.hathitrust.org/Record/102484505

Hogue, J., & Hogue, J. (2014). The origin and development of the Pleistocene LSA in Northwest Africa: A case study from Grotte des Pigeons (Taforalt), Morocco [PhD thesis]. University of Oxford.

Humphrey, L., Bello, S. M., Turner, E., Bouzouggar, A., & Barton, N. (2012). Iberomaurusian funerary behavior: Evidence from Grotte des Pigeons, Taforalt, Morocco. Journal of Human Evolution, 62(2), 261–273. https://doi.org/10.1016/j.jhevol.2011.11.003

Kadri, M., Khalloufi, H., & Azough, A. (2020). V-Museum: A virtual museum based on augmented and virtual realities for cultural heritage mediation. *2020 International Conference on Intelligent Systems and Computer Vision (ISCV)*, 1–5. https://doi.org/10.1109/ISCV49265.2020.9204253

Kharroubi, A. (2010, May 15). La grotte des pigeons délivre ses secrets. *Aujourd'hui le Maroc*. https://aujourdhui.ma/culture/la-grotte-des-pigeons-delivre-ses-secrets-91406

Li, J., Nie, J.-W., & Ye, J. (2022). Evaluation of virtual tour in an online museum: Exhibition of Architecture of the Forbidden City. *PLoS ONE*, *17*(1), e0261607. https://doi.org/10.1371/journal.pone.0261607

Mariotti, V., Bonfiglioli, B., Facchini, F., Condemi, S., & Belcastro, M. G. (2009). Funerary practices of the Iberomaurusian population of Taforalt (Tafoughalt; Morocco, 11–12,000BP): New hypotheses based on a grave-by-grave skeletal inventory and evidence of deliberate human modification of the remains. *Journal of Human Evolution*, *56*(4), 340–354. https://doi.org/10.1016/j.jhevol.2009.01.001

OECD. (2020). *OECD tourism trends and policies 2020*. OECD. https://doi.org/10.1787/6b47b985-en

Pietroni, E. (2019). Experience Design, Virtual Reality and Media Hybridization for the Digital Communication Inside Museums. *Applied System Innovation*, *2*(4), Article 4. https://doi.org/10.3390/asi2040035

Reynolds, T. (2020). Cemeteries and sedentism in the later Stone Age of NW Africa: excavations at Grotte des Pigeons, Taforalt, Morocco (Monographien des Römisch Germanisches Zentralmuseum 147). Mainz: Römiisch Germanisches Zentralmuseum; 978-3-88467-312-6 hardback €136. Antiquity, 94(377), 1378-1380. https://doi.org/10.15184/aqy.2020.147

Rizvic, S., Okanovic, V., Boskovic, D. (2020). Digital Storytelling. In: Liarokapis, F., Voulodimos, A., Doulamis, N., Doulamis, A. (eds) Visual Computing for Cultural Heritage. Springer Series on Cultural Computing. Springer, Cham. https://doi.org/10.1007/978-3-030-37191-3_18

Smith, C. (Ed.). (2020). *Encyclopedia of global archaeology*. Springer International Publishing. https://doi.org/10.1007/978-3-030-30018-0

This is. (n.d.). *This Is | Branding, Event, Web and Digital Marketing*. Retrieved February 24, 2023, from https://thisis.ma/

Turner E, Humphrey L, Bouzouggar A, Barton N (2020) Bone retouchers and technological continuity in the Middle Stone Age of North Africa. PLoS ONE 15(3): e0230642. https://doi.org/10.1371/journal.pone.0230642

3D Scanning: Understanding the differences in LIDAR, photogrammetry and infrared techniques. (n.d.). Engineering.Com. Retrieved January 23, 2023, from https://www.engineering.com/story/3d-scanning-understanding-the-differences-in-lidar-photogrammetry-and-infrared-techniques

UNCTAD-ICC. (2012). Morocco oriental region. The iGuides. Retrieved February 20, 2023, from https://www.theiguides.org/

Appendices

Appendix A: Informed Consent Agreement for Participation in a Research

Study Investigator: Rion Crear, Olivia Deckers, Soumaya El Mansouri, Lauren Eppinger, Matthew Resmini

Contact Information: gr-rabat23-passagers@wpi.edu

Title of Research Study: Creating a Digital Platform to Raise Awareness About the Grotte des Pigeons

Sponsor: *Association Passagers*

Introduction:

The Grotte des Pigeons is a cave located in the Berkane province of eastern Morocco. The cave is broadly recognized as one of the oldest human burial sites in the world and its excavated remains show evidence of successful completion of the surgical practice known as trepanning dating back 12,000 years. Excavations have helped to uncover the diet, lifestyle, and mortuary history of the early humans who inhabited the cave and the surrounding area. However, despite its immense archaeological significance, the cave remains largely unknown outside of scientific circles, particularly amongst local Moroccans.

Our sponsor, *Association Passagers*, is a non-profit organization located in Oujda, Morocco. Since its founding in 2011, its mission has been to serve youth in Morocco, Senegal, and France with the goal of ensuring better local and national development in each respective country. As an organization of young people themselves, *Association Passagers* believes that reaching out to Morocco's youth will garner ambitious minds armed with fresh ideas to promote economic growth in their communities.

You are being asked to participate in a research interview. Before you agree, you must be fully informed of the purpose of our research, procedures, and any outstanding effects of participating in this interview. This form will present you with that information so you may be fully informed before deciding on your participation.

Purpose of the study:

Our involvement with the Grotte des Pigeons includes creating a digital museum that will publicize knowledge of the site's history and culture, highlight its cultural significance, and be integrated into a virtual platform that will encourage tourism to the area, contributing to local economic development. We will create 3D images of artifacts excavated from the cave, a catalog of artifacts that will be published, and a 360-degree scan of the inside of the cave. Our deliverables will be integrated into a website produced by *Association Passagers* designed to attract tourism to the Tafoughalt region.

Procedures to be followed:

The interviewee will first be asked to describe their knowledge level of/experience with the Grotte des Pigeons. Participants will be asked to speculate about public interest in the cave and finally inquired about specific information regarding the origin, excavation date, and attributes of individual artifacts in the university's collection. Participation time depends on the number of artifacts that will be discussed. This is dependent on participants' early answers to interview questions. However, we estimate that the interview will take no longer than 1-2 hours.

We would prefer the interview to be recorded and transcribed. With the permission of the interviewee, we will voice record the interview so that we may put direct quotations into our catalog. Again, the interviewee will be asked to consent to their answers being used in our virtual museum as well as any identifiable characteristics of themselves that may be revealed throughout the interview. The transcripts will then be translated from English to French, Darija, and Standard Arabic.

We expect to interview 1-3 experts at the university. 1-2 team members will conduct these interviews so as to not overwhelm the interviewee and so that the remaining team members may image the artifacts.

Risks to study participants: There are no reasonably foreseen risks or discomfort from participation in this research.

Benefits to research participants and others: No benefit to the participant other than the potential to publicize their field of interest. Their name or identifying characteristics may be featured in the platform. No monetary compensation.

Record keeping and confidentiality: Information received from this interview will be interpreted and shared within the research group, sponsor group, and *This Is* company that has been contracted to build the virtual platform. Any information that is wished to be shared within our report will be done so with first initial last name only. Only information that is directly related to the construction of the virtual museum will be shared. Records of your participation in this study will be confidential as permitted by law. However, the study investigators, the sponsor, or its designee and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name.

Compensation or treatment in the event of injury: There is no reasonable expectation of harm or injury from this research.

For more information about this research or about the rights of research participants, or in case of research-related injury, contact the alias listed at the top of the page. If further assistance is needed, contact IRP Manager Ruth McKeogh, Tel.

508 831- 6699, Email: irb@wpi.edu and/or the Human Protection Administrator Gabriel Johnson, Tel. 508-831-4989, Email: gjohnson@wpi.edu

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

By signing below, you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

_____ Date: _____

Study Participant Signature

_____

Study Participant Name (Please print)

_____ Date: _____

Signature of Person who explained this study

Appendix B: Key Meeting Questions for Collaborators

Name of Organization	**Key Questions**	**Type of Interview**
Association Passagers	Can you describe the goal of the current project platform, including any specific features you will design? How does our virtual museum of the Grotte des Pigeons fit into the overall platform? How does it support the goal of *Association Passagers*?	Conversation (open-ended)
This Is (Oujda)		Conversation (open-ended)

Appendix C: Tafoughalt Interview Questions with Professor Hassan Aouraghe

WPI Students: Rion Crear, Olivia Deckers, Soumaya El Mansouri, Lauren Eppinger, Matthew Resmini

Date: March 28, 2023

Location: Mohammed I University, Oujda, Morocco

Cave's Relevance to the General Public

1. We are trying to gather information about the knowledge and perceptions of Tafoughalt amongst the general public in Oriental Region. Please note that these questions require speculation.
    a. To your best estimate, could you describe the knowledge level of the cave amongst Moroccans in the Oriental Region in the following categories?
        i. Existence of the Cave
        ii. Knowledge of the Cave's Scientific Significance
        iii. Knowledge of the Cave's Cultural Significance
    b. Which features of the cave do you believe are most interesting to the general public?
        i. Do you think advertisement of the cave through a website would increase overall interest in the cave?
    c. If the caves had open access to the public, do you think Tafoughalt has potential to be used as a tourist attraction for the Oriental Region?
        1. i.e., Do you think the cave provides enough intrigue to help attract visitors to the region?

Cave's Relevance to the Scientific Community

2. We would next like to gather information about the overall scientific significance of the cave from the perspective of a professional.
    a. Skulls with evidence of trepanation has been publicized as potentially the most notable discovery from Tafoughalt. Can you describe the significance of these discoveries of trepanation to the greater scientific community?
        i. In Morocco
        ii. Internationally
    b. Beyond trepanation, what are the most significant discoveries to come out of Tafoughalt?
        i. What do these discoveries reveal? i.e. Why are they important?
    c. How have the cave's discoveries contributed broadly to knowledge of early human life?
        i. Can you describe human occupation of the cave? Years of occupation and how the cave was used in those periods.

Cave's Cultural Importance to the Oriental Region

3. We would also like to gain insight into the perception of the cave as an important site of cultural heritage for the Oriental Region.
    a. Do you think the cave has cultural significance to the people of the Oriental Region? To Morocco?
        i. Do you think the cave is a source of pride/identity?
        ii. Has there been significant interest in the cave's preservation?

Additional Resources

4. Do you know of artifacts located in Rabat or other institutions?
5. Do you have names/contacts of other researchers with knowledge of the cave/its artifacts?
6. Are there specific textbooks to gather additional information about the cave's significance?

Appendix D: Tafoughalt Interview Questions with Professor Abdeljalil Bouzouggar

WPI Students: Rion Crear, Olivia Deckers, Soumaya El Mansouri, Lauren Eppinger, Matthew Resmini

Date: April 11, 2023

Location: National Institute of Archaeology and Heritage, Rabat, Morocco

**Reading of consent statement and project objectives

Cave's Relevance to the General Public

1. We are trying to gather information about the knowledge and perceptions of Tafoughalt amongst the general public in the Oriental Region. Please note that these questions require speculation.
    a. To your best estimate, could you describe the knowledge level of the existence cave amongst Moroccans in the Oriental Region? Morocco?
    b. Can you describe public knowledge of the cave's scientific significance? i.e., How much does the general public know? What pieces of information might be missing?

Cave's Cultural Importance to the Oriental Region

2. How do the people of the Oriental Region view the cultural heritage of the cave?
    i. Do you think the cave is a source of pride/identity?
3. Is the cave a source of cultural identity for the country?

When speaking to Professor Aouraghe in Oujda, picnicking and hiking in Tafoughalt was mentioned as a common activity for families in the area.

4. What is Tafoughalt most associated with for people in the region?
5. Picnic
6. Hiking
7. Cave
8. Scientific Cave Site
9. Cultural Heritage Site

Digital Museum

As we mentioned, part of our project is providing digital components for an online museum for the cave. Ultimately, the hope is that the museum will become part of a larger website advertising Tafoughalt and the Berkane Province as a place for tourism. We were curious about your opinions on positioning the cave as a potential tourist attraction.

10. With an online presence, do you think the cave provides enough public intrigue to help attract tourists/visitors to the Oriental Region?
11. Need more physical infrastructure?

Script/Teaching Methods

As part of our project, we are also working on a script for the short, animated film to be used on the website for a younger audience.

12. In your experience teaching, what aspect(s) of the cave do students tend to find the most interesting?
    a. Are there specific aspects you believe we should focus on when trying to educate the public?

Additional Resources

13. Do you have names/contacts of other researchers with knowledge of the cave/its artifacts?

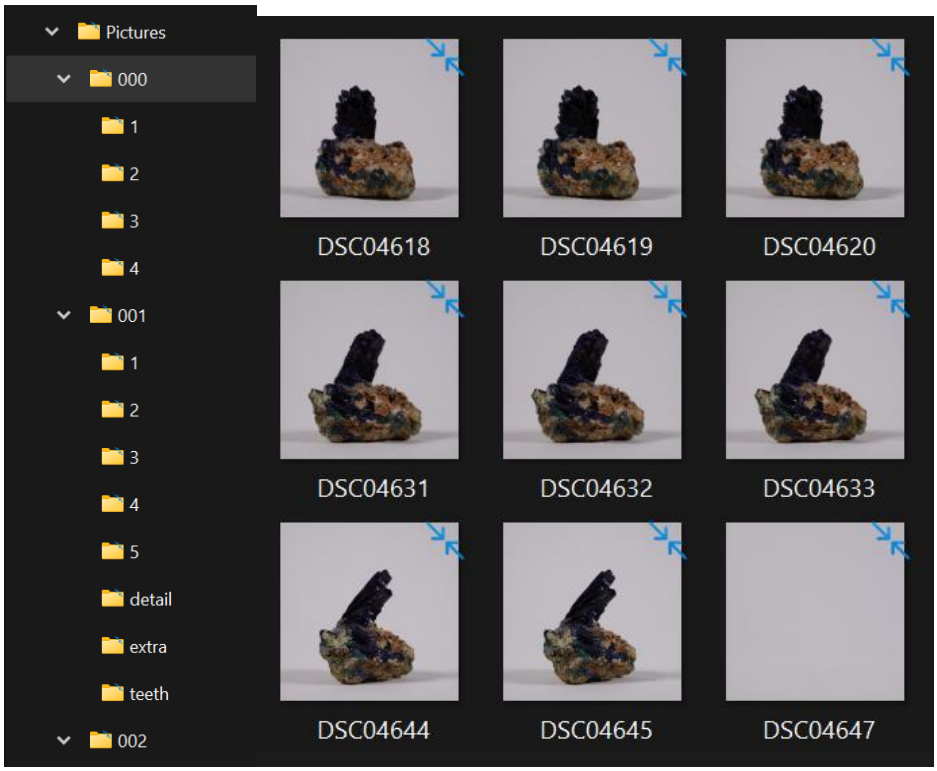
Appendix E: Instruction Manual for Agisoft Metashape

This manual outlines the steps taken to go from photos of artifacts to a 3-dimensional model. The software used was Agisoft Metashape Professional and the devices used were 2 Windows laptops.

Laptop	1	2
GPU	NVIDIA RTX 3060 Laptop	NVIDIA 1650 MAX Q Design
CPU	12th Generation Intel i7	12th Generation Intel i7
RAM (GB)	16	16

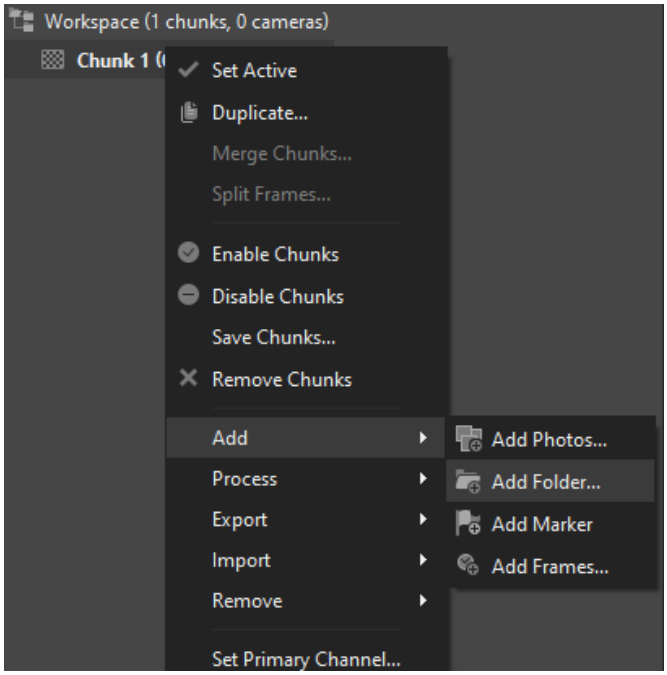
Data organization:

In between each camera angle change, all photos were removed from the camera and placed into numbered folders on an external hard drive. This was done to keep the photos grouped with their respective mask photo, a photo of the setup without the object used by the software to eliminate the background from the rest of the photos.

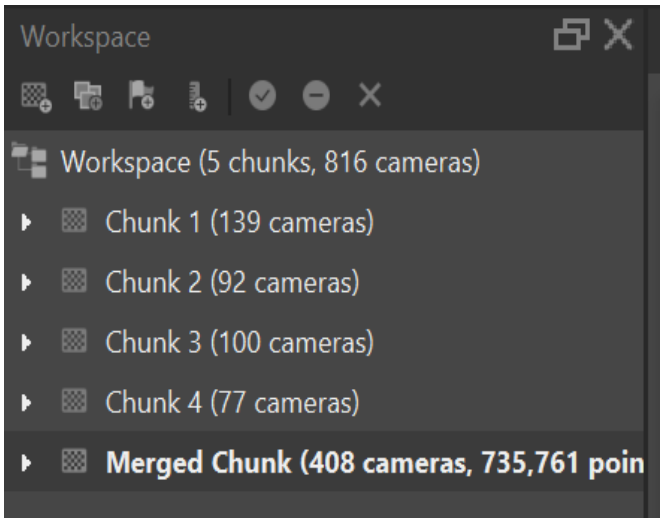


Project Setup:

Open a new project and add the first photo folder to the current chunk.



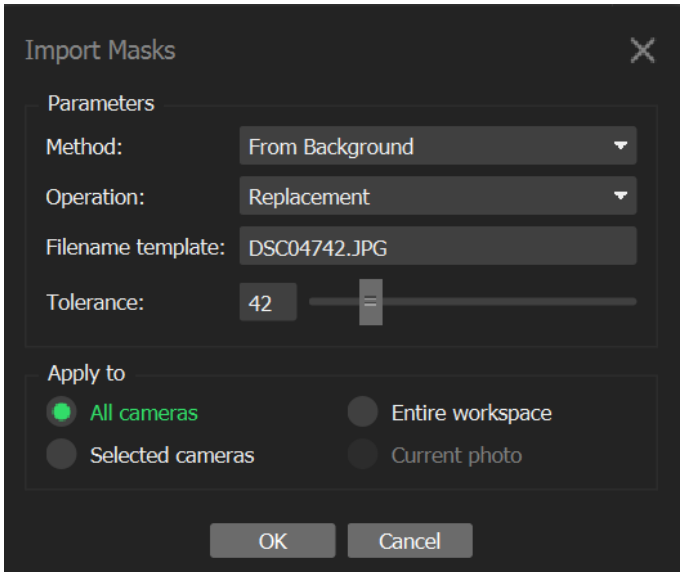
Continue adding chunks to the project and adding photo folders to those chunks until all photos are loaded into project. Chunks are used for organizational purposes and to speed up masking of photos.



Processing:

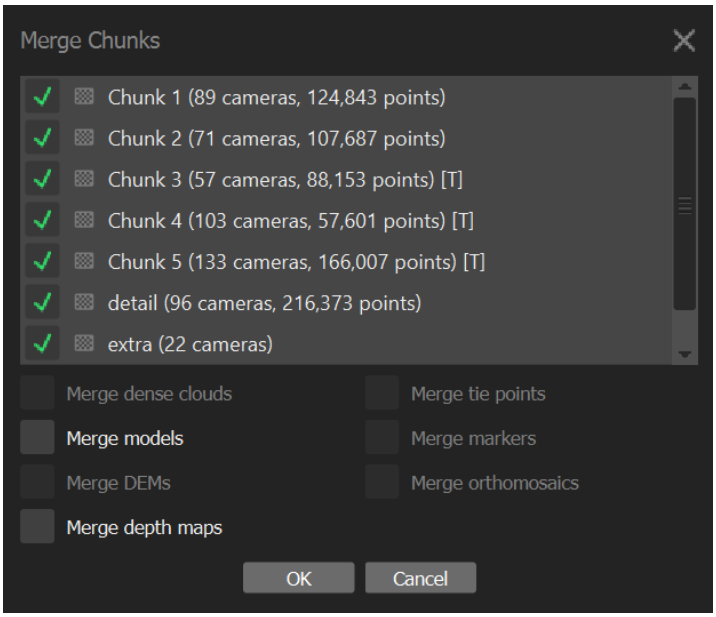
Mask Generation:

Starting with the first chunk, begin masking all photos by right clicking on the chunk and selecting mask images, then import masks. The following settings were used:

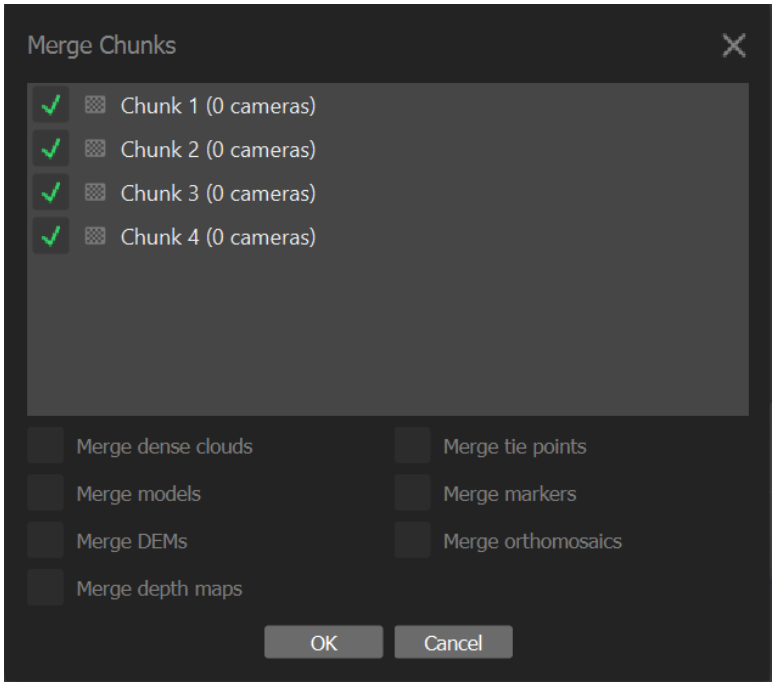


Be sure to change the filename to the exact name of the mask image and select the folder that corresponds to the chunk being worked in when prompted. The tolerance setting is estimated based on how different the background and the object look. Higher tolerances should be used when contrast is high and vice versa. The highest tolerance used during the project was around 100 and the lowest was around 20. If the results of the masking are unsatisfactory, reset all masks and try again with a higher or lower tolerance. If the masking is only slightly off, each picture may need to be adjusted manually using the selection tools. In the case of the skulls, the teeth needed to be manually adjusted in most photos as the color is similar to the white background.

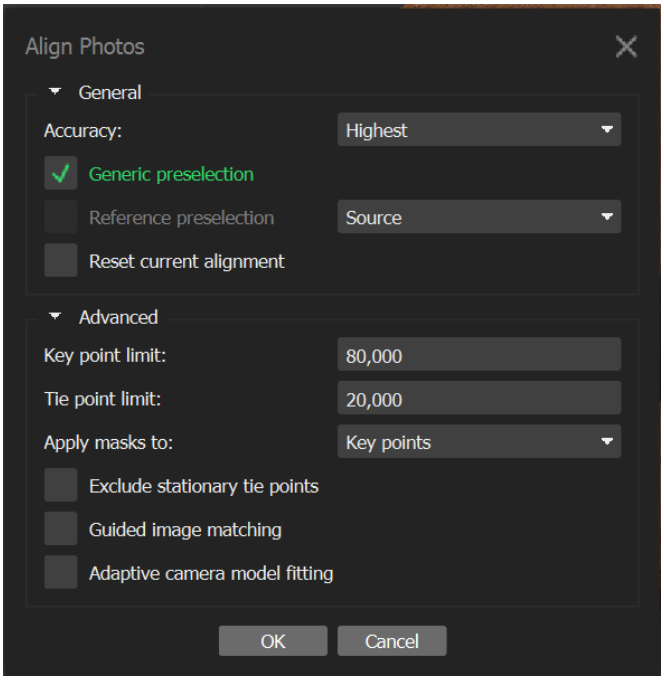
Merging Chunks and Aligning Photos:



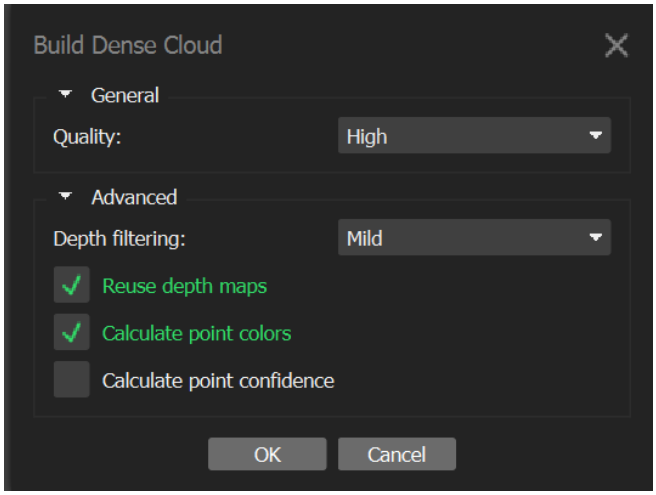
After all chunks are fully masked, they should be merged under Workflow, Merge Chunks. Make sure all chunks are selected as shown below.



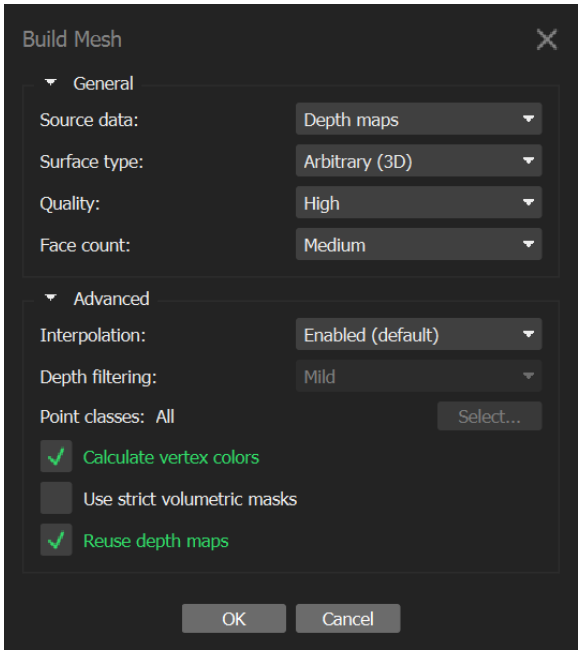
From this merged chunk, align photos can be selected under process. The following settings were used:



The resulting point cloud should be cleaned up using the manual selection tools. Background sections are more easily removed now than after the mesh is generated. An optional next step is to generate a dense point cloud under workflow.

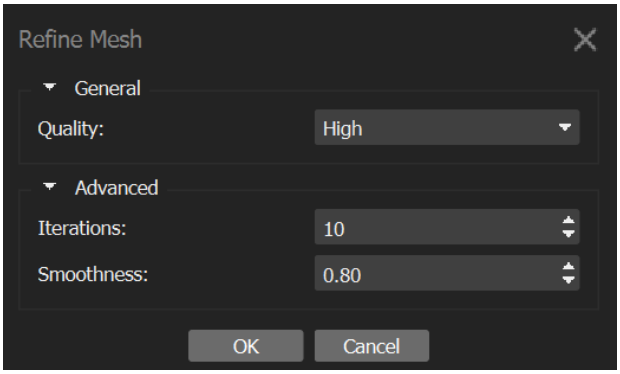


This is a good option if the initial point cloud has weak areas and could potentially fix them. The other option is to add more photos of the object with a focus on the weak areas. When the point cloud is satisfactory, generate the mesh. The following settings were used:



In the case a dense cloud was created, change source data from Depth maps to Dense cloud.

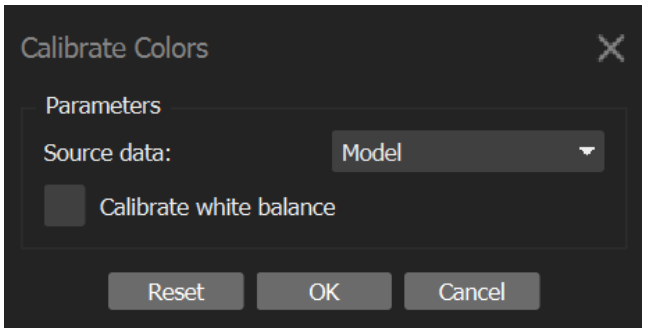
If the mesh is incomplete, there are a few options under Tools, Mesh such as Fill Holes that can fix minor discrepancies. The manual selection tools can be used to remove remaining sections of the background and other unwanted artifacts. If an unwanted artifact is attached to the main model, it will leave a hole in the mesh when removed. To repair this the Close Holes tool under Tools, Mesh, should be used followed by the Refine Mesh tool under the same menu. For Close Holes, the slider should be moved far enough that the hole is covered in the preview. For Refine Mesh the following settings were used:

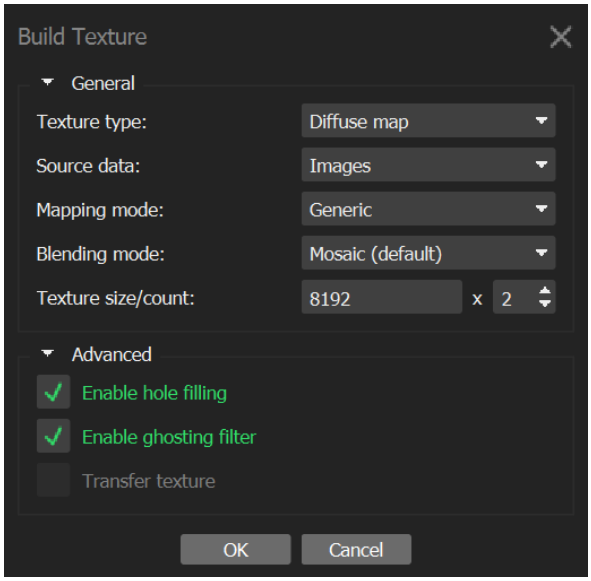


The combination of these two tools fills in the holes and colorizes the patched areas to match appropriately. In the case that the mesh is significantly incomplete, more photos will need to be added and the previous steps will need to be repeated.

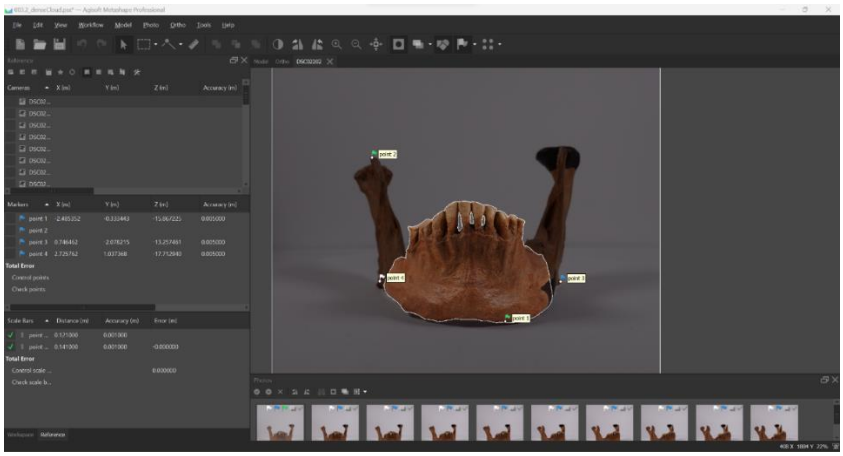
Texture Generation:

The last step is to generate texture which can be done in a few ways. The simplest method is to run Color Correction under Tools and then run the Generate Texture tool under workflow. In this case the following settings were used:



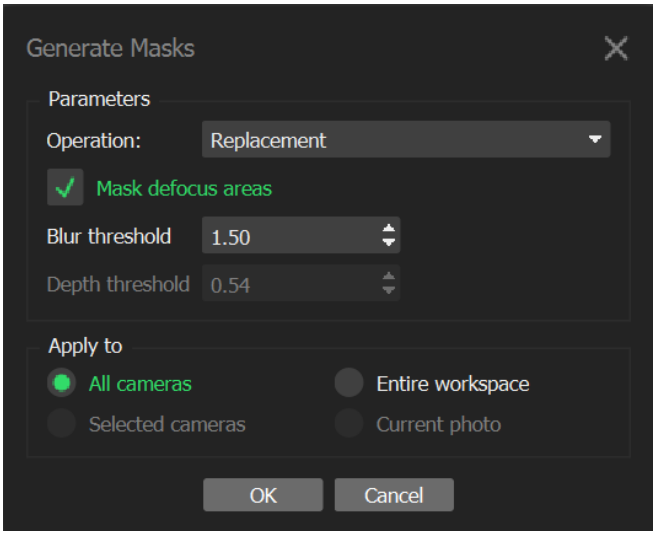


The method used for this project was to first add scale bars to an image and re mask photos with the defocus tool. This automatically masks all photos to only include the parts of the image that are in focus which helps eliminate blurry areas on the final model.



The following steps are used to accomplish this:

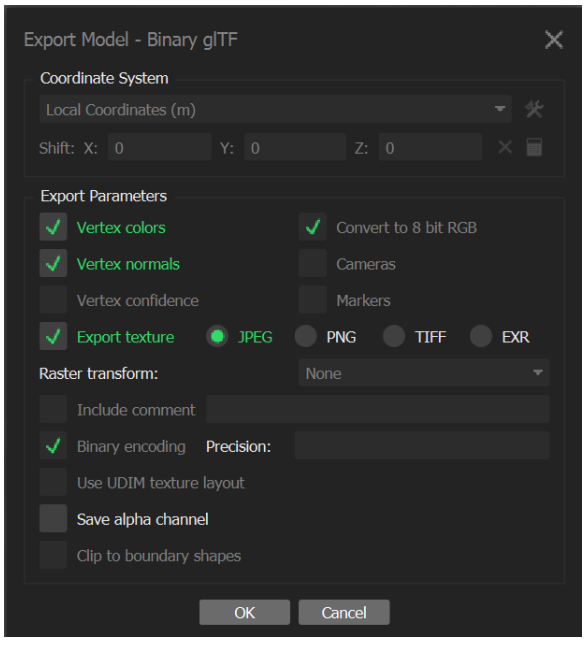
1. Place two markers on an image
2. Highlight both markers in reference menu
3. Select “Add scale bar”
4. Set distance
5. Repeat at least once more on a different image
6. Click Refresh button at top of reference menu
7. Select Tools, Mesh, Generate Masks



The blur threshold will need to be adjusted based on results. A lower threshold will be able to eliminate more blurring but too low of a threshold will create issues with the texture usually in the form of streaks. After all photos have been re masked, the Build Texture tool can be run using the same settings as above.

In the case of a more complicated model, it may be necessary to run the Decimate Mesh tool under Tools, Mesh with the default settings. The texture will need to be re-run after doing this and it will reduce file size without hurting model quality.

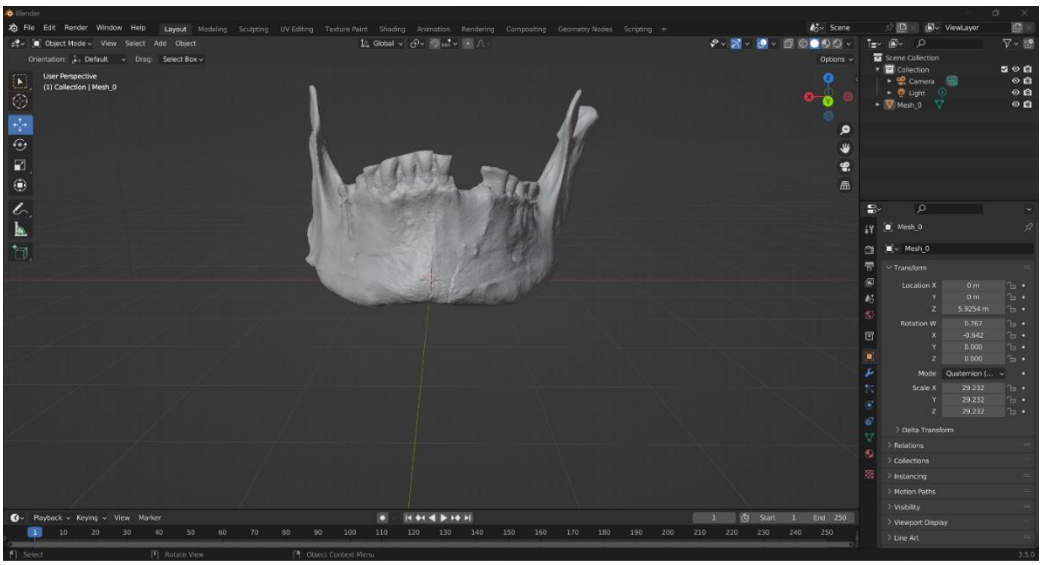
Once the model is complete it can be exported. GLB files were used for this project with the following export settings:



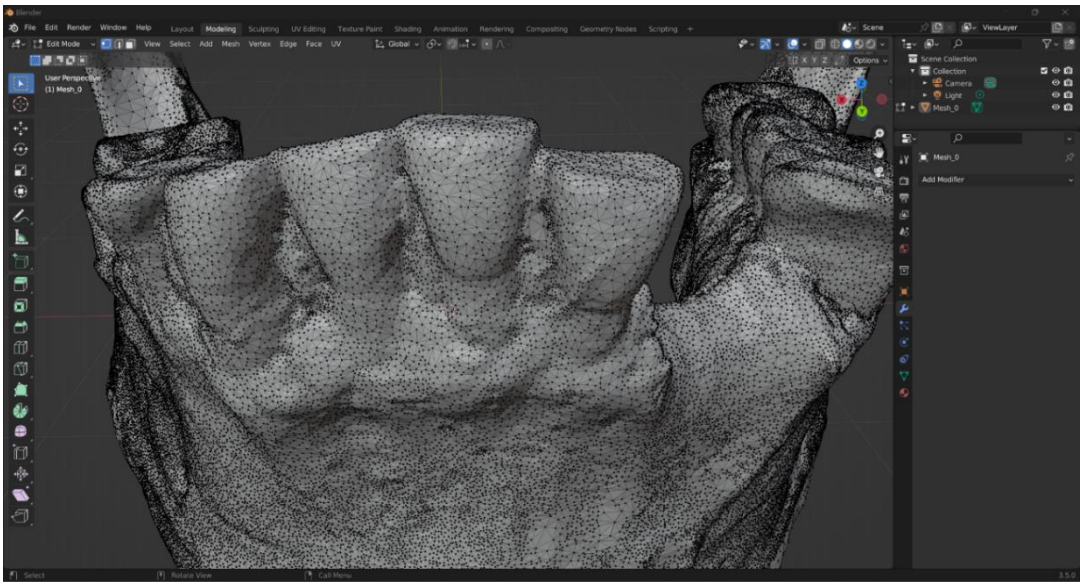
For a few models, Blender was used to touch up holes in the mesh that Agisoft's hole closing tool would not fix as well as touch up texture discrepancies.

Appendix F: Blender Guide

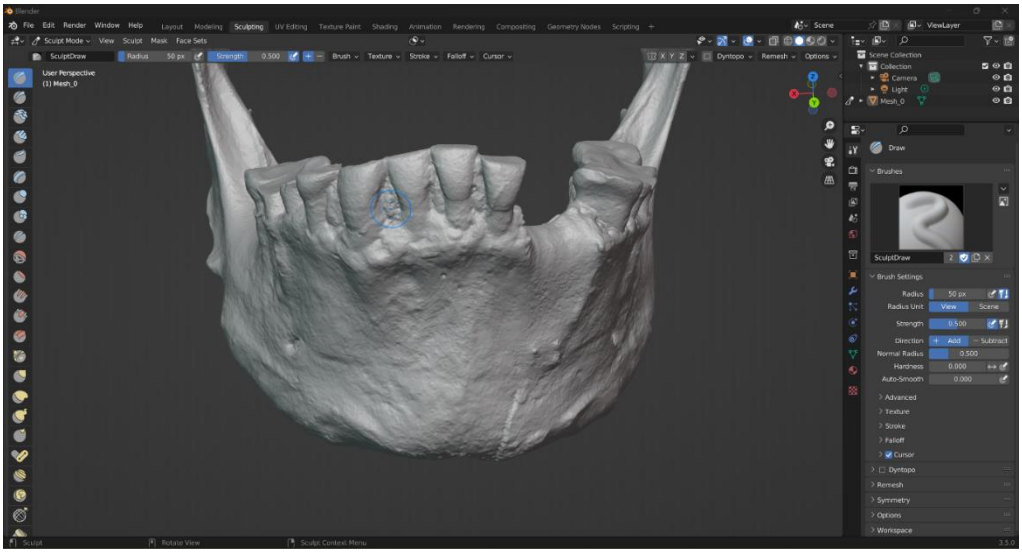
This appendix covers the techniques used in the digital modeling software Blender to repair errors in a few of the models. The main tools used were mesh editing and texture painting. First, the models were imported. File, Import, giTF 2.0 (.glb/.gitf). The model was then scaled up and rotated to the desired orientation. Both tools can be found in the left side tool bar of the Layout menu pictured below.



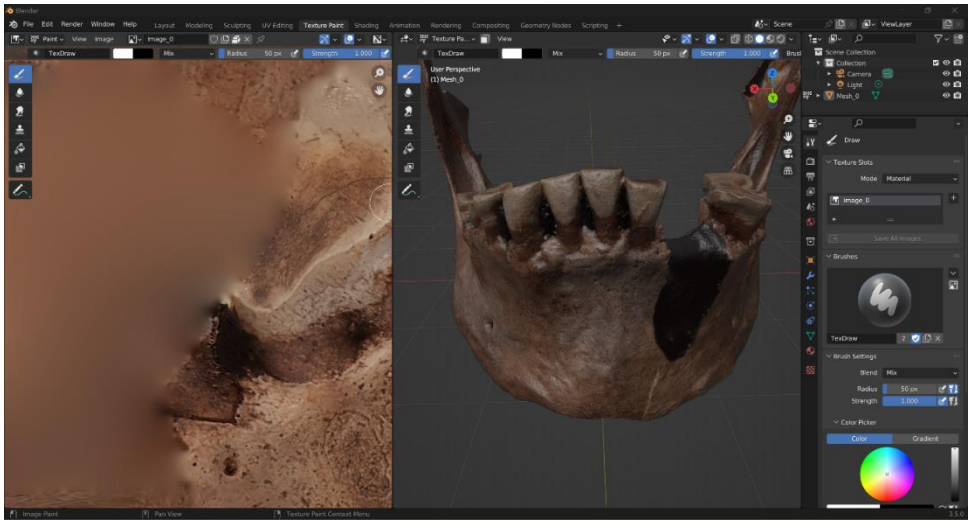
The next step was to edit the mesh to remove unwanted sections and fill holes. This was done in the Modeling menu pictured below using the cursor selection tool to select vertices and faces on the mesh and using the delete key to remove them and the alt + F keyboard shortcut to add faces and fill holes.



Following the mesh editing, it was necessary to smooth out the edited areas using the Sculpting menu and the variety of tools it provides. This was done purely through trial and error, and it is best to experiment with the tools and see which work best for the issue at hand.



The next step was to fix the texturing on edited sections using the Texture Paint menu shown below. The colors could be matched with the color selection tool to touch up areas where the mesh was edited.



One other tool that was used was the Decimate tool which decreased the number of faces on the model therefore decreasing the file size. Due to using high quality settings in Agisoft, some models ended up with face counts in the millions which can safely be lowered by half or more with no noticeable loss in detail of the model. This will in turn greatly decrease the file size of the model. This is desirable because Blender is extremely prone to becoming unresponsive and crashing which can be helped by having smaller files.

Appendix G: Equipment List

The equipment below was used for accomplishing our objectives:

- Sony RX100

- Ricoh Theta V

- Go Pro MAX

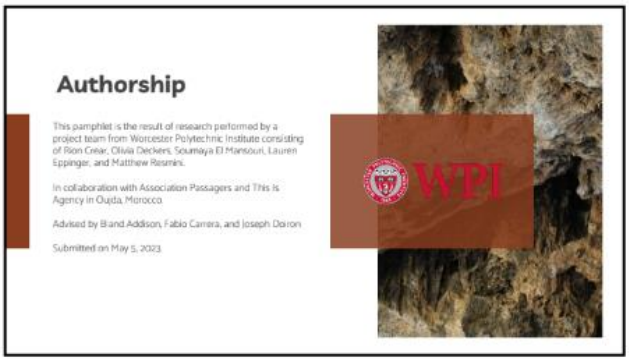
- Tripod (Magnus PV-7451M)

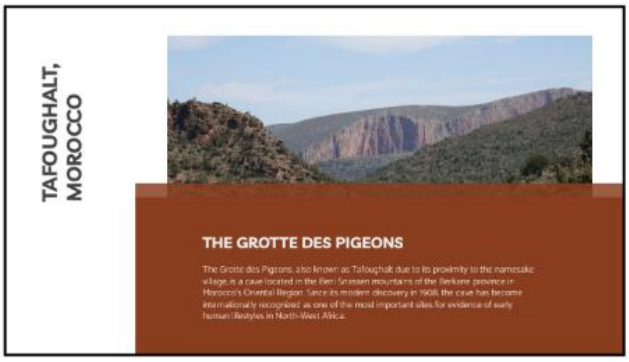
- Lights (Genaray SP-E-500D SpectroLED)

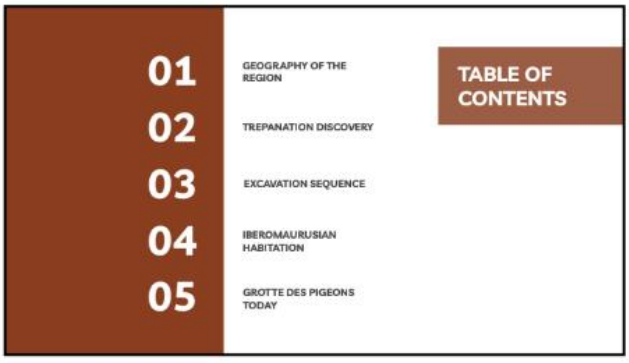
- Lazy Susan

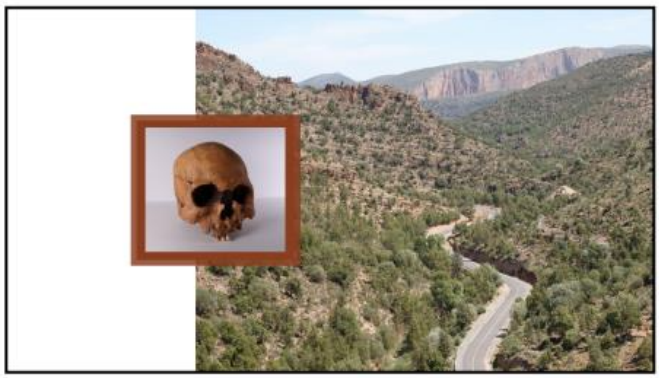
Appendix H: Educational Guidebook

Below are pages of the comprehensive guidebook about the Grotte des Pigeons. A downloadable PDF is located both on the team website and in the submissions.



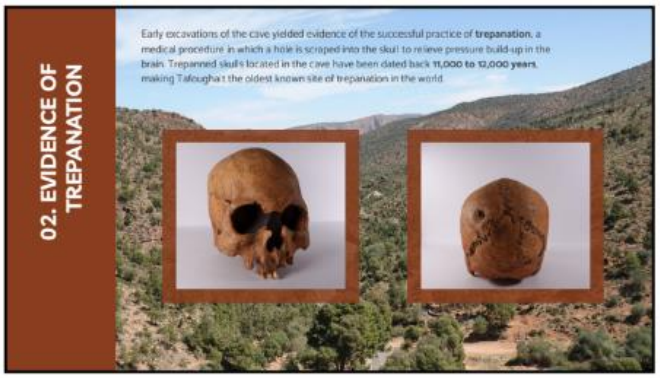




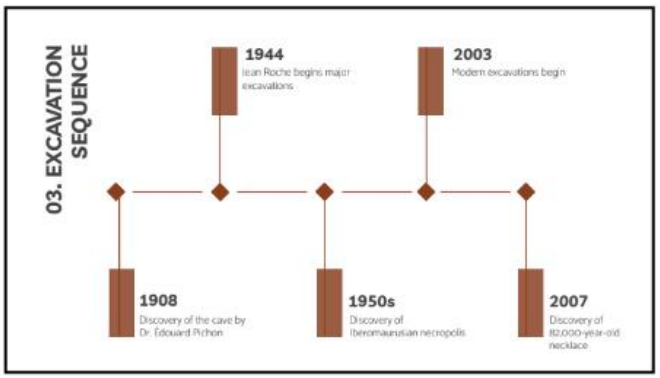



01. GEOGRAPHY
The cave is one hour from both Oujda, the capital city of the Oriental Region, and Nador, a coastal city known for its large Marchica Salt Lagoon.


Nador, Morocco
Oujda, Morocco

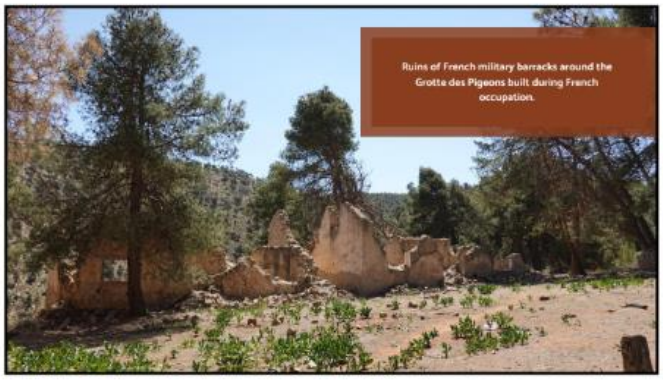

02. EVIDENCE OF TREPANATION
Early excavations of the cave yielded evidence of the successful practice of **trepanation**, a medical procedure in which a hole is scraped into the skull to relieve pressure build-up in the brain. Trepanned skulls located in the cave have been dated back **11,000 to 12,000 years**, making Taforalt the oldest known site of trepanation in the world.


Fragment of a skull showing evidence of an incomplete trepanation. The rounded appearance of the cavity indicates bone regeneration after the procedure.
MOHAMMED I UNIVERSITY
OUJDA, MOROCCO


03. EXCAVATION SEQUENCE
1908
Discovery of the cave by Dr. Edouard Pichon
1944
Jean Roche begins major excavations
1950s
Discovery of Iberomaurusian necropolis
2003
Modern excavations begin
2007
Discovery of 82,000-year-old necklace

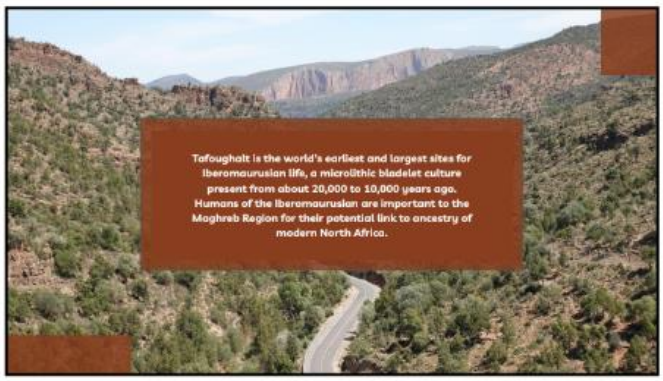

ARCHAEOLOGICAL EXCAVATIONS
~200
Skeletons Excavated
4
Major Excavations
10m
Archaeological deposit


FRENCH OCCUPATION
In 1907, France began its conquest of Morocco, resulting in the creation of the French protectorate in 1912 following the Treaty of Fez. Under the protectorate, the French military used the Grotte des Pigeons in 1939 to shelter livestock and troops after artificially leveling the floor with lime mortar, a process which incidentally helped with the preservation of the sediment and artifacts below.


Ruins of French military barracks around the Grotte des Pigeons built during French occupation.


Since 1964, decades of excavations have revealed layers of cave stratigraphy that create a detailed archive demonstrating the succession of human civilization dating back well over 100,000 years. Today, Tafoughalt remains one of few sites in the world to contain evidence of human life during the Upper Pleistocene, roughly 126,000 to 11,700 years ago.
Grey Series:
15,000 to 12,500 cal BP
Yellow Series:
85,000 - 15,000 cal BP


04. IBEROMAURUSIAN
Although humans inhabited the Grotte des Pigeons since the beginning of the Upper Pleistocene, excavations from periods of later habitation during the Iberomaurusian mark its most significant discoveries.


Tafoughalt is the world's earliest and largest sites for Iberomaurusian life, a microlithic bladelet culture present from about 20,000 to 10,000 years ago. Humans of the Iberomaurusian are important to the Maghreb Region for their potential link to ancestry of modern North Africa.

TAFOUGHALT, MOROCCO

IBEROMAURUSIAN FUNERARY PRACTICES

The Iberomaurusian is marked distinctly by their use of bladelet technology which has been found in vast amounts across multiple layers of the Grotte des Pigeons. Cave stratigraphy also contains cut-marked and modified bone, retouched tools, and over 200 skeletons, making the Grotte des Pigeons one of the largest known burial sites from the period. Additional excavations have revealed Iberomaurusian funerary practices such as unique burial positioning and ochre staining of bones.

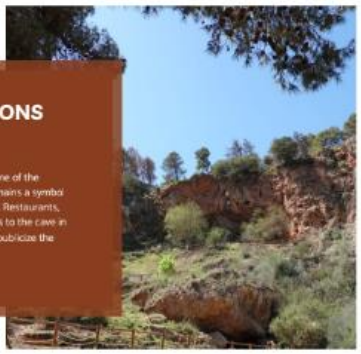
Iberomaurusian Habitation

The Grotte des Pigeons was regularly inhabited throughout the Iberomaurusian period despite changes in fauna throughout the grey series indicating significant climate changes during the time. There is a relationship between the appearance of pine and evergreen trees with periods of notable environmental cooling very close to the onset of the **Younger Dryas**, approximately 13,000 years ago. Dating evidence shows continued habitation until this time before there may have been a possible break in settlement from around 11-10,000 years ago due to environmental changes. It is thought that the cave was chosen by early humans not only because of its strategic view point, but also for its ability to sustain human life throughout these extensive environmental changes.

Despite its significant scientific value, the cave remained generally unknown across the Oriental Region until the discovery of an **82,000-year-old** necklace made of land mollusks. This piece marks some of the earliest human evidence of personal ornaments and symbolic behavior and became a symbol of the cave's cultural significance. Following this discovery, public visits to the cave increased as onlookers came to watch excavations in the early 2000s.

05. GROTTE DES PIGEONS TODAY

Today, the Grotte des Pigeons' connection to some of the earliest known evidence of human civilization remains a symbol of cultural pride for people of the Oriental region. Restaurants, hiking trails, and picnic spots have increased visits to the cave in recent years, and there are continuing efforts to publicize the cave's international scientific significance.



PRESERVING NATIONAL HERITAGE

King Mohammed VI's later commitment to the protection of cultural heritage aligned crown politics with the preservation of the Grotte des Pigeons, leading to the creation of protective infrastructure around the cave.

TAFOUGHALT ATTRACTIONS

HIKING

The Beni Snassen mountains is a stunning limestone mountain range for hiking.

RESTAURANTS

Upon entering Berkane, the road filled with cafes and restaurants.

GROTTE DU CHAMEAU

Only ten minutes from the Grotte des Pigeons, the Grotte du Chameau contains some of the oldest stone inscriptions in Africa.