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TOURAL

Multidimensional model of tourism verticals driving the sustainable balanced growth among rural & remote grids and urban clusters of rural regions, fostering macro-regional cooperation

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Deliverable D5.2: Short Description

This deliverable consolidates the results of Tasks T5.3 and T5.4.

Task T5.3 focuses on the design and upgrade of the existing MedDiveInThePast web platform into an augmented and rebranded platform, namely the Rural Heritage platform. It has been enriched with TOURAL destinations, adapted to regional and macro-regional needs, linked with destinations already present in the Mediterranean sea-basin, and enhanced with destination management functionalities for tourists, regional stakeholders, and policy makers.

Task T5.4 focuses on the repurposing, development, and customisation of VR and serious-game tools aimed at providing an improved dry-diving and immersive tourism experience in TOURAL regions. This includes a virtual diving application with interactive real-time navigation, augmented information on underwater cultural and natural heritage sites, and region-specific serious-game instances inspired by local heritage assets.

Overall, the deliverable provides the technical and functional description of the augmented MedDiveInThePast web platform, namely the Rural Heritage platform, the VR diving application, and the serious-game-based experience layer. It also documents their complementary role within the TOURAL Digital Platform as integrated tools for destination promotion, heritage interpretation, and user engagement.

Keywords: Rural Heritage Platform, Virtual Reality (VR) Tourism, Dry-Diving Experience, Serious Games, User Engagement, Immersive Tourism Experience

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Executive Summary

This deliverable presents the work carried out under Tasks T5.3, "*Augmented MedDiveInThePast Web Platform*", and T5.4, '*'VR Tools for Enhanced Tourists Experience"*, within Work Package 5 of the TOURAL project. It documents the design, development, and integration of digital tools that aim to enrich visitors' experiences in TOURAL regions through an augmented web platform, immersive virtual reality applications, and interactive gamified environments, while contributing to the broader TOURAL objective of promoting sustainable, place-based, and technology-enabled tourism development in rural and remote areas.

More specifically, the deliverable addresses two complementary lines of work. Task T5.3 focuses on the evolution of the Rural Heritage platform, building on the MedDiveInThePast platform to incorporate TOURAL destinations, destination-specific content, and functionalities tailored to tourists, regional stakeholders, and policy actors. Task T5.4 focuses on the development and adaptation of immersive tools, including a VR diving application for underwater cultural and natural heritage sites and serious-game experiences inspired by the cultural assets of the participating regions.

The deliverable also explains how these tools contribute to the emerging TOURAL digital ecosystem. The augmented web platform operates as an access point to destination content, points of interest, multimedia assets, and region-specific information, while the VR and game-based applications provide more immersive and experiential modes of interaction with heritage resources. In this way, D5.2 complements the analytical and decision-support tools developed in other WP5 tasks by focusing on the visitor-facing and experience-oriented dimension of the project's ICT suite. These tools are hosted within the TOURAL digital platform, a unified digital environment through which users can access tools developed across the project, including tools originating from both WP3 and WP5. This platform is presented in detail in D5.1.

Overall, the work reported in this deliverable supports TOURAL's ambition to combine cultural heritage valorisation, digital innovation, and sustainable tourism planning through interoperable tools and regionally adaptable services. The resulting solutions contribute not only to visitor engagement and destination visibility, but also to the wider project objective of fostering smart, sustainable, and multi-dimensional tourism offerings across the TOURAL pilot regions.

List of Symbols and Abbreviations

Abbreviation	Meaning
CCT	Cultural & Creative Tourism
CH	Cultural Heritage
CST	Cultural Science Tourism
KAC	Knowledge Awareness Centre
MDM	Multidimensional Model
MRC	Macro-Regional Cooperation
POI	Point Of Interest
RRG	Rural and Remote Grids
SBG	Sustainable Balanced Growth
SLT	Silver Tourism
TV	Tourism Verticals
UCCST	UCNHT-CCT-CST-SLT
UCH	Underwater Cultural Heritage
UCNHT	Cultural & Nature Heritage Tourism
UCRR	Urban Clusters of Rural Regions
UW	Underwater
VR	Virtual Reality
WP	Work Package

1 Introduction

1.1 Purpose of the Deliverable

Deliverable 5.2, Augmented Web Platform & VR Tools for Enhanced Tourists Experience, presents the description of the augmented MedDiveInThePast web platform developed under Task T5.3, and the VR tools for enhanced tourists' experience, developed under Task T5.4.

The work done within Task T5.3 was set to design an augmented instance of the previous "MedDiveInThePast" web platform (originally developed within the BLUEMED project) into the upgraded and rebranded "Rural Heritage" platform enriching it with the TOURAL destinations, after parameterising it towards the needs of each region and macro-region, linking the new destinations with those already present in the Mediterranean sea-basin to reinforce the multi-destination concept, and enhancing it with further functionalities. This deliverable documents how each of these objectives was addressed, the conceptual reframing the task required, and the collaborative process through which the platform was delivered.

The work done within Task T5.4 was focused on the repurposing and evolution of existing VR and game-based tools into enhanced digital experiences for tourists visiting TOURAL regions. This included the development of a virtual diving application designed to provide an immersive exploration of underwater cultural and natural heritage sites through real-time or simulated interaction, as well as the enrichment of the experience with augmented information, multimedia content, and interactive storytelling elements. In parallel, the task also covered the design and adaptation of a serious game inspired by TOURAL regions, with the aim of transforming heritage content into an engaging, educational, and interactive experience that strengthens user participation and cultural awareness.

Together, these tools serve a complementary purpose within WP5: the augmented web platform provides structured access to destination content, points of interest, and multimedia material, while the VR and serious-game tools extend this access into immersive and experiential forms of engagement. Their combined role is to enrich the tourists' experience, promote heritage interpretation, and support the visibility and attractiveness of TOURAL destinations. Both tools coexist within the TOURAL Digital Platform, which acts as a common front-end environment for accessing the project's digital tools and services in an integrated and user-oriented manner.

1.2 Relation to other activities

The Rural Heritage platform exchanges content and links with several other project activities, among them the destination material shared with the project's wider communication channels (WP6 – Communication & Dissemination).

Moreover, the content of some visitor experiences presented in Rural Heritage platform feeds from T3.3 (input content from pilot sites & services), as well as from T3.5 (input content from KACs designed within TOURAL project).

The platform also acts as the front-end surface for the WP5 toolset, providing the connecting tissue between the web experience and the VR / dry-diving tools developed in T5.4 (see the VR Tools section).

The tools developed under T5.3 and T5.4 are hosted within the TOURAL Digital Platform together with the other digital assets created in the project, ensuring a unified and coherent user experience. The VR-related tools and other experiential content described in this deliverable are also intended to be integrated into the KACs, where they will strengthen the digital experience of visitors and support the interpretation of local heritage assets.

This integrated setup ensures that the Rural Heritage platform, the VR tools, and the additional content assets developed across the project work as complementary components of the broader TOURAL digital ecosystem.

Finally, the tools developed under the tasks covered by this deliverable, and more generally under WP5, are closely linked to WP6 activities, especially Task T6.2, 'Exploitation & Business Planning for Project Outcomes,' and Task T6.4, 'Replication Roadmap for Uptaking.' This is because the deliverable presents the solutions primarily as technical tools, while their exploitation and replication will be addressed through WP6, as part of KER4, KER5.

1.3 Structure of the deliverable

This deliverable is structured into 7 main chapters.
Following the present introduction, Chapter 2 presents the augmented MedDiveInThePast web platform, its role in the TOURAL ecosystem, its target users, and its technical architecture. Also, it provides the core functionalities of the platform, including tourism experience services, cultural content integration, personalisation features, and user interaction flows.
Chapters 3 and Chapter 4 together cover the two technical dimensions of Task T5.4. Chapter 3 focuses on the VR tools developed for enhanced tourists' experience, covering design principles, content creation, interaction models, deployment, and implementation details. Chapter 4 presents the serious game experience, including the photogrammetry workflow, 3D reconstruction process, automatic fragmentation, puzzle design, and gamification elements.
Chapter 5 summarises the validation and user testing activities, Chapter 6 addresses sustainability and exploitation, while Chapter 7 concludes the deliverable.

Overall, the structure reflects the two main pillars of D5.2, namely the Rural Heritage platform and the VR and serious-game tools, as integrated components of the broader TOURAL digital environment.

2 Augmented "MedDiveInThePast" Web Platform: the "Rural Heritage" platform

This chapter documents the work carried out under Task T5.3, whose objective was to evolve and augment an existing digital asset of a past EU funded project into a public-facing platform capable of expressing the full breadth of the TOURAL tourism offer. This chapter describes what the platform is and the meaning that it carries within the project, the methodology through which it was conceived and populated, the experience it delivers to its users and finally, the way its content was rolled out across the pilot regions. The technical description and realisation process of the platform (i.e. its architecture, technologies, backend services, data model and front-end implementation), are presented in Chapter 2.8.

2.1 Rural Heritage Platform Overview

The starting point for T5.3 was the MedDiveInThePast platform, an asset from BLUEMED project[1] - (Interreg MED project, co-financed by ERDF) conceived to promote Underwater Cultural Heritage (UCH) sites across the Mediterranean through diving and dry-diving experiences. While that platform offered a robust technical foundation and a proven multi-site logic, the scope of TOURAL is substantially broader: the project addresses rural and remote regions whose value lies not only in underwater archaeology, but equally in on-land natural heritage, living cultural traditions, museums and Knowledge Awareness Centres (KACs), and experiential tourism. A platform built around the notion of a single underwater "site" could not, on its own, carry this wider narrative.

For this reason, the platform was re-conceived and rebranded as the Rural Heritage platform, available at https://rural-heritage.iti.gr/. The rebranding signals a deliberate shift from a single-theme, underwater-centric catalogue towards a holistic destination-promotion environment to showcasing the complete spectrum of TOURAL destinations and their Points of Interest (POIs). The platform retains the multi-destination logic and the mapping and diving heritage of its predecessor, while extending them to land-based heritage and to the macro-regional cooperation dimension that lies at the heart of the project.

2.2 From "Site" to "Destination": Conceptual Evolution

The single most important design decision of T5.3 was conceptual rather than technical and it is worth stating its meaning explicitly within the TOURAL framework. The inherited model organised content around the ***cultural site*****:** a discrete, georeferenced monument such as an underwater wreck. However, TOURAL promotes ***destinations*****:** coherent territorial units (an island cluster, a coastal stretch, a delta, a protected landscape, etc.) that bundle many heterogeneous assets under a single regional identity. Re-orienting the platform around the "*destination"* rather than the "s*ite*" required the consortium to align on a shared vocabulary and information model before any interface could be finalised. That particular conceptual change allowed each pilot region to be published as a self-contained whole that aggregates its underwater, natural, cultural, museum/knowledge and experiential assets, rather than as an isolated collection of monuments.

As the public-facing showcase of the project's tourism offer, the Rural Heritage platform is the entry point through which tourists, regional stakeholders and policy makers discover and explore the pilot regions. It is conceived as an open and accessible resource whose purpose is to give visibility to rural and remote areas and to make their cultural and natural heritage discoverable by a broad, international audience. Underwater sites that already existed in the wider Mediterranean ecosystem are cross-referenced from the predecessor platform rather than duplicated, so that a

[1] https://bluemed.interreg-med.eu/

visitor exploring a TOURAL destination can navigate seamlessly towards the broader Mediterranean diving and heritage network. This cross-referencing is the practical expression of the multi-destination concept and of the macro-regional cooperation that the project pursues.

The platform followed a similar structure and "content model frame" per destination. Within this model, each destination created its own narrative, quick facts, thematic pillars, sub-regions, POIs and media. This guarantees a consistent user experience across all pilots while allowing every region to express its distinctive identity.

The outcome is a platform whose information architecture faithfully expresses TOURAL's actual purpose: each pilot region is published as a self-contained destination that aggregates its underwater, natural, cultural, museum/knowledge and experiential assets, rather than as an isolated collection of sites. In Figure 1, the Rural Heritage homepage is presented.

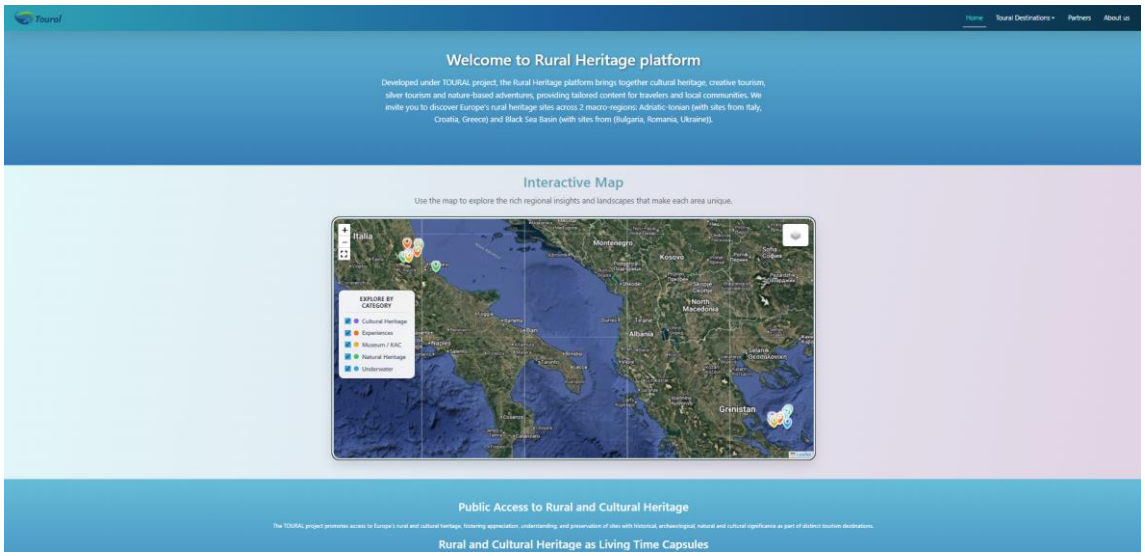

Figure 1 Rural Heritage platform - homepage and interactive map

2.3 Purpose and Target Users

The platform was designed to serve three primary user groups, each with distinct needs and each addressed through a tailored value proposition. By supporting destination promotion, content management and evidence-based regional visibility at the same time, the platform acts as a shared surface across the different audiences of the TOURAL digital environment. Table 1 summarizes the main target groups and what the platform offers to each of them.

Table 1 Overview of the Rural Heritage platform target user groups and the main value proposition addressed to each group.

User group	What the platform offers them
Tourists	An inspiring, mobile-friendly discovery experience: an immersive destination narrative, curated quick facts and thematic pillars, an interactive map of geolocated POIs with category filtering, rich "why visit / details" content, practical infrastructure information, and embedded video with direct links to the VR / dry-diving experiences for non-divers.
Regional stakeholders	A structured, continuously editable showcase of their territory's assets, managed through the headless CMS without technical skills. Stakeholders (rural tourism SMEs, local providers, guides, museums, visitor centres, DMOs, KAC staff and rural tourism associations) contribute and curate destination content, highlight conservation

	priorities and local value, and present a coherent regional identity to an international audience.
Policy makers	A consolidated, comparable overview of the heritage and tourism assets across all pilot regions and the wider macro-region, supporting evidence-based promotion decisions, cross-regional cooperation and the positioning of rural/remote areas within balanced growth strategies.

2.4 Platform Design and Co-Creation Methodology

Because the platform had to express a shared conceptual model and host content from every pilot region, it could not be designed or populated in an ad-hoc manner. Task T5.3 therefore followed a structured, iterative methodology, organised around three complementary processes: an internal design and co-creation process, through which the platform itself was conceived and built; a content-collection process, through which destination content was gathered and published; and a visitor-experience process, through which the resulting interface guides users through the offer. This section describes the first of these; Sections 2.5 and 2.6 describe the other two.

The design process was deliberately collaborative and proceeded in three phases following an iterative, spiral logic.

Conceptual alignment was first. Before any interface could be finalised, all the partners agreed on a shared vocabulary and information model (in particular the move from “site” to “destination” described above). This alignment was reached collectively and was deliberated through the project’s PSCs, so that every pilot partner shared a common understanding of what the platform represents and how its own territory would be described within it. The emphasis throughout was on the methodology and the shared model rather than on individual contributions.

The following step was the interface co-design. A front-end design team produced successive sets of interface mock-ups for the destination page, the interactive map and the POI views. These mock-ups served as the concrete basis for discussion and were refined across multiple revision cycles by a joint co-design working group, which progressively settled the page structure and the underlying content model while ensuring technical feasibility and consistency with the wider WP5 toolset. Working from agreed mock-ups kept the design grounded in what visitors would actually see and do.

The final phase was enrichment and final tailoring. Once the platform design was stable, it was then enriched, region by region, with destination content supplied by the pilot-site partners through the structured workflow described in the following Sections of this chapter. In short, the first step was to create the mock-ups, the second to build the platform on the agreed model, and the third to populate it with regional content from each pilot destination.

2.5 Content Architecture and the Zone-based authoring Methodology

Alongside the technical architecture presented in Section 2.8, Task T5.3 delivered an equally important asset: a structured, repeatable methodology for collecting, validating and publishing destination content. Because the platform must eventually host every TOURAL pilot, content could not be authored region by region in isolation. Instead, a zone-based content model was designed that maps one-to-one onto a simple authoring template, allowing each pilot partner to contribute high-quality, platform-ready content in a consistent form.

2.5.1 The Destination Page Zone Model

Every destination page is organised into a fixed set of content zones and four thematic tabs (Description, POIs, Infrastructure, Videos). The zones impose a deliberate editorial rhythm (from a single evocative tagline, through a factual narrative, to scannable highlights, thematic pillars and sub-region detail) so that every destination reads coherently regardless of which partner

authored it. Figure 2 - Figure 3 illustrate the zone layout as rendered on the platform along with the final result of a finalised “Destination” page tab.

Table 2 summarises the five zones and their authoring rules.

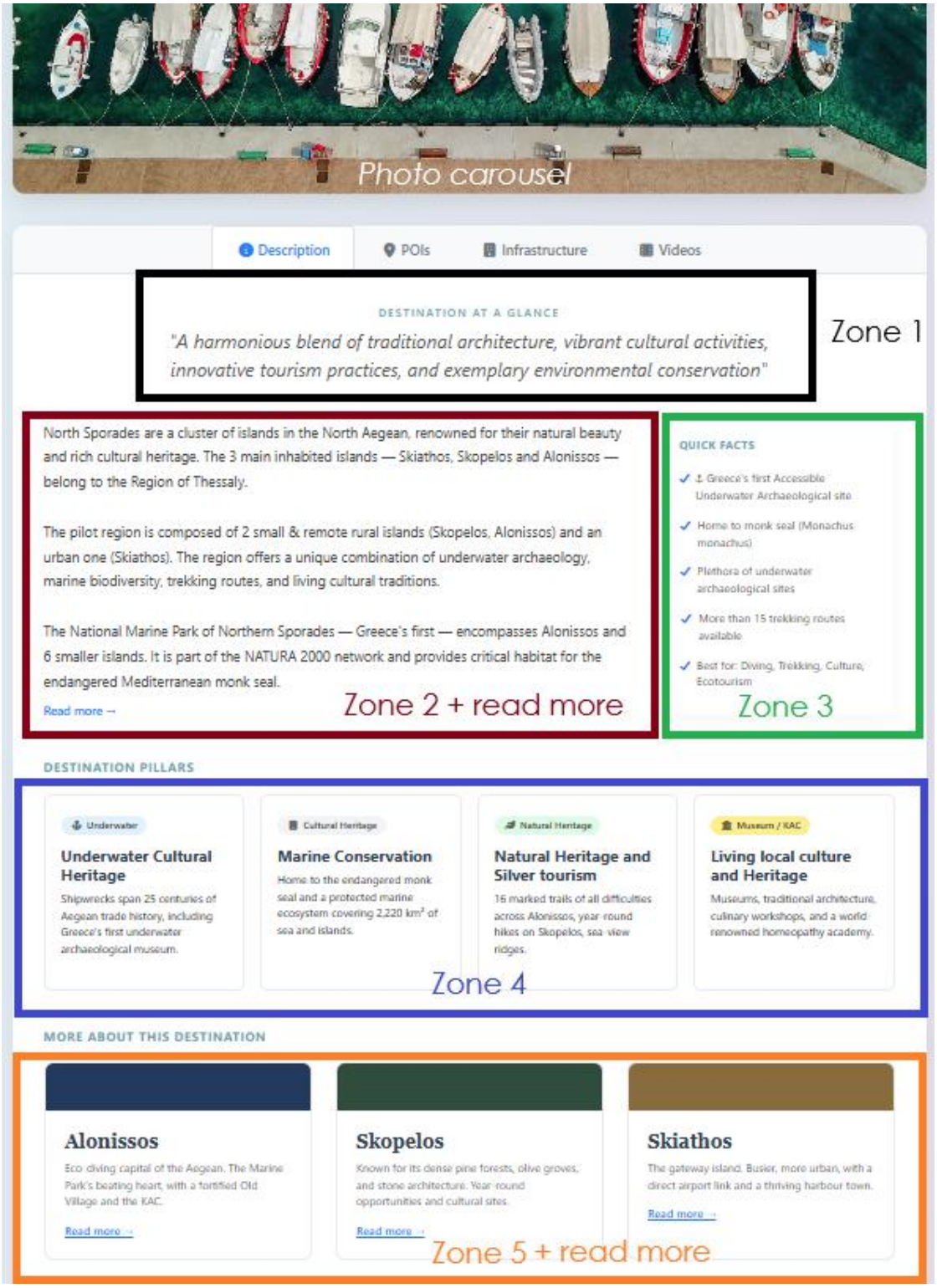

Figure 2 The Rural Heritage destination-page zone model — the photo carousel and tab navigation (Description / POIs / Infrastructure / Videos) above the five content zones used to structure every destination.

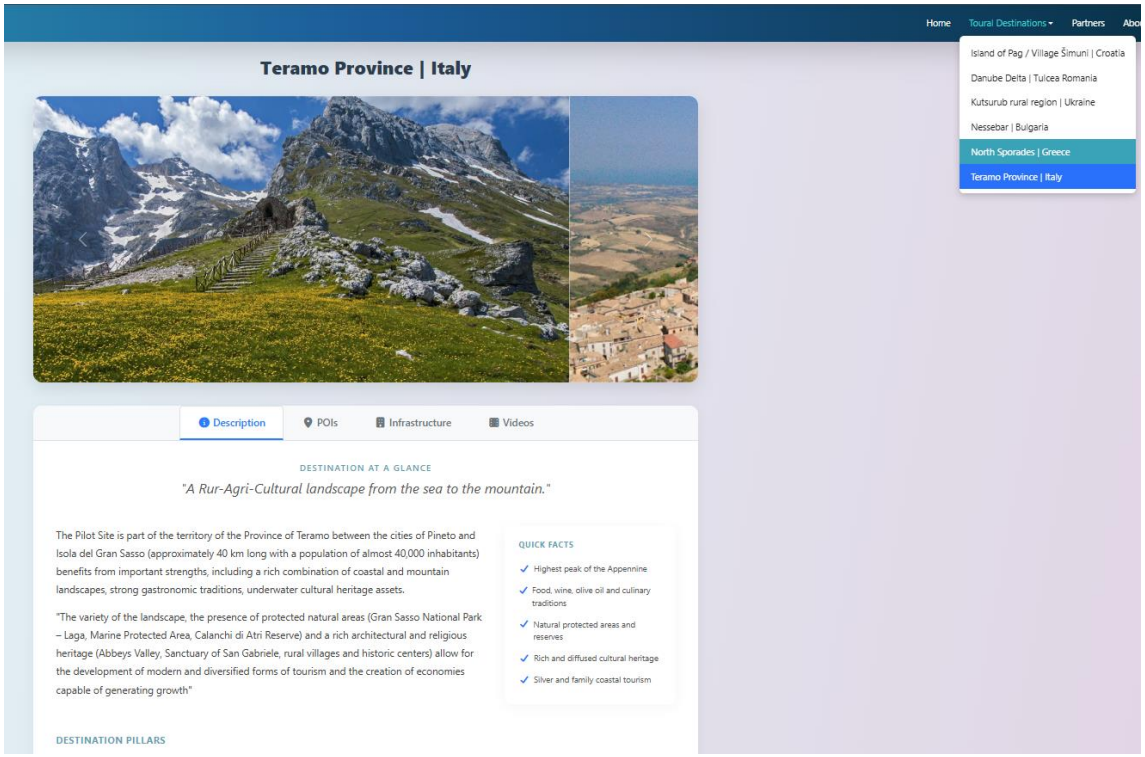

Figure 3 Destination-page navigation tabs and photo carousel.

Table 2 Five-zone model for Rural Heritage destination pages.

	Purpose	Content rule / example
Zone 1	Destination at a glance	A single evocative tagline (max ~20 words). N. Sporades: "A harmonious blend of traditional architecture, vibrant cultural activities, innovative tourism practices, and exemplary environmental conservation."
Zone 2	Narrative	The main descriptive text introducing the destination, with an optional expanding "read more" block for additional context.
Zone 3	Quick facts	Up to 5 scannable highlights (≈ 7 words each), e.g. "Greece's first Accessible Underwater Archaeological site".
Zone 4	Destination pillars	Up to 4 thematic pillars that frame the destination's identity — each linked to a heritage category.
Zone 5	More about this destination	Up to 3 expanding blocks describing sub-regions, with an optional "read more" (e.g. the islands of Alonissos, Skopelos and Skiathos).

2.5.2 Points of Interest as the core discovery unit

Within each destination, the Point of Interest (POI) is the central unit of discovery and the most distinctive feature of the platform. A POI represents a single, georeferenced heritage asset — a shipwreck, a marine park, a museum, a monastery, a trail, a workshop — that a visitor can locate on the map, read about, and use as the starting point of a real or virtual visit. POIs are what turn

an attractive regional narrative into a concrete, explorable offer, and they are the principal mechanism through which the platform makes rural and remote heritage tangible and discoverable.

Each POI is described through a consistent record so that it behaves identically across destinations: a title; a category drawn from the 5 distinct categories; a short preview description of up to about 35 words; coordinates (a Google Maps URL or latitude/longitude); two expanding fields, "Why visit" and "Details"; and an associated photo, as seen in Figure 4. POIs that already existed in the predecessor platform are referenced rather than re-created, preserving the multi-destination linkage and avoiding duplication.

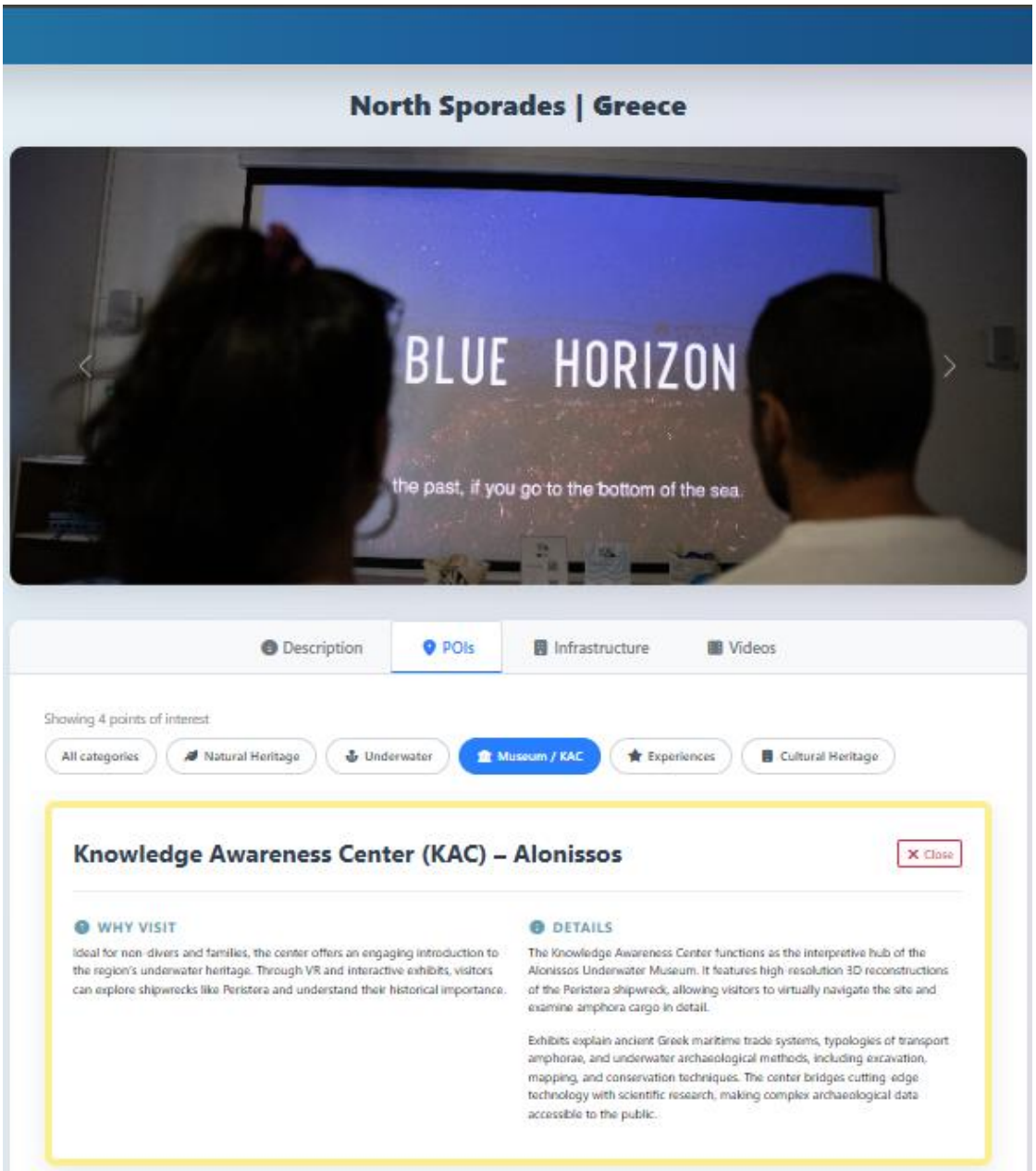

Figure 4 Point of Interest (POI) detail view – KAC of Alonissos

2.5.3 The Structured Content-Collection Workflow

To operationalise the zone model, a dedicated Excel content template was produced and distributed to the pilot partners. The template mirrors the platform exactly: one sheet captures the

Destination zones (1–5), a second captures the Points of Interest, and further sheets capture the Infrastructure texts and the Video links. Each partner fills the template for their region, and the structured entries are then mapped directly into the corresponding content collections and published. This one-to-one correspondence eliminates ambiguity between what a partner wrote and what appears on the platform.

The end-to-end workflow of the Task T5.3 implementation is:

- **Desk research and sourcing.** An initial catalogue of candidate POIs was compiled for each pilot (title, category, description, accessibility, local value and coordinates), providing a common starting point for all regions.
- **Excel template creation and distribution.** A structured authoring template, mirroring the platform's zones and tabs, was prepared and distributed to the pilot-site partners.
- **Partner authoring.** Each pilot completes the regional content template, refining the narrative, quick facts, pillars, sub-regions and POI texts to reflect local knowledge.
- **Validation.** The content management team reviewed the submitted material for completeness, adherence to the length rules and consistency with the zone model.
- **Ingestion and publication**. . Validated content was entered into the CMS and rendered automatically by the front end across all zones, tabs, map markers and media carousels.

The Infrastructure and Videos tabs (Figure 5) are populated through the same template, completing the practical and multimedia picture of each destination alongside the narrative and the POIs.

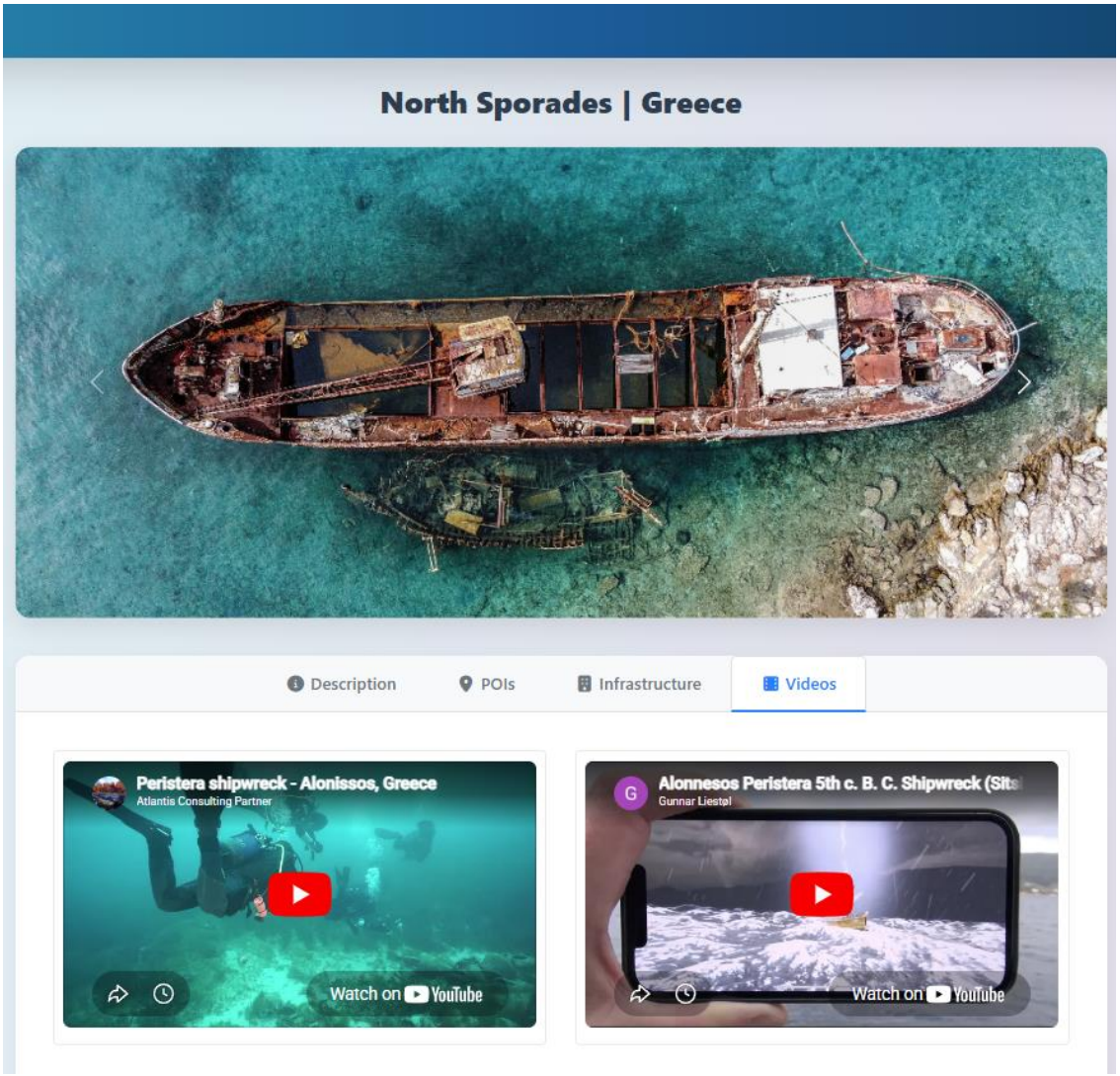

Figure 5 Videos tabs

2.5.4 Category-Based Classification and Filtering

TOURAL's conceptual backbone is the multidimensional UCCST model (UCNHT-CCT-CST-SLT). However, early in the co-design, it was agreed with the pilot partners that exposing this model and its terminology directly to end-users would burden the visitor experience without adding value. Instead, the consortium opted for an intuitive, attractive filtering system in which every POI is assigned to one clear, recognisable heritage category. The model still informs the design (the categories collectively cover its dimensions) but the visitor simply sees and filters by familiar themes. Five categories are used: Underwater, Natural Heritage, Museum / KAC, Cultural Heritage, Experiences, as presented in Table 3.

Table 3 The five heritage categories used to classify and filter POIs

Category	Typical content
Underwater	Shipwrecks, underwater archaeological sites, diving and snorkelling experiences (the heritage inherited from MedDiveInThePast).
Natural Heritage	Marine parks, protected landscapes, trekking routes, biodiversity and silver-tourism walks.

Museum / KAC	Museums, archaeological collections and Knowledge Awareness Centres offering VR / dry-diving.
Cultural Heritage	Traditional settlements, monasteries and churches, festivals and tangible/intangible heritage.
Experiences	Culinary workshops, wellness, festivals and other participatory, experiential offerings.

On the interactive map (Figure 6) each category is rendered with its own colour-coded marker, and an overlay menu lets the visitor toggle categories on and off in real time (Figure 7). The relational data model keeps the system future-proof: although each POI is currently assigned to a single category, the underlying Many-to-Many relationship between POIs and categories allows assets that span several themes to be accommodated in future expansions without any structural change.

Figure 6 Interactive map and category filtering.

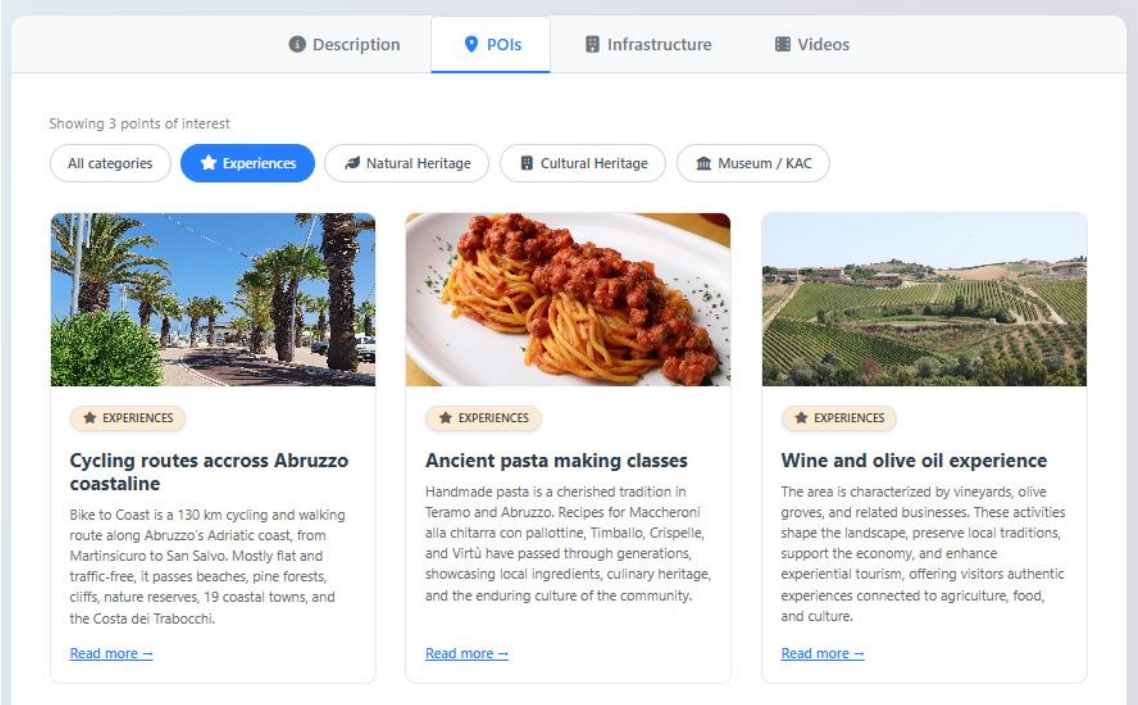

Figure 7 Same category filtering using of POIs tab

2.5.5 Regional parameterisation and multi-destination linking

The same engine and content model serve every pilot, but each destination is parameterised independently: its own zones, pillars, sub-regions, category mix, POIs, infrastructure notes and videos. This delivers the consistency that evaluators and visitors expect, while letting each region foreground what makes it distinctive (i.e. underwater archaeology in the North Sporades, delta ecosystems on the Danube, dry-stone landscapes and salt pans on Pag, etc.). The destinations are then presented together within the platform, so that the user reads them as a single, navigable macro-regional offer rather than as a set of disconnected pages. Existing underwater POIs are linked across to the wider Mediterranean network, reinforcing both the multi-destination concept and the macro-regional cooperation dimension of the project.

2.6 Core Functionalities

Building on the content model above, the platform exposes a coherent set of functionalities for discovery, exploration and engagement. These are described here (Section 2.6) from the visitor's perspective. The underlying technical implementation is detailed in Chapter 2.8.

2.6.1 Tourism Experience Services

At the heart of the experience is an advanced interactive map built with Leaflet, offering multiple base layers (OpenStreetMap, satellite, hybrid, terrain, roadmap) and full-screen viewing. Geolocated POIs are shown as custom, colour-coded markers by heritage category; an overlay menu enables real-time category filtering; and marker pop-ups act as deep links that carry the visitor directly to the relevant destination and POI detail. Around the map, the destination pages deliver the curated narrative, quick facts, thematic pillars and sub-region detail, while a dedicated Infrastructure tab and a Videos tab complete the practical and multimedia picture

2.6.2 Cultural Content Integration

Cultural, natural and underwater content is integrated through the structured zone-and-POI model. Rich text in the "Why visit" and "Details" fields is safely parsed, and embedded media such as video is handled securely, preserving an engaging, media-rich presentation. Crucially, underwater

content is bridged to the VR and dry-diving tools and to the Knowledge Awareness Centres, so that underwater heritage which is physically accessible only to certified divers becomes available to every visitor through virtual reality. This web-to-VR bridge connects the platform developed in this task with the immersive tools described in the later chapters, and it is one of the points at which the two halves of the deliverable meet.

2.6.3 Personalisation and Filtering Features

Personalisation is delivered primarily through the category-based filtering described in the previous sections regarding the types of POIs, allowing each visitor to shape the map and content around their own interests diving, nature, culture, museums or experiences. The interface remembers the visitor's browsing context, such as the active tab, the selected filters and any open POIs, so that navigation between the map and the destination pages feels continuous: selecting a marker, for example, opens the corresponding destination, switches to the POIs tab, expands the exact POI and scrolls smoothly to it.

2.6.4 User Interaction Flows

The principal interaction flows were defined during the co-design phase and validated against the mock-ups:

- **Discover → explore:** a visitor lands on a destination, reads the at-a-glance tagline and narrative, scans the quick facts and pillars, then moves to the POIs tab or the map.
- **Map-driven exploration**: the visitor filters categories on the map, taps a marker, and is deep-linked into the specific POI detail.
- **Cross-destination navigation**: from any destination the visitor can move to sub-regions or to linked Mediterranean sites, reinforcing the multi-destination experience.
- **From web to VR:** Underwater POIs and Knowledge Awareness Centres connect the web experience to the dry-diving and VR tools, completing the journey for non-divers

2.7 Content Roll-Out across the Pilot Regions

The methodology described above was applied uniformly across all TOURAL pilot destinations. Rather than treating any single region as a demonstrator, the platform was populated by replicating the same zone model, authoring template and validation workflow for every pilot, so that the regions could be published together as one coherent macro-regional offer. The first destination to be fully populated served simply to validate the methodology end-to-end and the same approach was subsequently followed for the remaining TOURAL pilot regions; the content profile it produced is used here to illustrate the structure that every destination follows.

Progress on content population was tracked through a small set of internal content KPIs: the number of published destinations, the number of POIs per destination, category coverage per destination, completeness of the five zones, and the availability of media and cross-network links. These indicators were used to track and validate content provision within the task's implementation iterations; they are an internal completeness check rather than a basis for comparing pilots against one another. A destination is considered complete when it presents a full five-zone narrative, a balanced category coverage and a set of published POIs with media.

Content profiles of the pilot destinations

Table 4 - Table 9 record the content profile of each pilot destination using the same five-row structure, so that completeness and category coverage can be read consistently across regions. The North Sporades profile, which validated the methodology, is given in full; the remaining profiles follow the identical structure and are completed by the respective pilot-site partners as their content is published.

North Sporades (Greece). Published as an island cluster in the North Aegean comprising the inhabited islands of Skiathos, Skopelos and Alonissos (presented as Zone 5 sub-regions),

anchored by Greece's first underwater archaeological museum at the Peristera shipwreck and by the National Marine Park of Northern Sporades.

Table 4 Content profile - North Sporades, Greece

Reference pilot – N. Sporades, Greece	Delivered content
Destination narrative (Zones 1–5)	Tagline, full narrative with read-more, 5 quick facts, 4 destination pillars, 3 sub-region blocks (Alonissos, Skopelos, Skiathos).
Points of Interest	17 POIs published across all five categories.
Filtered POIs by category	Underwater (7), Museum / KAC (4), Experiences (3), Natural Heritage (2), Cultural Heritage (1).
Multimedia	Photo carousel per destination/POI and curated video content in the Videos tab.
Cross-network linking	Underwater POIs linked to existing MedDiveInThePast Mediterranean sites and to the KAC VR experiences.

Table 5 Content profile - Teramo / Abruzzo, Italy

Reference pilot – Teramo, Abruzzo, Italy	Delivered content
Destination narrative (Zones 1–5)	Tagline, full narrative, 5 quick facts, 3 destination pillars, 3 sub-region blocks (Atri, Abbeys Valley, Sea and Mountain)
Points of Interest	9 POIs published across 4 categories
Filtered POIs by category	Experiences (3), Natural Heritage (3), Cultural Heritage (2), Museum / KAC (1)
Multimedia	Photo carousel per destination/POI and video content (2)
Reference pilot – Teramo, Abruzzo, Italy	Delivered content

Table 6 Content profile - Pag, Croatia

Reference pilot – Pag Croatia	Delivered content
Destination narrative (Zones 1–5)	Tagline, full narrative, 5 quick facts, 4 destination pillars, 3 sub-region blocks (Town of Pag, Simuni, Letavica)
Points of Interest	19 POIs published across 5 categories
Filtered POIs by category	Experiences (3), Natural Heritage (6), Cultural Heritage (6), Museum / KAC (2), Underwater (1)
Multimedia	Photo carousel per destination/POI and video content (3)
Reference pilot – Pag Croatia	Delivered content

Table 7 Content profile - Nesebar, Bulgaria

Reference pilot – Nesebar, Bulgaria	Delivered content
Destination narrative (Zones 1–5)	Tagline, full narrative, 5 quick facts, 4 destination pillars, 3 sub-region blocks (Historical Heart, Modern Resort Hub, Northern Coastal Side)
Points of Interest	13 POIs published across 5 categories
Filtered POIs by category	Experiences (1), Natural Heritage (2), Cultural Heritage (5), Museum / KAC (3), Underwater (2)
Multimedia	Photo carousel per destination/POI and video content (2)
Reference pilot – Nesebar, Bulgaria	Delivered content

Table 8 Content profile - Danube Delta, Romania

Reference pilot – Danube Delta, Romania	Delivered content
Destination narrative (Zones 1–5)	Tagline, full narrative with read-more, 5 quick facts, 4 destination pillars, 8 sub-region blocks (Crișan, Murighiol, Jurilovca, Sfântu Gheorghe – Sulina, Chilia, Vadu, Letea, Tulcea)
Points of Interest	28 POIs published across 4 categories
Filtered POIs by category	Museum / KAC (3), Experiences (9), Natural Heritage (6), Cultural Heritage (10).
Multimedia	Photo carousel per destination/POI and video content (7)
Reference pilot – Danube Delta, Romania	Delivered content

Table 9 Content profile - Kutsurub, Ukraine

Reference pilot – Kutsurub, Ukraine	Delivered content
Destination narrative (Zones 1–5)	Tagline, full narrative with read-more, 5 quick facts, 3 destination pillars, 3 sub-region blocks (Olbia, Coast of Dnipro-Bug estuary, Local crafts and arts)
Points of Interest	10 POIs published across 4 categories
Filtered POIs by category	Museum / KAC (1), Experiences (4), Natural Heritage (4), Cultural Heritage (1)
Multimedia	Photo carousel per destination/POI and video content (3)
Reference pilot – Kutsurub, Ukraine	Delivered content

2.8 System Architecture

The system architecture of the Rural Heritage platform follows the decoupled/headless architecture pattern, completely separating the presentation layer (Frontend) from the data management layer (Backend/CMS). This approach was selected to ensure high performance, flexibility for future expansions, and an optimized user experience (UX). **Content owners maintain and extend their destinations directly through the headless CMS, so the platform can grow continuously (new POIs, destinations and media) without front-end redeployment, ensuring the showcase remains current throughout and beyond the project lifetime.**

2.8.1 Web Platform Architecture

Instead of implementing a traditional CMS, the platform is designed as a Single Page Application (SPA) that communicates dynamically via RESTful APIs with a Headless CMS (Strapi)[2]. Strapi feeds structured data (JSON) directly to the user interface.

To support this architecture, the platform's development followed a strictly modular logic. Reusable Angular components were created to consume dedicated services and interact seamlessly with the Strapi endpoints. The core implementation features include:

- **Data Handling:** Client-side filtering logic was implemented (e.g., showing or hiding points of interest on the map based on their category) to minimize redundant server calls and improve interface speed.
- **Browsing Experience:** Dynamic image carousels and tab-based navigation systems were developed on the destination pages. This allows the user to explore descriptions, POIs, infrastructures, and videos smoothly without ever needing to reload the page.
- **Media Management:** The platform dynamically parses image and video URLs (safely handling YouTube iframe embeds via Angular's DomSanitizer[3]), composing absolute paths based on the API's environment variables.
- **Deployment & Security:** The overall architecture is supported by a hosting environment configured with an Nginx web server[4]. Nginx acts as a reverse proxy to serve the Angular application and securely route requests to Strapi. SSL/TLS certificates (HTTPS) are applied across the entire system, ensuring the encryption and integrity of data during transmission.

Figure 8 displays the architectural overview of the platform.

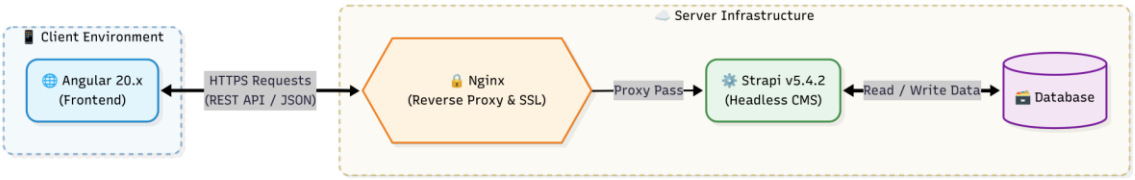

Figure 8 High-level architectural overview of the Rural Heritage web platform

[2] https://strapi.io/

[3] https://angular.dev/api/platform-browser/DomSanitizer

[4] https://nginx.org/en/

2.8.2 Technologies Used

The platform's implementation was based on modern, open-source, cutting-edge technologies:

- **Frontend Framework:** Angular 20.x[5] with TypeScript[6].
- **UI/UX & Styling:** Bootstrap 5.3[7], PrimeNG 20.x[8], FontAwesome[9].
- **Geospatial & Mapping:** Leaflet 1.9[10] (with Fullscreen and Routing support) for interactive map visualization and different view available.
- **Backend Runtime & Content Management:** The backend runs on a **Node.js[11] (v22.x)** runtime environment. **Strapi Headless CMS (v5.4.2)** was selected as the core content management system and API provider.
- **Web Server & Security:** Nginx Reverse Proxy, SSL/TLS Certificates (HTTPS).

2.8.3 Backend Services

The core of the backend services is powered by the Strapi Headless CMS, which serves as the central data repository for the platform. The backend is responsible for aggregating, storing, and managing the majority of the information corresponding to the pages of the platform like pilot destinations and the partners of the project. By centralizing this content, the system provides a comprehensive and unified access point, dynamically displaying all site data for the project partners and end-users.

To efficiently support the platform's requirements, a relational schema was designed from the ground up. The detailed architecture of these foundational data models (collections, content types, and relations) is presented and analyzed in subsection 2.8.4.

The system exposes this aggregated content through highly configurable API endpoints, fully protected by SSL certificates. The frontend executes complex API calls utilizing advanced Strapi querying features (such as deep filtering, sorting, and dynamic population) to retrieve the information needed.

2.8.4 Data Model

To effectively manage and deliver the complex information required by the TOURAL project, the backend utilizes a highly relational and modular data schema within the Strapi Headless CMS. This architecture is designed to minimize data duplication while maximizing the flexibility of the content presented to end-users and project partners.

The core data architecture is built upon three primary, interconnected collections:

- **Destinations (`RH-Destination`):** This acts as the root entity for each pilot site or region. It contains localized metadata (Display Name, Slug) and utilizes repeatable modular components to structure the user interface dynamically. These components

[5] https://angular.dev/

[6] https://www.typescriptlang.org/

[7] https://getbootstrap.com/

[8] https://primeng.org/

[9] https://fontawesome.com/

[10] https://leafletjs.com/

[11] https://nodejs.org/en

include quick facts, destination pillars, island/sub-region breakdowns, and multimedia tabs.

- **Points of Interest (`RH-POI`):** This collection stores the granular entities within a destination. Each POI holds precise spatial data (Latitude/Longitude coordinates), descriptive rich text detailing its significance ("Why Visit", "Details"), and its own media assets.
- **Categories (`RH-Category`):** A taxonomy collection used to classify POIs (e.g., Natural Heritage, Underwater, Museums). This enables the frontend to dynamically filter map markers and content based on user preferences.

Figure 9 presents the entity-relationship schema of the core data models within the Strapi Headless CMS, highlighting the connections between Destinations, POIs, and Categories.

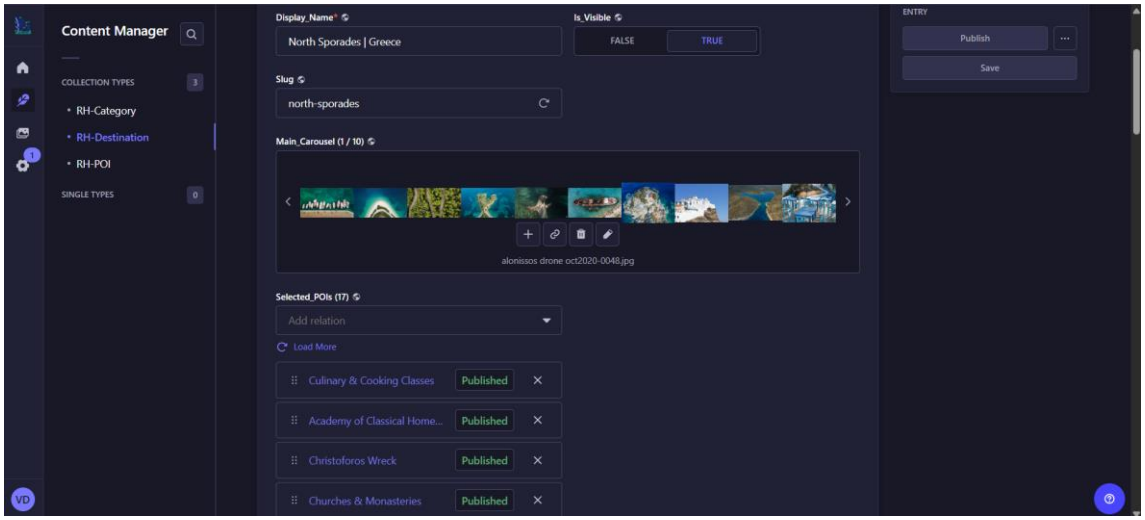

Figure 9 Strapi CMS content management interface

Relational Mapping: The core of this schema lies in its relational links. A single **Destination** is linked to multiple **POIs** (One-to-Many / Many-to-Many). In turn, each **POI** has a Many-to-Many relationship with **Categories**, meaning a single POI can belong to multiple thematic categories simultaneously (although currently each POI is assigned to a single category, this relational structure future-proofs the system to accommodate POIs that may span multiple themes in future expansions). Additionally, the Destination's internal components (such as the "Destination Pillars") maintain direct relational links to Categories, allowing the frontend to dynamically fetch and display POIs associated with specific regional pillars.

A separate, standalone collection (Partner-toural) is also maintained to manage the project's data, utilizing repeatable asset components to display sub-partners, links, and organizational descriptions seamlessly on the platform. Figure 10 illustrates depicts the structural schema, specific data fields, and the relational mapping (One-to-Many and Many-to-Many connections) between Destinations:

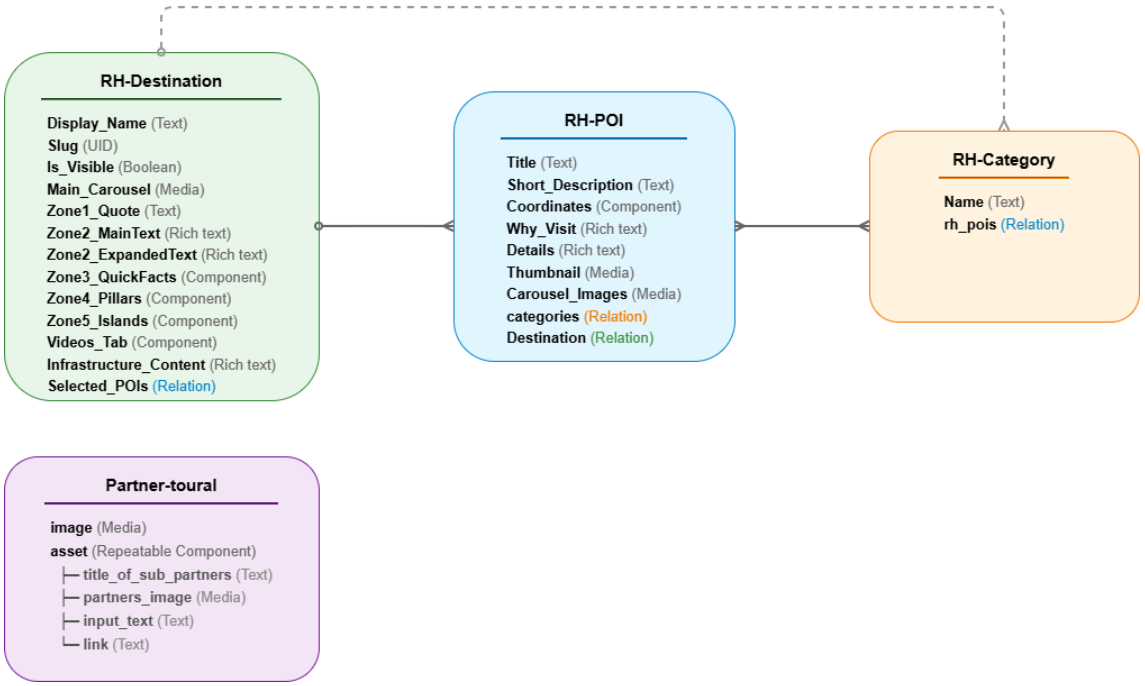

Figure 10 Entity-Relationship (ER) diagram detailing the core data models within the Strapi Headless CMS.

2.8.5 Frontend Interfaces

The user interface has been developed using Angular 20, emphasizing interactivity and the visualization of geospatial data. Its key features include:

- **Advanced Interactive Map:** Implemented with the Leaflet library, the map supports multiple base layers (OpenStreetMap, Google Satellite, Hybrid, Terrain, and Roadmap) alongside full-screen capabilities. It dynamically visualizes Points of Interest (POIs) using custom, color-coded SVG markers based on heritage categories. The map is further enhanced by an interactive overlay menu for real-time category filtering and pop-ups that act as deep links, directly connecting users to specific destination details.

- **Dynamic Routing & Advanced State Management:** The platform utilizes the Angular Router in combination with browser localStorage to maintain the user's browsing context across different views. The system remembers active tabs, selected filter categories, and even specific open POIs. For example, navigating from a map marker automatically redirects the user to the corresponding Destination page, opens the "POIs" tab, expands the exact location, and triggers a smooth scroll to that specific element.

- **Optimized Rendering & Dynamic Content Delivery:** The interface features adaptive image carousels that automatically update their media pool depending on whether the user is viewing the general destination or a specific POI. To prevent layout shifts and ensure a stable interface, tab-based navigation is optimized using advanced CSS visibility techniques rather than structural DOM destruction. Additionally, Angular's `DomSanitizer` is strictly enforced to safely parse rich text and embed external multimedia (e.g., YouTube iframes), fully protecting the application against Cross-Site Scripting (XSS) vulnerabilities.

Responsive Layouts & Fluid Animations: Designed with Bootstrap 5, PrimeNG UI components, and modern CSS Grid layouts, the platform guarantees flawless, accessible operation across mobile, tablet, and desktop devices. The visual experience is further polished

with hardware-accelerated CSS transitions, collapsible "read more" zones, and smooth fade-in animations that elevate the user experience without sacrificing rendering speed.

3 VR Diving Experience for Underwater Heritage Exploration

This chapter presents the VR tools developed under Task T5.4 to enhance the tourist experience in TOURAL regions through immersive digital interaction with underwater cultural and natural heritage. The chapter focuses on the VR diving application, describing its purpose, design rationale, development methodology, content production pipeline, interaction logic, deployment configuration, and implementation at the pilot sites.

The objective of the application is to provide an accessible dry-diving experience that allows users to explore underwater heritage environments without physical diving equipment or specialized training. In this way, the VR tool supports heritage interpretation, visitor engagement, and destination visibility within the broader TOURAL digital ecosystem.

3.1 Scope and Purpose

The VR diving application was designed as an immersive experience layer that complements the Rural Heritage platform by extending destination discovery into interactive virtual exploration. Its role is not limited to visualization, but also includes educational storytelling, interpretation of points of interest, and improved user engagement through interactive and multimedia content.

The application addresses the need for a realistic yet accessible representation of underwater heritage sites, enabling users to navigate digital reconstructions, discover contextual information, and experience selected pilot locations in a more experiential format. It therefore functions as a visitor-facing tool that translates heritage assets into a guided, engaging, and technologically enriched tourism experience.

The application was developed for the three underwater pilot sites of TOURAL: Simuni on the Island of Pag in Croatia, Nesebar in Bulgaria, and Peristera in the Northern Sporades in Greece. It combines immersive visualization technologies with interactive storytelling and real-time environmental data to create an engaging exploration experience.

3.2 Design and Development Approach

The VR Diving application combines immersive visualization technologies, interactive storytelling, and real-time environmental data to create an engaging exploration experience. Its core functionality is based on intuitive underwater navigation, real-time response to user actions, live integration of underwater camera feeds, and enrichment of the experience with augmented information and 3D models of underwater sites.

The main technological innovations of the application include:

- High-fidelity 3D visualization of the pilot sites and their surrounding environments.
- Integration of detailed 3D models representing underwater archaeological assets, marine flora, and marine fauna.
- Realistic underwater rendering through the implementation of caustic lighting effects that simulate light refraction beneath the water surface.
- Custom rendering techniques and shaders to support immersive and dynamic water visualization.
- Integration of live underwater camera feeds, enabling users to observe real-time conditions at selected pilot sites.
- Ambient underwater soundscapes and spatial audio effects to enhance immersion and presence.
- Interactive exploration and educational storytelling through multimedia-enhanced Points of Interest.

As a result, the application provides an accessible way to explore underwater cultural heritage sites that may be difficult or impossible to visit physically. It supports heritage interpretation and

visitor engagement by making underwater environments available to a wider audience through digital means.

3.3 VR Design Principles

The VR Diving application was designed according to established VR design principles to provide an immersive, intuitive, and accessible experience. Its usability was guided by efficiency, effectiveness, learnability, memorability, and user satisfaction. The development pipeline followed a spiral model, with iterative design, implementation, and evaluation informed by testing with partners and feedback from local stakeholders and domain experts gathered through meetings, interviews, and structured data collection.

Throughout development, core UI design principles were applied to ensure that the system remained understandable and user-friendly:

- Clarity: Understandable interfaces that guide the user without confusion.
- Consistency: Visual and functional consistency to build user trust.
- Feedback: Clear and timely information about system actions and status.
- Accessibility: Designing for everyone, following standards such as WCAG.
- Visual Hierarchy: Placing elements to guide the user's attention toward important points.
- Simplicity: Focusing on the essentials and avoiding unnecessary complexity.
- User-Centric Design: A process grounded in user research and continuous optimization based on user needs.

3.4 Content Creation Pipelines

The development methodology followed a structured content-creation pipeline for building the virtual environments of TOURAL. The process began with the realistic reconstruction of the underwater setting, with the aim of capturing the spatial, visual, and environmental characteristics of each pilot site as accurately as possible. It then continued with the enrichment of the scenes through additional visual elements, annotations, environmental data, and live streaming where available. The overall development pipeline is depicted in Figure 11, which presents the main stages of the content creation and deployment process.

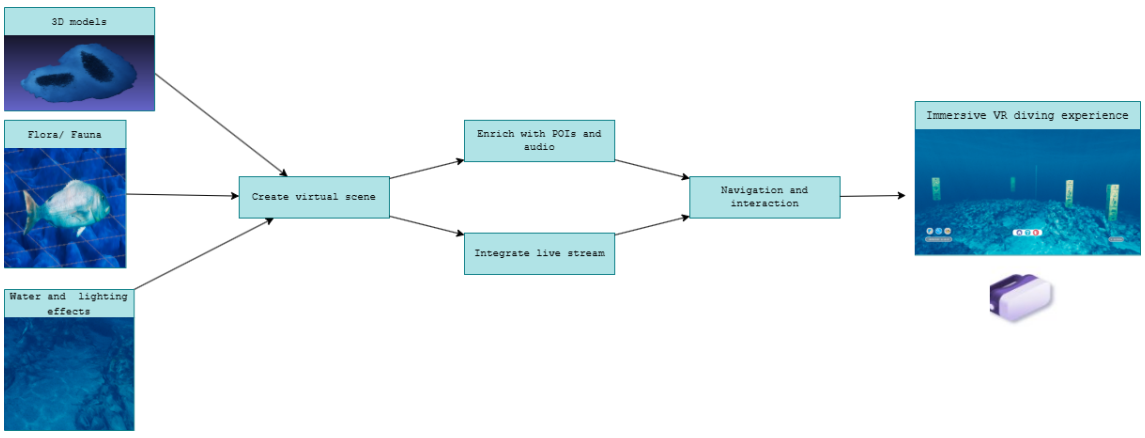

Figure 11 Schematic diagram of the VR diving application development process

3.4.1 Creation of Underwater Environment

The creation of the underwater environment relied on a combination of reconstructed assets, terrain modelling, visual effects, and shader-based rendering. The objective was to produce an immersive scene that reflects both the physical structure and the atmospheric conditions of underwater heritage sites. Special attention was given to lighting, post-processing, and dynamic visual elements, so that the virtual environment would reproduce the visual complexity of the underwater world in a credible and engaging manner.

3.4.1.1 *Underwater Landscape and Cultural Heritage*

Seabed and Underwater Cultural Heritage: The central component of the underwater scene is the seabed, which contains shipwrecks and submerged structures of historical, archaeological, and cultural significance. To represent these features faithfully, high-resolution 3D reconstructions were generated through underwater photogrammetry. This process was used to model the main archaeological assets of the pilot sites, including the Byzantine amphora cargoes and related shipwreck remains from Peristera, Simuni, and Nesebar. The resulting models were integrated into the virtual environments to preserve the spatial and visual characteristics of the original sites. To support real-time rendering, the meshes were optimized through decimation, reducing computational load while maintaining visual fidelity.

The shipwrecks in the Peristera area, which is used as an example, are illustrated in Figure 12, Figure 13, Figure 14, and Figure 15 depict the shipwrecks in the broader Peristera area.

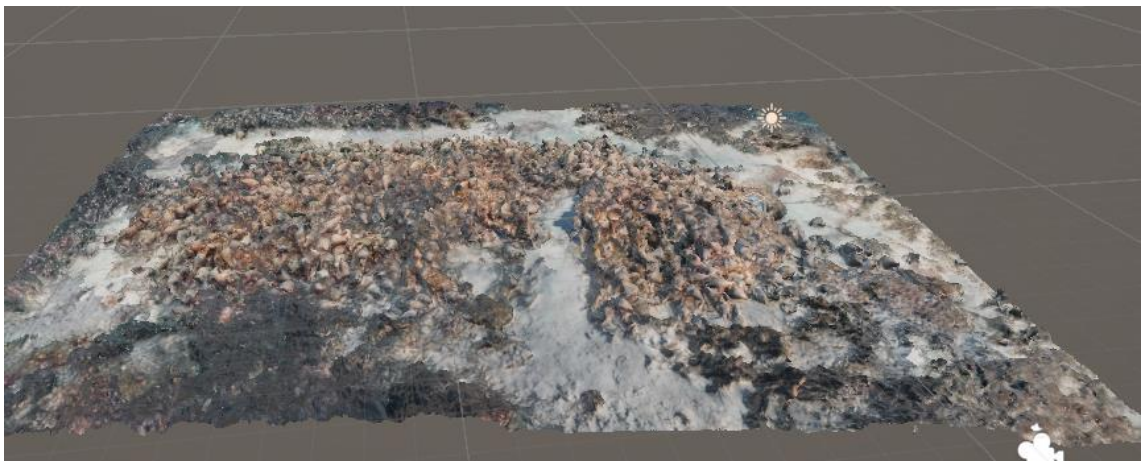

Figure 12 Main Peristera's shipwreck

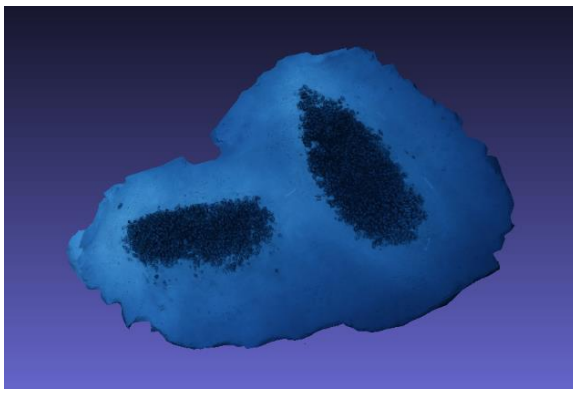

Figure 13 Peristera adjacent shipwreck AB

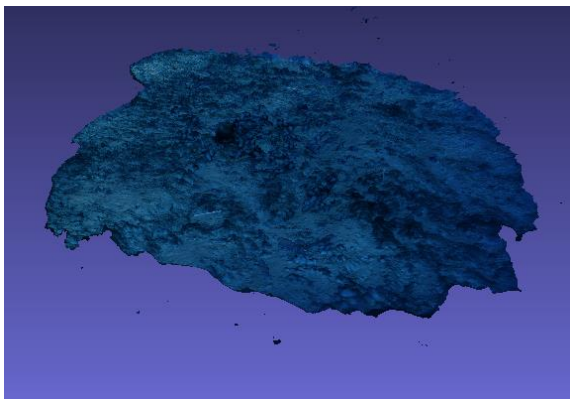

Figure 14 Peristera adjacent shipwreck D

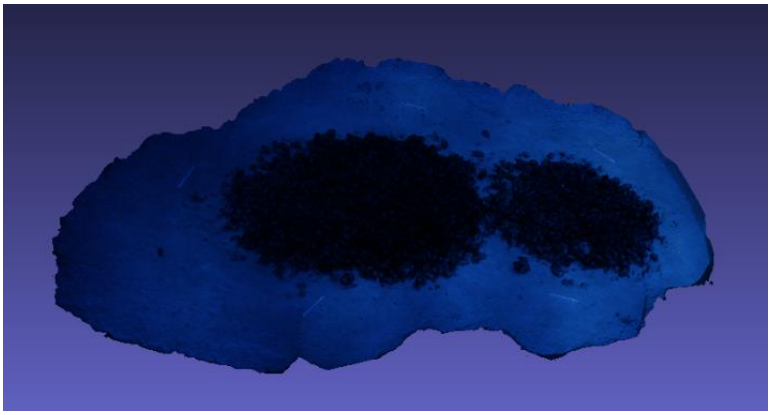

Figure 15 Peristera adjacent shipwreck G

Surrounding Space (Terrain): To model the surrounding underwater environment, bathymetric data were acquired for the pilot sites in order to accurately represent depth variations and seabed morphology below sea level. The collected data were processed using GeoTIFF files containing Digital Elevation Model (DEM) information, from which heightmaps were generated. These heightmaps were subsequently imported into the Unity development environment to create terrain models that faithfully reproduce the real-world bathymetric characteristics of each pilot site. This approach enabled the realistic representation of underwater topography, including depth gradients, depressions, and other seabed features, thereby enhancing the spatial accuracy and immersion of the virtual environment.

In cases where bathymetric data were not available for a given pilot site, a procedural approach was adopted. Specifically, a custom shader named Custom/Sea Terrain was developed within the Unity environment to simulate seabed morphology. This shader creates a dynamic and parametrically controlled surface, simulating the morphology of the marine terrain through deformation of the geometry using simplex noise. The implementation is based on the tessellation technique, which, in computer graphics, refers to the process of subdividing polygonal meshes, with the aim of increasing geometric detail and optimizing rendering performance. Additionally, parameters such as the scale and frequency of the noise are adjustable, while normal maps and settings for the Smoothness and Metallic properties are supported, contributing to the realistic display of materials and lighting. The shader is designed for opaque rendering, with provision for future integration of transparency, if required.

3.4.1.2 *Marine Ecosystems*

For a faithful representation of marine ecosystems, it was necessary to realistically model both the underwater landscape and the life forms that govern these systems. This includes the flora, fauna and the natural relief of the seabed. For their realistic integration into the system, marine flora and fauna are implemented using dynamic shaders, which give movement and liveliness to the content, giving it the character of moving elements.

Flora: Two types of underwater plant models were used to create the underwater flora, in order to achieve greater variety and realism in the simulation. These models form extensive underwater meadows, which are an important part of the ecosystem. In this way, it is possible to faithfully represent the species Posidonia oceanica, also known as Poseidon's grass or Mediterranean cassette, which is an endemic marine plant of the Mediterranean Sea.

Furthermore, in addition to the use of photorealistic models for the underwater flora, specially designed shaders allow for realistic movement of the algae, simulating hydrodynamic forces. This movement is implemented through multi-layered noise textures that create random fluctuations, enhancing the sense of naturalness.

Fauna: In order to realistically represent the marine habitats found within the pilot sites, a series of expert interviews and consultation meetings were conducted to collect the necessary ecological and environmental information. Based on this knowledge, the identified habitats were accurately modeled and integrated into the virtual environments. To facilitate the realistic reconstruction of marine species and objects from these areas, despite the limited availability of multi-view imagery, a single-image 3D reconstruction approach was employed. Specifically, a recently introduced transformer-based method, Amodal3D, capable of handling object occlusions, was utilized as an offline reconstruction step. This approach enabled the creation of a comprehensive database of fauna models tailored to each region. Performing the reconstruction process offline, rather than in real time, significantly reduced computational requirements while maintaining an effective balance between visual realism and system performance. Figure 16 illustrates the 3D models reconstructed through the single-image reconstruction pipeline for the Peristera pilot site. In cases where sufficient visual or ecological information was unavailable for reconstructing specific species, a collection of freely available 3D models of Mediterranean fish species was employed to represent the underwater fauna. These models enhanced the realism of the virtual environments while providing a diverse and representative depiction of the pilots marine ecosystems.

Figure 16 Reconstructed 3D models of marine fauna (fish species)

Another integral aspect of fauna representation was the simulation of organism movement. Marine species often exhibit collective behaviours, moving in groups or schools, while the underwater environment is generally characterized by a sense of calmness and smooth, continuous motion. Nevertheless, these organisms may also react dynamically to environmental changes, accelerating suddenly or altering their trajectories to avoid potential threats and hazardous conditions. To capture these behaviours, a flocking algorithm was implemented to simulate the coordinated movement of fish schools. The algorithm enables individuals to move cohesively while maintaining separation and alignment with neighbouring fish, resulting in realistic group dynamics and natural swimming patterns. This approach enhances the visual authenticity of the underwater ecosystem and contributes to a more immersive user experience.

Beyond collective flocking behaviour, individual fish movement was further refined through a dedicated animation shader. A controller was used that moves the fish in a straight line, while the deformation of the mesh is carried out through a shader, simulating the movement of their body

and giving the illusion of animation. The parameters that define the movement include the wobble frequency, which determines the rate of body wobble, the wobble speed along the straight path, and the wobble distance, which determines the range of lateral displacement. In addition, the weight (twirl strength) and the twirl centre (twirl centre) control the dynamics of the rotational movement, giving the fish a more realistic behavior during movement. In terms of appearance, the size and position of the eyes (eye width, eye height, eye position) are adjusted for greater variety and naturalness, while the color (colour 1 light, colour 1 dark, colour 2 light, colour 2 dark) of the fish can be adjusted to reflect different species or lighting conditions.

To enhance biodiversity, additional groups of fish were created using Unity's particle system, which disperses models in space and allows them to move in different directions (north, south, east, west) and at different speeds.

Dust particles/floating particles: In addition, special particle systems simulate floating dust particles and water bubbles, significantly improving the user experience and enhancing immersion in an underwater environment. For this purpose, a particle system is used that renders the multiple particles as horizontal billboards, with random orientations and increased movement speeds, simulating natural collisions and the mobility of particles in water.

3.4.1.3 *Realistic Underwater Lighting and Water effects*

The system accurately represents the behaviour of light in underwater environments. Light attenuates progressively with depth, with denser water producing characteristic green and blue hues. Light beams from the lens are refracted by waves on the surface, creating dynamic caustics that reflect off rocks and coral. For realistic shading, soft shadows are used that depend on the turbidity of the water.

Caustics effect: The caustics effect simulates the characteristic patterns of light that form when sunlight passes through the moving surface of the water and refracts onto submerged surfaces such as the seabed, rocks, and shipwreck structures. This effect is typically most visible at shallower depths, where sunlight penetration remains strong. In Unity, it is achieved using a URP (Universal Render Pipeline) projector, combined with a dynamic, animated texture or shader that projects shifting light patterns onto underlying geometry, mimicking the natural distortion caused by surface wave motion. The effect contributes significantly to the sense of underwater realism, as it reproduces one of the most visually distinctive and recognisable phenomena associated with shallow underwater environments.

Realistic water shader: The realistic water shader governs the visual behaviour of the water surface and body within the application, simulating properties such as transparency, reflectivity, refraction, and colour variation with depth. The shader typically combines several techniques, including normal mapping to simulate surface ripples and wave motion, Fresnel-based reflectivity to adjust how reflective the water appears depending on viewing angle, and depth-based colour blending to reproduce the gradual shift toward darker blue or green tones as depth increases. Together, these elements create a convincing and dynamic representation of the underwater medium, reinforcing the overall sense of immersion within the virtual diving environment.

Visual Effects and Post-Processing

To further enhance depth and visual realism, the system incorporates a series of additional rendering effects:

- Volumetric Light: The lens beams appear as visible "rays" thanks to special shaders that simulate dust and bubbles in the water.
- Dynamic Fog: Dense fog that increases with depth, reducing visibility for a dramatic effect.
- Screen Space Reflections: Reflections on metal surfaces that are updated in real time.
- Post-process effect: Appropriate post-processing effects were applied to enhance the visual fidelity of the underwater environment. The Depth of Field effect simulates the focusing

property of a camera lens, which can only focus accurately at a certain distance, leaving objects out of focus blurry. This technique contributes to the realistic rendering of the visual experience in underwater scenes, as the turbidity of the water reduces the visibility and sharpness of objects. At the same time, through the color grading process, a subtle blue tint was applied, which highlights the sense of ocean depth and the atmospheric quality of the environment.

- Underwater effect: This shader applies an image distortion effect that simulates the visual experience underwater. Using Simplex noise, a wavy pattern is produced that shifts the UV coordinates of the base texture, creating the illusion of movement and refractive distortion of light. The _NoiseScale, _NoiseFrequency, _NoiseSpeed and _PixelOffset parameters allow control of the intensity, frequency, wave speed and pixel offset respectively, giving flexibility in adjusting the effect for a more realistic rendering of the underwater environment.

3.4.2 Surface-Level Environment (Above Sea Level):

To provide a more complete spatial experience, the areas above sea level were also reconstructed. Local and partner imagery, together with Google Maps API and Google Earth data, were used to model the surrounding landscape. Where sufficient information existed, nearby islands and coastal features were recreated as 3D models. Panoramic skyboxes were integrated into Unity to provide a realistic horizon and aerial backdrop, while boats, seagulls, and other coastal elements were added to reinforce the sense of place.

The reconstructed above-water environment of Alonissos and Peristera is shown in Figure 17, which illustrates how the surface-level setting complements the underwater pilot site and supports a more complete interpretation of the location.

Figure 17 3D reconstructed model of Alonissos and Peristera islands

3.4.3 Live Streaming Integration

Where available, underwater streaming cameras are integrated into the application, providing live video feeds that combine synthetic virtual content with real-world environmental observations.

Users can access and toggle these live streams through interactive panels within the application, allowing them to seamlessly switch between the virtual experience and real-time underwater views. The virtual camera panels are positioned to correspond with the actual physical locations of the deployed cameras, creating a stronger connection between the virtual environment and the real-world site. This integration enhances situational awareness, enriches the educational value of the experience, and enables users to observe current underwater conditions alongside the reconstructed virtual environment. Furthermore, where live streaming cameras are available at the pilot sites, real-time video feeds can be utilized to dynamically update the appearance of the 3D models by projecting the streamed imagery directly onto the reconstructed geometry. This approach enables the virtual environment to reflect current conditions observed at the site, creating a closer correspondence between the digital representation and the real-world underwater environment. By continuously mapping live camera textures onto the 3D surfaces, users can observe temporal changes in visibility, lighting conditions, marine life activity, and other environmental factors, thereby enhancing the realism, authenticity, and dynamic nature of the virtual diving experience.

3.4.4 Scene Enrichment and Interactive Storytelling

To enhance the educational and cultural value of the virtual environments, the underwater scenes were enriched with augmented content related to the historical, archaeological, and cultural significance of the featured sites. This additional content enables users to gain deeper insights into the archaeological findings and their historical context while exploring the virtual environment. Points of Interest (POIs) were identified through consultations, meetings, and interviews with project partners, domain experts, and site custodians, ensuring that the presented information accurately reflects the significance of each location and artifact. The collected knowledge was transformed into textual narratives that are presented to users through interactive annotations and information panels, supporting a structured storytelling experience. Furthermore, each POI is associated with a narrated audio transcript, allowing users to listen to contextual information while exploring the site. This multimodal presentation of information enhances immersion, improves accessibility, and contributes to a more engaging and informative user experience.

3.5 Interaction Models

This section discusses the navigation and interaction modules leveraged to provide an intuitive and immersive experience for end users.

Regarding navigation within the scene, users can move freely through the submerged environment using either keyboard input or VR controllers. Users can navigate the virtual environment using standard keyboard controls, with the Q, W, E, A, S, and D keys mapped to movement actions, while camera orientation and view direction are controlled using mouse input. Figure 18 presents the basic navigation rules for keyboard control. On VR devices, movement is achieved through controller-based input, allowing users to navigate by pressing the A button and moving in the direction of their gaze or look vector. Interaction with virtual objects and interface elements is performed using the controller grip buttons, enabling intuitive and immersive engagement with the environment. Movement has been designed to be smooth and to follow the natural laws of underwater diving, mimicking pressure variations with respect to depth in order to give users a realistic feeling of swimming and diving. Furthermore, users can adjust their diving velocity using a sea scooter. POIs act as pathfinding targets, and an arrow indicator guides users back toward the area of interest when needed.

Figure 18 Guidelines for the VR diving application

The VR diving application is an interactive experience that allows users to engage with various components within the scene. Clicking on POIs, represented as real-world underwater labels, activates text descriptions and audio narrations, and can also enable underwater live streaming where available. An underwater scanner allows users to scan artifacts, such as amphorae, and receive descriptive information about them, providing a more realistic and educational experience. Additionally, users can activate a flashlight to enter night mode, simulating a night dive and allowing them to explore the shipwreck in darkness.

Figure 19 Sea scooter instance from the VR diving application

3.6 Deployment

3.6.1 Devices

The application is deployed across multiple platforms to ensure accessibility and broad user engagement. A desktop-based WebGL version is available and hosted through the Digital platform, integrated into the overall application ecosystem. This version provides a simplified and performance-optimized representation of the full system, enabling seamless execution directly within web browsers without the need for additional installations.

In addition, a fully immersive VR version of the application has been developed for Meta Quest devices. This version is intended for use in educational and demonstration contexts, including deployments such as KAC Alonissos, which will be hosted following project completion. The VR version offers enhanced interaction capabilities and a higher level of immersion compared to the WebGL counterpart.

3.6.2 Environment

The application was developed using Unity 6.0.0.41[12] with the Universal Render Pipeline (URP), ensuring compatibility across both WebGL and standalone VR deployments, including Oculus/Meta Quest[13] devices. The chosen development environment enables efficient rendering performance, visual consistency, and cross-platform scalability, supporting both lightweight browser-based execution and high-fidelity immersive VR experiences.

3.7 Implementation Details and Description of app

3.7.1 Pilot Sites

3.7.1.1 *Peristera*

The Peristera shipwreck[14] is one of the most significant ancient shipwrecks discovered in the Mediterranean Sea. Dating to approximately 425–420 BC, it is renowned for its exceptionally well-preserved cargo of around 4,000 amphorae, making it one of the largest known merchant vessels of the Classical period. Today, the site forms part of the Alonissos Underwater Museum[15] and is accessible to certified divers, offering a unique opportunity to explore an important underwater archaeological monument in its natural setting.

The shipwreck lies on a sloping seabed at depths ranging from approximately 23 to 27 metres below sea level. Within the VR Diving application, the Peristera site has been faithfully reconstructed through detailed 3D models and contextual historical information, enabling users to virtually explore the archaeological site and its cultural significance. Figure 20 and Figure 21 present the amphora types associated with the Peristera shipwreck

[12] https://unity.com/releases/editor/whats-new/6000.0.4f1

[13] https://www.meta.com/ca/quest/

[14] https://en.wikipedia.org/wiki/Peristera_shipwreck

[15] https://museum.alonissos.gov.gr/en/home/

Figure 20 Types of amphorae found in the Peristera shipwreck

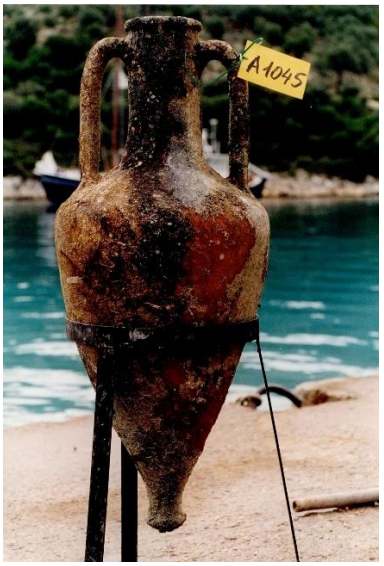

Figure 21 Types of amphorae found in the Peristera shipwreck

In addition to the main shipwreck, the application includes neighbouring underwater archaeological sites that are currently inaccessible to recreational diving because of their greater depths, which range from approximately 35 metres to 45–55 metres below sea level. Their inclusion highlights the value of digital technologies in providing a dry-diving experience, allowing visitors to explore underwater cultural heritage that would otherwise remain inaccessible to the general public.

The marine fauna observed in the Peristera area includes characteristic Mediterranean species such as sea bream, dentex, grouper, white seabream, and chromis. The seabed is predominantly covered by extensive meadows of Posidonia oceanica, an endemic seagrass species of the Mediterranean Sea. Figure 22 presents live footage illustrating the surrounding landscape and the movement of marine fauna.

Figure 22 Live footage from the Peristera underwater camera feed

3.7.1.2 *Simuni*

The Simuni shipwreck is a Roman-era merchant vessel dating to the 1st century BC, discovered in 2018 near Cape Letavica on the island of Pag. The wreck lies approximately 130 metres offshore at a depth of 37–39 metres, on a seabed where a rocky slope gradually transitions into sand. The site contains a dense concentration of between 400 and 800 amphorae, predominantly of the Lamboglia 2 type, including several morphological variants. Based on their typological characteristics, the amphorae date to the Late Roman Republic and confirm the vessel's role in Adriatic trade networks. Most of the amphorae are heavily encrusted with marine deposits and have become cemented together into a compact assemblage, while only a small number have been displaced. The main concentration extends over 23–24 metres, suggesting that the original merchant ship was approximately 25–30 metres in length. The spatial arrangement of the cargo indicates that it remained largely intact during the sinking, rather than being scattered afterward.

Additional finds further support the identification of the site as a shipwreck. Approximately 38 metres northeast of the amphora deposit, a 1.6-metre-long lead stock from a composite lead-wood anchor has been discovered, likely belonging to the same vessel. Nearby, the base of a large ceramic vessel of undetermined date was also identified.

Due to its considerable depth, the site is largely inaccessible to recreational divers. This makes it a strong candidate for inclusion in virtual reality (VR) diving applications, enabling wider public access to this otherwise restricted underwater cultural heritage.

3.7.1.3 *Nesebar*

The underwater cultural heritage of Nesebar[16] , ancient Mesambria, comprises submerged remains of fortification walls and structures associated with the city across several historical periods, including Ancient Greek, Hellenistic, Roman, Byzantine, and Medieval Bulgarian phases. The site lies within the historic peninsula of Nesebar, a UNESCO World Heritage Site, and has been the subject of underwater archaeological surveys since 1960, with renewed investigation efforts beginning in 2017. The submerged remains of the ancient city, including walls and structures off the Old Town coastline, rest at shallow depths of approximately 1.5 to 5 metres, making them among the most accessible underwater archaeological monuments in the Black Sea region.

Due to the combination of submerged archaeological remains and the surrounding marine environment, characterised by rocky outcrops and diverse marine life, the Nesebar site offers a unique opportunity to combine archaeological storytelling with natural heritage interpretation within the VR Diving application. This enables users to explore both the submerged urban structures and the underwater ecosystem of the Black Sea coast within a single immersive experience. In Figure 23, Figure 24 the orthomosaics of the Nesebar site are depicted.

[16] https://balkanheritage.org/underwater-archaeology-field-school-in-the-black-sea/

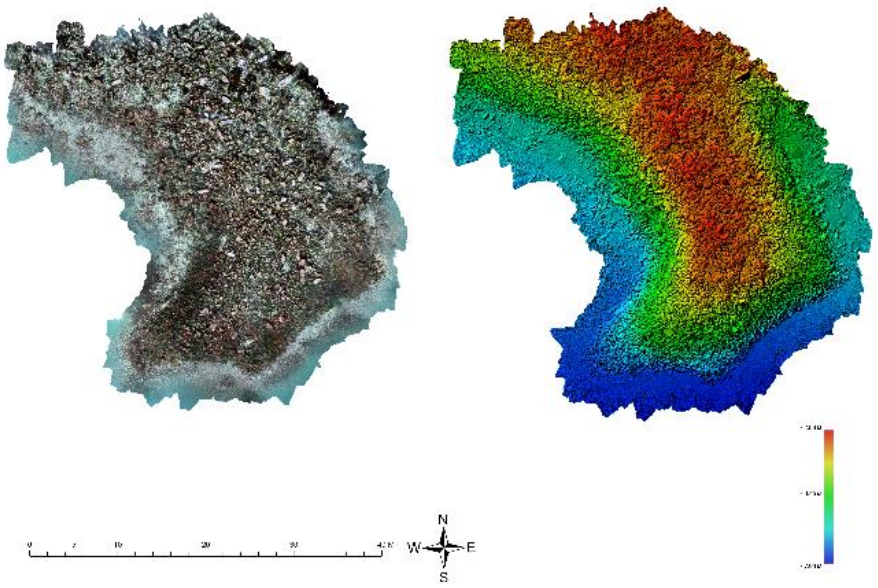

Figure 23 Orthomosaics of Nesebar

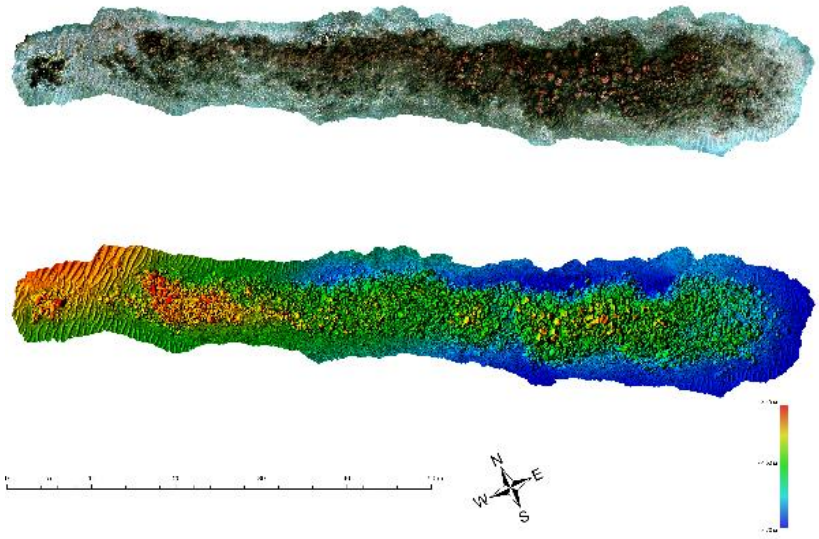

Figure 24 Orthomosaics of Nesebar

3.7.2 VR Diving App Demonstration

The main menu of the application provides access to the three underwater pilot sites: Simuni on the Island of Pag in Croatia, Nesebar in Bulgaria, and Peristera in the Northern Sporades, Greece. Figure 25 shows the front page of the VR diving application.

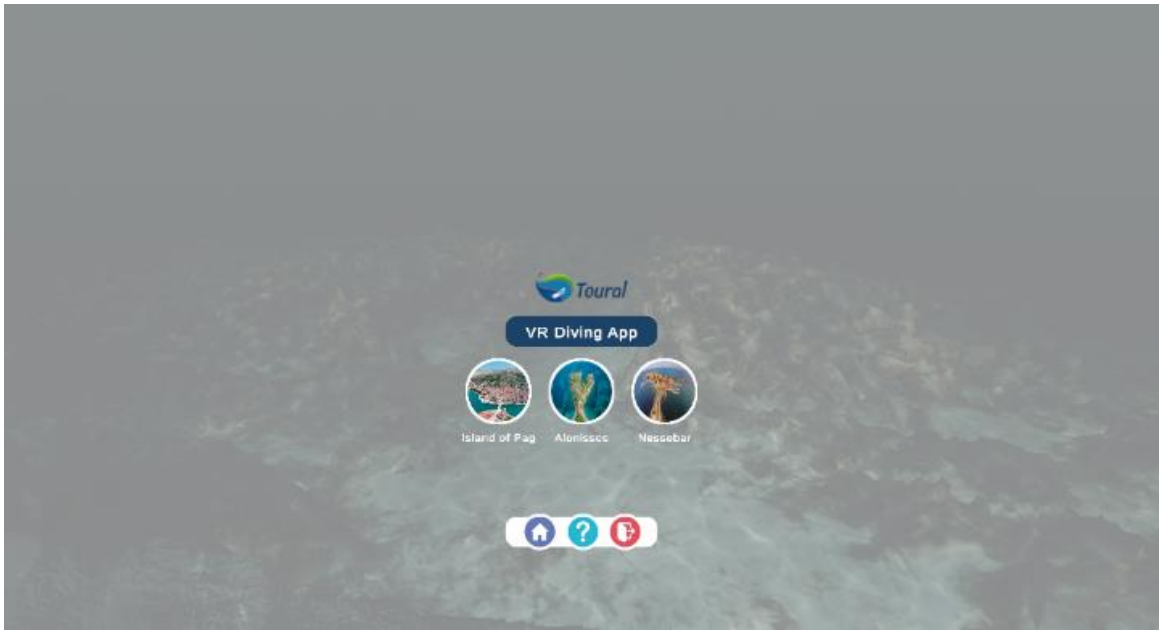

Figure 25 Front page of the VR diving application

Users can navigate through the 3D underwater environment using keyboard controls and a first-person camera view controlled with the mouse, as described in Section 3.5. Navigation instructions can be accessed at any time by selecting the information icon. The underwater environment features a high-quality photorealistic reconstruction of the shipwreck and its amphora cargo. The models were produced through underwater photogrammetry, described in Subsection 3.4.1.1. To enhance realism and immersion, lighting conditions and water effects described in 3.4.1.3 are implemented within the environment. This demonstration showcases Peristera as the reference pilot site, located near Alonissos in the Northern Sporades, Greece. The overall underwater environment is portrayed in Figure 26.

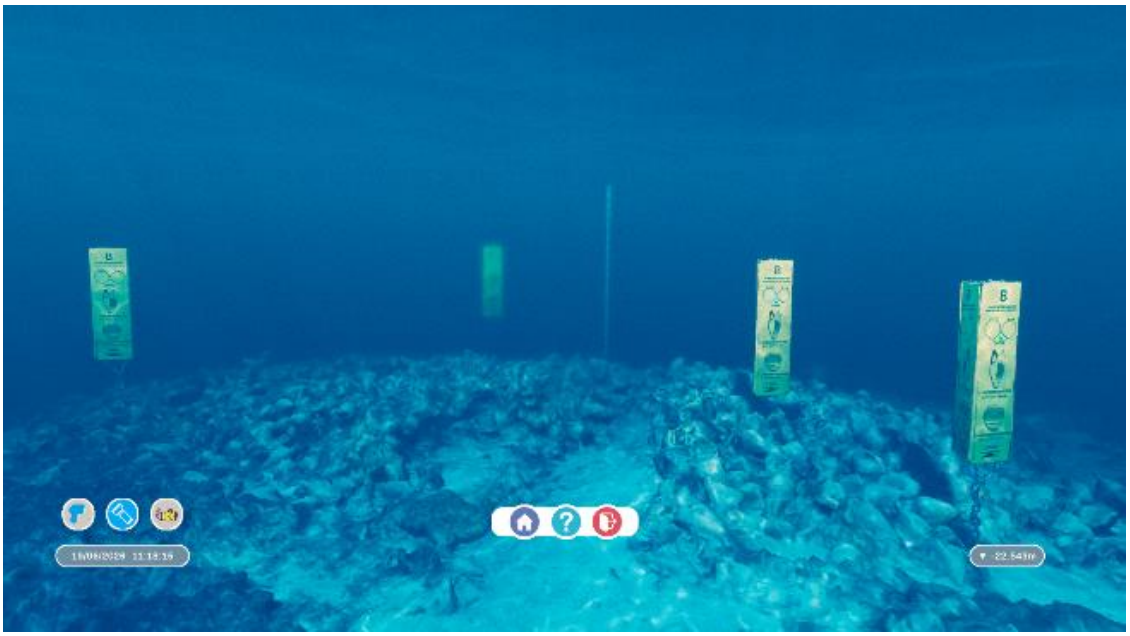

Figure 26 Underwater environment of the Peristera pilot site

Representative species of the local marine ecosystem have also been integrated throughout the environment based on 3.7.1.1. The fish exhibit realistic flocking behaviour, creating a dynamic and lifelike underwater ecosystem. Figure 27 depicts the historical content represented by a POI label.

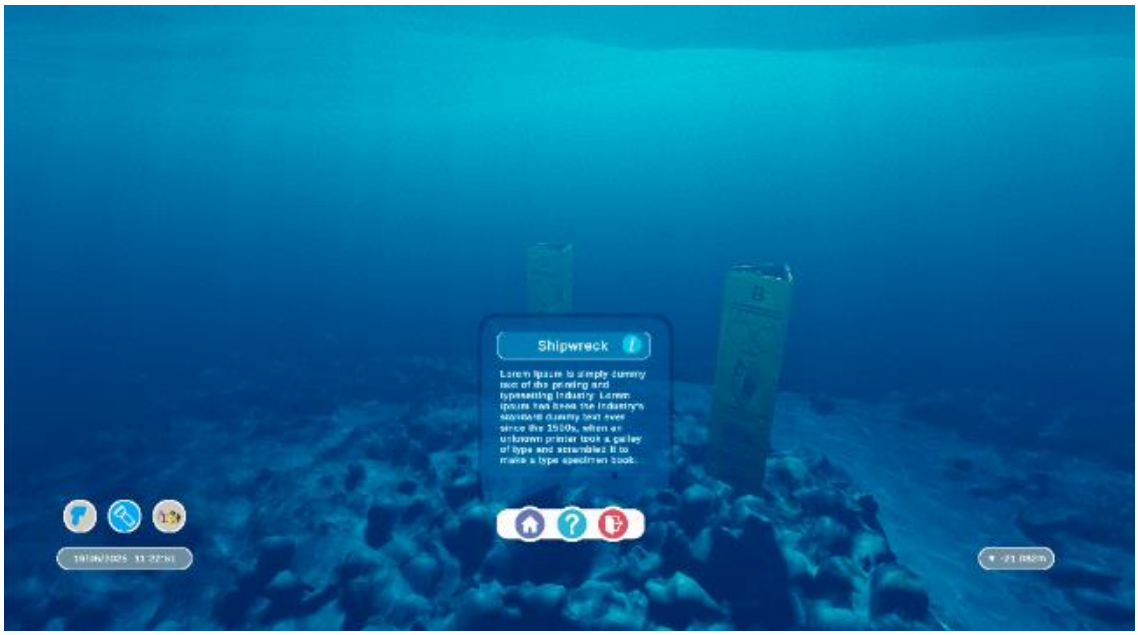

Figure 27 POI (Point of Interest) visualization

Users can also scan amphorae throughout the scene using an underwater scanning tool, enabling them to retrieve detailed information about each artifact, along with access to corresponding 3D models. By scanning specific areas of the shipwreck, users can inspect high-quality reconstructed models of amphorae recovered from the site. In particular, the application provides access to a detailed 3D reconstruction of amphora A1033, allowing users to closely examine its geometry and structural characteristics.

Figure 28 Underwater scanner detecting amphorae

In addition, the application integrates live underwater camera feeds provided by NOUS[17]. NOUS has integrated and installed five underwater streaming cameras positioned around the main shipwreck site at Peristera, as depicted in Figure 29. These real-time video streams enable users to observe the current state of the underwater environment while simultaneously exploring its virtual reconstruction. In this example, a live feed from Camera 5 at the Peristera shipwreck is displayed. Virtual cameras positioned within the scene correspond to the physical locations of the deployed underwater cameras, strengthening the connection between the virtual environment and the real site.

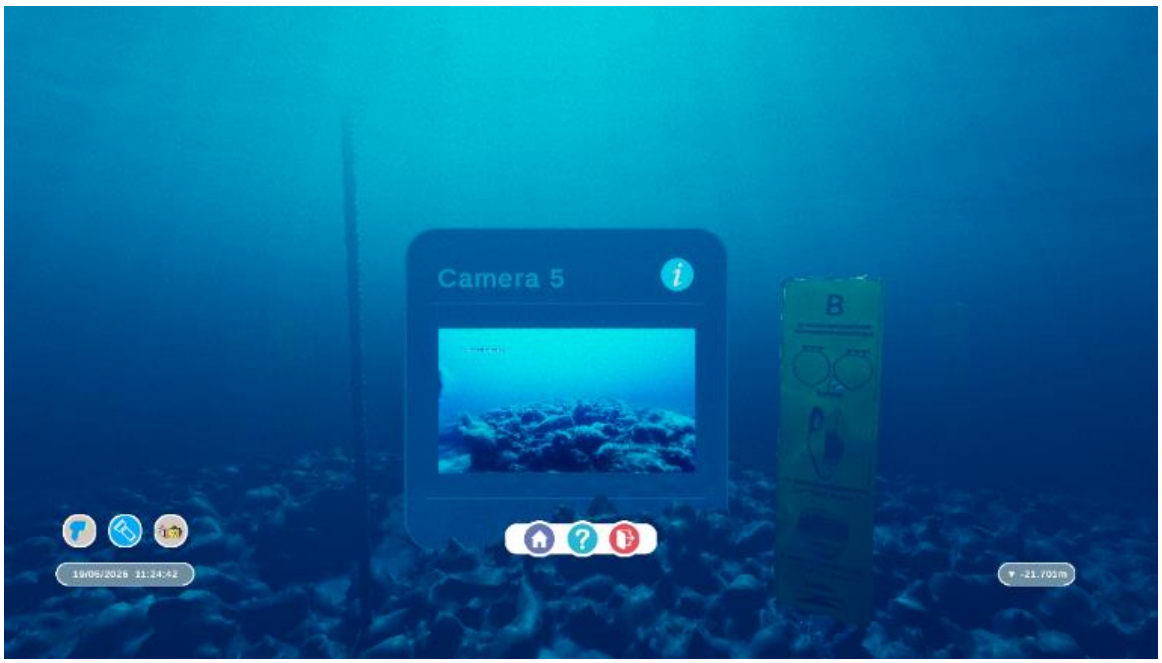

Figure 29 Live streaming integrated into the application

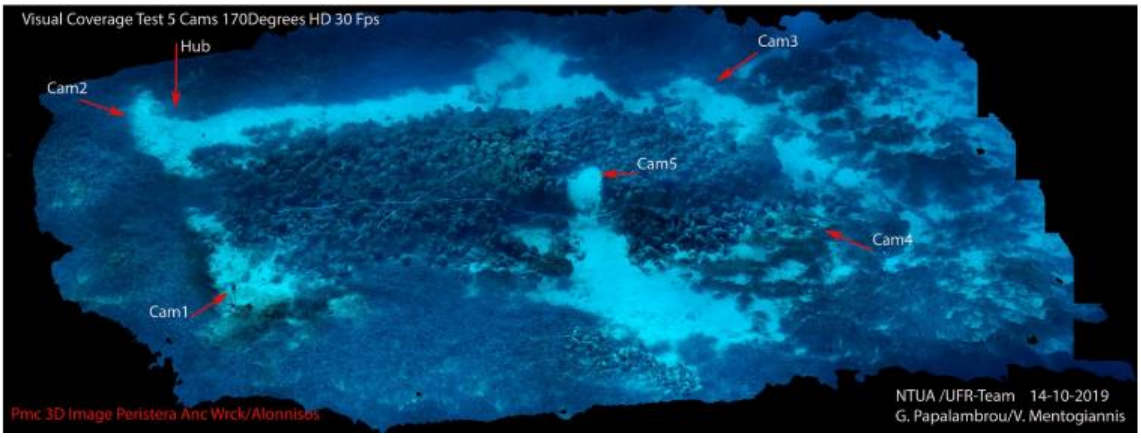

Figure 30 Setup of real-world positions of live feed cameras at the Peristera shipwreck

To provide a more complete experience, the application also includes a reconstruction of the above-water landscape surrounding Peristera Island based on technical descriptions on 3.4.4. This contextual environment allows users to better understand the geographical setting of the underwater archaeological site.

[17] https://nous.com.gr/projects/peristeras-ancient-ship-wreck/

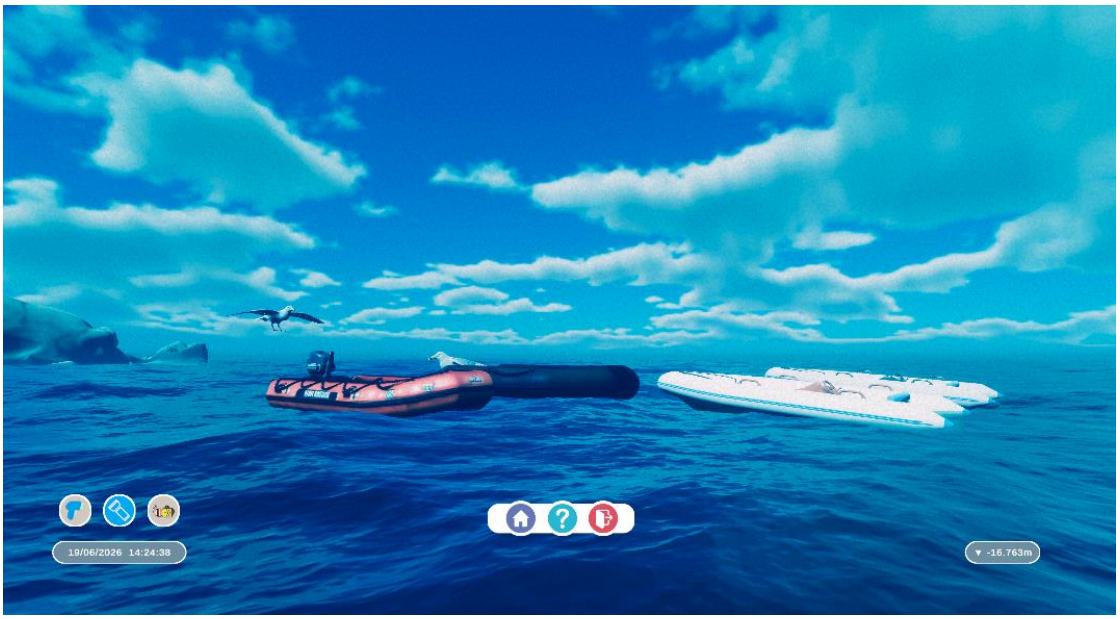

Figure 31 Surface-level visualization of the Peristera pilot site

Finally, users can activate a virtual flashlight and switch to Night Dive Mode. This feature simulates the conditions of a real night dive, allowing visitors to explore the shipwreck in darkness while relying on artificial illumination, thereby offering an additional level of realism and immersion. An example of the night-diving experience is illustrated in Figure 32.

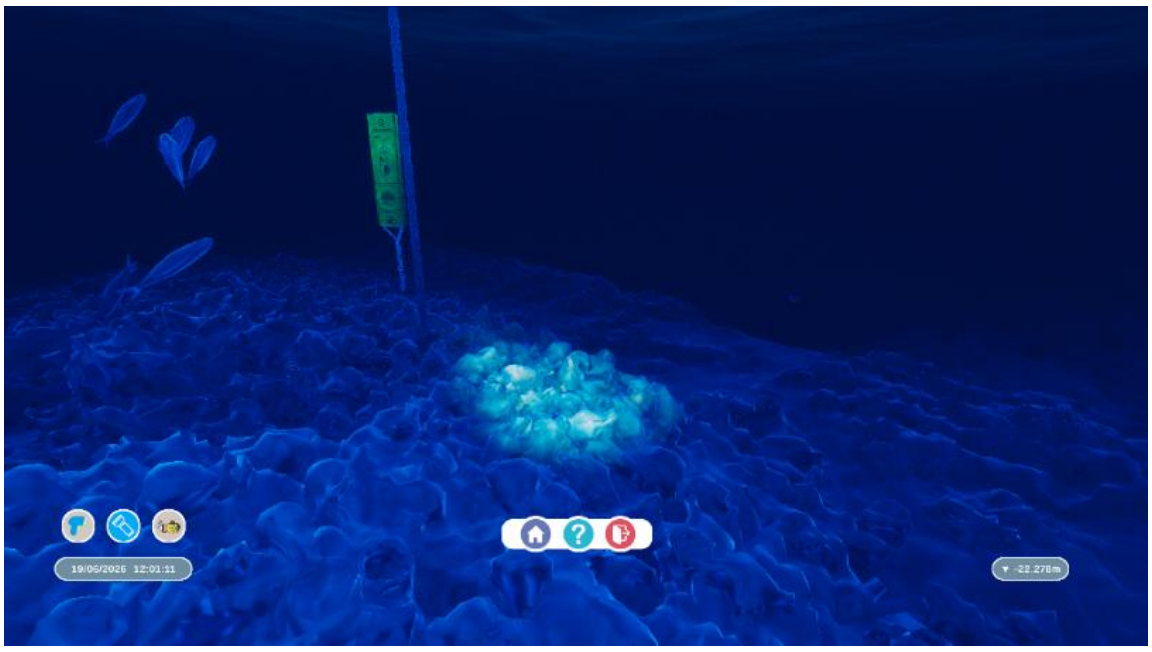

Figure 32 Night dive experience visualization

4 Serious Game Experience for Heritage Interpretation

This chapter presents the Serious Game experience layer of the TOURAL digital platform, focusing on the transformation of cultural heritage assets into interactive serious-game content. It describes the complete pipeline through which physical objects are digitized, reconstructed as high-quality 3D models, optimized for real-time use, and automatically fragmented into puzzle pieces for gameplay. The chapter also outlines the design and implementation of the serious game itself, including the user interface, gameplay flow, and the historical objects featured within the application.

As shown in Figure 33, the process begins with photographic documentation of an object and continues through photogrammetric reconstruction, mesh optimization, fragmentation, and integration into the final game environment. Each step contributes to the creation of an interactive experience that transforms heritage artifacts into engaging digital content.

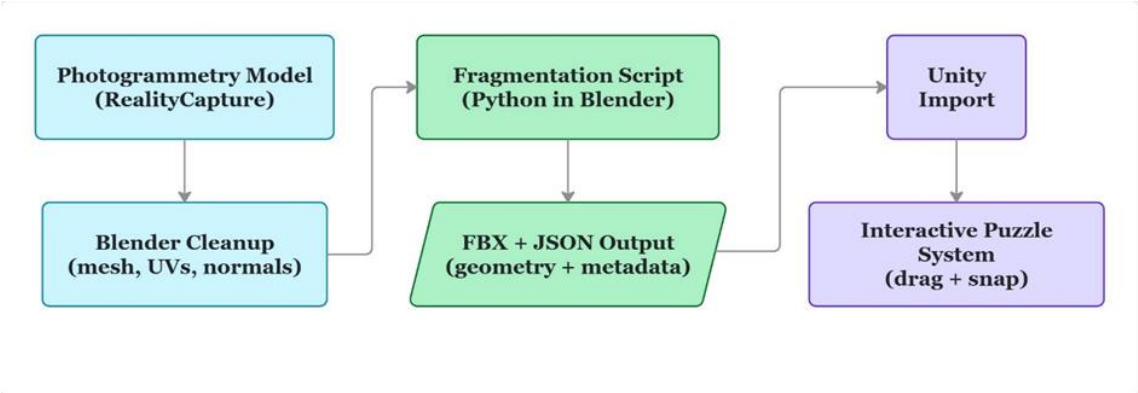

Figure 33 Serious Game menu during playtime

A serious game[18] is a game designed primarily for purposes other than entertainment, such as education, training, awareness, or behavioural engagement, while still using game mechanics to create an immersive and motivating experience. In the context of TOURAL, the serious game is used to support cultural learning and heritage interpretation by turning archaeological and historical objects into interactive puzzle-based experiences.

4.1 Photogrammetry methodology and 3D reconstruction

Photogrammetry[19] is a widely used image-based 3D reconstruction technique for creating digital replicas of physical objects or environments from multiple 2D images. The method reconstructs three-dimensional geometry by estimating camera parameters and identifying corresponding features across overlapping images. Its core principles rely on feature matching and geometric triangulation.

In the framework of the "Toural" project, a specialized digitization methodology was implemented to support the technical requirements of the application. This task involves the high-fidelity 3D reconstruction of selected historic toys and artifacts, particularly in cases where ready-made 3D game assets from partners and pilot sites are not available, determining which models can be effectively replicated using close-range photogrammetry. These digital assets serve as the core visual components of the interactive application, transforming physical museum objects into accurate digital entities.

[18] https://en.wikipedia.org/wiki/Serious_game

[19] https://en.wikipedia.org/wiki/Photogrammetry#cite_note-1

The integration of advanced three-dimensional digitization into the TOURAL project serves a multi-faceted purpose. Beyond creating immutable digital replicas that safeguard cultural heritage against physical degradation, these assets dramatically enhance user interaction within the digital environment. Furthermore, the generated 3D models provide a robust foundation for interactive mechanics, kinetic simulations, and immersive user experiences, while simultaneously maintaining a high standard of precision for educational and academic reference.

4.1.1 Technical methodology and photogrammetric pipeline

The photogrammetric pipeline consists of several stages:

- ***Feature Extraction.*** The first step involves detecting distinctive and repeatable keypoints in each image. These features correspond to visually salient points such as corners, blobs, or textured regions. Feature extraction algorithms such as SIFT, ORB, and AKAZE are commonly used because they are robust to scale, rotation, and moderate illumination changes.
- ***Feature Matching.*** Once features are extracted, corresponding keypoints are identified across multiple images. This process establishes spatial relationships between images by detecting the same physical points observed from different viewpoints.
- ***Structure from Motion (SfM).*** Structure from Motion estimates both camera parameters and scene geometry simultaneously. More specifically, it determines the intrinsic camera parameters (such as focal length and lens distortion) and the extrinsic parameters (camera position and orientation). Using the matched feature points, triangulation is applied to reconstruct a sparse 3D point cloud representing the scene structure. The reconstruction is further refined using bundle adjustment, a global optimization technique that minimizes reprojection error.
- ***Multi-View Stereo (MVS).*** Following sparse reconstruction, Multi-View Stereo densifies the point cloud by estimating depth information for a significantly larger number of image pixels. Unlike SfM, which relies on sparse feature correspondences, MVS performs dense matching across overlapping images to generate a dense 3D representation.
- ***Mesh Reconstruction.*** The dense point cloud is then converted into a continuous surface representation, typically in the form of a triangulated mesh. This step creates a connected geometric model of the object or scene.
- ***Texturing.*** In the final stage, texture information from the original images is projected onto the mesh surface. This produces a photorealistic 3D model by preserving color and surface details from the input images. However, several considerations must be taken into account during image acquisition to ensure accurate reconstruction. Images should be captured from multiple viewpoints to achieve complete coverage of the object or scene, maintaining approximately 70–80% overlap between consecutive frames so that sufficient common visual information is available for matching. For each region of the object, several images should be taken from different viewing angles, while keeping the shooting distance as stable as possible to preserve consistent scale and image quality. All images should be sharp, well-focused, and captured with an adequate field of view, using consistent camera orientation and smooth transitions between successive viewpoints to avoid gaps in geometric information. Strong shadows, reflections, motion blur, and abrupt lighting changes should be avoided, as they negatively affect feature detection and matching; for the same reason, textured surfaces are preferable, since featureless or reflective materials are generally harder to reconstruct reliably.

4.1.2 Image Acquisition and Computational Processing

Within the "Toural" project, close-range photogrammetry was used to digitize selected historic toys and artifacts, converting physical museum objects into accurate 3D digital assets. This image-based method extracts geometric and textural information directly from a series of overlapping

photographs, making it well suited to the non-invasive digitization of fragile or valuable items. The number of images and the specific acquisition conditions varied depending on the object's size, geometry, and surface complexity, with image overlap maintained at a level sufficient to ensure reliable feature matching across consecutive frames.

The acquired images for each object were processed using RealityCapture, a photogrammetry software suite that performs the full reconstruction pipeline described in Section 4.1.1 in an automated manner. The process begins with feature detection and matching across the image set, followed by Structure-from-Motion computation, which estimates the camera parameters for each photograph and generates a sparse point cloud representing the scene's initial geometry. Using these estimated camera poses, the software then performs Multi-View Stereo reconstruction to produce a dense point cloud containing a significantly higher density of 3D points.

From the dense point cloud, a polygonal mesh is generated, representing the continuous surface geometry of the object. This mesh typically requires refinement to remove noise, floating artifacts, or non-manifold geometry introduced during reconstruction. Finally, the original photographs are used to generate texture maps, which are projected onto the optimized mesh to produce a photorealistic 3D model suitable for integration into the Toural application. The internal faces are shown in Figure 34.

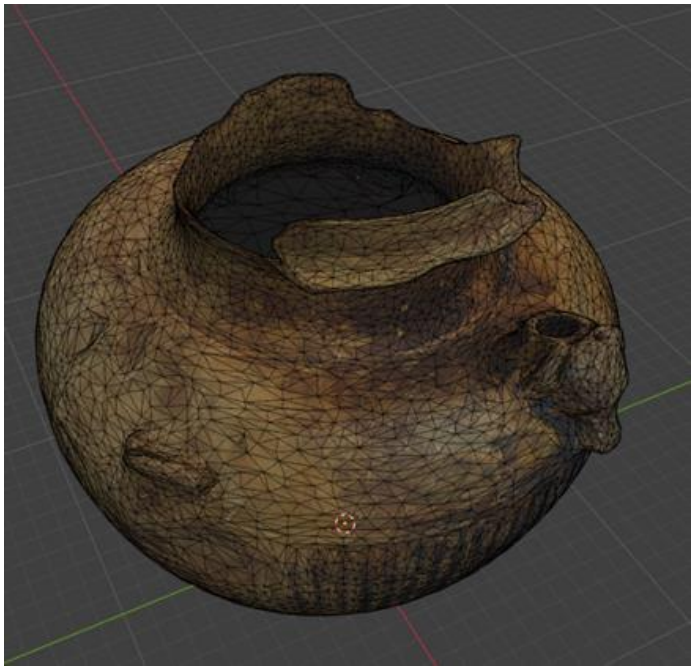

Figure 34 Amphora Internal Faces

4.1.3 Post –Scanning cleanup and mesh refinement

Following the initial photogrammetric reconstruction, the raw 3D model was imported into Blender to undergo a rigorous cleanup and optimization process, ensuring the asset is fully functional, lightweight, and ready for deployment within the Unity game engine. This post-processing pipeline focused on eliminating redundant internal geometry, sealing structural holes, correcting UV texture mapping, and validating surface normals.

The first phase of the refinement process involved the removal of internal geometry. Photogrammetric scans often generate erratic, non-visible faces inside the mesh—such as within the hollow structures of an amphora—which unnecessarily increase the polycount and degrade performance. By utilizing specialized diagnostic viewport overlays that color-code the orientation of the surfaces, the internal mesh was effectively isolated from the exterior shell. This allowed for

the precise selection and deletion of all hidden internal faces and floating geometry, particularly around the inner neck area in a vase model, clean-cut from the outer surface. The removal progress is shown in Figure 35 and Figure 36.

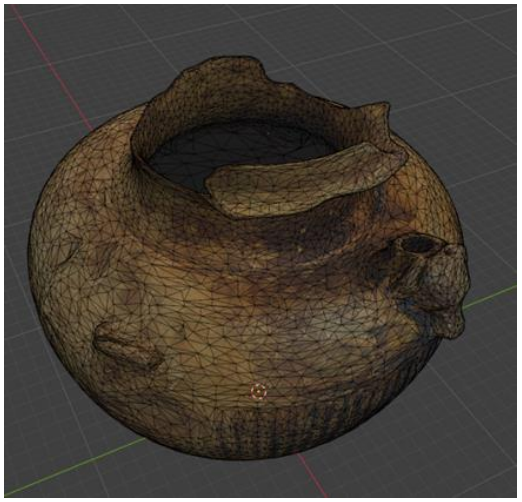

Figure 35 Before the removal of internal faces

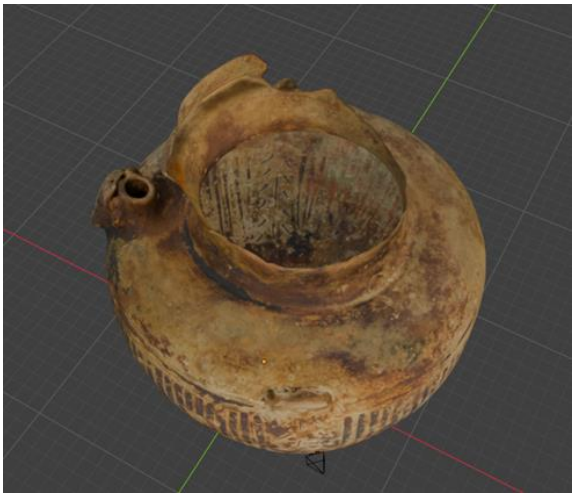

Figure 36 After the removal of internal faces

The removal of artifacts and irregular scanning noise left behind several open boundary loops and structural gaps. To restore the geometric integrity of the asset, these open boundaries were identified, and edge-loop fill techniques were applied. By capping these holes with new, clean polygonal faces, the model was transformed into a manifold, watertight mesh, which is a fundamental prerequisite for any subsequent fragmentation or puzzle-piece scripting.

Because these newly created faces lacked coordinate data on the original texture map, manual UV alignment was required to prevent visual stretching or clipping errors inside the application. The new polygons were isolated within the UV Editor and mapped directly onto a uniform, neutral zone of the texture file that matched the surrounding colors. This step eliminated any harsh texture seams, ensuring complete visual continuity across the bottom of the object.

The final stage of the pipeline, which is standard practice both after manual editing and after executing the model-splitting scripts for the puzzle mechanics, involved validating the face orientation. Using a diagnostic orientation overlay, the model was inspected for any inverted normals, which would otherwise render faces invisible or cause shading glitches in Unity. A global recalculation was performed to ensure all surface normals point uniformly outward, guaranteeing correct light interactions and flawless rendering when the user interacts with the final 3D puzzle components. A model with corrected normals is shown in Figure 37.

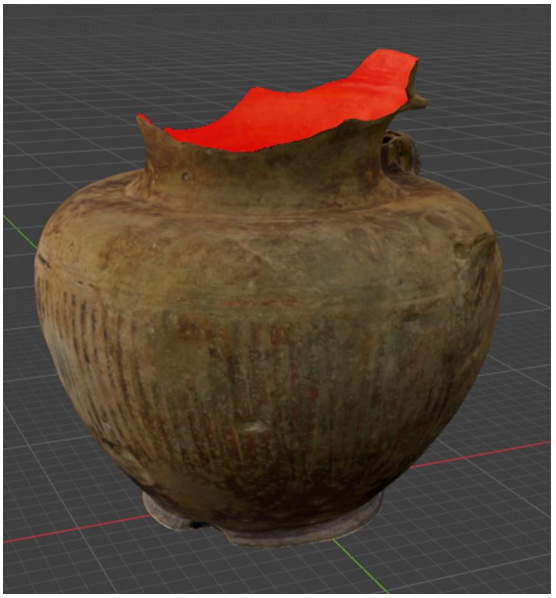

Figure 37 Amphora with Correct Normals

Before the model proceeds to the fragmentation script, it must satisfy the following conditions:

- Only the external surface remains, with no internal geometry or floating faces.
- The mesh is fully closed, with no holes or open edges.
- Missing areas have been rebuilt with continuous geometry.
- All faces have outward-facing normals.
- All UV islands are valid and correctly assigned.

Once these conditions are met, the model is ready for the fragmentation stage that generates the puzzle pieces used in the serious game.

4.2 Automatic Fragmentation in Blender

Once the 3D model has been fully cleaned and optimized, it undergoes an automated fragmentation process to generate the puzzle components used in the serious game. This process is executed in Blender through a custom Python script, crack_segmentor_and_anchors_corrected.py. The script is designed to split a single solid mesh into a predefined number of puzzle pieces in a single run, while preserving the original mesh topology as much as possible.

A key feature of the algorithm is that it partitions the model along existing edges without introducing new vertices. This ensures that the resulting pieces remain geometrically compatible and can later be reassembled seamlessly in Unity without visible gaps. At the same time, the script identifies adjacent pieces, computes their shared boundaries, and extracts the anchor points used for snapping and tracking in the game engine. The complete input-output result of the process is illustrated in Figure 38, while the separated pieces with debug anchor spheres are shown in Figure 39.

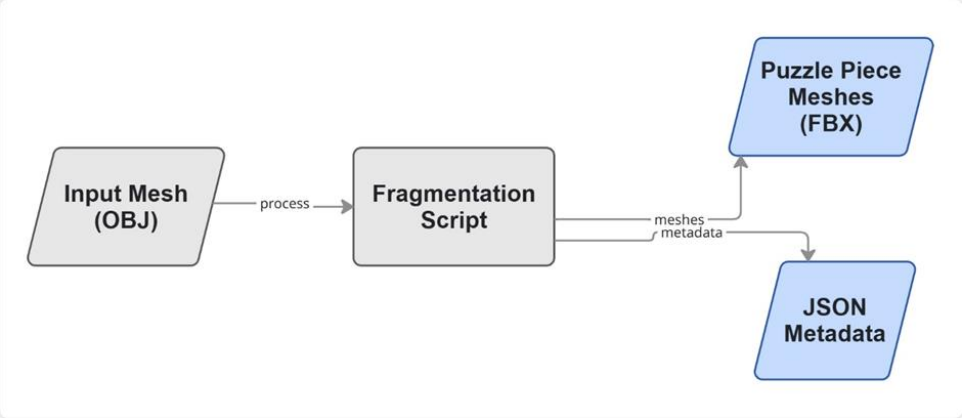

Figure 38 Fragmentation Script Input and Output

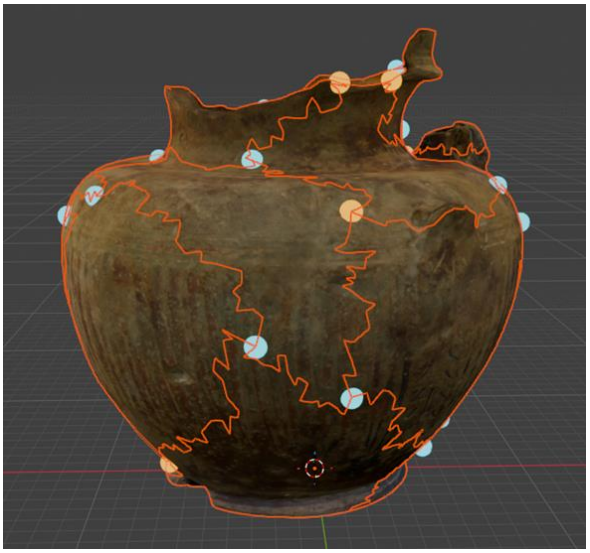

Figure 39 Blender Scene After Running the Script (Separated Pieces with Debug Anchor Spheres)

4.2.1 Algorithmic Pipeline and Stage Breakdown

The fragmentation script follows a six-stage algorithmic pipeline.

Stage 1 — Build a Face Adjacency Graph:
The script reads the entire mesh and constructs a network where every polygon is a node. Two faces are connected only if they share a full edge. This allows the script to work with logical face relationships rather than raw vertex coordinates.

Stage 2 — Grid Projection and Seed Placement:
The bounding box of the object is projected onto the XY plane and divided into a grid matching the target piece count. The script automatically adjusts the grid's rows and columns to best fit the object's physical aspect ratio. It then places one starting face (a "seed") in each grid cell, spacing them as far apart as possible to ensure even distribution.

Stage 3 — Grow Regions (Stochastic Prim):
Starting from each seed, regions expand outward by claiming adjacent faces. Every candidate's face is assigned a random weight, and the lowest-weight face is claimed next. This randomness produces irregular, natural-looking, crack-like boundaries instead of artificial straight lines. A uniformity parameter set at 0.5 balances organic shapes with consistent piece sizes.

Stage 4 — Remove Enclosed Pieces:
The script checks for instances where a piece is completely surrounded by a single neighbor, which would make the puzzle unsolvable in gameplay. Any enclosed pieces are automatically merged into their surrounding neighbor.

Stage 5 — Detect Boundaries and Compute Anchor Points:
For every pair of adjacent pieces, the script identifies the edges forming the crack line between them. It looks for the tips (ends) of this boundary line. These points are saved as absolute coordinates (anchor_min and anchor_max) which Unity will use to snap the pieces together. If a boundary forms a closed loop without tips, a geometric fallback assigns the extreme ends of the boundary's axis as anchors.

Stage 6 — Extract Pieces and Export Data:
Each piece is extracted as a new, independent mesh object, keeping its original vertex positions, UV coordinates, and material assignments perfectly intact. In Figure 39 there is an example in the amphora. The script automatically hides the original model and generates a structured JSON file containing all neighbor maps and anchor coordinates.

4.2.2 Normals Check and export

Before exporting the final assets for Unity, a quick quality assurance check is required for the surface normals. Because the automated script cuts directly through existing geometry, some faces along the newly created border seams might occasionally become inverted. This will cause them to look invisible or render incorrectly inside the game engine. Whenever flipped normals are detected, they are corrected in Edit Mode by recalculating the face orientation, as shown in Figure 40.

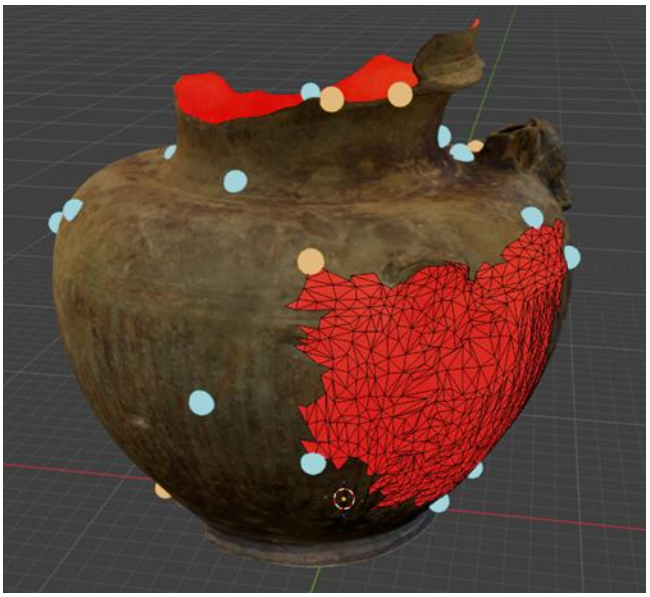

Figure 40 Amphora Piece with Flipped Normals

Each difficulty setting, corresponding to 6, 12, or 18 pieces, is exported as an independent asset package containing:

1. AmphoraXPieces.fbx: All X mes[20] objects (one per puzzle piece), with UV maps and material references. A 3D mesh model is a digital surface model (DOM) that digitally represents an object in 3D. The model consists of corner points (vertices), edges and faces.
2. puzzle_data_X_pieces.json: Neighbor relationships and anchor coordinates for all piece pairs.

4.2.3 Puzzle Data Json File

The FBX file exported from Blender has only geometry — it tells Unity what the pieces look like and where they are in space, but nothing about how they relate to each other. Unity has no way of knowing which pieces are neighbors, where the boundary between two pieces lies, or which specific points should be used for snapping.

This information could theoretically be recomputed at runtime in Unity by comparing vertex positions across all piece pairs. In practice this approach has two problems: it is computationally expensive for larger piece counts, and it is numerically unreliable when working with floating-point mesh data that has gone through export and import. The correct approach is to compute this data once, during the Blender processing stage where exact mesh topology is available and supply it to Unity as a precomputed file.

The JSON file is that precomputed file. It is generated automatically by the fragmentation script at the end of each run and acts as a bridge between the geometry processing in Blender and the gameplay logic in Unity.

4.2.4 File explanation

The JSON file stores the following data for every puzzle piece:

- Piece identity — a unique index and the exact object name, used by Unity to match each file entry to the correct GameObject in the scene.
- Neighbor list — for each piece, the list of all pieces that share a crack boundary with it. Each neighbor entry has:
  - The neighbor's index and name.
  - anchor_min - one endpoint of the shared crack boundary (3D coordinates).
  - anchor_max - the opposite endpoint of the same boundary (3D coordinates).

The two anchor points define the tips of the crack line where two pieces meet. These are the positions Unity uses to place snap targets. They are stored in Blender's coordinate system and converted to Unity's coordinate system at import time, which will be explained later in this deliverable.

A Unity method reads the JSON file once, when the puzzle scene loads and uses it to initialize the entire puzzle — binding pieces to their data, placing snap targets at the anchor positions, and establishing which pieces can connect to which. The file is the sole source of truth for all that logic; Unity performs no geometric computation of its own.

4.3 Designing the Puzzle Game

The core vision of the TOURAL application is the transformation of cultural heritage into an interactive digital experience through the manipulation of digitized historical artifacts. To support this objective, static 3D models were converted into a dynamic puzzle-based gameplay environment. The main design challenge was the creation of a system in which scattered

[20] https://cgisutic.wordpress.com/wp-content/uploads/2016/07/computer_graphics_principles_and_practice.pdf#page=238&zoom=100,0,370 , pg 193

fragments of an object, such as a historic vessel or a traditional artifact, could be manually reassembled by the player.

To enable this interaction, a clear link was established between raw 3D geometry and gameplay logic. The puzzle could not function if the pieces remained fully independent or if their structural relationships were not defined in advance. For this reason, the system was organized around two main components: a persistent state manager responsible for game progression and a data-driven structure based on information exported from Blender, which defines the placement, adjacency, and connection rules of the puzzle pieces.

4.3.1 Main menu

The user interface of the TOURAL serious game was designed to remain simple, clean, and easy to navigate. Its structure supports the combination of historical learning and gameplay, ensuring that user engagement is maintained throughout the experience. The application is divided into two main areas: the Gallery, where artifacts and their historical background are explored, and the Play mode, where a selected object is transformed into a puzzle activity.

4.3.1.1 *Entering the Main Menu and Settings*

When the application is launched, the Main Menu screen is displayed, as shown in Figure 41. The app was designed with a minimal design. A minimal interface was adopted, with three main options placed at the bottom of the screen: Play, Gallery, and Settings. The limited number of controls makes the interface easy to read and allows the available actions to be identified without confusion.

Figure 41 Starting Scene

The Settings menu, shown in Figure 42, is presented as a compact overlay window. Through this panel, music and sound effects can be adjusted or muted before returning to the main screen. Audio settings apply consistently both in the menu environment and in the serious game scene.

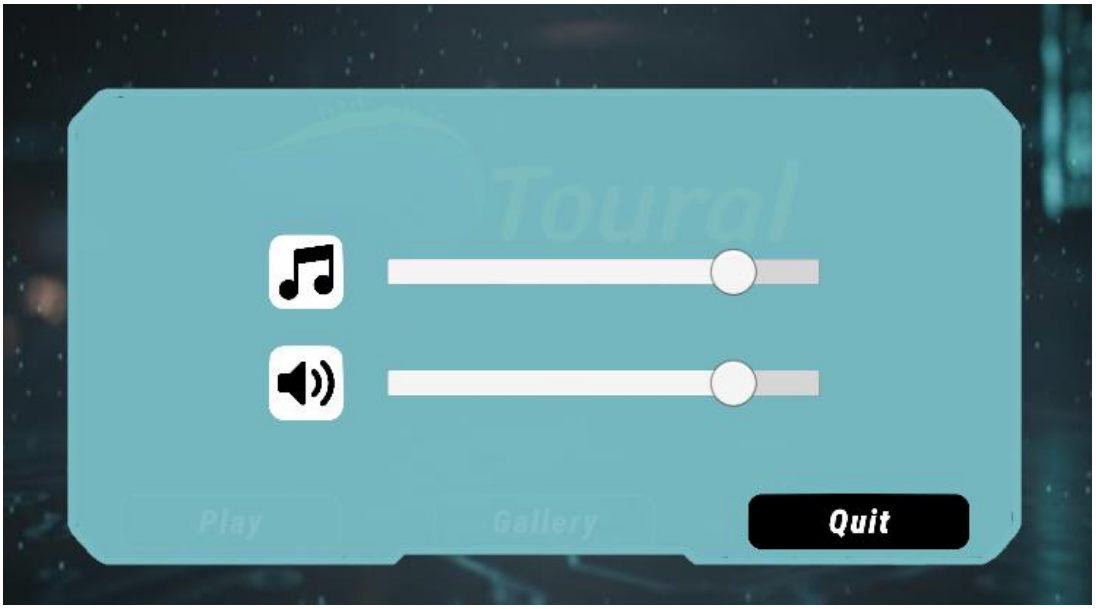

Figure 42 Settings Panel

4.3.1.2 *The Gallery: Exploring the Artifacts and History*

When the Gallery option is selected, the screen shown in Figure 43 is displayed, functioning as a digital museum environment. All discovered items are presented collectively, while a scrollable bar at the bottom allows browsing through thumbnails of the available historical objects. When a specific item is selected, such as the Old Woven Carpet, a text window appears over the screen and presents the full narrative associated with the object. The same narrative is later unlocked when the puzzle is completed, allowing historical interpretation to be linked directly with gameplay progression.

Figure 43 Gallery with information about item

4.3.1.3 *The Play Menu: Selecting Levels and Difficulty*

When the Play option is selected, the interface changes to an open-book layout, as shown in

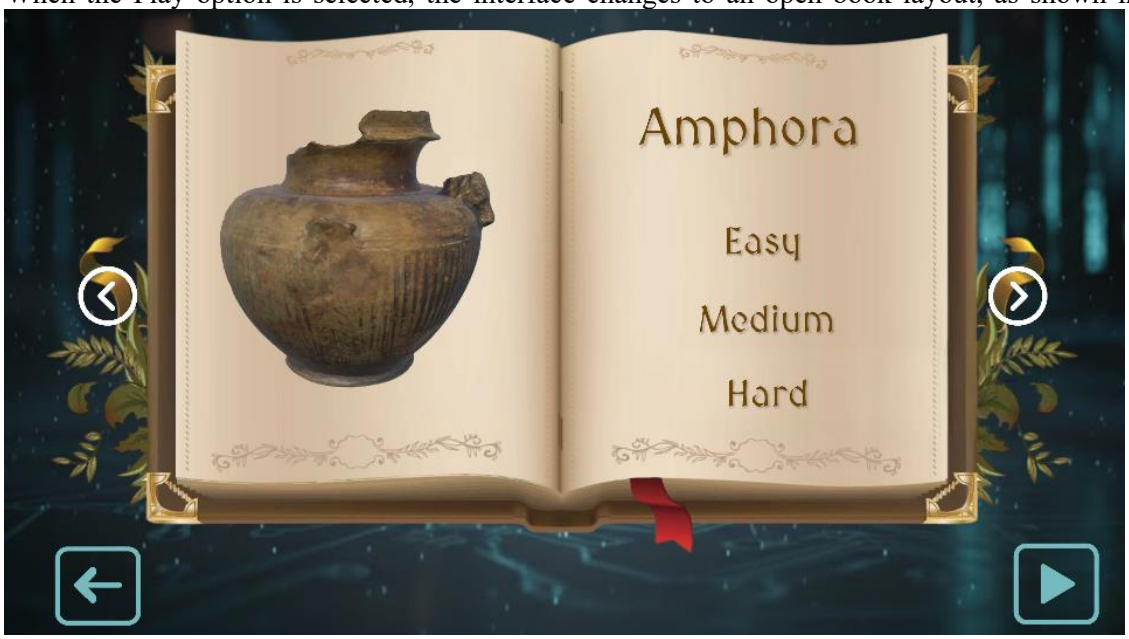

Figure 44. This design was chosen to evoke the feeling of opening a journal or field notebook before beginning an archaeological exploration. On the left page, a single object is presented as the focus of the next level, while the right page provides the available difficulty options: Easy, Medium, and Hard.

The difficulty level determines the number of puzzle pieces used in the game. Six pieces are assigned to Easy mode, twelve pieces to Medium mode, and eighteen pieces to Hard mode. After the desired level has been selected, the player is transferred to the gameplay scene.

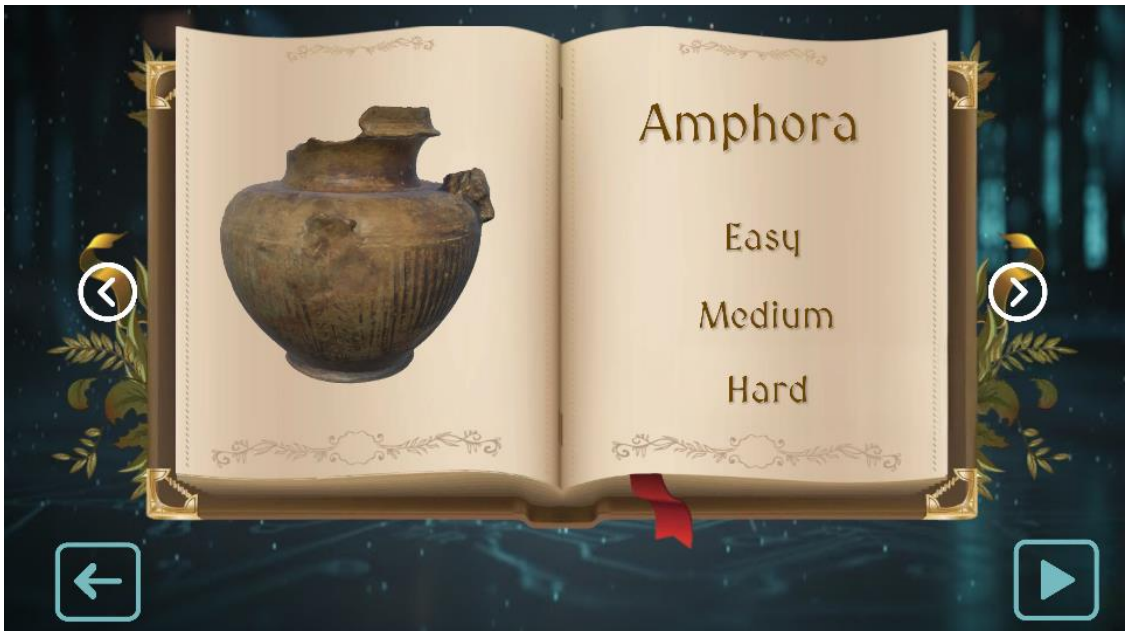

Figure 44 Scenario Selection Book

4.3.2 Game

This section presents the core gameplay component of the serious game, including its setup, mechanics, and interaction logic. A detailed overview is provided of how the TOURAL puzzle experience is initialized and executed, with emphasis on both the design philosophy and the technical implementation.

4.3.2.1 *Puzzle Construction and Initialization*

The gameplay environment is initialized through the PuzzleLoader.cs script, which is responsible for loading and configuring the entire scene at runtime. A fixed sequence of operations is executed in order to build the puzzle environment. The overall initialization process is illustrated in **Error! Reference source not found.** while the main runtime processing stages are described in detail Figure 45.

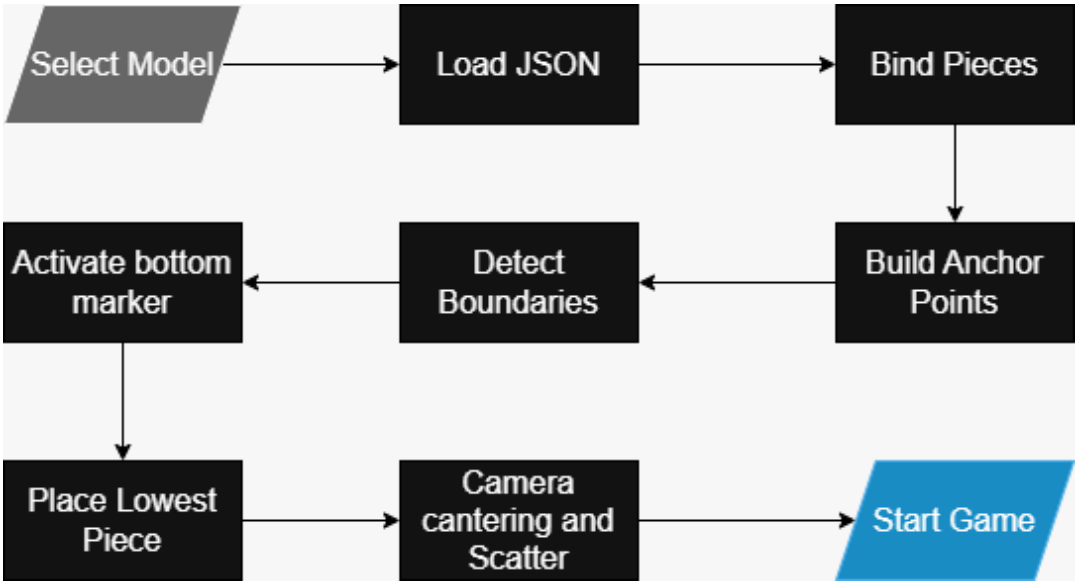

Figure 45 Puzzle Initialization

Step 1 — Select the correct model:

The loader holds three distinct variations of the asset container, for each model (6, 12, and 18 pieces). It instantly instantiates the one matching the player's chosen artifact and difficulty.

Step 2 — Load JSON:

The script retrieves the correct data file from the resources folder and parses the text into the data models, establishing the logical rules of the puzzle.

Step 3 — Bind Pieces:

The script loops through all the meshes inside the selected artifact. For every piece, it dynamically attaches the physics components required for gameplay: a precise MeshCollider so players can click its exact shape, a kinematic Rigidbody to register physics events, and the CellDrag script to enable mouse manipulation. At this stage, the solved positions are recorded, and shadow casting is optimized to ensure high performance.

Step 4 — Build Anchor Points:

The loader reads the boundary coordinates from the data file and translates them from Blender's coordinate space into Unity's 3D space. It merges nearby boundaries together into unified "Anchor Points" in the world, which act as the physical targets where pieces will lock together.

Stage 5 — Detect Boundaries and Compute Anchor Points: For every pair of adjacent pieces, the script identifies the edges forming the crack line between them. It looks for the tips (ends) of

this boundary line. These points are saved as absolute coordinates (anchor_min and anchor_max) which Unity will use to snap the pieces together. If a boundary forms a closed loop without tips, a geometric fallback assigns the extreme ends of the boundary's axis as anchors.

Step 6 — Activate Bottom Anchors:

To prevent the puzzle from being overwhelming, the game guides the player with a progressive assembly flow. At the start, it scans all the anchor points, finds the ones at the absolute bottom, and activates only those. This gives the player a clear, logical starting area: the base of the object.

Step 7 — Pre-Place Lowest Piece:

To give the user a helpful anchor to build upon, the game automatically solves the very first base piece for them. The script calculates the average height of each piece's markers and locks the lowest structural piece into its true position. It then activates all the anchors attached to its borders, making its immediate neighbors the first available targets for the player.

Step 8 — Camera Centering and Scattering:

The script calculates the true center of the fully assembled model so the player's camera can orbit it perfectly. Finally, it disperses all remaining pieces onto a random circle far away from the center. By normalizing the distribution vectors, the pieces are spread out evenly on the perimeter of the circle, creating a clean, organized, and uncluttered playing field.

Step 9 —Start game:

The game experience, with the user view a puzzle with different pieces and have to stick them together.

4.3.3 Piece Interaction, Dragging, and Snapping Mechanics

The CellDrag.cs component handles mouse input. Instead of relying on basic click events—which would cause multiple overlapping pieces to be picked up at the same time—the script fires a precision raycast from the camera through the mouse position. It gathers every piece hit by the ray, sorts them by depth, and only allows the player to drag the absolute closest piece.

While dragging, the piece follows the cursor smoothly at a fixed depth plane. To keep the gameplay area under control and prevent players from accidentally throwing pieces off-screen, a distance constraint constantly checks the piece's position against the center of the puzzle. If a piece is dragged too far, its position is instantly clamped along a maximum safety radius. Moreover, the player can get the selected piece closer in Y axis, with the mouse wheel.

When a player moves a piece close to an active anchor point, the system initiates a validation pipeline to see if the piece fits:

- **Active Check:** The game verifies if the approached anchor point is active (meaning it connects to a piece that has already been placed).
- **Component Validation:** It checks if the colliding object is a valid snap marker, ignoring raw mesh geometry.
- **State Check:** It confirms that the player is actively dragging the piece, preventing resting items from locking automatically.
- **Neighbor Verification:** It queries the data map to confirm that this piece is an authentic structural neighbor for this specific anchor slot.

If all checks pass, the piece is accepted. It teleports smoothly to its pre-recorded solved position and locks its input permanently. It then unlocks its own neighbor anchors, creating a progressive wave of new targets that guides the player's assembly from the bottom all the way to the top.

4.3.4 Menu and Information

The serious game has a pause menu, as illustrated in Figure 46, which is embedded within a stone-textured panel featuring metallic reinforcements, thereby maintaining visual consistency with the overall environment of the serious game.

The interface provides the player with the following core functional options:

- **Settings:** Allows the user to adjust game parameters, such as audio, same as main menu.
- **Restart:** Enables the player to instantly restart the current level or mission from the beginning.
- **Main Menu:** Navigates the user back to the main game scene, where the user can select another scenario.
- **Return to Game:** Closes the pause overlay and seamlessly resumes active gameplay.

At the top center of the screen, the interface is complemented by an analog clock, which serves the time-tracking requirements of the in-game challenges, counting the time user spent to complete the scenario.

Figure 46 Serious Game menu during playtime

4.3.4.1 *Camera Orbit and Victory Systems*

A dedicated camera controller allows the artifact to be viewed from any angle. By holding the right mouse button, the camera can be rotated horizontally and vertically around the center of the model, while the scroll wheel is used for zooming. To preserve usability, the vertical pitch is clamped so that the camera cannot flip upside down or pass through the floor plane. In addition, a 2D camera mode is provided for artifacts that are better presented in a flat format, which is displayed through a 2D view of the 3D item.

When the PuzzleLoader confirms that all pieces have been locked into their solved positions, the victory script is triggered and the Win Panel is displayed. The panel congratulates the player and presents contextual information about the completed object. After the information is shown, two actions are available: a return to the main menu or an immediate restart of the same puzzle through the optimized restart loop.

4.4 Serious Game Design Elements

4.4.1 Object-Based Serious Game 1

This unique artifact is an intact ancient Greek *kratera* discovered during underwater archaeological research in the flooded territory of Olbia. Characterized by its inverted bell shape, high stand, and dual handles, this vessel was traditionally used at banquets for mixing wine with water and is noted for its elegant artistic detail. It stands as a one-of-a-kind discovery, representing the only complete kratera of its kind found in its entirety, with no other museum in Ukraine possessing such a rare and perfectly preserved specimen. This item is a clasical 3D puzzle in the serious game. The item is shown in Figure 47.

Figure 47 Serious game item: Kratera

4.4.2 Object-Based Serious Game 2

The "Polog," a traditional woolen woven carpet from the early 20th century found in Enisala, Romania, is a prized artifact held by the ICEM Tulcea Museum of Ethnography and Folk Art. Representing a rich cultural synthesis of Romanian, Balkan, and Oriental influences, the carpet is adorned with intricate symbolic motifs—such as the "tree of life," doves, and the "lost path"—that reflect themes of nature, fertility, and protection. Crafted on a horizontal loom, this geometric masterpiece serves as a profound expression of Dobroudjan heritage, where every woven pattern connects generations through a symbolic narrative of balance, harmony, and the cyclical nature of life. This item is featured in the serious game using a 2D camera to emphasize its unique form. The item is shown in Figure 48.

Figure 48 Serious game item: Polog

4.4.3 Object-Based Serious Game 3

In the Nesebar part of the serious game there are 4 objects. The first one is a marble statuette depicts the goddess Cybele seated on a throne, standing at a height of 0.18 meters. She is dressed in a long chiton and draped in a himation that covers the back of her head, shoulders, and legs, gathering on the left side of her lap. Her hair is parted in the middle and cascades down her shoulders, and she wears a kalathos on her head. The goddess's arms are currently broken from the elbow down, and a small lion lies on her lap, facing right with its head turned forward. The piece dates back to the 4th–3rd century BC. This item is depicted in Figure 49.

Figure 49 Serious game item: Marble statuette of goddess Cybele

The second is a marble statuette with a group representation of the goddess Hecate, standing at a height of 0.43 meters with a top column diameter of 0.085 meters. It depicts three female figures positioned around a central column, all wearing kalathoi on their heads and dressed in chitons that are girdled just below the breasts. In their left hands, the figures hold torches that run along the full height of the column. With their right hands, two of the figures hold vessels, while the third holds her chiton. The statuette is currently fragmented at the bottom, and the surfaces of the figures show some chipping. It was discovered in 1962 in the Old Town of Nessebar, northwest of the corner of the "Dzhabonkata" house, during excavation works for a sewage system. This item is depicted in Figure 50.

Figure 50 Serious game item: Marble statuette of the goddess Hecate

The third is alekythos, made of red clay, with visible traces of red slip and a flat, fluted handle. It is uniquely shaped as the head of Dionysus wearing an ivy wreath that features two small berries. The vessel has a height of 0.18 meters, a mouth diameter of 0.03 meters, and a base diameter of 0.08 meters. It dates back to the period between the 1st century BC and the 1st century AD. This item is depicted in Figure 51. presents the vase. This exquisitely decorated ceramic vessel is a remarkable example of ancient pottery from the Bulgarian lands, characteristic of the prehistoric periods (likely the Chalcolithic era, 5th millennium BC). During this time, early communities in the Balkans achieved extraordinary mastery in ceramic production, transforming everyday items into true works of art.

The vase features a distinct biconical profile with small, symmetrical lug handles, suggesting it was carefully handled and perhaps used to store valuable goods, oils, or utilized in specific ritual practices. Its most striking feature is the intricate geometric ornamentation. The surface is adorned with elegant, swirling white lines and precisely dotted bands set against a polished, reddish-brown background. This complex decorative scheme—often achieved through incrustation with white clay or bone material—highlights the advanced craftsmanship, aesthetic values, and rich cultural heritage of the ancient societies that inhabited the region.

Figure 51 Serious game item: Alekynthos

Figure 52 Serious game item: Vase

4.4.4 Object-Based Serious Game 4

The Letavica Amphora (Figure 53) is discovered at the underwater archaeological site near Cape Letavica on the island of Pag, Croatia. The main feature of the site is a dense concentration of around 400 clearly identifiable amphorae, primarily classified as Lamboglia 2 types, represented by several morphological variants. Based on their shape and typological characteristics, the amphorae date to the 1st century BC, corresponding to the period of the Late Roman Republic.

Letavica Amphora is one of amphorae recovered from the remains of a Roman merchant shipwreck, representing an important example of the maritime trade that connected the eastern Adriatic with the wider Mediterranean during antiquity.

Transport amphorae were widely used in the Roman period for carrying valuable commodities such as wine, olive oil, and other food products. Their standardized shape made them ideal for efficient storage and transport aboard merchant ships, making them one of the most recognizable artefacts of ancient maritime commerce.

Figure 53 Serious game item: Letavica Amphora

5 Validation Activities

The digital tools developed under Tasks T5.3 and T5.4 were subject to a series of technical, functional, and content validation activities throughout their development and deployment process. The objective of these activities was to ensure the correctness, usability, stability, and consistency of the developed solutions before their integration into the TOURAL digital ecosystem.

5.1 Technical Validation

Technical validation focused on verifying the correct operation of the Rural Heritage platform, the VR Diving Application, and the Serious Game components across their intended deployment environments.

Technical Validation Items are presented in Table 10 for the Rural Heritage platform

Table 10 Technical validation activities performed for the Rural Heritage platform

Technical Validation Item	Description
Page loading	Verification of correct rendering and navigation across all platform pages.
Multimedia rendering	Verification of image galleries, embedded videos, and media assets.
CMS integration	Verification of data exchange between the Angular frontend and the Strapi Headless CMS.
Interactive map functionality	Verification of map rendering, marker visualization, and navigation capabilities.
Category filtering	Verification of real-time filtering of Points of Interest based on heritage categories.
Responsive design	Verification of correct operation across desktop, tablet, and mobile devices.
Browser compatibility	Verification across modern web browsers.
Secure access	Verification of HTTPS connectivity and secure content delivery.

For the VR Diving Application, Table 11, technical testing focused on scene loading, rendering performance, interaction mechanisms, multimedia presentation, and compatibility across both WebGL and Meta Quest deployment environments.

Table 11 Technical validation activities performed for the VR Diving Application

Technical Validation Item	Description
Scene loading	Verification of correct loading of underwater environments and assets.
Rendering performance	Verification of stable rendering and visual performance.
WebGL deployment	Verification of browser-based deployment and execution.
Meta Quest deployment	Verification of operation on VR devices.
POI loading	Verification of correct visualization and activation of Points of Interest.
Audio functionality	Verification of narration, environmental sounds, and multimedia playback.
Live-stream integration	Verification of camera feed integration where available.

The Serious Game components, Table 12, were tested to verify correct object interaction, puzzle functionality, user interface behaviour, and game progression logic.

Table 12 Technical validation activities performed for the Serious Game

Technical Validation Item	Description
3D model loading	Verification of correct loading and visualization of game assets.
Object interaction	Verification of interaction mechanisms with puzzle components.
Drag-and-drop mechanics	Verification of object manipulation functionality.
Snapping functionality	Verification of correct placement and alignment of puzzle pieces.
Progression logic	Verification of game completion and progression workflows.
Menu navigation	Verification of navigation between game screens and information panels.

5.2 Functional Validation

Functional validation activities were performed throughout the implementation process to verify that the developed tools fulfilled their intended objectives and user interaction scenarios.

For the Rural Heritage platform, Table 13, validation confirmed that users are able to explore destinations, point-of-interests, and category filtering. Also, they can use multimedia presentation, and cross-linking between platform content and immersive experiences.

Table 13 Functional validation activities performed for the Rural Heritage platform

Functional Validation Item	Objective
Discover destinations	Explore available TOURAL destinations through the platform.
Explore Points of Interest	Access detailed information for heritage assets and attractions.
Filter content	Navigate content based on thematic heritage categories.
Use map-based navigation	Move from map markers to destination and POI information.
Access multimedia content	View images, videos, and supporting digital material.
Access immersive experiences	Navigate towards VR and other immersive tourism experiences where available.

For the VR Diving Application,

Table 14 presents the validation activities examined user navigation, interaction with points of interest, activation of multimedia content, environmental exploration, and educational storytelling mechanisms.

Table 14 Functional validation activities performed for the VR Diving Applicatio

Functional Validation Item	Objective
Navigate underwater environments	Explore reconstructed underwater heritage sites.
Locate Points of Interest	Identify significant archaeological and natural heritage assets.
Access contextual information	Receive educational information through annotations and multimedia content.
Interact with virtual content	Engage with interactive elements within the virtual environment.
Experience dry-diving tourism	Access underwater heritage without physical diving requirements.

For the Serious Game components, Table 15 presents the validation focused on gameplay mechanics, object manipulation, puzzle completion processes, and the presentation of heritage-related information.

Table 15 Functional validation activities performed for the Serious Game

Functional Validation Item	Objective
Complete puzzle scenarios	Successfully interact with and solve the game challenges.
Access heritage information	Learn about cultural heritage objects and their significance.
Follow the gameplay workflow	Progress through the game according to the intended user flow.
Engage with heritage through gamification	Experience educational content through interactive gameplay mechanisms.

5.3 Content Validation

Content validation was carried out in collaboration with the participating pilot regions and pilot leaders. Destination narratives, points of interest, multimedia resources, and heritage descriptions were reviewed and refined through iterative content collection and validation cycles.

The adopted content authoring methodology ensured consistency across destinations while allowing each pilot region to maintain its own identity and cultural characteristics. This process contributed to the creation of a coherent and comparable visitor experience across the TOURAL ecosystem.

Continuous validation stages also include user-oriented testing with real users and practical destination actors, such as tourists, local stakeholders, rural tourism providers, museum/KAC staff and guides, to assess usability, accessibility, storytelling clarity, trip-planning usefulness, and the perceived value of the immersive experiences.

Overall, the validation activities confirmed the operational readiness of the developed solutions and supported their integration into the wider TOURAL digital environment.

6 Sustainability and Exploitation

The solutions developed under Tasks T5.3 and T5.4 were designed with long-term sustainability and future extensibility as key requirements. Their modular architecture and content-driven approach allow the developed tools to remain operational and continue evolving beyond the duration of the TOURAL project.

The Rural Heritage platform is supported by a headless content management architecture that enables the continuous addition and update of destinations, points of interest, multimedia resources, and tourism-related information without requiring modifications to the underlying software infrastructure. This approach facilitates future content expansion and supports the onboarding of additional destinations and stakeholders.

Similarly, the VR Diving Application was designed as a reusable framework that can accommodate new underwater cultural heritage sites, environmental datasets, 3D reconstructions, and storytelling scenarios. Additional immersive experiences can therefore be incorporated with limited technical effort, extending the applicability of the solution to new locations and use cases.

The Serious Game components follow a modular design approach that enables the creation of additional heritage-based scenarios and educational experiences based on the same technological foundation. This allows future adaptation to different cultural assets, visitor groups, and educational contexts.

Exploitation concerns the potential uptake and use of the developed solutions by museums, visitor centres, DMOs, cultural heritage institutions and tourism organisations for visitor engagement, destination promotion and heritage interpretation.

The VR Diving Application and the Serious Game have been designed to support deployment within the TOURAL Knowledge Awareness Centres (KACs). Through these installations, visitors can access immersive experiences even when direct access to underwater cultural heritage assets is not possible. The KACs therefore function as local gateways connecting visitors with the digital experiences developed in TOURAL while supporting education, awareness raising and destination promotion.

Beyond the project lifetime, the developed solutions may support a variety of exploitation pathways. These include possible deployment within museums, visitor centres, destination management organisations, and cultural heritage institutions seeking to enhance visitor engagement through digital technologies. The solutions may also contribute to tourism promotion activities, educational initiatives, and heritage interpretation actions at local, regional, and macro-regional levels.

Overall, the ICT tools presented in this deliverable have been designed with exploitation potential in mind. Further analysis of their exploitability will be delivered within T6.2 and the respective deliverable. Through their interoperable design and scalable architecture, the developed tools provide a sustainable digital foundation capable of supporting future tourism, cultural heritage, and visitor engagement activities beyond the scope and duration of the TOURAL project.

7 Conclusions

This deliverable presented the work performed under Tasks T5.3 and T5.4 of the TOURAL project, focusing on the development of visitor-oriented digital tools designed to enhance tourism experiences across the participating pilot regions.

The work resulted in the delivery of three complementary digital assets. First, the Rural Heritage platform was developed as an evolution of the MedDiveInThePast platform, extending its scope from underwater cultural heritage sites to destination-oriented presentation of cultural, natural, and experiential tourism assets across TOURAL regions. Through a common content model, structured authoring methodology, and interactive map-based exploration mechanisms, the platform provides a unified environment for discovering destinations, points of interest, infrastructure, and multimedia content.

Second, a VR Diving Application was developed to provide immersive dry-diving experiences for underwater cultural heritage sites. The application combines realistic environmental reconstruction, interactive storytelling, live-streaming integration, and educational content to allow visitors to explore underwater heritage assets regardless of their diving experience or physical accessibility constraints.

Third, an augmented experience layer based on serious-game principles was developed to support visitor engagement through interactive learning and heritage interpretation. By combining photogrammetric reconstruction, object interaction, and gamified exploration, the serious-game component provides an additional mechanism for communicating cultural heritage content to diverse audiences.

Together, these tools constitute the visitor-facing dimension of the TOURAL Digital Platform and complement the analytical, monitoring, and decision-support services developed in other project work packages. Their interoperable design enables seamless navigation between destination information, immersive virtual experiences, and educational content, supporting a richer and more engaging tourism experience.

Overall, the solutions presented in this deliverable contribute to the wider TOURAL vision of promoting sustainable tourism development through digital innovation, cultural heritage valorisation, and enhanced visitor engagement across rural, remote, and culturally significant regions.