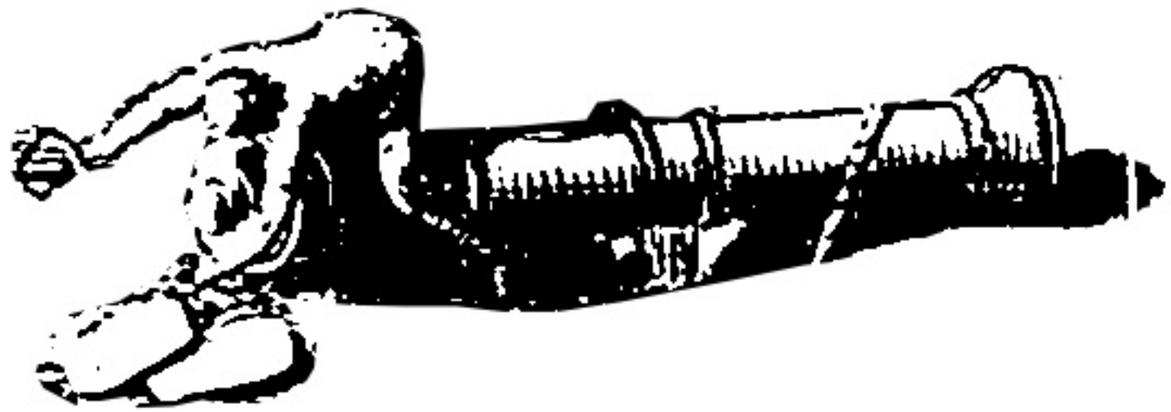
IMMERSIVE SHIPWRECKS



FOR FUTURE MEMORY

IMMERSIVE SHIPWRECKS



FOR FUTURE MEMORY

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0 INTRODUCTION

“O BARCO VAI DE SAÍDA”



[CÉLIA QUICO]

This book is a tangible result of a journey that began in mid-March 2024, during a FilmEU meeting in Aarhus, Denmark. The meeting gathered both ‘old and new sailors’ from eight higher education institutions: Lusófona University (Portugal), LUCA School of Arts in Belgium, IADT - Dún Laoghaire Institute of Art Design and Technology in Ireland, TLU - Tallinn University in Estonia, NATFA - National Academy for Theatre and Film Arts “Krustyo Sarafov” in Bulgaria, VŠMU - The Academy of Performing Arts in Slovakia, LMTA – The Lithuanian Academy of Music and Theatre, plus VIA University College, Denmark.

At that time, FilmEU_WIRE issued a call for proposals addressing the Horizon Mission ‘Restore our Oceans and Waters’. Perhaps because we were near the Aarhus harbor - or perhaps because I was working on a pilot project about lighthouses - , the theme of shipwrecks emerged naturally and gained clarity within a few days.

The initial idea had two main points: to bridge factual shipwrecks of the past with a simulated future shipwreck caused by rising sea levels. For the past, I recalled the *San Pedro de Alcántara* shipwreck. During a September 2023 field trip to Berlenga Grande for the *Beyond the Lighthouse* project, I walked along the Peniche coastline and found a sign at Ilheu da Papôa marking the site of that 1786 shipwreck. For the future, I imagined a worst-case scenario for our planet. While dramatic, this extreme scenario might trigger deeper reflection and action.

Upon returning to Portugal, I sent a brief description to the FilmEU colleagues I had just met in Aarhus. We quickly assembled a team and submitted the proposal by late April 2024. These ‘adventurous sailors’ included Anabela Cruces, Dulmaa Purev-Ochir, Fernando Angelino, João Alves, José Gomes Pinto, Pedro Sousa, Nuno Cintra Torres, Rute Muchacho, and Valter Arrais from Lusófona University, as well as Joachim Pietsch and Robert Griffin from IADT. Recently joining the FilmEU community were Elena Trenchev, Radostina Neykova, and Yoan Kadiev from NATFA, and Thomas Bøgevald Bjørnsten from VIA. In June, we received the news that the project was funded. We were off, determined to do our best with the resources at hand and find solutions for the challenges ahead.

As usual, the actual journey differed from the original plan—or the chart, to keep with maritime metaphors—but we certainly did not shipwreck. This book is a positive example of those differences; it is an unplanned output deriving from the project, available in both digital and printed versions.

The book summarises and expands on the research conducted during the project’s 20-month duration. In the first chapter, Célia Quico and Pedro Sousa (Lusófona University) present the *Immersive Shipwrecks* project, describing the journey that led to this point, the major outputs, and the main lessons learned. Acknowledging the importance of the *San Pedro de Alcántara* iconography, the second chapter focuses on 18th-century shipwreck visuals, including drawings, engravings, and paintings.

Next, Robert Griffin and Joachim Pietsch (IADT) elaborate on user-testing methodologies for the *Immersive Shipwrecks* VR experience, proposing a structured approach specifically for Head-Mounted Display (HMD) environments. This is followed by Fernando Angelino (Lusófona University), who provides an overview of how immersive technologies can enhance ocean literacy across all levels of education. The final chapter, by Anabela Cruces (Lusófona University), offers a glimpse into the future by looking at the impacts of climate change on the Peniche peninsula and the Portuguese coast.

In short, the Immersive Shipwrecks pilot project aimed to bring together different stories, issues, and media, but most importantly, it tried to bring people together. It created new connections and reinforced relationships between individuals and their institutions. This book is part of a larger journey—both individual and collective—intended to foster the shared understanding and goals, so badly needed in the polarised world we navigate today. After all, as the project's main immersive video concludes: 'We are all in the same boat".

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① IMMERSIVE SHIPWRECKS

PAST AND FUTURE SHIPWRECKS REPRESENTED IN EARLY XXI-CENTURY IMMERSIVE MEDIA



[CÉLIA QUICO]
[PEDRO SOUSA]

ABSTRACT

The pilot project *Immersive Shipwrecks* aimed to enhance ocean literacy among young people by exploring two issues through a creative and artistic lens: the historical impact of a specific shipwreck and the projected future impacts of climate change on European coastal areas, thereby addressing the EU Mission “Restore our Oceans and Waters”.

Led by Lusófona University (Portugal) alongside FilmEU partner institutions such as IADT (Ireland), NATFA (Bulgaria), and VIA University College – Aarhus (Denmark), the project focused on the 1786 sinking of the *San Pedro de Alcántara* in Peniche, Portugal. This location served as a narrative bridge connecting historical 3D underwater worlds with future climate simulations of sea-level rise.

The main output was an 8-minute, 360-degree video combining archival images, drone footage, LiDAR scanning, 3D animations, and AI-generated animations, optimised for virtual reality headsets and dome projections, which has already been presented and demonstrated in April 2026 to the FilmEU community and the Peniche local community.

INTRODUCTION

The main goal of the pilot project *Immersive Shipwrecks* was to increase ocean literacy by telling the stories of shipwrecks along Europe’s coastline. The project utilised multiple media and points of contact, including virtual reality (VR), an immersive installation, and a responsive website. This work was a joint effort between researchers from Lusófona University (Portugal), IADT (Ireland), NATFA (Bulgaria), and VIA University College – Aarhus (Denmark).

Following the FilmEU_WIRE call for proposals launched early 2024, the project addressed the EU Mission “Restore our Oceans and Waters” by exploring two issues through a creative and artistic lens: the historical impact of a specific shipwreck and the projected future impacts of climate change on European coastal areas.

The main research question aimed to determine if and how VR can increase ocean literacy, particularly among young people. At the heart of the project was the production of two 3D worlds: the first representing the underwater resting grounds of a historical European shipwreck, and the second simulating a future underwater world based on scientific scenarios of sea-level rise.

These elements formed the basis of the proposal submitted in late April 2024. As the project formally concluded in April 2026, this chapter revisits the journey made so far, describing key accomplishments and outcomes alongside the challenges faced, while envisioning future adventures in unexplored seas.

THE SHIP LEAVES THE HARBOUR...

The *Immersive Shipwrecks* project formally started in September 2024: however, historical research began before that date. This involved gathering relevant bibliography and iconography online, as well as contacting experts and archives specialised in maritime heritage and, in particular, the *San Pedro de Alcántara* shipwreck.

Important contributions during this first phase came from French maritime archaeologist Jean-Yves Blot, who provided key bibliography and shared unpublished information from the archaeological campaigns he led alongside Maria Luisa Blot between 1984 and 1999. Information was also gathered at the National Centre for Nautical and Underwater Archaeology (CNANS), the Navy Museum Library in Lisbon, and the Peniche Municipal Library. Further contacts were made with experts including Francisco Benitez Aguilar, author of the book *O Príncipe Inca*, and Augusto António Alves Salgado, director of the Portuguese Navy Museum.

Another priority during this phase was the development of a dedicated website. Designed to serve as both an archive and a showcase, the website promotes the project to audiences beyond the FilmEU community and supports future partnerships with cultural and educational institutions. Following the creation of the project's graphic identity, the first version of the website was launched in November 2024, coinciding with the WIRE Summit in Tallinn, Estonia. The site has been regularly updated throughout the project and will continue to be maintained until the end of 2026.
https://shipwrecks.filmeu.eu

While regular team meetings were held via videoconference approximately once a month, finding a time that suited the majority of the team proved challenging. As the project progressed and time constraints increased, general meetings became less frequent; however, the principal investigator kept all members informed of progress via email and MS Teams.

To complement the online meetings, the *Immersive Shipwrecks* team gathered in Portugal from 20 to 22 March 2025 to discuss ideas and define the project's course of action. The three-day agenda included presentations from invited guests Jean-Yves Blot and Francisco Benitez Aguilar, whose research is central to the project. Augusto António Alves Salgado, director of the Portuguese Navy Museum, also participated, as well as Anabela Cruces, director of Environmental Sciences at Lusófona University, who delivered a presentation on the impacts of climate change along the Portuguese coast. The meeting program included a field visit to the *San Pedro de Alcántara* shipwreck site in Peniche, as well as the newly inaugurated National Museum of Resistance and Freedom at the Peniche Fortress. The team also visited the Navy Museum at the Jerónimos Monastery in Lisbon.

Several key outcomes emerged from this gathering, such as the decision to center the project on Peniche, Portugal. This location provided a bridge between past and future stories, allowing audiences to "time travel" within a concrete territory and creating a consistent narrative by anchoring historical shipwrecks and future climate scenarios to a specific place. The team also decided to prioritise the development of a 360 degree video designed for both individual headsets and collective immersive installations. The project website serves as a complementary resource for audiences to learn more about maritime history and climate change impacts, while the primary target audience was defined as young people from 10 to 15 years old.

Following the team meeting, the project moved into the pre-production and production of its primary output: a 360 degree immersive video. The team chose the 360 degree video format over an interactive VR application to ensure greater accessibility, a decision also informed by previous experiences with the pilot projects *Nazaré Imersiva* (2020–2021) and *Beyond the Lighthouse* (2023–2024). By April 2025, the script and storyboard were largely completed, and in early May, production began across four main areas: acquiring archival images of the *San Pedro de Alcántara*, securing a supplier for the LiDAR scanning and photogrammetry of Ilhéu da Papôa, filming ground-based video footage in Peniche, and creating a 3D animation of Earth simulating a 70-meter sea-level rise.

Production gained momentum after the summer break with the involvement of two undergraduate animation students from Lusófona, Caroline Soares and Felipe Kenji. Supervised by Pedro Sousa and Célia Quico, they worked from September to November 2025 to animate archival images, including oil paintings by Jean Pillement and engravings by Luis Paret and Josef Ximeno. This core animation team met weekly via Zoom and used Discord to share and discuss drafts. To capture a better view of the sites connected to the shipwreck story, additional 360 degree video footage was filmed by drone in October 2025 at various locations including Ilhéu da Papôa, Porto da Areia Norte, the Cabo Carvoeiro lighthouse, and Atouguia da Baleia.

Meanwhile, besides the 3D animation of Earth simulating a 70-meter sea-level rise, Pedro Sousa continued developing the 3D environments, using the LiDAR data of Ilhéu da Papôa as the basis for the shipwreck site and Pillement's paintings to guide the atmosphere and color palette. He also created a 3D animation of the ship's journey from Callao, Peru, based on an 18th-century planisphere. Sound production ran in parallel, starting with Portuguese voiceovers by journalist Mário Galego and English recordings by Michael Glennon from IADT. The final sound design was completed by João Alves, from Lusófona, during February and March 2026, following the final cut and the full integration of all video footage and animations.

Past Shipwrecks
Immersive Shipwrecks
Past And Future Shipwrecks Represented In Early XXI-Century Immersive Media
[Célia Quico]
[Pedro Sousa]

THE SHIP ARRIVES TO ITS DESTINATION - REFLECTIONS ON THE JOURNEY SO FAR...

Like the preceding *Beyond the Lighthouse* pilot project, *Immersive Shipwrecks* has been a significant learning experience. It allowed team members to share expertise and collaborate with colleagues from partner institutions, always trying to find creative ways to maximize limited resources. Furthermore, the project integrated students into various stages of the work. With increased budget for human resources and clearer information regarding the material resources available at each FilmEU HEI for pilot projects, the team could expand these efforts. This foundation makes it possible to pursue larger funding applications, such as Creative Europe.

Despite heavy workloads, the team met regularly to exchange ideas and make progress. Communication was primarily managed via email, MS Teams, and Zoom. While face-to-face meetings were difficult to setup, a successful in-person event was held in Portugal from March 20 to 22, 2025. The pilot was largely implemented as planned. Some initial ideas, such as the AR application, were dropped due to time and resource constraints. However, new initiatives emerged, including the e-book and printed book, which provided a concrete way for more team members to contribute, and also to prepare for future external funding proposals.The main challenge remains the limited time each member had available: balancing a modest-budget project with existing responsibilities is challenging. However, with this kind of exploratory project in a way we are “planting seeds” across several areas: while not every idea will flourish, this process is essential for long-term growth.

The project team produced a 360 degree video with a duration of 08m47s, optimised for VR headsets and dome projection and accessible via YouTube for mobile, tablet, and PC. This video incorporates three 3D worlds representing past shipwreck sites both on land and underwater. It also features two 3D globes, one illustrating future sea-level rise scenarios and the second illustrating the 1784–1786 journey of the *San Pedro de Alcántara*. Additional content includes six 2D short animations, three GenAI animations, and three soundtracks featuring Portuguese and English voiceovers with musical scores. Technical assets include a digital twin of the Ilhéu da Papôa, 45 minutes of 360 degree drone footage, and 36 minutes of ground-based 360 degree video.

Main dissemination materials consisted of a dedicated website for mobile and desktop use, an e-book in PDF format, and a limited print run of 50 books. The project was further disseminated through several presentations across various events. Internal sessions were held at the FilmEU WIRE Summit in Sofia (4 June 2025), the CICANT Lunch for Science at Lusófona (18 February 2026), the FilmEU WIRE Writers Room (26 February 2026), and the FilmEU WIRE Summit in Lisbon (15 April 2026). Public engagements included the IV Congresso da Rede Nacional de Estudos Culturais at Universidade Lusófona (27 June 2025) and the 240th anniversary of the San Pedro de Alcántara shipwreck in Peniche (1 February 2026). Additionally, pubic demonstrations were co-organised with the Municipality of Peniche (28 April 2026), with the participation of 120 secondary school students and about 50 people from local community. Following the project’s formal conclusion on 30 April, the team aims to submit at least two journal papers, deliver two academic conference presentations, and prepare a new proposal for external funding.

Key findings from the artistic research highlight that on-site engagement is vital, as moving beyond online research to visit physical locations and meet experts and local people provides a much deeper understanding of both the setting and the narrative. This sense of connection extends to the collaborative environment, where having the team in the same room for discussions proved essential; online meetings, while functional, have inherent limitations for fostering creative synergy. Regarding visual synthesis, the integration of archival imagery with 3D rendering emerged as a promising area for further development. Finally, while the use of Generative AI for 360 degree content shows significant potential, it remains technically limited, particularly in the effective stitching of AI-generated images, which has not yet reached a fully satisfactory standard.

The intangible connections fostered by these pilot projects are perhaps as important than the tangible outputs. These projects build links between people and their institutions, representing small steps toward greater cooperation. Ideally, future efforts will avoid “shipwrecking” if we continue to work together with the same sense of connection and shared responsibility found in a enthusiastic ship’s crew. “Navegar, navegar...”

Past Shipwrecks
Immersive Shipwrecks
Past And Future Shipwrecks Represented
In Early XXI-Century Immersive Media
[Célia Quico]
[Pedro Sousa]



Figure 1: Immersive Shipwrecks - 360-degree video frame “IIhéu da Papoa animation by day”



Figure 2: Immersive Shipwrecks - 360-degree video frame “IIhéu da Papoa animation by night”



Figure 3: Immersive Shipwrecks - 360-degree video frame “IIhéu da Papoa by night with Ruiz and Pavon books”



Figure 4: Immersive Shipwrecks - 360-degree video frame “IIhéu da Papoa by day with PIIIement paintings”



Figure 5: Immersive Shipwrecks - 360-degree video frame “San Pedro de AIcántara shipwreck above water”



Figure 6: Immersive Shipwrecks - 360-degree video frame “San Pedro de AIcántara shipwreck underwater”



Figure 7: Immersive Shipwrecks - publIc demonstration event at CCI Peniche, 28 AprIl 2026



Figure 8: Immersive Shipwrecks - public demonstration event at CCI Peniche, 28 April 2026

Past Shipwrecks
Immersive Shipwrecks
Past And Future Shipwrecks Represented
In Early XXI-Century Immersive Media
[Célia Quico]
[Pedro Sousa]



Figure 9: Immersive Shipwrecks - public demonstration event at CCI Peniche, 28 April 2026



Figure 10: Immersive Shipwrecks - public demonstration event at CCI Peniche, 28 April 2026

Past Shipwrecks
Immersive Shipwrecks
Past And Future Shipwrecks Represented In Early XXI-Century Immersive Media
[Célia Quico]
[Pedro Sousa]



Figure 11: Immersive Shipwrecks - 360-degree video frame “Ilhéu da Papoa drone footage”



Figure 12: Immersive Shipwrecks - 360-degree video frame “Cabo do Carvoeiro drone footage”

IMMERSIVE SHIPWRECKS: THE SAN PEDRO DE ALCÁNTARA SHIPWRECK (1786) PENICHE, PORTUGAL

The story of the *San Pedro de Alcántara* shipwreck is fascinating in many ways. It is a truly global narrative connecting Cuba, Peru, Brazil, Portugal, and Spain—a story of greed and cruelty, but also one of remarkable resilience and recovery.

The ship carried twice its intended cargo: approximately 600 tons of copper, 153 tons of silver, and 4 tons of gold, alongside a collection of Chimú ceramics. Most notably, the vessel held political prisoners from the Túpac Amaru II rebellion alongside the ship's crew. Of the 430 people on board, 130 perished in the wreck, while 300 survived.

Among the survivors was Fernando Túpac Amaru Bastidas, the last living son of Túpac Amaru II and Micaela Bastidas, leaders of the first major independence rebellion in the Spanish American colonies (1780–1783). Only ten years old at the time, Fernando witnessed the brutal torture and execution of his parents and older brother by the Spaniards in Cusco's Plaza de Armas. Spared execution because of his age, he was instead condemned to a life of captivity.

Fernando was one of the prisoners destined for Cádiz, Spain, aboard the *San Pedro de Alcántara* when it departed from the port of Callao, near Lima. The overloaded ship leaked throughout its journey, necessitating a four-month stop in Rio de Janeiro for repairs. Despite these efforts, the ill-fated vessel sank near Peniche, Portugal, on 2 February 1786.

News of the disaster spread quickly, and a salvage operation began almost immediately, drawing people from across Europe to recover the underwater treasure. Over three years, hundreds of people participated in the recovery, including 40 divers who successfully reclaimed more than 750 tons of copper, silver, and gold from the seabed.

Two centuries later, from 1987 to 1999, the remains of the *San Pedro de Alcántara* became the focus of a research program financed by the Instituto Português de Arqueologia. Led by underwater archaeologists Maria Luisa Pinheiro Blot and Jean-Yves Blot, this study established the wreck as one of the most thoroughly researched on the Portuguese coast. It remains highly significant across multiple disciplines today.

Ultimately, tragic stories of shipwrecks can also serve as lessons in both resilience - and restoration.

IMMERSIVE SHIPWRECKS: 360 DEGREE VIDEO SCRIPT (VOICE OVER)

Part I – Future global shipwreck

This is our planet.
Our origin.
Our home.

Blue Planet – bluer than we've ever seen it before.
The total melt-down of the poles and glaciers led to a 70-meters increase in ocean water levels, compared to the beginning of the first phase of the so-called Industrial Revolution.

Almost all major cities are underwater.

The global sinking of Earth's coastal areas was catastrophic for Humanity, but it was also an opportunity to recover - and even to be reborn.

Drawing inspiration and strength from past catastrophes and tragedies throughout the history of mankind, Humanity came together determined to reconnect with the planet... and with each other.

One such catastrophe was the shipwreck of the San Pedro de Alcántara, one of the most extraordinary shipwrecks in history, the San Pedro de Alcântara, a Spanish warship which wrecked off the western coast of Europe with 430 men, women, and children aboard…

Part II – Past shipwreck: San Pedro de Alcántara

We are now in the year 1786, in the Gregorian calendar.

At half past ten on the evening of February 2, the San Pedro de Alcántara collides with the rocks of Ilheu da Papôa, near Peniche in Portugal.

This 64-gun ship was overloaded, carrying precious cargo from the port of Callao in Peru: more than 600 tons of copper and more than 150 tons of silver and gold. A fortune for the time.

The ship was also carrying a precious scientific collection, collected over 10 years by the Spanish botanists Ruíz and Pavón and the French botanist Dombey.

Was the fate of the San Pedro de Alcantara sealed when it left Callao, near Lima, Peru, in April 1784? The ship should have taken six months to make the journey to Cádiz, Spain.

But the ship' overload forced it to stop in Talcahuano, Chile, and return to Callao for repair. From here, it departed again in December 1784.

After sailing around the entire South America, the San Pedro de Alcántara makes another stop in Rio de Janeiro for 4 months of repair. And from here, it left at the end of 1785, crossing the Atlantic, with the aim of ending the journey in Cádiz...

On that night of February 2, 1786, the sea was calm and the wind was fair…

Navigational error was the cause of this disaster. That night, 130 people died and 300 people survived.

On board were political prisoners from the 1782 rebellion led by Tupac Amaru II. Until that time, this was the largest insurgency of indigenous people in Latin America against Spanish colonizers. On the San Pedro de Alcantara was the son of Tupac Amaru, young Fernando, who witnessed the public execution of his father, mother, and older brother.

After the tragedy, it was time to bury the dead, care for the living and rescue the riches from the bottom of the sea.

The rescue operations of San Pedro de Alcantara were one of the most extraordinary in history, with the participation of hundreds of people, in the service of the Crown of Spain and with the support of the Crown of Portugal. Over the course of three years, more than 40 divers recovered almost the entire cargo of precious metals from the ship in apnea, using only cables and pulleys, a remarkable feat for the time.

The shipwreck, as well as the rescue of the ship's cargo, lit up the imagination of artists such as French painter Jean Pillement, who made several drawing and paintings shortly after this event.

Part III – Present: Peniche today

And there is much more from San Pedro de Alcántara that we inherited. The efforts of archaeologists Jean-Yves Blot and Maria Luísa Pinheiro Blot, who led research campaigns at the site from 1986 to 1999, were essential to rediscover this story.

Among the various findings from these archaeological campaigns at sea and on land, the discovery of a silver stirrup with the head of a faun and fragments of a piece of Chimú ceramic with a human face should be mentioned.

More significant was the discovery in a mass grave of the remains of a prisoner, still with an iron shackle around his tibia and fibula. In the same mass grave, archaeologists also found bones of a 6-year-old child.

The legacy of San Pedro de Alcántara was still present in Peniche: on the Ilhéu da Papôa, in the Porto da Areia do Norte, in the Cabo Carvoeiro Lighthouse, in the Church of São Pedro…

And this legacy was also present in the memory of the people of Peniche – and even in their DNA.

In the end, tragedy turned into strength and, even more, it connected people from around the world.

After all, we are all in the same boat...

Past Shipwrecks
Immersive Shipwrecks
Past And Future Shipwrecks Represented
In Early XXI-Century Immersive Media
[Célia Quico]
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IMMERSIVE SHIPWRECKS: 360 DEGREE VIDEO CREDITS

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Luis Paret &Josef Ximeno (1786) “Desgracia Imprevista e la Felicidad Inesperada” (inv. 992.68.1, Museu Nacional de Arqueologia)
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② THE SAN PEDRO DE ALCÁNTARA SHIPWRECK AS REPRESENTED IN LATE 18TH-CENTURY DRAWINGS, ENGRAVINGS AND PAINTINGS



[CÉLIA QUICO]

Past Shipwrecks

The San Pedro de Alcántara shipwreck as represented in late 18th-century drawings, engravings and paintings

[Célia Quico]

ABSTRACT

The sinking of the *San Pedro de Alcântara* off Peniche, Portugal, in February 1786, and its subsequent salvage operations inspired several artistic representations by Spanish and French artists. Vicente Mariani recorded the human struggle for survival against the cliffs of Ilhéu da Papôa, while Luis Paret y Alcázar created a split-frame depiction documenting apnea divers recovering 750 tonnes of metal cargo from the seabed.

French painter Jean-Baptiste Pillement established the dominant visual record of the event. His topographically accurate sketches and oil paintings provide a consistent historical archive of the coastal landscape and rescue efforts. Preserved today in international museum collections from Lisbon to New York, these works retain significant documentary value, capturing both the specific coastal topography of Peniche and the details of this maritime disaster recovery.

INTRODUCTION

The *San Pedro de Alcântara* shipwreck inspired several artistic representations shortly after the event occurred in February 1786. These works reflect the intense public interest and curiosity surrounding the tragedy, as well as the pioneering underwater salvage missions that followed. Artists from Spain and France, most notably Jean-Baptiste Pillement, used their talents to document the human disaster and the remarkable recovery of the ship's treasure.

THE SAN PEDRO DE ALCÁNTARA SHIPWRECK SEEN BY VICENTE MARIANI AND LUIS PARET Y ALCÁZAR

One of the most dramatic representations of the shipwreck was created by the Spanish artist **Vicente Mariani** (1). His work captures the ship at a striking moment, appearing as if it has been cut horizontally in two: the top half remains on the surface while the bottom half is still visible. This scene depicts the struggle for survival of the hundreds on board. While some fight for their lives in the water or cling to wooden debris, others are rescued by locals lowering ropes from the cliffs of Ilhéu da Papôa.

Another important part of this story was the salvage operation in Peniche from 1786 to 1788, which was accurately and beautifully and rendered by the Spanish artist **Luis Paret y Alcázar** in *Desgracia Imprevista e la Felicidad Inesperada* (2), with engraving by his fellow countryman **Josef Ximeno**. This image is like a horizontal "split-screen" movie: it displays the intense action at the sea surface, with numerous boats and people dedicated to the salvage missions. In the background, the rugged cliffs and rocks of the Ilhéu da Papôa are visible; atop the cliffs, a few observers stand near a small house and two windmills.

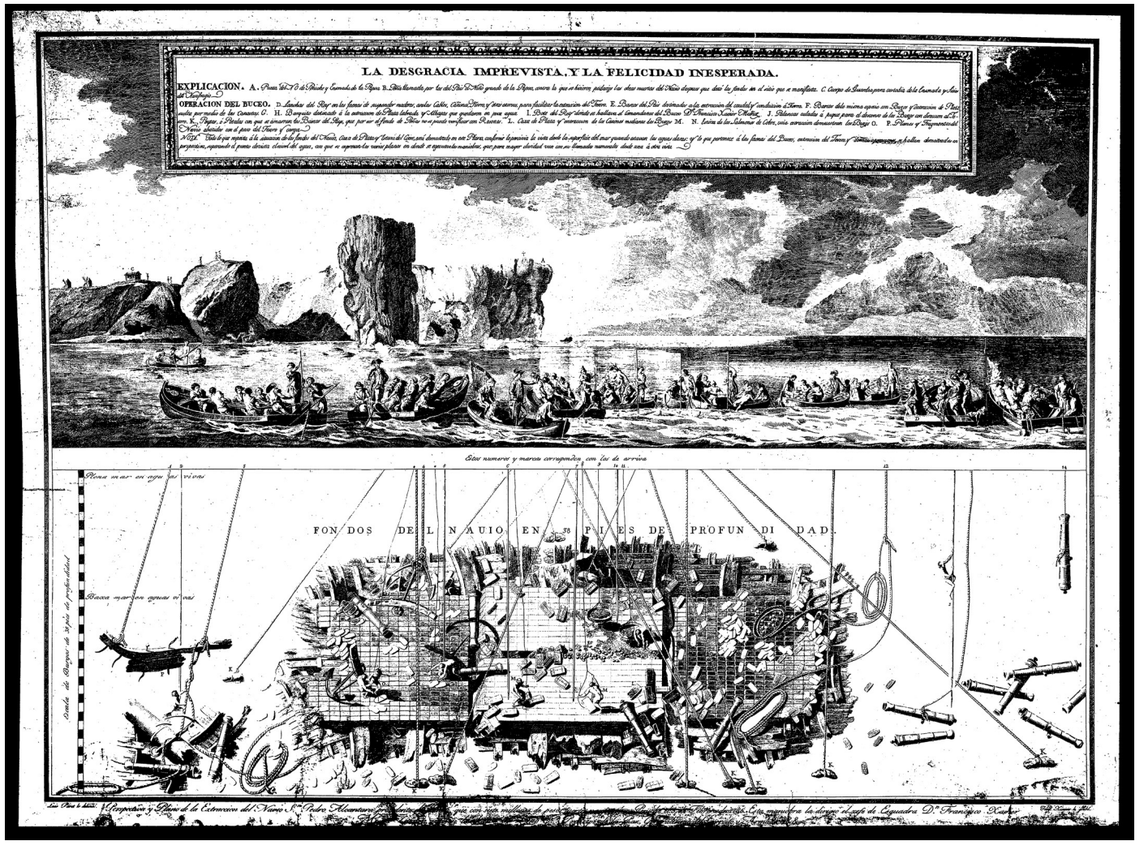


Figure 1: Luis Paret & Josef Ximeno (1786). Desgracia Imprevista e Ia FeIicidad Inesperada. (inv. 992.68.1) Museu NacionaI de Arqueologia, Lisbon

The lower-half of the image is extraordinary in its beauty and complexity. It shows "buzos" diving in apnea, using only ropes and long wooden poles with almost no other equipment to support their work. On the seafloor, the lower section of the wreck holds its cargo: over 750 tons of metal, including 600 tons of copper bars and wooden chests filled with gold and silver coins. The artist depicts this underwater scene like a theatre set, where the naked divers move like dancers in every direction until they must surface for air.

Archaeologists Jean-Yves Blot and Maria Luísa Blot (2014) consider this artistic document to be highly realistic. It shows clearly how the heavy metal cargo and the ship's keel became immobilised on the seabed. This visual evidence confirms the testimonies of survivors, who described how the ship "lost its bottom" the moment it struck the reef. Furthermore, the engraving provides vital details about the salvage operations, documenting the recovery of cannons and various other artefacts scattered around the wreckage (Santos, 2013).

THE SAN PEDRO DE ALCÁNTARA SHIPWRECK SEEN BY JEAN-BAPTISTE PILLEMENT

Before Mariani and Paret, the French painter **Jean-Baptiste Pillement** had already produced a series of artworks about the shipwreck that may have inspired these Spanish artists. Born in Lyon, Pillement traveled across Europe as a decorative painter for wealthy patrons in France, Italy, England, Austria, Poland, Spain and Portugal. Despite working for the elite of his time — including Queen Marie Antoinette — he died in poverty in 1808 (Santos, 2020).

Pillement stayed in Portugal three times: in 1755, 1766, and finally from 1780 to 1786. After living in Portugal for six years, he moved to Cádiz, where he was commissioned to create two oil paintings representing the *San Pedro de Alcântara* shipwreck and its rescue mission (Santos, 2020).

A sketch by Pillement established the visual style for later works. It captures the dramatic landscape of Papôa, specifically the prominent rocks that stand before the island like guardians (3). Between these rocks, the ship is seen sinking as a human tragedy unfolds. In the foreground, people climb the rocks or cry out for those still struggling for their lives, while atop the high cliffs, dozens of witnesses watch the disaster. The artist interprets the scene with a dramatic intensity that can be classified as pre-romantic. However, Pillement is also highly realistic in his depiction of the cliffs, which suggests he visited the location shortly after the shipwreck occurred (Santos, 2013).

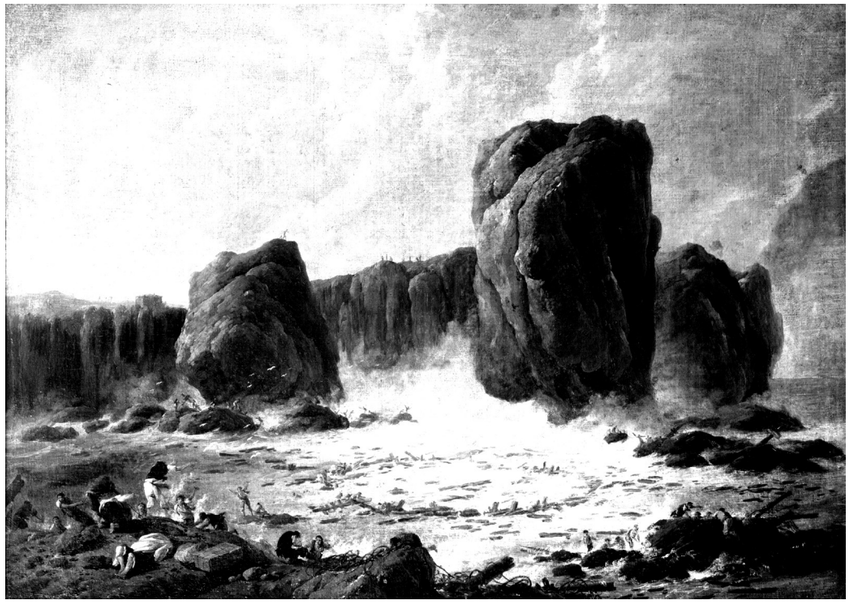


Figure 2: Jean-Baptiste PiIIement (1786) "Naufrágio do San Pedro de Alcántara". (inv. 992.66.1) Museu NacionaI de Arqueologia, Lisbon

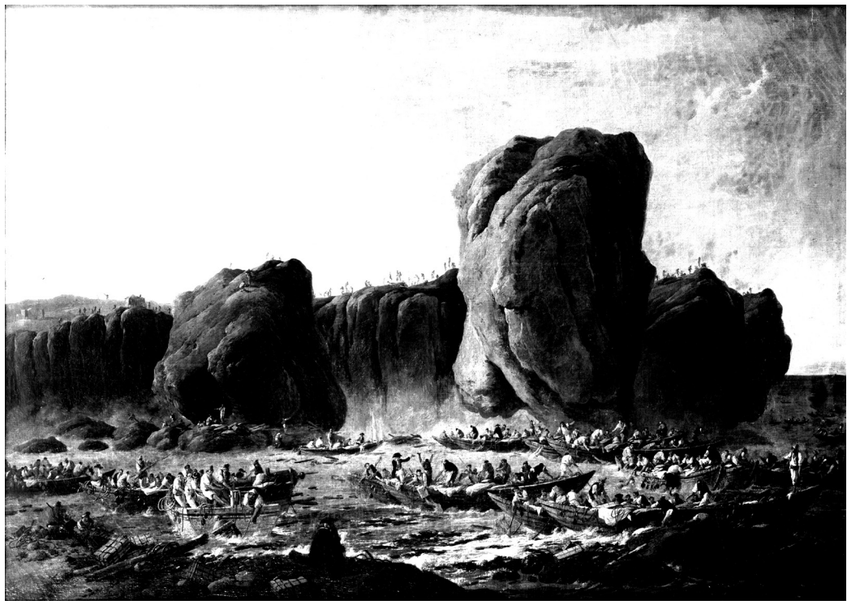


Figure 3: Jean-Baptiste Pillement (1786) Salvamento do San Pedro de Alcántara. (inv. 992.67.1) Museu Nacional de Arqueologia, Lisbon

From this initial drawing, Pillement produced a series of similar images specifically documenting the event and the subsequent rescue mission. These include two oil paintings, *Naufrágio do San Pedro de Alcántara* (4) and *Salvamento do San Pedro de Alcántara* (5), both of which are currently held by the Museu Nacional de Arqueologia in Lisbon.

Pillement's other oil paintings and pastels show subtle variations of the shipwreck and the Papôa landscape. Examples include *Tempestade com Naufrágio (Nocturno)* (6), *Depois do Naufrágio* (7), and *Naufrágio do S. Pedro de Alcântara* (8). In these artworks, the point of view remains nearly identical. The ship's position, the state of the sea, the atmospheric conditions, and the location of the survivors are depicted with a consistency and precision that serves as a reliable historical record (Santos, 2013).

In Portugal, Pillement's shipwreck paintings are held in at least three museum collections: besides the Museu Nacional de Arqueologia in Lisbon, also the Museu Nacional de Soares dos Reis in Porto, and the Museu Marítimo de Ílhavo. Internationally, his shipwreck scenes and pastels are featured in several prestigious institutions. The Museu do Prado in Madrid holds *Náufragos Llegando à la Costa* (9), while the Tokyo Fuji Art Museum displays *A Wreck at the Rocky Seaside* (10). Additionally, Pillement's shipwreck pastels can be found at the Metropolitan Museum of Art in New York—*Shipwreck during a Tempest* (11)—and at the Uffizi Gallery in Florence—*Burrasca di Mare* (12).

IN CONCLUSION

The similarities and differences between these shipwreck representations take on new meaning in the age of Generative Artificial Intelligence. Unlike AI-generated content, these images were created by hand. They were produced using oil or pastel on canvas and paper, relying on human skill rather than software, hardware, and digital networks.

Even though nearly 240 years have passed, these pictures still stand the test of time. While other shipwreck representations are more famous — such as Turner's *The Shipwreck* (13) and *The Wreck of a Transport Ship* (14), or Géricault's *The Raft of the Medusa* (15) — the artworks by Pillement, Paret, and Mariani still continue to draw interest and even fascinate. These images are compelling for their documentary value in capturing the coastal landscape, their dramatic perspective on the tragedy at Peniche, and their focus on the human capacity to recover from disaster.

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(5) Pillement, J.-B. (1786). Salvamento do San Pedro de Alcántara [Oil on canvas]. (inv. 992.67.1) Museu Nacional de Arqueologia, Lisbon, Portugal.

(6) Pillement, J.-B. (1792). Tempestade com Naufrágio (Nocturno) [Pastel on paper]. (inv. 18 Pm CMP/16) Museu Soares dos Reis, Porto.

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Past Shipwrecks

[Fernando Angelino]

③

IMMERSIVE OCEANS

Leveraging Virtual and Augmented Reality to Advance Ocean Literacy

The San Pedro de Alcántara shipwreck as represented in late 18th-century drawings, engravings and paintings

Immersive Oceans

Future Shipwrecks

[Célia Quico]

LEVERAGING VIRTUAL AND AUGMENTED REALITY TO ADVANCE OCEAN LITERACY



[FERNANDO ANGELINO]

[Fernando Angelino]
Leveraging Virtual and Augmented Reality to Advance Ocean Literacy
Immersive Oceans
Future Shipwrecks

ABSTRACT

This work explores the integration of immersive technologies, such as Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR), and Artificial Intelligence (AI), to enhance ocean literacy education across all levels of schooling. By leveraging these innovative tools, educators can create engaging, experiential learning environments that foster critical thinking, collaboration, and a deeper understanding of marine ecosystems.

The insights gathered highlight the importance of accessibility, curriculum integration, and user-friendly design, while emphasizing the need for teacher training and community engagement. This approach not only motivates students but also equips them with the knowledge and skills necessary to address pressing ocean-related challenges.This work advocates for ongoing research and evaluation to continuously improve the effectiveness of immersive technologies in promoting ocean literacy.

Keywords: Ocean Literacy, Immersive Technologies, Experiential Learning, Curriculum Integration

INTRODUCTION

In an era where the health of our oceans is increasingly threatened by climate change, pollution, and overfishing, fostering ocean literacy among students and future generations has never been more critical. Ocean literacy—the understanding of the ocean's influence on us and our influence on the ocean—serves as a foundation for informed decision-making and responsible stewardship of marine resources.

This chapter explores the transformative potential of immersive technologies, including Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR), and Artificial Intelligence (AI), in promoting ocean literacy across diverse educational settings.

As traditional teaching methods often struggle to engage students in complex environmental issues, immersive technologies offer innovative solutions that create interactive and experiential learning environments. By simulating real-world marine ecosystems and challenges, these technologies not only captivate students' attention but also enhance their critical thinking and problem-solving skills. This chapter synthesizes insights from recent research, highlighting the importance of accessibility, curriculum integration, and user-friendly design in the effective implementation of these tools.

THE URGENCY OF OCEAN LITERACY IN THE DIGITAL AGE

Various types of literacy, such as science literacy, digital literacy, environmental literacy or ocean literacy point to skills that are essential in our time, and that goes beyond reading and writing in the classical sense.

Ocean literacy is increasingly recognized as a critical component in addressing global environmental challenges, particularly in the digital age. Ocean literacy is crucial for achieving global commitments to sustainable development by 2030 and beyond. It is essential for catalysing behaviour changes necessary for a sustainable future (Glithero et al., 2025; Kelly et al., 2022a). Ocean literacy is conceptualized as a multidimensional construct encompassing the awareness, knowledge, and behavioral intentions necessary to foster sustainable human-ocean interactions (Wang et al., 2025)

It encompasses the understanding of how human actions impact the ocean and vice versa. This understanding is vital for fostering sustainable behaviours and policies that protect marine ecosystems. The urgency for ocean literacy is underscored by pressing issues such as climate change, biodiversity loss, and pollution. These challenges necessitate a well-informed public that can advocate for sustainable ocean management (Kelly et al., 2022a; McCauley et al., 2021). Engaging diverse populations, especially in urban areas where direct interaction with the ocean is limited, is crucial. Strategies must be developed to enhance societal connections to the ocean, which can catalyze behaviour changes necessary for sustainability (Kelly et al., 2022a; McRuer et al., 2025).

The integration of ocean literacy into educational systems is critical for fostering a collective understanding of marine ecosystems' vulnerability and the urgency of their protection and this is particularly important for coastal communities that rely on these ecosystems for their livelihoods (González et al., 2026; Mokos et al., 2020). The urgency of ocean literacy is evident in the need for transformative communication and training tools that can effectively engage ocean citizens from all backgrounds in co-designing ocean sustainability pathways. Extended Reality (XR) immersive technologies like Virtual Reality (VR) and Augmented Reality (AR) are powerful tools for enhancing ocean literacy. They provide engaging, interactive experiences that can make complex oceanic concepts accessible and relatable. These technologies facilitate experiential learning, allowing users to explore marine environments virtually. This can enhance emotional connections to the ocean and motivate individuals to act for its conservation (Hetherington et al., 2026a).

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These technologies offer unique opportunities to engage learners in interactive and experiential learning, which is crucial for understanding complex marine environments and fostering a connection to the ocean. Immersive technologies, such as VR, AR, and Mixed Reality (MR) create engaging and interactive learning experiences that can significantly enhance student interest and motivation. For example, VR-based learning systems allow students to explore underwater environments in 3D, which can be both educational and motivational (Chen et al., 2026; Ikramov et al., 2025). AR games have also been shown to increase awareness and willingness to participate in marine conservation efforts, indicating their potential to complement traditional educational methods (Cifra et al., 2025).

OCEAN LITERACY, EXPERIENTIAL LEARNING, AND IMMERSION

Ocean literacy must be framed as a strategic global challenge that requires collaboration across nations and disciplines. The interconnectedness of ocean health with climate change and public health emphasizes the need for a unified approach. Effective ocean literacy initiatives should integrate insights from various fields, including marine science, psychology, and education. This transdisciplinary approach can help address the diverse dimensions of human-ocean relationships and promote effective policymaking.

Ocean literacy can serve as a policy mechanism to align with global sustainability goals, such as the United Nations Sustainable Development Goals (SDGs). By embedding ocean literacy into educational frameworks and public policy, stakeholders can enhance community resilience and promote sustainable practices (Glithero et al., 2025; Husna et al., 2024; McRuer et al., 2025; Scowcroft et al., 2021).

Referring to some foundational and conceptual works about ocean literacy, the existence of the International Ocean Literacy Survey (OLS) which measures ocean knowledge across the world, already translated into 17 languages and tested in 24 countries is one significant tool to address the ocean literacy status. Psychometric analyses show that IOLS is a valid and reliable instrument that measures a single factor - ocean literacy (Fauville et al., 2019).

The United Nations Ocean Decade Ten Goals and Challenges[1], the Unesco Ocean Literacy seven Principles Framework[1] and, the National Oceanic and Atmospheric Administration (NOAA) seven Essential Principles of Ocean Literacy Framework[3], are considered among the most relevant organizations in the education and conservation of the ocean and ocean literacy areas.

(1) https://oceandecade.org/
(2) https://oceanliteracy.unesco.org/
(3) https://oceanservice.noaa.gov/

Regarding the evolution of the concept of ocean literacy, which has gained increasing recognition as a mechanism for change within the United Nations Ocean Decade's goals, McKinley et al., (2023) propose a new framework with ten dimensions of ocean literacy. In their work, Glithero et al. (2025); Kelly et al. (2022b) discuss the importance of improving public understanding of the ocean and sustainable ocean use, known as "ocean literacy", to achieve global commitments to sustainable development by 2030 and beyond. They identify four key drivers that can also influence and improve ocean literacy: (1) education, (2) cultural connections, (3) technological developments, and (4) knowledge exchange and science-policy interconnections. The authors present an "ocean literacy toolkit" that provides a practical framework for enhancing ocean connections across diverse contexts worldwide. The toolkit includes best practice principles, a design and implementation framework, and examples of successful ocean literacy initiatives.

Online educational platforms, including MOOCs (Massive Open Online Courses), have emerged as effective means to democratize ocean literacy. They can reach a global audience, fostering awareness and engagement with marine issues. For instance, the "Exploring Our Oceans" MOOC has successfully engaged thousands of participants worldwide, demonstrating the potential of digital learning environments (Fielding et al., 2019).

Immersive technologies, particularly virtual reality (VR) and augmented reality (AR), are also playing a transformative role in enhancing ocean literacy initiatives globally. These technologies provide engaging, interactive experiences that can significantly improve understanding and attitudes towards ocean conservation and sustainability among diverse audiences. AR and VR cater to various learning preferences, making complex subjects more approachable. They facilitate hands-on practice in simulated environments, which is particularly beneficial in educational settings where traditional methods may fall short (Klippel et al., 2025a; Varpe et al., 2026a).

Integrating ocean literacy into educational curricula is essential for fostering a generation that values and understands the ocean. This includes developing resources that are culturally relevant and accessible to diverse audiences. Practical contributions also involve creating participatory initiatives that engage local communities in ocean conservation efforts. This can help bridge the gap between scientific knowledge and community action, ensuring that ocean literacy is not just theoretical but actionable (McCauley et al., 2021; Nicola et al., 2025a).

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VR/AR ARE PARTICULARLY POWERFUL FOR OCEAN EDUCATION

Ocean education often involves complex and abstract concepts. VR and AR can visually depict these concepts, making them easier to understand. For example, students can explore underwater ecosystems, observe marine life, and understand oceanic processes in a highly interactive manner, allowing students to experience the ocean in a way that traditional methods cannot, making learning more captivating and enjoyable (Kononov et al., 2025; Spivey et al., 2025; Vashisht, 2024). VR and AR enable students to engage in hands-on practice through simulations and interactive experiences. This is particularly useful in ocean education, where real-world field trips can be logistically challenging and expensive. These technologies also provide a safe environment for students to conduct experiments and explore the ocean without the risks associated with real-life underwater activities (Naqvi et al., 2024; Varpe et al., 2026b).

Immersive media, particularly AR, can bridge the gap between distant environmental issues and learners by providing experiential marine environmental education. VR simulations, such as underwater virtual reality field trips, enable learners to experience marine environments without physical presence, enhancing their understanding of marine ecosystems and environmental dynamics. For instance, platforms like V-CURRENTS offer underwater virtual reality field trips, making the ocean accessible to learners who might otherwise have limited exposure to marine environments (Ikramov et al., 2025; Klippel et al., 2025a).

Rigorous experimental research demonstrates that XR technologies produce measurable learning outcomes and behavioural changes related to ocean literacy. The study by Markowitz et al. (2018) tested immersive VR with over 270 participants across four different learning settings, showing that people consistently demonstrated knowledge gains about ocean acidification and climate science after experiencing virtual underwater worlds. This research is particularly significant because it validated learning effects across diverse participant groups including high school students, college students, and adults, using multiple assessment measures from learning gain scores to qualitative teacher feedback.

Research indicates that immersive learning tools can significantly increase knowledge acquisition and awareness of ocean-related issues. The immersive and interactive nature of VR and AR has been shown to improve knowledge retention and comprehension. Students are more likely to remember what they have learned when they can interact with the material in a meaningful way. These technologies foster the development of critical thinking, problem-solving, and collaborative skills which are essential for understanding and addressing complex environmental issues related to the ocean (Ali et al., 2022).

For example, a study involving an AR game-based educational tool demonstrated substantial improvements in students' understanding ocean literacy dimensions, including knowledge, awareness, and activism (Leitão et al., 2025). Programs that integrate immersive technologies have shown to revitalize student interest and engagement in ocean literacy topics. For instance, a project in Brazil that combined theoretical lessons with hands-on activities resulted in improved student attitudes and a deeper connection to local marine environments (Pazoto et al., 2023). VR and AR can also make the ocean accessible to students who may not have the opportunity to experience it in person. This is particularly important for students in landlocked areas or those with physical limitations by addressing challenges related to accessibility in ocean education. These technologies can provide diverse learner populations with equal opportunities to engage with marine content, regardless of their geographical location or physical abilities. The above-mentioned technologies can enhance students' awareness of sustainability issues and the importance of ocean conservation.

By immersing students in virtual ocean environments, they can develop a deeper understanding and appreciation of marine ecosystems (Zekeik et al., 2026a). VR experiences, such as Underwater Virtual Reality (UVR), create high levels of presence and emotional engagement, which can trigger powerful emotions like awe and empathy. This emotional connection can improve ocean literacy by making marine environmental issues more relatable and urgent, and VR diving experiences also allow students to observe marine life and ecological issues firsthand, increasing their motivation to learn about and protect the ocean (Fauville et al., 2024).

Immersive technologies can be systematically integrated into existing ocean literacy curricula. A conceptual framework has been proposed by Muktiarni et al (2025) to embed VR and AR into vocational education, particularly in tourism, aligning with Sustainable Development Goals (SDGs). This framework emphasizes the need for curricula to include ocean-related competencies and immersive tools. Several of these tools facilitate collaboration and dialogue among learners, although challenges such as the lack of real-time interaction need to be addressed and platforms like the Iliad Academy provide comprehensive resources and training on digital ocean technologies, fostering interdisciplinary collaboration and knowledge-sharing (Hetherington et al., 2026a; Shahinyan & Kazanjian, 2025).

Research shows that XR technologies effectively improve ocean literacy by increasing knowledge gains, strengthening environmental attitudes, and enhancing donations to conservation causes. Studies reveal that the more students explore virtual marine environments, the better they learn complex concepts like ocean acidification.

However, researchers note that understanding XR learning outcomes requires examining multiple aspects of the technology rather than individual components in isolation. This suggests that future research should take more holistic approaches when evaluating the effectiveness of XR interventions for ocean literacy, considering how different technological elements work together to produce learning outcomes (Aguayo et al., 2023).

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APPLICATIONS OF VR IN OCEAN LITERACY

VR technologies are increasingly being integrated into ocean literacy education, enhancing student engagement and understanding of marine ecosystems. In this section, a summary of VR projects and technologies is listed regarding their implementation in educational settings, and their main goals and outcomes.

Immersive VR platforms such as V-CURRENTS, CoSpaces EDU, UVR, VR-Ocstal, and VREX are effectively utilized for teaching ocean literacy. These platforms offer engaging, realistic, and interactive experiences that enhance learning and foster a deeper connection to marine environments. However, the integration of these technologies requires careful consideration of teacher involvement and the emotional impact on learners. Some of the additional key findings and benefits of the above technologies and projects are an improvement in engagement and learning, a relevant emotional and psychological impact, and stronger collaborative learning.

To enhance ocean literacy education in schools, several innovative immersive technologies can also be utilized. These key technologies provide engaging, interactive, and effective learning environments that can significantly improve students' understanding and appreciation of marine ecosystems, such as underwater VR experiences, AR game-based learning, among others.

VR and AR are powerful tools for enhancing ocean literacy education in schools. However, challenges such as technological limitations, lack of teacher training, and funding issues must be addressed to fully realize their potential. By integrating gamification techniques, problem-based learning (PBL) or inquiry-based learning (IBL), which foster collaborative learning environments, educators can create a more dynamic and impactful ocean literacy curriculum that prepares students to engage with global conservation efforts effectively.

CHALLENGES AND LIMITATIONS

Implementing immersive technologies such as VR, AR, and MR in education, particularly for ocean literacy, presents several challenges and limitations. The integration of extended reality into educational frameworks offers a ground-breaking approach to deepening the public's understanding of marine ecosystems and their critical role in planetary health. These can be broadly categorized into technological, financial, pedagogical, and contextual barriers.

TECHNOLOGICAL CHALLENGES

The integration of immersive technologies requires significant technical knowledge and expertise, which can be a barrier for educators who may not be proficient in these technologies. Also, many educational institutions, especially in developing countries, face infrastructure limitations and lack the necessary infrastructure to support immersive technologies. Effective use of VR often requires robust internet connectivity, which can be a significant barrier in many educational settings, especially in rural or underdeveloped areas. Limited bandwidth can restrict the use of high-quality VR applications, leading to a subpar educational experience (Mondal & Mondal, 2025; Yadav, 2025). Content availability might also be a problem since a lack of localized and relevant content that aligns with the curriculum, makes it difficult for educators to effectively integrate these technologies into their teaching practices (Msweli & Kgopa, 2025).

FINANCIAL CHALLENGES

The initial investment for VR technology can be substantial, which includes the cost of headsets, computers, and other necessary hardware. This financial barrier is particularly pronounced in resource-constrained environments, where schools may struggle to afford such technology (Zekeik et al., 2026b). To develop and scale immersive technology solutions to be sustainable over the long term is also challenging due to the high initial investment and ongoing maintenance costs (Bosman et al., 2024; Mondal & Mondal, 2025). Several socio-economic disparities significantly influence the accessibility and adoption of immersive technologies in education. In resource-constrained environments, high costs, limited access to technology, and socio-cultural resistance can impede the integration of AR and VR. These factors vary across regions, with developing countries facing more pronounced challenges compared to developed nations (Mondal & Mondal, 2025). In some cases, institutional resistance to change and a lack of strategic investment in technology can further complicate the adoption of immersive learning tools. Effective implementation requires not only financial resources but also a supportive policy environment that encourages innovation in teaching practices (Cabero-Almenara et al., 2026; Msweli & Kgopa, 2025).

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PEDAGOGICAL CHALLENGES

A significant barrier is the lack of adequate training for educators. Many teachers feel unprepared to integrate these technologies into their teaching practices due to insufficient professional development opportunities. Effective use of immersive technologies requires comprehensive teacher training and ongoing professional development to ensure educators are comfortable and proficient in using these tools. Current knowledge shows that immersive technologies need to be carefully integrated into the curriculum to ensure they meet educational objectives and enhance learning outcomes. This requires thoughtful instructional design and alignment with pedagogical goals. To effectively incorporate immersive technologies, pedagogical frameworks must also evolve. Current curricula often do not systematically integrate ocean-related competencies or immersive tools, necessitating the development of new models that link technology with knowledge, skills, and sustainability values. Educators need to adopt flexible, multi-tiered training frameworks that cater to varying levels of experience among teachers (Izouaouen et al., 2025; Muktiarni et al., 2025). The development of robust methodologies to evaluate the effectiveness of immersive technologies in achieving learning outcomes is also essential. This includes assessing user satisfaction, motivation, and learning progress (Law et al., 2008; Mamadiyarov et al., 2025; Mendoza et al., 2023).

CONTEXTUAL CHALLENGES

One of the unique challenges in ocean literacy is making distant and often abstract oceanic issues relatable and engaging for students. Immersive technologies can help bridge this gap, but their effectiveness depends on how well they are integrated into the learning experience. Ensuring that all students, regardless of their background, have equitable access to immersive learning experiences is crucial. This includes addressing the digital divide and ensuring that marginalized groups are not left behind (Klippel et al., 2025b; Nicola et al., 2025b). The complexity of virtual environments can be overwhelming, leading to disengagement if not managed properly. Educators must be aware of these potential challenges and design experiences that are both engaging and manageable for learners. An effective usage of VR in ocean literacy education also depends on the availability of localized content that resonates with students' experiences and environments. The absence of such content can limit the relevance and impact of VR applications. (Ndjama & van der Westhuizen, 2024). Immersive experiences can foster a deeper connection to ocean literacy by allowing students to explore underwater environments virtually. However, educators need to ensure that these experiences are meaningful and relevant to students' lives to maintain motivation and interest (Hetherington et al., 2026b; Ikramov et al., 2025).

While immersive technologies hold great potential for enhancing ocean literacy education, addressing the technological barriers, adapting pedagogical frameworks, considering socio-economic factors, and understanding psychological challenges are crucial for successful implementation. By strategically overcoming these challenges (high costs, hardware and software limitations, internet connectivity issues, and the necessity for comprehensive teacher training), educators can create more engaging and effective learning experiences that promote a deeper understanding of ocean ecosystems and sustainability.

CONCLUSION AND RECOMMENDATIONS

The effective promotion of ocean literacy through immersive technologies requires considerable access to technological infrastructures, specialized educational content and software, a pedagogical redesign and training, supported by significant collaboration and an interdisciplinary approach.

To effectively promote ocean literacy through immersive technologies, several recommendations can also be made. These suggestions aim to address the challenges and barriers identified earlier, ensuring that educators and students can fully benefit from the potential of immersive technologies.

Encourage educational institutions to apply for grants and funding from government agencies, NGOs, and private organizations dedicated to educational technology and environmental education and develop partnerships between schools, local governments, and businesses to share the costs of acquiring and maintaining immersive technology resources.

Invest in improving internet connectivity and technological resources in schools, particularly in underserved areas, to ensure that all students have access to immersive technologies and establish dedicated VR labs in schools or community centres where students can access immersive technologies without the need for individual ownership.

Collaborate with marine scientists, educators, and content creators to develop localized and contextually relevant VR content that aligns with ocean literacy goals and curriculum standards. Promote the creation and sharing of open-source VR educational materials that can be adapted and used by educators worldwide.

Implement ongoing professional development programs that equip educators with the skills and knowledge to effectively integrate immersive technologies into their teaching practices. Foster communities of practice where educators can share experiences, resources, and best practices related to the use of immersive technologies in ocean literacy education and ensure that VR applications are designed with usability in mind, minimizing technical barriers and cognitive load for students. Also develop immersive technologies that are accessible to all students, including those with disabilities, to ensure equitable learning opportunities.

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Organize community events, workshops, and campaigns to raise awareness about ocean literacy and the role of immersive technologies in education to engage parents, local communities, and marine organizations in the development and implementation of immersive technology initiatives to foster a collaborative approach to ocean literacy.

Develop robust methodologies to evaluate the effectiveness of immersive technologies in achieving learning outcomes related to ocean literacy and collect feedback from students and educators to continuously improve the immersive learning experience and address any challenges that may arise.

Support research initiatives that explore the most effective ways to integrate immersive technologies into ocean literacy education, including case studies and pilot programs while encouraging the development of new immersive technologies and applications that specifically target ocean literacy and environmental education.

The observation of some of these recommendations by educational institutions could help to promote a supportive environment for the integration of immersive technologies, ultimately enhancing ocean literacy and fostering a deeper understanding of marine ecosystems among students.

All the oceans and maritime environments in general will appreciate and be grateful for all efforts developed in this regard!

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④ USER TESTING METHODOLOGIES FOR IMMERSIVE SHIPWRECKS 360 DEGREE VIDEO EXPERIENCE



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User Testing Methodologies For Immersive
Shipwrecks 360 Degree Video Experience
Future Shipwrecks

ABSTRACT

360 degree videos offers transformative potential for immersive digital experiences, yet developing high-quality applications remains a significant challenge due to the limitations of traditional usability testing methodologies. Conventional 2D-based frameworks, such as Nielsen's heuristics and WIMP-based (Windows, Icons, Menus, Pointers) interfaces, often fail to account for unique VR variables, including 3D spatial interaction, presence, immersion, and physiological factors like cybersickness. This research aims to address the gap in platform-agnostic evaluation frameworks by reviewing established User Experience (UX) methodologies and proposing a structured user testing approach specifically for Head-Mounted Display (HMD) environments.

INTRODUCTION

Background

360 degree videos are a type of immersive media experience that belong to the family. Virtual Reality (VR) applications. VR is defined as a "class of technologies that are new, rapidly evolving, and capable of reshaping practices, industries, or social relations" (Sawyer & Tyworth, 2011). While technical advances have made VR more accessible, the difficulty of developing high-quality, user-centric experiences has prevented it from reaching the mainstream. User testing for VR presents challenges that transcend traditional usability testing; variables such as immersion, hardware constraints, and physiological responses require a specialized methodology. Rotolo, Hicks, and Martin (2015) identified five key attributes of emerging technologies: radical novelty, relatively fast growth, coherence, prominent impact, and uncertainty. These attributes create a fast-changing landscape that demands creative new approaches to development frameworks, design patterns, and, crucially, user testing.

Problem Statement

Current 2D-based user testing methodologies can be applied and adapted to evaluate immersive experiences. Existing frameworks for screen-based, WIMP (Windows, Icons, Menus, Pointers) interfaces do not adequately account for the unique challenges of 3D spatial interaction, presence, and immersion. Systematic reviews note that 360 videos boost motivation and information retention in education but face logistical barriers like small sample sizes and HMD discomfort. (Ranieri et al 2016).

Research Objectives

- To review established 2D UX and usability testing methodologies and evaluate their applicability to VR and immersive experiences.

- To examine how immersion and presence are defined and measured in immersive environments.

- To identify gaps in current VR-specific design and evaluation frameworks.

- To propose and apply a methodology for user testing a specific immersive experience: the Shipwrecks experience.

Scope and Limitations

This report focuses on head-mounted display (HMD)-based VR experiences, with reference to the Immersive Shipwrecks experience (Quidco, et al 2026). While augmented reality (AR) and mixed reality (MR) are discussed where relevant, they are not the primary focus. The review of literature is primarily from 2018 onwards, though foundational theories (e.g., presence, flow) are referenced where necessary.

LITERATURE REVIEW

User Experience Design and Human-Centred Design

User experience encompasses all aspects of the end-user's interaction with a company, its services, and its products (Norman, 1998). Human-centred design (HCD) is an approach to systems design that aims to make interactive systems more usable by focusing on human factors, ergonomics, and usability knowledge (ISO, 2019). The International Organization for Standardization (ISO) codified HCD as international best practice in software and systems design in both 2010 and 2019.

Design for 2D screen-based systems is a well-established field. Models such as Norman's design principles, Schneiderman's (2016) eight golden rules, and Nielsen's (1994) usability heuristics have been used for decades and share common recommendations around consistency, visibility of system status, feedback, error prevention, and recovery. Accessibility standards, such as the Web Content Accessibility Guidelines published by the W3C (2025), further codify testable criteria for inclusive digital design.

Differences Between 2D WIMP and Immersive Interfaces

Unlike 2D interfaces that operate on a flat x-y axis, 3D immersive interaction adds depth and scale (x-y-z axis), where both objects and the user possess volume and orientation. 3D immersive environment have not yet developed a standardised set of interaction paradigms and UI metaphors that are common in 2D WIMP systems (e.g., files, recycling bins

Key additional challenges for VR UX include:

- Spatial Interaction: 3D object placement, scale, locomotion, and navigation;
- Presence and Immersion: Supporting spatial, social, and cognitive presence;
- Input Methods: Gestures, gaze, voice, and controllers that feel intuitive;
- Ergonomics: Minimising cybersickness, fatigue, and maximising comfort;
- UI and Information Design: Balancing HUDs vs. diegetic UI and managing cognitive load;
- Safety and Ethics: Preventing physical collisions and protecting user privacy.

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Development Tools and Ecosystems

Most XR experiences are built with game engines primarily Unity and Unreal Engine, which provide systems for rendering, physics, audio, animation, UI, and scripting. Platform-specific middleware such as Unity XR Interaction Toolkit (XRI), Meta's Interaction SDK, Apple's ARKit, and Microsoft's MRTK3 provide pre-built components for common VR interactions, though these tend to be proprietary and platform-dependent.

OpenXR is an open standard supported by Meta, Microsoft, Valve, Google, HTC, and others — represents a significant step towards platform-agnostic development. No-code and low-code tools such as Spatial.io, ShapesXR, and ZapWorks further lower the barrier to entry, though they introduce concerns around proprietary lock-in and data privacy (Slovák et al., 2020).

360 degree videos are edited and produced in industry-standard editing environments, such as Adobe Premiere or DaVinci Resolve.

Generative AI is increasingly disrupting development workflows. Tools such as Luma, Polycam, Meshy AI, and Kaedim AI enable 3D asset creation from text, images, or video.

Existing VR UX Frameworks and Their Limitations

The absence of a platform-agnostic design and evaluation framework for XR is noted by both the W3C and ISO. The W3C's Immersive Web Working Group's recommendations are not yet finalised (W3C, 2024), while the ISO has focused primarily on technical standards, ergonomics, and health rather than UX frameworks.

The XR Association (XRA) published development guides beginning in 2019, covering design principles, safety, accessibility, and domain-specific guidance. However, these are industry-driven rather than grounded in empirical research, and they lack a systematic, platform-agnostic framework.

Academic efforts, such as the 11 guidelines derived by Vi, Silva, and Maurer (2019/2020), lack extensive empirical validation. Yang, Zhou, and Radu (2020) proposed the XR-Ed Framework with six design dimensions, though it operates at a macro level and offers limited guidance for lower-level design decisions.

Evaluation and Usability Testing in VR

Guo et al. (2023) discovered that applying Nielsen's 10 heuristics in VR creates difficulties in identifying and recording issues due to the immersive nature of the medium. They identified five critical challenges to the standard heuristic evaluation heuristics in a VR environment: inspecting and identifying issues, recording and describing issues, matching and analysing issues, and applying heuristics appropriately to VR.

Omar et al. (2024) similarly highlighted the lack of consensus around XR UX and proposed an extended set of 52 heuristics and 156 sub-heuristics adapted for the metaverse. While comprehensive, this represents a checklist approach rather than an empirically validated framework.

Immersion and Presence

Presence is defined as the psychological state of being “inside” a virtual environment (Slater & Wilbur, 1997). Slater (2009) distinguishes between Place Illusion (PI)—the feeling of being in a location—and Plausibility Illusion (Psi)—the feeling that the events occurring are real.

Presence is the psychological experience; immersion is the technological affordance that enables it.

Lombard (1997) defines immersion as the illusion of non-mediation. Immersion is the technological affordance that enables presence Slater identifies five factors that elicit high levels of presence:

- Inclusive: The extent to which physical reality is excluded. Shu et al. (2019) find significantly higher presence, self-efficacy, and engagement in HMD users compared to desktop users across 64 participants completing a virtual chemistry simulation.

- Extensive: The number of sensory modalities supported. Juan et al. (2009) highlight head tracking and multimodal input as key factors in presence with acrophobic participants.

- Surrounding: The extent of the user’s sensory field coverage.

- Vivid: The fidelity and richness of sensory input This has improved significantly over the different generation of headsets, e.g., the Quest HMD resolution increased from 1440 × 1600 per eye (Quest 1, 2019) to 2064 × 2208 (Quest 3, 2023).

- Matching (sensorimotor contingencies): The accuracy of sensorimotor contingencies (e.g., low-latency hand tracking). The Quest 3 headset tracks hands with a latency of approximately 70ms using inside-out tracking.

Evaluating Immersion

The Temple Presence Inventory (TPI), developed by Lombard, Weinstein & Ditton (2009), is widely used to compare presence across different media (TV, games, VR, etc.).

Hartman et al (2015)’s Spatial Presence Experience Scale (SPES) is a concise, eight-item diagnostic tool designed to measure a user’s subjective sensation of “being there” within a virtual or mediated environment. The researchers of this instrument define this experience through two distinct dimensions:

- Self-location: involving the feeling of being physically situated in the media space.

- Possible actions: relates to the perception of being able to act and move within that space.

Research Gap

Despite a growing body of work on immersion in VR UX and presence, there remains no empirically validated, platform-agnostic framework for evaluating immersive experiences across different contexts. Traditional heuristic evaluation methods are insufficient, and domain-specific tools (e.g., for the metaverse or education) lack broader applicability.

METHODOLOGY

This section outlines a mixed-methods approach to elicit feedback on self-location and possible actions using the Spatial Presence Experience Scale (SPES) within the Immersive Shipwrecks experience.

User testing before, during and at the completion of a project has many advantages. Developers can share findings promptly with design and engineering teams. Issues can be identified early before they become more time consuming and expensive to fix. This essay describes a formal usability test which is the practice of testing a design with a group of representative users. Observing them complete tasks to identify any pain points or design issues.

Participants

Participants will be pre-screened for medical conditions, including pregnancy, binocular vision abnormalities, or heart conditions. Following Nielsen’s (2000) assertion that five participants can identify up to 85% of usability problems, a small but targeted cohort will be used. Participants must provide informed consent and are briefed on their right to withdraw if they experience cybersickness.

Preparation and Environment

Participants need to be able to move around safely so a space of at least 2m x 2m free of any obstacles is required. The immersive studio in IADT is a large room where this is possible. This is critically important because the headset obscures physical reality and users may collide with walls or other people. The test can be conducted using a Head-mounted Display (HMD) like the Meta Quest 3. In preparation the HMDs need to be fully charged and cleaned with a lens wipe, The participants will adjust the head strap and the interpupillary distance (IPD) to the their requirements to avoid eye strain and cybersickness. By fully utilising the Quest 3’s high resolution (2064 x 2208 per eye) the “Vivid” factor of immersion can be enhanced. However, higher visual detail can sometimes increase cybersickness.

Table 1: Hardware and Software requirements for Immersive Shipwrecks usabiIity test

Item	Specification / Version	Purpose
HMDI Device	[e.g., Meta Quest 3]	Primary display device for the Shipwrecks experience
Dev Environment	Adobe Premiere	Development platform
Presence Scale	Spatial Presence Experience Scale (SPES)	Measuring user presence
Recording Software	OBS or built-in logging	Capturing user behaviour and “think-aloud” audio

Procedure

It is helpful to sequence the experiment into the following steps outlined below. These testing is usually concerned with impression, comfort, immersion, learnability, navigation or interactions of the immersive environment. The participants are tested on their understanding of the topic of the immersive video after the active testing phase.

① Briefing: Participants are briefed and medically pre-screened to ensure that their participation is safe.

② Onboarding: Participants are familiarised with the HMD controls and given instruction how to navigate inside the immersive environment.

③ Active Testing: Participants will complete the Immersive Shipwrecks experience while using the think-aloud protocol expressing reactions and emotions in real-time. This session data is recorded using a screencast recording software, such as OBS.

④ Debriefing: Completion of the SPES questionnaire and a post-session qualitative interview to elicit free-form qualitative feedback of their experience and their understanding of the subject-matter.

While engaged in the active testing phase participants are asked to follow the “think out aloud” protocol, while completing the experience, this allows observers to take note of any issues or difficulties encountered. The test can be recorded in first person view using the screen capture feature on the Quest 3 HMD, the view can also be streamed to another computer for recording.

Post-test interviews are used to capture more qualitative feedback.

Data Collection

The survey design is a combination of quantitative and qualitative measures:

The quantitative measures are as follows:

- Participants success in navigating and completing the immersive experience.

- Transcripts can be used for thematic analysis to group findings by theme.

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[Joachin Pietsch]

- The level of immersion will be analysed by completing the SPES questionnaire to gain presence scale scores for the prototype.

The qualitative measures are:

- A think-aloud protocol during completion of task inside the VR environment.

- A post immersion Interview to elicit further feedback from the participants that is not covered by the questionnaire and task completion.

- Any issues highlighted can be ranked according to severity from small cosmetic changes to critical problems that prevent tasks from being completed.

POST-IMMERSION ASSESSMENT (SPES INSTRUMENT)

After concluding the active test session, the participants will complete the Spatial Presence Experience Scale (SPES) questionnaire which consists of an 8-item self-report measure rated on a 5-point Likert scale (1: I do not agree at all, 5: I fully agree)

It measures 2 sub-dimensions:

- Self-Location: (e.g., “I felt like I was actually there in the environment.”)
- Possible Actions: (e.g., “I felt like I could move around among the objects.”)

CONCLUSION

This report examined how established 2D user testing methodologies can be applied to the evaluation of immersive experiences. The literature review established that traditional frameworks including Nielsen’s (1994) usability heuristics, Norman’s (1998) design principles, and ISO 9241-210 (2019) do not adequately address the challenges of 3D spatial navigation, embodied input, presence, and cybersickness.

By combining task-based testing with the SPES instrument, developers can gain a holistic view of both functional performance and the quality of immersion. While the Immersive Shipwrecks pilot was concluded in April 2026, this proposed methodology provides a replicable, platform-agnostic framework for future immersive experience evaluation.

User Testing Methodologies For Immersive Shipwrecks 360 Degree Video Experience
Future Shipwrecks

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⑤ ON FUTURE SHIPWRECKS

IMPACTS OF CLIMATE CHANGE ON THE PENICHE PENINSULA AND THE PORTUGUESE COAST



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Impacts Of Climate Change On The Peniche
Peninsula And The Portuguese Coast
On Future Shipwrecks
Future Shipwrecks

ABSTRACT

The Peniche coastline is a dynamic system shaped by the interaction between natural processes and human occupation over time. During the Last Glacial Maximum, around 20,000 years ago, mean sea level was about 120 m lower than today, placing the coastline much further west. Following deglaciation, sea levels rose throughout the Holocene, causing marine transgression and the silting of estuaries. This led to the formation of sand spits, lagoons, and the tombolos of Peniche and Baleal.

Historical cartography from the 16th to 19th centuries documents the coastline's evolution, depicting isolated islands, emerging isthmuses, lagoon systems, and changing estuarine dynamics. These records are key to understanding recent landscape transformations. A notable example of the coastline's hazards is the 1786 shipwreck of the Spanish vessel San Pedro de Alcántara near Papoa, illustrating the dangers of rocky seabeds and harsh ocean conditions.

Human occupation dates back to the Paleolithic, as shown by sites like Furninha Cave. During the Neolithic and Roman periods, marine resources were widely exploited. Today, rising sea levels linked to climate change increase the risk of coastal erosion and flooding in low-lying areas, threatening the stability of the Peniche coastline.

PENICHE: A CHANGING COASTLINE AND HUMAN OCCUPATION – 20,000 YEARS OF ADAPTATION

How did the coastal zone of the Peniche region evolve after the last glaciation and how was the human occupation of this territory until about 1000 years ago?

The evolution of the coastline in the Peniche region can be reconstructed by studying the geological record preserved in boreholes in the sedimentary deposits of these coastal areas. In other words, we can study the deposits in places that have experienced siltation. Over time, these deposits will overlap and store the history of environmental variations in each place, acting as sheets in an encyclopaedia. These geological data can be supplemented by archaeological studies and analysis of historical sources, including cartographic, ichnographic and written documents.

At the height of the most recent glacial period (the Würm glaciation), which occurred approximately 20,000 years ago, the volume of water retained outside the major ocean basins caused the mean sea level (MSL) to be 120 metres lower than it is today. In the Peniche region, the continental shelf extended further west, with the coastline located 10–20 km from its current position (Figure 1). This indicates that the contemporary coastline of the last glaciation would be positioned even further west.

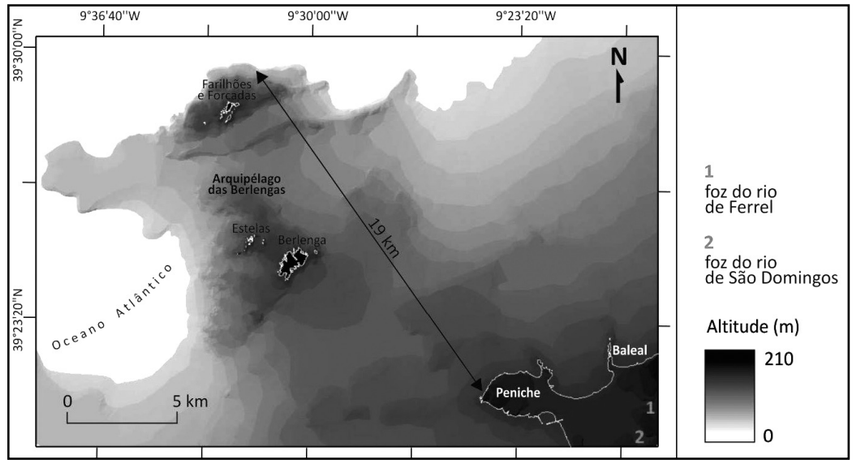


Figure 1 - Approximate outline of the coastline of the Peniche region at 18,000 BP ago.

Image Sources: [Adapted from Pancada, 2011]

Archaeological studies have made it possible to identify several places in the Peniche region with evidence of human occupation during this cold period when the sea level was low: the most important of the sites with Palaeolithic remains is the Furninha Cave (aged between 1.2 million and 12,000 years) (Raposo, 1995; Cunha *et al*., 2017; Figueiredo *et al*., 2020).

Later, during the Neolithic period (8000–5000 years ago), the MSL reached close to its current level, and we witnessed the flooding (HOLOCENE TRANSGRESSION) of low-lying coastal areas such as valleys and bays.

Traces of Neolithic occupation in the Furninha Cave suggest that Homo sapiens used it as a necropolis, and the dating of human bones indicates that the cave was last used in the late Neolithic–Chalcolithic period (Cardoso & Carvalho, 2010/2011). In the Peniche region, there is another Neolithic site in the Baleal area where clusters of malacological fauna were found. Starting with a more monospecific level of oysters, the fauna evolved to include a greater diversity of species, including malacofauna and ichthyofauna, as well as lithic industry and some ceramics. The reduced material density of the archaeological site (a shell midden) seems to confirm its association with the exploitation of aquatic resources (Rendeiro, 2018; [1]). The presence of shells in the region attests to the proximity of the sea to this area during the Neolithic period.

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When the Romans arrived in this territory, Peniche and Baleal were already islands, as well as Berlengas, with the rise of the SLR. Roman remains in the region, such as the Murraçal or Morraçal da Ajuda site (which features pottery ovens), indicate occupation between the last quarter of the 1st century BC and the beginning of the 3rd century AD. This pottery, which had four ovens [2], was found by a Roman citizen Lucius Arvénio Rustico. The presence of this pottery, one of the oldest built in Lusitania at the beginning of the Roman Empire, on the island of Peniche, and the associated remains, attest to the importance of fishing in Peniche during the High Empire, from the first to the beginning of the second century, as well as to the fish canning industry. Common ceramics indicate the need for local and regional consumption of these containers in daily domestic life, and loom weights suggest artisanal weaving activity (Cardoso & Rodrigues, 2005). Its operation ceased at the end of the second and beginning of the third century AD, seemingly due to political instability affecting the entire Roman Empire (Cardoso *et al*., 2016), as well as the large concentration of fish derivative factories in the estuaries of the Tagus, Sado and Algarve (Cardoso & Rodrigues, 2005).

Another set of archaeological remains from the Roman era (Archaeological Site of Rua Azedero Perdigão), possibly dating from the first to third centuries AD, once again highlights the significance of the Roman settlement on the island of Peniche. Analysis of the archaeological materials and the site's historical context allows us to formulate some hypotheses about its function: it may have been a warehouse to support port activity or a structure for preparing and producing fish products [3].

Traces of Roman occupation were also found on the island of Berlenga (at the site known as the 'Fishermen's Quarter' between the end of the first century BC and the fifth century AD), which seem to be related to the use of the island as a port of refuge on Roman long-distance routes, as reflected in underwater and ceramic finds. Conversely, the significant presence of locally produced amphorae in the Fishermen's Quarter may suggest a different type of occupation, possibly involving the permanent settlement of populations engaged in fishing and fish processing, similar to what occurs today (Bugalhão & Lourenço, 2011).

Around 2000–1500 years ago, the coastline of this region was dotted with islands (the Berlengas, the Farilhões, Peniche and the Baleal), home to communities closely associated with maritime activities. The rivers of Ferrel and São Domingos flowed freely into the ocean, and their estuaries were more extensive further upstream.

How has this coastal zone evolved in the last 1000 years, how have human communities adapted in recent centuries and what landscape have the navigators who approached this region seen?

Observing the Peniche region currently and using altimetric data, it is possible to obtain the map of slopes where the existence of three streams is noticeable (Figure 2): the Ferrel stream further north, the São Domingos stream in the intermediate position, and a smaller stream to the south-west of the latter. The three streams have parallel valleys and the same direction of water runoff, from south-east to north-west. However, this direction is interrupted, deflecting the course of the three streams to the west, where they begin to circulate through the same valley. This deflection appears to be a consequence of the growth of a sandspit to the south-west, which was anchored on the coast between Ferrel and the island of Baleal (Figure 3). Blot (2003, cited *in* Pancada, 2011) suggests that this sandy structure was formed in the 14th century and is visible as a sandy formation.

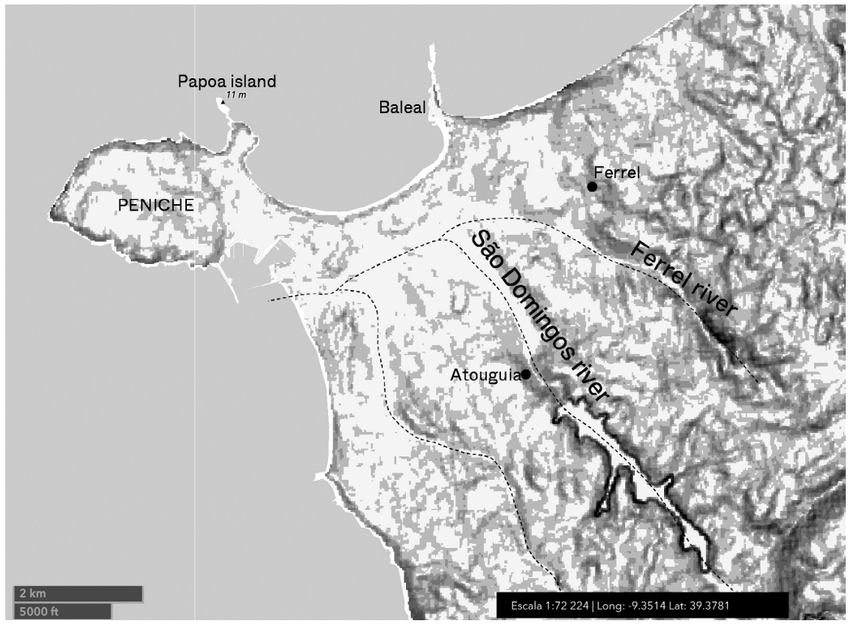


Figure 2 – Representation of the Peniche region, slope map showing drainage lines.

Image Sources: [Adapted using maps from geoportal.lneg.pt]

However, we believe that the confinement of the area between the island of Peniche and the mouths of the Ferrel and São Domingos estuaries would have been formed much earlier, around 5000 years ago. More recent geological data (Torres, 2013; Torres & Pereira, 2015), resulting from borehole studies in the agricultural floodplain north of Quinta dos Salgados and Porto de Lobos, indicate that the greatest marine influence occurred around 5090 years ago (cal BP), when sedimentation changed to finer sediments (muddy sands), denoting a decrease in the energy of the coastal environment. What was probably an exposed coastline with islands a little over 3 km from the mouth of three streams would have become a bay (lagoon) enclosed by the growth of sandbanks. Figure 3 illustrates the main evolutionary phases of the Peniche coastline.

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Confinement began around 6000–5000 years ago and continued, resulting in a decrease in hydrodynamics that promoted the silting of the stream valleys (2000 years BP).

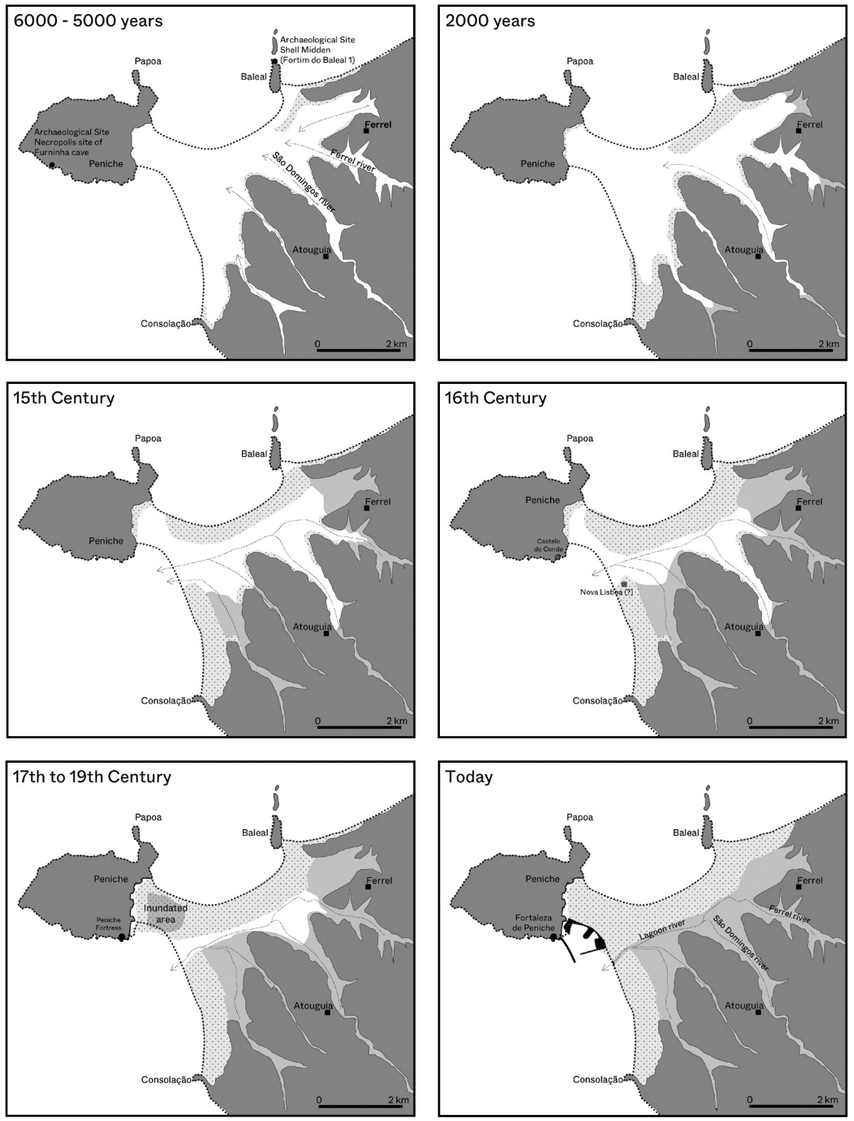


Figure 3 – Changes in the region between Peniche, Atouguia and Baleal over the last 6,000 years (the dotted line shows the position of the current coastline).

Historical documentary evidence shows that the island of Peniche was used as a shelter by local fishermen and had a small settlement until the end of the 16th century. It was only in the sixteenth century that this small village received royal recognition from King Manuel I. This development occurred because of the silting of the São Domingos river, which made it difficult for boats to access the port in Atouguia da Baleia. The emergence of a land connection to the island of Peniche, coupled with this difficulty, caused communities to progressively migrate to Peniche, leading to the decline of the housing nucleus of Atouguia and its medieval port (Oliveira, 2020). Sixteenth-century cartography (1560, 1561) shows a bay on the coast of this region with the village of Nova Lisboa marked on the south bank (Figure 4), as well as the island of Peniche in front. The south bank is marked with the reference “Castelo do Conde” (Figure 4A, 4B).

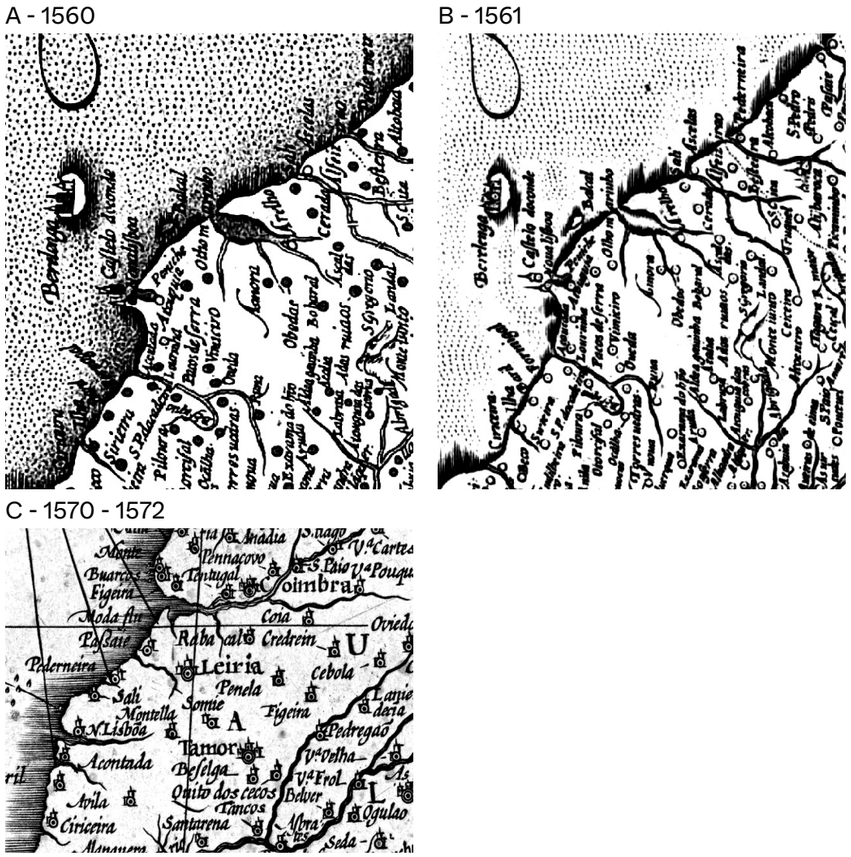


Figure 4 – [1560, 1561, 1570] - Maps of the region from 16th-century cartography: A – 1560 - PortugalIiae que olim Lusitania, novissima & exactissima descriptio [Material cartográfico] / Vernando AIvaro Secco]; B – 1561 - PortugalIiae que olim Lusitania, novissima & exactissima descriptio [Material cartográfico] / auctore Vernando AIvaroo Secco (Reprodução); C - Nova Hispaniae Descriptiom (1570 – 1612), Jodocus Hondius.

Image Sources: [A – available in: https://bndigital.bnportugal.gov.pt/records/item/15840-portugalliae-que-olimlusitania-novissima-exactissima-descriptio?offset=2] [B – available in: https://bndigital.bnportugal.gov.pt/viewer/16207/download?file=cc-665-a_0000.pdf&type=pdf&navigator=1] [C – available in: https://www.oldmapsonline.org/pt/maps/f86a5b6c-2f85-5488-869cee3fad034ddc?gid=15a1e0cf-174d-515b-9ddd-9dfb40f5a3cd#position=8.213/39.698/-9.182/2.18&year=1570]

The first defensive building on the island was constructed by the 3rd Count of Atouguia, D. Luíz de Ataíde, at the behest of his father, D. Afonso de Ataíde. Construction of the Round Fort began in 1557 and was part of the Fort of Peniche, whose construction was completed in 1578 (Oliveira, 2020). The reference to 'Castelo do Conde' in the cartography of the time must be due to the presence of the Round Fort, the construction of which was financed by the 3rd Count of Atouguia. The island of Baleal is also depicted without a land connection. Defensive structures in this coastal sector were of the utmost importance, as communities and vessels were subject to frequent attacks by pirates.

Seventeenth-century representations already show Peniche connected to the land by a tombolo. However, careful observation of the depicted details provides some interesting information, which we will refer to below:

• 1630 (Figure 5): a complete tombolo at Peniche, although the east wall of the island is visible;

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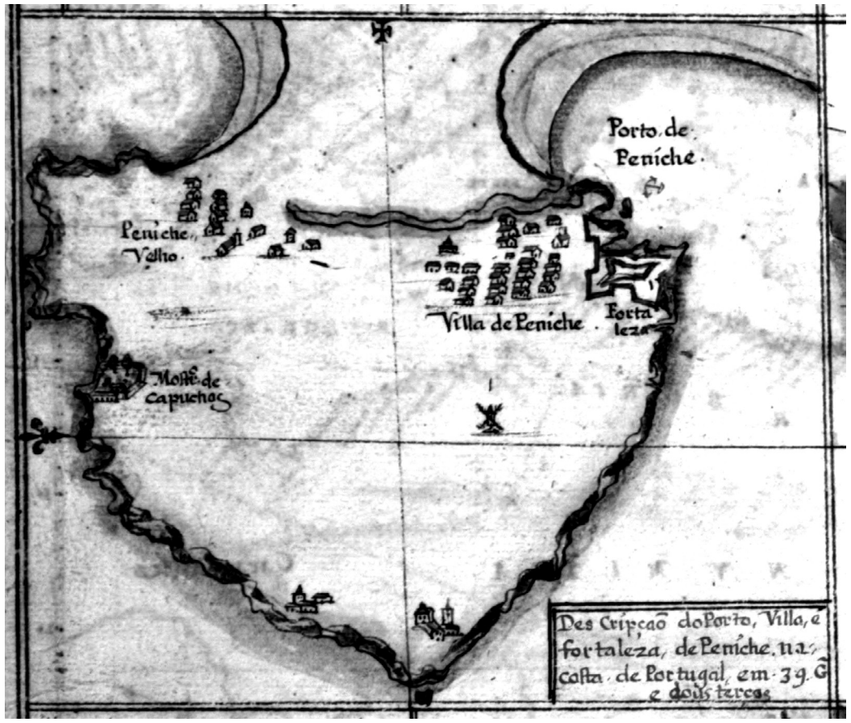


Figure 5 – [1630] - Map of the region from 17th-century cartography: "Taboas geraes de toda a navegação, divididas e emendadas por Dom Ieronimo de Attayde com todos os portos principaes das conquistas de Portugal delineadas por João Teixeira cosmographo de Sua Magestade, anno de 1630".

Image Sources: [https://www.loc.gov/resource/g3200m.gct00052/?sp=7&r=-0.01,0.002,0.848,0.49,0]

• 1634 (Figure 6): reveals a lagoon between Peniche and the mainland, surrounded by agricultural fields to the east and sand to the west;



Figure 6 – [1634] – Map of the region from 17th-century cartography: «La descripción de España y de las costas y puertos de sus reinos» (1634) - Pedro de Teixeira.

Image Sources: [NEREA, 2003. (2003). La "descripción de España y de las costas y puertos de sus reinos" de Pedro Teixeira (1634). PEREDA, FELIPE/FERNANDO MARÍAS (EDS.)]

• 1648 (Figure 7) – the island of Peniche depicted as being connected to the mainland, with its fortress and harbour facing south. The island of Baleal is represented as a small point, disconnected from the mainland;

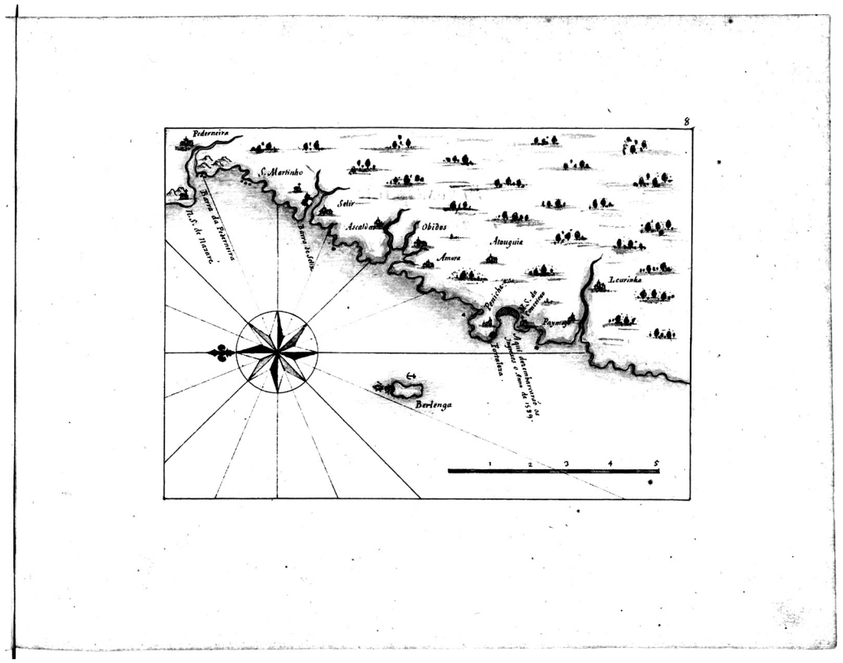


Figure 7 – [1648] - Map of the region from 17th-century cartography: "Descripção dos portos maritimos do Reyno de Portugal par João Teixeira, Cosmographo de S. Magestade. Anno 1648 / par F. de Lapointe".

Image Sources: [https://gallica.bnf.fr/ark:/12148/btv1b550101920/f1.item]

• 1641–1657 (Figure 8): the island of Baleal is connected to the mainland (this is the first cartographic representation of the isthmus). Peniche and its tombolo. The River São Domingos is shown passing north of the village of Atouguia. Upstream of this, a bridge can be seen. Note the shift to the south-west in the terminal section, where it flows into the southern edge of Peniche. Salt pans are represented on the north side of the island of Peniche, inside the moat wall.

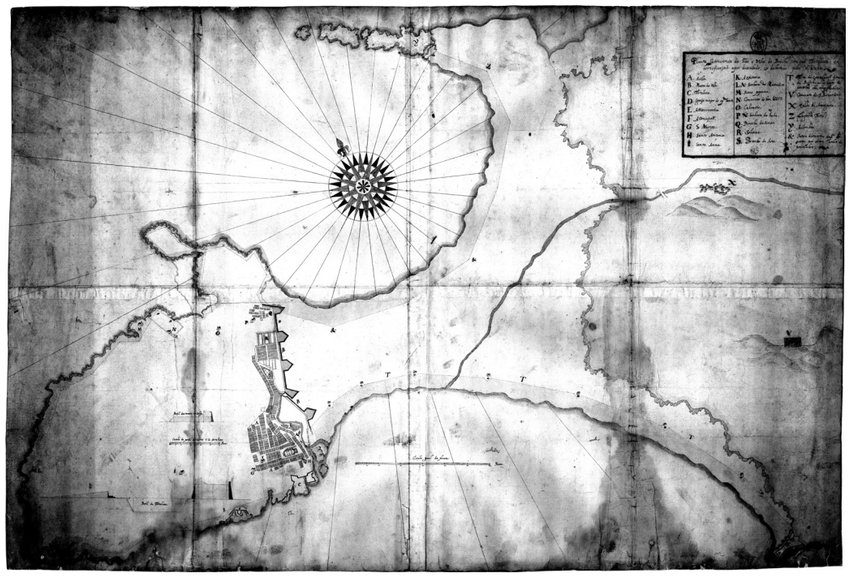


Figura 8 – [1641 - 1657] - Map of the region from 17th-century cartography: "PIanta Geométrica da IIha e ViIIa de Peniche, João GiIot".

Image Sources:[https://bndigital.bnportugal.gov.pt/records/item/33445-planta-geometrica-da-ilha-e-villa-depeniche?offset=2]

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• 1705, 1708 and 1724 (Figure 9): a representation of Peniche connected to the mainland.

A - 1705



B - 1708



C - 1724



Figure 9 – [1705, 1708, 1724] - Maps of the region from 18th-century cartography: A – 1705(?) - "AtIas de PortugaI"; B – 1708 – "Le PortugaI et ses Frontières : Levée sur Ies Iieux par ordre de PhiIippe IV, Roy d'Espagne, augmenté et corrigé sur de nouveaux mémoires / Par G. BaiIIeux; Dédié au Roy par son très humbIe et très obéissant serviteur et sujet Gaspar BaiIIieu Ingenieur et Geogr. BaiIIieuI, Gaspard »; C – 1724 – « AtIas de PortugaI".

Image Sources: A compilation of a historical atlas comprising maps of Portugal from the 16th, 17th and 18th centuries (https://purl.pt/786)

• 1800 (Figure 10): representation of the connection between the Peniche causeway and the island via the flooded moat. The entrance to the island is depicted as a bridge with access via the Bridge Bastion (point F).

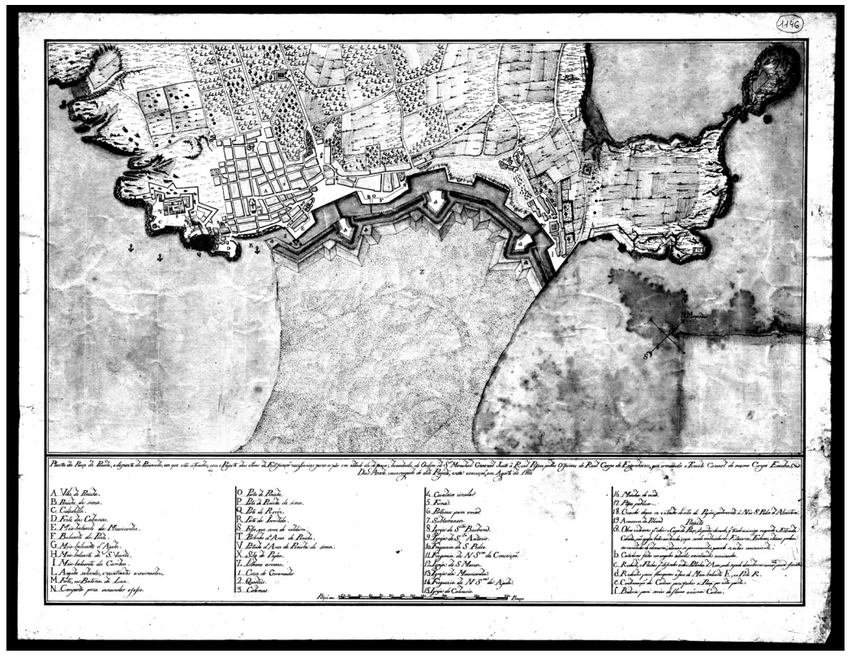


Figure 10 – [1800] – Map of the region from 19th-century cartography: "PIanta da Praça de Peniche, e de parte da Peninsula, em que está situada, com o projecto das obras de fortificação necessarias para a pôr em estado de defensa [MateriaI cartográfico] / Ievantada de ordem do Sr. MarechaI GeneraI junto á ReaI Pessoa peIos oficiaes do ReaI Corpo de Engenheiros, que comanda o Tenente CoroneI do mesmo Corpo Euzebio Dias Azedo, encarregado do dito projecto, e sua execução".

Image Sources: [Biblioteca Nacional de Portugal: https://purl.pt/3940]

• 1813 (Figure 11): shows the islands of Peniche and Baleal connected to the mainland (map with Baleal tombolo). The streams are shown with the final section deflected to the southwest, flowing into the ocean after cutting through a dune field or sandbank extending to Peniche Island. To the north of this, a triangular area without the granular texture of the dunes is represented, which may indicate that the area floods temporarily. This map depicts the Cabo Carvoeiro Lighthouse, which was built in 1790 [4] following the shipwreck of the São Pedro de Alcântara in 1786. The ship had come too close to the coast and crashed into the rocky seabed near the imposing cliffs of the Papoa island.

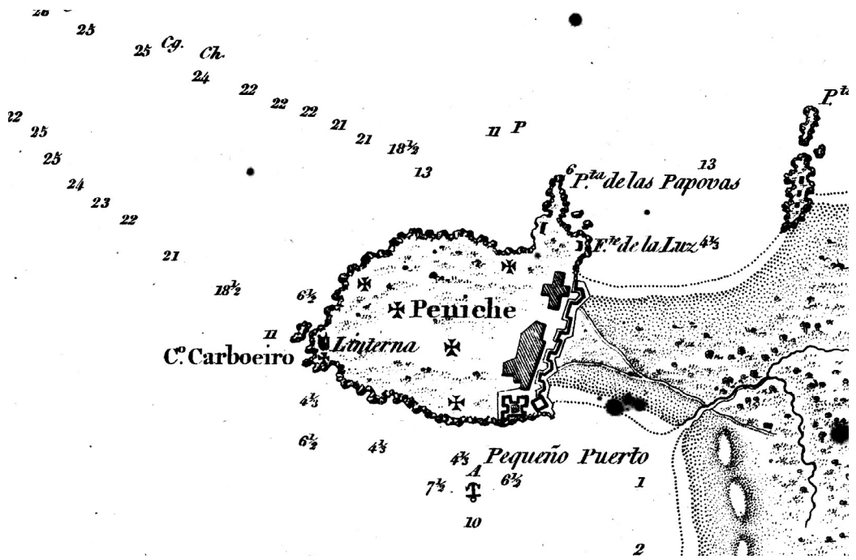


Figure 11 - [1813] - Map of the region from 19th-century cartography: "PIano de Ia Peninsula de Peniche e Islas Berlingas situado eI Co. Carboeiro en Ia Iatitud N. de 39°. 21'. 00". y Iongitud de 3°. 08'. 15". aI O. de Cadiz. Bauzá, FeIipe".

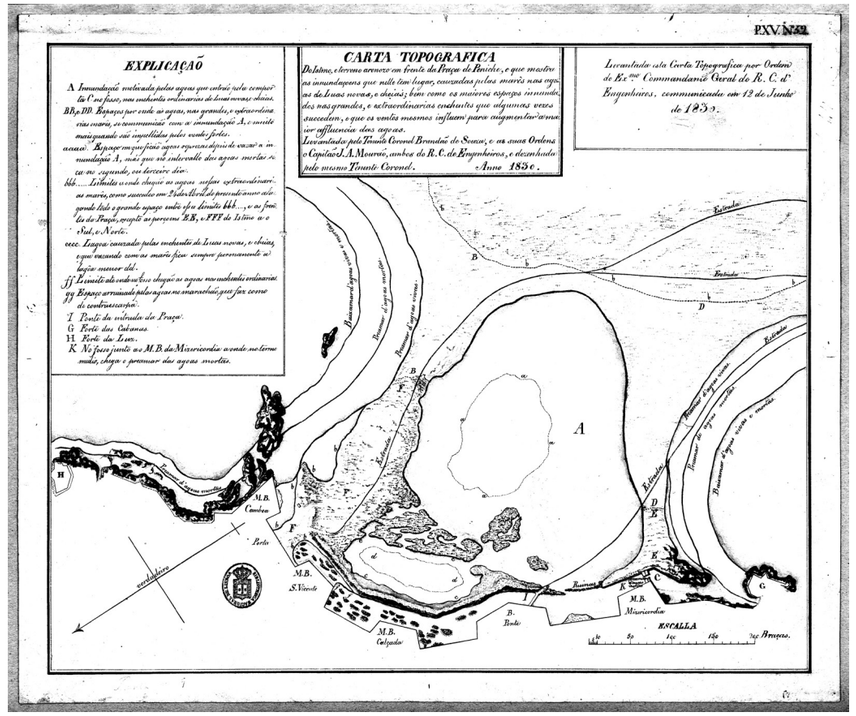
Image Sources: [https://www.oldmapsonline.org/pt/maps/56d487c6-ea47-4d65-b76d-c1dbb296a550?gid=73fcf8aae4b2-4969-8195-919069e6a782#position=10.3766/39.4281/-9.4725/3.52&year=1813]

• 1830 (Figure 12) – one of the most interesting representations of the "Isthmus and the sandy terrain in front of the Peniche Square, and which show the floods that take place in it, caused by the tides of the waves of new moons, and floods,...". This topographic map shows the flooded area in front of the moat wall, and it appears that the collapse of the earthen embankment that confines the moat waters may be responsible for the passage of water to this lower-lying area. It is also noticeable from the representation and description that, during spring tides, the isthmus is submerged, preventing access to the island of Peniche by land.

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Figure 12 - [1830] - Map of the region from 19th-century cartography: "Carta Topografica do Istmo, e terreno arenozo em frente da Praça de Peniche, e que mostra as innunda... / Levantada peIo Tenente CoroneI Brandão de Souza, e as suas Ordens o Capitão J. A. Mourão, ambos do R. C. de Engenheiros, e dezenhada peIo mesmo Tenente CoroneI"

Image Sources: [Biblioteca Nacional de Portugal - https://bndigital.bnportugal.gov.pt/viewer/32888/?offset=2#page=1&viewer=picture&o=info&n=0&q=]



Currently, the lower-lying areas of the Isthmus of Peniche, which are prone to submersion during spring tides, are completely occupied by port, commercial and residential infrastructure. The occupation of risk areas must be taken into account in spatial planning.

WHAT DO THE SEABED HIDE IN THE PENICHE REGION?

Could it be that the bottom of the Peniche region is different and can increase the risks of shipwrecks?

Observing the continental shelf surface sediment chart (EMODnet Map Viewer [5]) reveals what lies beneath the ocean's surface. This document reveals the type of material on the ocean floor between Cabo Mondego and the Peniche region (Figure 13). The grey colour indicates areas with rocky outcrops, devoid of sediment cover resulting from the erosion of continental landforms, which are transported to the coast by rivers.

Note the striking contrast between the northern and southern regions of Nazaré (Figure 13). Sediment-covered seabed predominates to the north, while rocky seabed dominates to the south. Why is there this difference? The Nazaré Canyon, a deep submarine valley located off the Portuguese coast, influences the distribution of sediments on the continental shelf in this region. Extending for around 200 km, it begins at a depth of -50 m and reaches depths of over 5000 m, influencing the dynamics of the waves and concentrating energy to create some of the largest waves in the world off the coast of Nazaré (Masson *et al*., 2011).

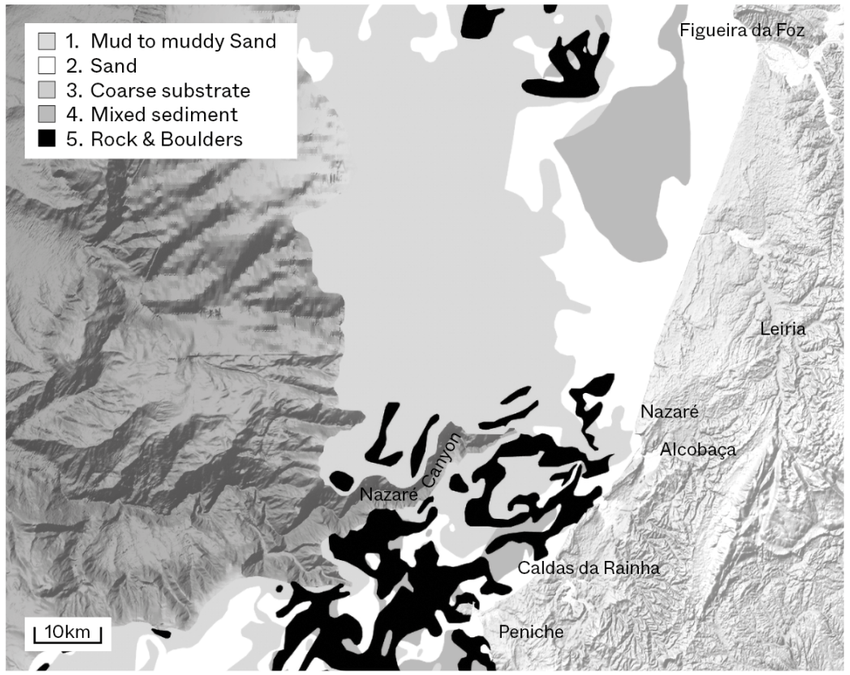


Figure 13 – Seabed type in the submerged area between Figueira da Foz and Peniche. Note the presence of the Nazaré underwater canyon, near the town of the same name.

Image Sources: [Adapted from: https://emodnet.ec.europa.eu/geoviewer/]

This structure (Nazaré Canyon) will have a huge impact on coastal sedimentary dynamics, disrupting the longitudinal transport of sediments along the coast. In general, the drift of coastal sediments from north to south dominates on the western Portuguese coast. The presence of a morphological structure embedded in the headwater zone close to the coastline (-50 m) will favour the capture of sediments from coastal sediment transport. Additionally, transfers by gravitational flows, particularly turbidity currents, which facilitate the rapid transportation of fine and coarse sediments to abyssal zones, will be favoured.

Consequently, the area to the south of the Nazaré Canyon has a sedimentary deficit and is more rocky, while the area to the north has sediment-rich bottoms. The ocean floor near Peniche contains a variety of materials, with a clear predominance of rock. These extend towards and beyond the Berlengas and Farilhões islands. The area surrounding Peniche (formerly “Peniche Island”) has rocky seabed, with sandy sediments closer to the coastline.

CLIMATE CHANGE AND IMPACTS ON THE PENICHE REGION AND THE PORTUGUESE COAST

AND THE FUTURE? What transformations could occur in this region as a consequence of climate change?

The future evolution of the coastline depends on the forcing factors. Currently, in the context of climate change, this evolution is accelerating, and coastal communities must be able to adapt at a faster rate.

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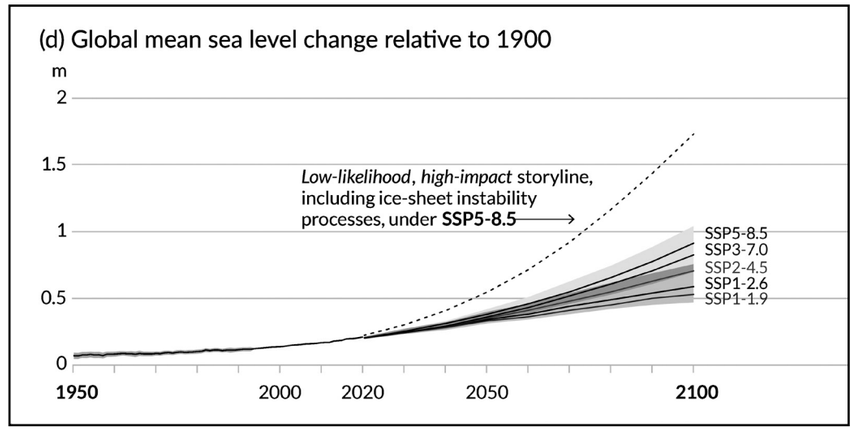
As the current rise in the MSL in Portuguese territory is controlled by global factors, it is important to understand how the MSL has evolved in recent years and how it will evolve in the future, based on models.

For the first case, we can refer to the Cascais tide gauge record (Portugal), which has recorded tides since the end of the 19th century. This allows us to derive the pattern and rate of increase of the NMM over the last 144 years (Antunes, 2019). The MSL has risen by about 20 cm during this period. Rates of rise have varied between approximately 2 and 4 mm per year over time.

To obtain projections for the future, the Intergovernmental Panel on Climate Change (IPCC) provides the results of modelling in the ‘Summary for Policymakers’ (SPM) report (IPCC, 2021). This report represents the contribution of Working Group I to the Sixth Assessment Report (AR6), addressing the latest physical knowledge on the climate system and climate change, and bringing together the latest advances in climate science. This report provides insight into the evolution of the global average sea level from the 20th century to the year 2100 (Figure 14). A continuous rise has been observed since around 1950, as evidenced by actual instrumental data. This increase is associated with global warming, which causes ocean water to expand thermally and glaciers and polar ice caps to melt. Different future scenarios emerge from the present day depending on greenhouse gas emissions. These scenarios, known as SSPs, illustrate potential trajectories of sea level rise. In the most optimistic scenario, the rise could reach approximately 0.5 metres by 2100. In the most pessimistic scenarios, it could exceed one meter. The shaded areas represent the uncertainty associated with the projections. The graph also shows an acceleration in the rate of rise over time, which will have significant impacts on coastal areas.

Figure 14 – The projections for gIobaI mean sea IeveI for each of the five scenarios, with the shaded areas representing the uncertainty ranges. The bIack Iines represent the observations, and historicaI values are incIuded in the graph to provide context for the projected future changes.

Image Sources: [IPCC (2021) , available in: https://pure.iiasa.ac.at/id/eprint/19094/?utm_source=chatgpt.com; https://www.ipcc.ch/report/ar6/wg1/; https://www.ipcc.ch/report/ar6/wg1/downloads/figures/IPCC_AR6_WGI_SPM_Figure_8.png)]



By consulting possible scenarios based on IPCC report projections and looking to the future, scientists can create visualisation models that allow them to anticipate which coastal areas are at risk of flooding. For Portugal, a platform featuring a ‘future scenario viewer’ has been developed (https://snm-portugal-visualizador-ulisboa.hub.arcgis.com/). These future flood scenarios were created using a 2 m resolution Digital Coastal Terrain Model, made available by the Directorate-General for Territory, which has a spatial resolution of 20 m since the results are national in scope. On this platform, it is possible to anticipate the areas affected by a rise in the MSL by 2050 and 2100 in the event of “extreme flood scenarios”.

Combined, these scenarios present extreme conditions that exacerbate the impact on coastal communities and infrastructure. The main observations are as follows (https://snm-portugal-visualizador-ulisboa.hub.arcgis.com/pages/inundacao-extrema) (Figure 15):

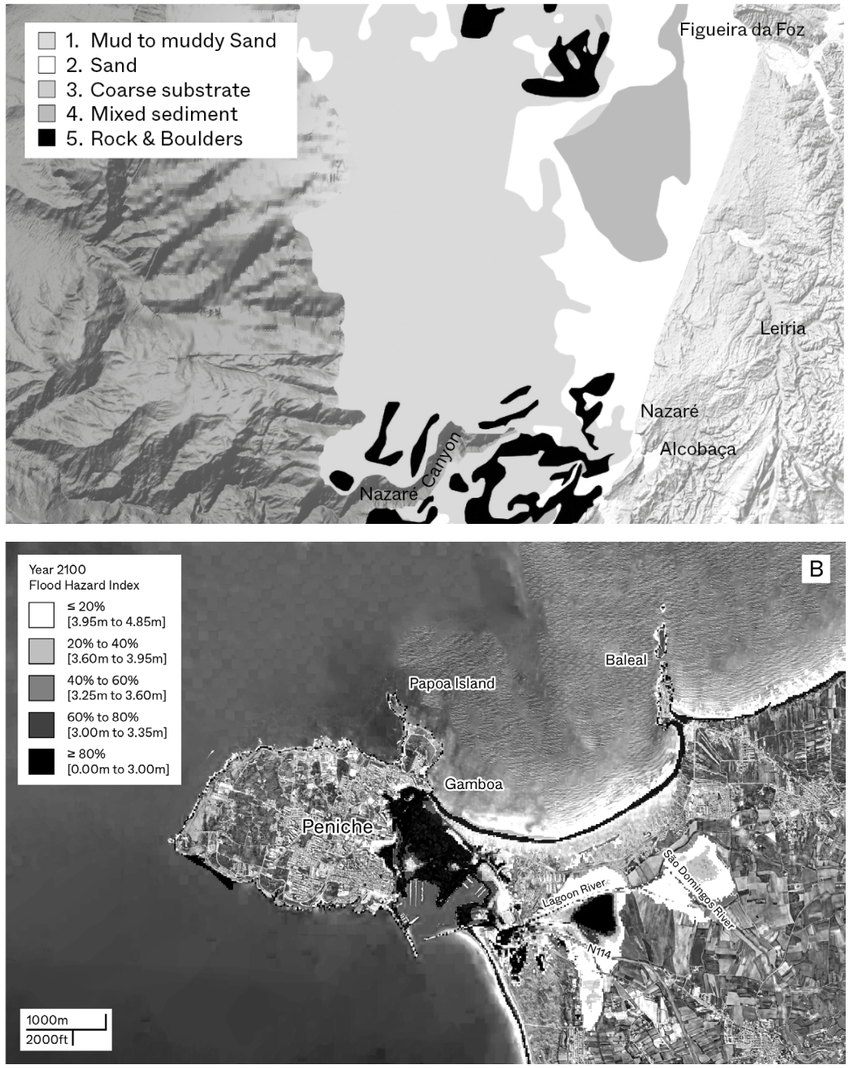


Figure 15 – Future flood scenarios for the Peniche region, showing the areas affected by the rise in mean sea level by 2050 (A) and 2100 (B), under 'Extreme Flood Scenarios'.

Image Sources: [Adapted from: "Visualizador" available in: http://www.snmportugal.pt/index_EN.html; https://snmportugal-visualizador-ulisboa.hub.arcgis.com/pages/inundacao-extrema]

• 2050 scenario: with an estimated sea level rise of 44 cm, erosion of the beaches in the Gamboa-Baleal (northern) and East Pier-Consolação (eastern) bays is expected. The Baleal isthmus is expected to narrow and the Peniche tombolo is expected to flood, as are the agricultural floodplains between the São Domingos river, the Lagoon river and the N114 road.

• 2100 scenario: with an estimated rise of 115 cm, the erosion of the Gamboa Baleal beach (to the north) is accentuated. The Baleal isthmus will shrink or disappear (be submerged). There will be greater flooding of the Peniche tombolo and an increase in the flood area of the São Domingos and Lagoon river floodplains.

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The future of our coastline depends on the choices we make now. Preservation does not mean preventing use; it means learning to coexist. This involves listening to science, respecting local knowledge, and recognising that the coast is not a limitless resource. The coast is a living system of which we are a part, whether we like it or not.

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IMMERSIVE SHIPWRECKS

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Authors Biographies

Immersive Shipwrecks

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Assistant Professor at the Faculty of Engineering (FE), Lusófona University, where she has been teaching since 2005 at various academic courses. She holds a bachelor's, master's, and doctoral degree in Geology from the University of Lisbon and has developed her career in the fields of coastal geology, environmental geology, and the evolution of the coastline since the last glaciation, having participated in several national/international projects. She has built a career marked by scientific rigor and involvement in applied and interdisciplinary projects, participating in research initiatives, collaboration with academic teams, and advising students (master's and doctoral levels). In parallel with her teaching and scientific work, she has been developing skills in academic organization and outreach, collaborating on institutional and pedagogical activities that contribute to the functioning and innovation of the FE: international coordinator and member of other academic governance commissions. Over the past 30 years, she has prioritized the transfer of knowledge to local and school communities, supporting "Clubes de Ciência Viva" (science clubs) and leading science outreach sessions for groups ranging from kindergarteners to university students and the general public. Since 1997, she has been dedicated to the study of coastal geology, with a particular focus on lagoon, estuarine, and dune environments, including interdune peatlands. She also conducts research on fluvial and palustrine environments and have a special interest in environmental monitoring, specifically the assessment of water, soil, and sediment quality as a result of human impact in these systems. She participates in studies at different temporal scales (micro, meso, and macro scales).
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More info: https://research.iadt.ie/en/persons/robert-griffin/







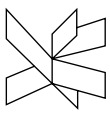


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