Virtual Girona: Discovering the Historical Walls

This pilot led by partner CRDI is focused on using available archival records about the structure and history of the now lost historical walls of the city of Girona to produce the most scientifically accurate 3D reconstruction of such city heritage. The walls were partly demolished at the beginning of the 20th century because of the new urban setting of the city, and so archaeological restoration was not possible anymore. 3D modelling and XR will let citizens and visitors go back to history and recover what was destroyed at that time.

The AI 3D Builder is used to generate 3D models of three towers, one bastion and a portion of the western walls from 2D image collection: cartography, engravings, photography, films and textual records. To achieve these goals, the CRDI worked on gathering, enriching and creating records in order to provide precise information that allows a realistic virtual reconstruction, besides all the images that will provide the texture of the walls and associated elements.

This accurate reconstruction can be accessed by users both as self-standing 3D models in a viewer, also published on Europeana, and with a walking tour realised with the 3D XR Studio tool, which can be accessed as a virtual tour online and as an Extended Reality experience in a guided pathway in the city of Girona.

The AR narrative of the hidden side of the Bibracte archaeological site

Located in central France, in the Morvan mountains, the Celtic city of Bibracte was mainly made up, until the mid-1st century BC, of wooden buildings, of which only limited archaeological traces are visible today, such as post holes, circulation levels, hearths, etc. Despite this scarcity of visible remains, the site's topography remains highly evocative, as variations in the terrain reveal the location of fortifications and numerous buildings, while also conveying the vast extent of the ancient city. The main interpretative challenge for visitors is therefore to help them see and understand these largely invisible remains in situ. Until now, interpretation at Bibracte has relied primarily on elements presented in the permanent exhibition, full-scale reconstructions and iconographic

materials, occasionally complemented by explanatory panels installed at selected locations on the site.

XR technologies now offer more integrated and immersive responses to this challenge, directly on the archaeological site. The tools developed within the project, AR Tour Builder and AR Tour Experience, enable the creation of a geolocated tour accessible via a mobile app. Through augmented reality, visitors can visualise 3D models positioned in their archaeological context and enriched with complementary media. This tour allows them to uncover the hidden side of Bibracte by accessing elements that have disappeared, are no longer visible on-site, or are not directly accessible to immediate perception or understanding, such as backfilled remains and traces of earlier excavations phases, evolution of buildings, particularly stone structures whose final state alone has been preserved, hypotheses regarding building elevations and objects, now housed in the museum, presented within the context of their discovery.

The creation of a new life of St. Neophytos' *Enkleistra* in Cyprus in the virtual space

In this scenario set in Paphos, visitors to the ancient Monastery of St. Neophytos encounter a digital representation of the saint, who once lived in the *Enkleistra*. The avatar speaks according to a predefined script and serves as a guide to the hermitage, its purpose, history, and the figures depicted within. The *Enkleistra* is part of a historically significant monastic complex that faces threats from environmental changes and increasing visitor numbers. Access to the site is limited, both due to the remoteness of the monastery and the physical layout of the *Enkleistra*, which consists of a series of hand-cut caves situated high on a cliff face, accessible only by a steep flight of steps, with some areas closed to the public.

This implementation targets the general public and school-aged audiences, aiming to communicate the cultural and spiritual value of the site as well as the challenges it faces. The experience also demonstrates how immersive technologies can contribute to raising awareness around environmental risks and the preservation of cultural heritage, drawing inspiration from the saint's meditations and framing

them within contemporary concerns of sustainability and responsible tourism. Upon entering the *Enkleistra*, the visitor is greeted by a digital avatar of the saint, which appears to step out of the fresco into 3D space. The avatar introduces itself and explains the iconographic and historical meaning of the frescoes. As the visitor moves through the space, the avatar remains present, while the liturgy recorded on 28 September 2025, day of the discovery of the saint's relics, plays in the background. This augmented scene is experienced through a Meta Quest 3 headset, either in AR, layered over the real cave interior, or as a fully 3D virtual simulation.

The scenario is designed to function in two modes: as a mixed reality experience on-site at the monastery, and as a virtual reality version for remote access. This dual implementation ensures broader accessibility and maximises the educational and cultural impact of the experience. The avatars created in the scenario will also be made available as animated 3D models on Europeana.

2.4.1. VIRTUAL GIRONA: DISCOVERING THE HISTORICAL WALLS

This scenario is about the virtual reconstruction of the western side of the walls of Girona city. The walls were partly demolished at the beginning of the 20th century because of the new urban setting of the city, and so archaeological restoration was not possible anymore. In the EUreka3D-XR project, 3D modelling and XR let us go back to history and recover what was destroyed at that time. Based on cartography, engravings, photography, films and textual records, we are able to visualise the walls again with a very realistic approach.

Using the tool that partner project Swing:It develops, an advanced AI-powered software pipeline to generate 3D models from 2D image collections, it is possible to create very realistic 3D models of the demolished walls. Besides, using the second tool also developed by Swing:It, a web-based and also a mobile application, it is possible to have an XR experience on-site.

Fig. 9. Sant Francesc Bastion. 1920, Adolf Mas. Ajuntament de Girona. CRDI

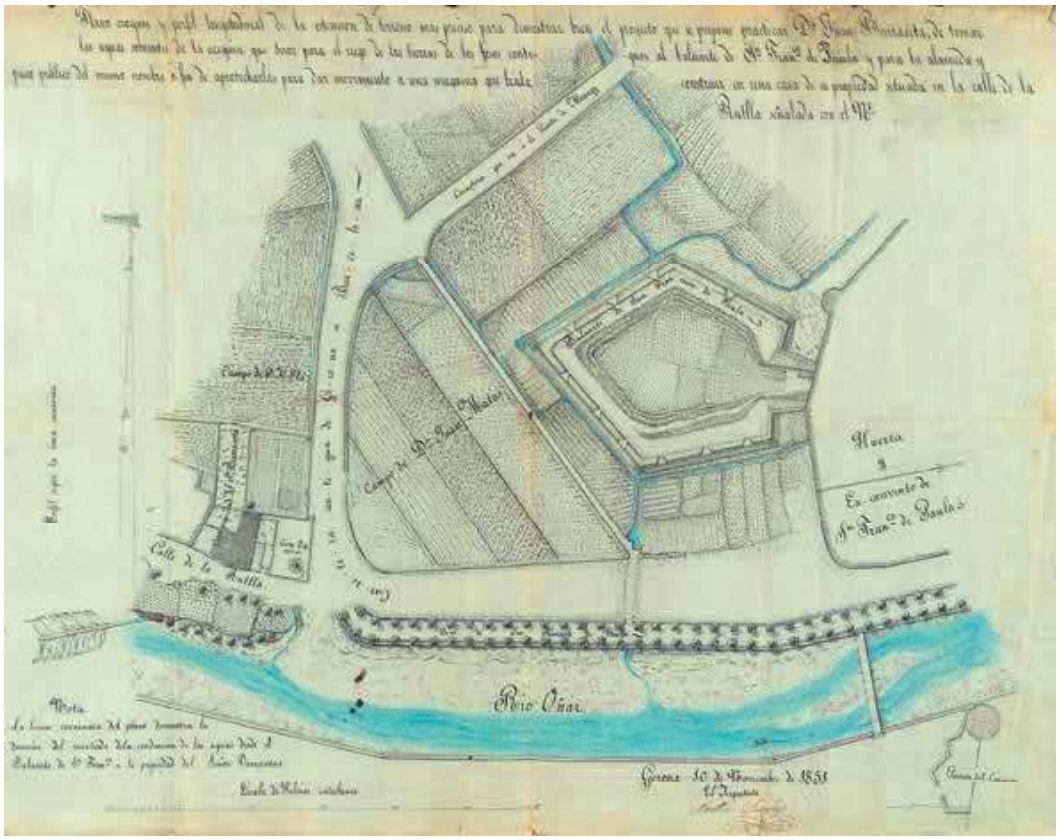

Fig. 10. Map of Sant Francesc bastion, 1851. Girona Municipal Archive

Target audiences / stakeholders

The Girona pilot utilises two tools, both provided by partner Swing:It: the AI 3D Builder and the 3D XR Studio. They are combined for the Girona pilot, but they are not directly connected, as each is a standalone solution, and have different audiences as well. The pilot as a demonstrator is targeting mainly archivists and records managers who may want to use the AI 3D Builder to generate 3D models from 2D content. Additionally, the use of 3D content in AR tours aims at engaging on one side curators and CHI staff who create the AR/XR tours, and city visitors and other local stakeholders who access the Girona walls application.

That creates different target audiences the pilot takes into account, the details for the various categories are provided in the subsections below:

Target audience for the use of the AI 3D Builder:

- **Archivists and other professionals in record management**: As primary custodians of historical records, archivists are the main target for this tool. Archives, museums and libraries hold the 2D sources (cartography, engravings, photographs, films, textual records) that are transformed into 3D models. The pipeline is designed to facilitate their work in digital reconstruction, offering an advanced solution to valorise and reuse archival records in new 3D/XR contexts.
- **Researchers in digital humanities**: Scholars working on digital reconstruction, urban history, or heritage visualisation will benefit from the capacity to generate accurate 3D models from documentary sources.
- **Technical staff at CHIs**: Professionals responsible for digitisation and digital asset management.

Additionally, other stakeholders are:

- Curators, CHI and archive institutions and their management
- CHIs digitisation departments
- Technology partners and developers in the digital heritage field
- Creative industries professionals
- Cultural tourism professionals

Target audience for the use of the 3D XR Studio, to create tours:

- Curators, CHIs managers, staff and professionals
- Researchers
- Educators
- Creative industries professionals
- Cultural tourism professionals

Target audience for the use of the 3D XR Studio, to visit the Girona walls:

- **Girona citizens**: Residents are the primary audience for on-site experiences, being directly interested in the virtual recovery of their city's lost heritage.
- **Tourists and cultural visitors**: People visiting Girona, interested in historical and cultural discovery through immersive and interactive experiences.
- **Educators and students**: Local schools and universities using XR on-site or remotely for educational purposes.
- **Cultural events organisers**: Entities planning guided tours, city events, or educational workshops.

Additionally, other stakeholders are:

- Girona municipality and local authorities.
- Tourism boards and cultural tourism operators.
- Educational institutions.
- Community associations promoting local heritage.

Content used in the scenario

The scenario starts from a variety of 2D documentation to produce 3D models. The content used in the scenario is therefore extensive, to grant the tool sufficient source materials and information details to generate accurate and scientifically-sound 3D models. A selection of the content is aggregated and published in Europeana.

The detailed list of content is listed below: these are the records and data provided for the virtual 3D reconstruction of the Girona city historical walls, in the sector designated as a pilot test. CRDI provided these records to Swing:It in order to have all the scientific

information required for the most realistic virtual approach with regards to target users and their devices, and to identify the set of images needed for the textures of the 3D models.

- **General plan of the section of the wall to be reconstructed**: The plan precisely defines the section of the wall to be virtually reconstructed through the creation of 3D models. It includes all the elements to be considered.
- **General plans of the section based on orthophotography**: It is the same plan as the previous one based on an orthophotograph. The orthophotograph provides the information needed to avoid collision while viewing the 3D model on-site.
- **Plan of the bastion**: This plan provides a detailed explanation of all the elements that were part of the bastion.
- **Plan of the vestiges of the bastion**: This plan explains the current state of the bastion, meaning it includes the elements that are still preserved. In addition to the plan of the bastion, the same document includes a view of the bastion, with the heights indicated.
- **Height of the wall**: This graphic provides information on the different heights of the wall, considering both the current level (plaza level) and the historical level. The various heights indicated are: tower section, wall section, wall-walk section, bastion section, moat section.
- **Current heights**: This graphic provides information on the different heights of the preserved vestiges of the wall. It distinguishes between the current plaza level and the historical level (parking level). The data included are: heights of the existing elements, altitudes from the 1869 plan.
- **Image of the powder warehouse**: Image of the preserved vestiges of the powder warehouse.
- **Drawing of the powder warehouse**: Map of the powder warehouse according to its original structure and in relation to the wall and the tower.
- **Photograph of the bastion**: Photograph of the bastion with the image of the sculpture *The Lion* in the foreground.
- **Photograph of the section of the wall with the three towers**: Photograph of the section of the wall adjacent to the bastion.
- **Photograph of the three towers**: Photograph of the three towers.

- **Photograph of the bastion**: Partial photograph of the bastion.
- **Photograph: general view**: Photograph of the general view of the bastion and the section of the wall to be recreated in 3D.
- **Historical plans of the section of the wall and bastion (1869)**: This is an original plan from 1869, when the wall had not yet been demolished. This plan was used as a reference for all the altitudes present in the plans created for this project.
- **Images for textures of the historical walls and bastions**: All these images are used to provide the texture of the walls and associated elements.

Fig. 11. The Àlvarez portal and a section of the Mercadal wall. 1896, Juli Vintró. Ajuntament de Girona - CRDI

Fig. 12. Works of demolition of the wall of the Mercadal.
1901-1908, Fotografia Unal. Ajuntament de Girona - CRDI

Narrative and storyboard

Users are able to watch the 3D models of the walls, towers and bastions on-site. The linked records and information to these models provide them a historical narrative. Audio records are in Catalan and English. This is the main information of the historical context:

- Girona celebrates 2,100 years since the foundation of the city by the Romans (Gnaeus Pompey the Great, in 76 BC).
- The medieval walls of Girona were built in the 15th century.
- The building of towers and bastions (16th-17th century).
- The walls and all these elements were partly demolished at the beginning of the 20th century.
- The walls of the eastern side were kept, although they were abandoned for many years.
- It was during the 1980s that the works carried out in different phases aimed to reuse a space for walking and enjoyment, more than carrying out an archaeological restoration.

- It is in the 21st century, in the framework of EUreka3D-XR project that the demolished part of the walls is being virtually reconstructed.

Fig. 13. Current view of the Sant Francesc bastion. Ajuntament de Girona - CRDI

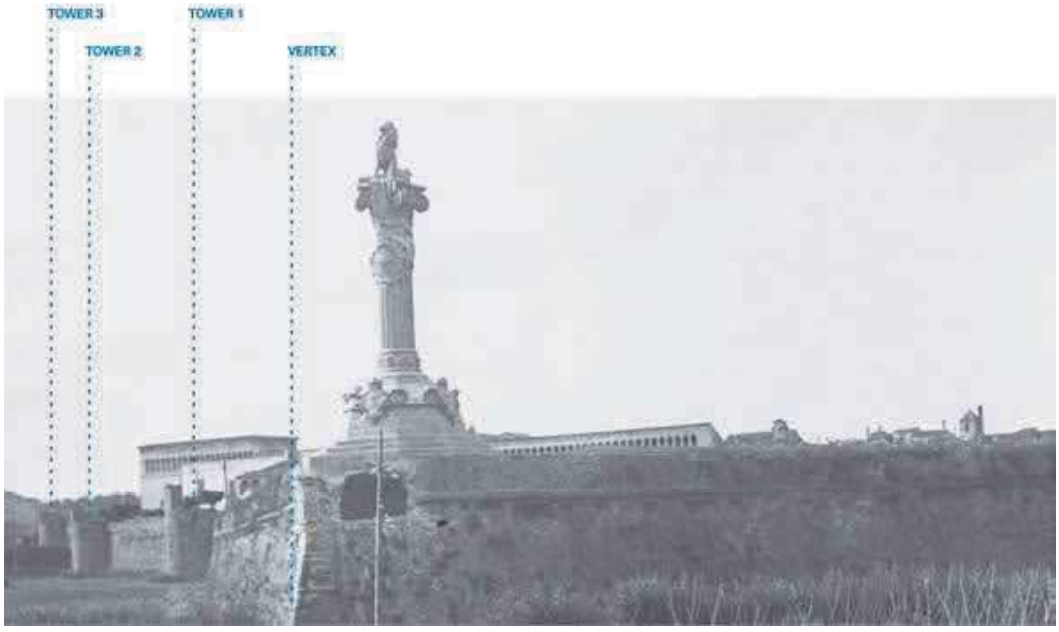

Fig. 14. Heritage photograph of the section of the wall adjacent to the bastion, with the three towers.

Interaction with end users

The Girona pilot utilises two tools, both provided by partner Swing:It.

AI 3D Builder is a professional tool for creating 3D models from properly generated collections of 2D materials. The tool is not specifically dedicated to end users such as site visitors, tourists or educators: it is rather targeted to cultural heritage curators, archivists, collection managers, etc.

In the pilot the AI 3D Builder is used for recreating the 3D-based virtual visualisation of the Girona walls. Once the 3D model is re-created by the curator, it can be rendered online as any 3D model, and also used in the 3D XR Studio tool for visualisation on-site via a mobile app and enable amazing XR experiences for tourists.

For the Girona prototype, the work with the 3D XR Studio includes the creation of a web+mobile application that shows the end user a predefined pathway along the perimeter of part of the former west Girona walls.

The user downloads the mobile app on their smartphone and walks by, following the pathway map on the display. Along the walk the user can access virtual objects in extended reality, by visualising the 3D models in the scene.

As a curator/admin, the mobile and the web apps also allow to build the pathway and define its elements (models, reference points, etc). He/she is supported with tools for precise selection, rotation, scaling, and repositioning of 3D models.

The user can experience the model along the path, just by following graphic instructions provided by the App. At every given reference point (Point of Interest) he/she can also obtain augmentative information as well as access the narrative and all the supplementary content created by the curators.

Workflow of the curator

Workflow for the AI 3D Builder

The AI 3D Builder pipeline is built upon Microsoft Trellis, an advanced AI model for image-to-3D conversion. This offers superior quality and ability to process multiple perspectives simultaneously, and supports local deployment for data security and control.

The curator accesses the tool via a web application that allows for processing 2D image collections, inputting various source photos as well as realistic illustrations and outputting industry-standard GLB files for broad compatibility. The AI handles the 2D-to-3D conversion, starting from images that the curator uploads in the tool. Guidelines are provided to the curator also including good practices for input photos and realistic illustrations as well as for quality of the output. The guidelines also include information about the elements to ensure optimal results across various input conditions (e.g., lack of details, missing perspectives, quality issues). Fine-tuning, also depending on the input conditions, requires a further crucial human refinement stage to improve the output generated by AI.

Once acceptable result is reached, the final GLB file can be normally stored, visualised, used, and also exported to other formats. The final model can be uploaded, for example, via the EUreka3D Data Hub which offers a 3D viewer and a full pipeline to safely store, manage and share 3D models and their associated metadata and paradata, also enabling publication on Europeana as open access data with a PID.

Workflow for the 3D XR Studio

The 3D XR Studio is a dual-component system comprising a web application and a mobile one devoted to the creation of XR experiences. The mobile app can also be used by curators for on-site refinement of the XR virtual area and precise 3D models placement.

When accessing the 3D XR Studio via a safe authentication mechanism, fully compatible with the EGI single-sign-on check-in adopted in the EUreka3D Data Hub, Cultural Heritage professionals and curators can easily create, organise, and distribute engaging

XR experiences for large audiences. The tool is based on a streamlined approach that is designed to significantly reduce the technical expertise required and allows for rapid prototyping and deployment of immersive content.

In the web application, curators operate as admins (editors of the XR experience). The tool implements a graphical interface (based on REACT technology) and features that enable admins to import and select 3D models to position them on a map.

More specifically, an admin can:

- define XR experience areas by inputting coordinates;
- provide a 3D map to visualise existing structures;
- import 3D models, and/or call to the Europeana API to fetch additional 3D models and ingest them in the 3D environment;
- arrange a precise positioning of the models within the virtual environment by defining coordinates, orientation, and scale.

In addition, the 3D XR Studio permits admins to create a mobile application for AR experiences on-site, which allows end users to follow the map and access the 3D models and narratives. The mobile app also has editing features for admins, who can:

- Place and manage 3D Objects in real-time in the XR scene (position, scale, etc.);
- Set 3D Objects visualisation (add visual occlusions);
- Handle Points (add, delete, move) that create the guided tour.

Fig. 15. General view on the WebApp with the wall 3D model positioned on the map

Fig. 16. Mockup for the 3D XR Studio: on the left what the curator sees when managing the 3D model of the wall (yellow indicates is selected), with tools for managing the models on the scene; on the right what the user sees when clicking on the interest point (pop-up audio)

Challenges encountered

The Girona prototype faced several challenges related to the digital reconstruction of lost heritage, the integration of AI-generated 3D content into XR environments, and the design of user-friendly tools for diverse audiences. One major challenge was the heterogeneity and variable quality of historical 2D sources, including gaps in visual documentation, missing perspectives, and inconsistencies across cartographic and photographic materials. These limitations required careful curatorial selection, interpretation, and iterative refinement of AI-generated 3D models to ensure historical plausibility and visual coherence.

Another challenge concerned the balance between automation and human expertise. While the AI 3D Builder significantly accelerates 2D-to-3D conversion, achieving high-quality and accurate results still requires human intervention for validation, fine-tuning, and contextual interpretation.

From a user experience perspective, the pilot also addressed the challenge of serving multiple user profiles –from archivists and curators to tourists and local citizens– each with different levels of technical expertise and expectations. Designing an XR mobile application that is both powerful for curators (in terms of editing and positioning 3D models) and intuitive for end users (in terms of navigation, comprehension, and engagement) required careful interface design and testing. Additionally, on-site XR experiences introduced technical constraints related to GPS accuracy, spatial alignment and device performance.

Fig. 17. Mock-up image of a user experiencing the 3D XR Experience Tool in front of the Sant Francesc Baluard. By Swing:It

Future developments

The scenario that has been developed in this project is considered as a pilot test. The City Council of Girona intends to continue with the 3D reconstruction of the entire wall. In this regard, the work on 3D model reconstruction is expected to continue, as it is part of a broader municipal project driven by the EUreka3D initiative. It is important to note that research into the urban history of the city began in the 1990s. The goal is to bring much of the content from these studies into a visual and accessible space for the public.

This prototype confirms the value of integrating AI-based 3D reconstruction, XR technologies, and archival expertise to recover and reinterpret urban heritage that can no longer be physically restored. By addressing professional workflows and public engagement within a single scenario, the pilot demonstrates how digital tools can bridge research, heritage management, and citizen-oriented experiences. As a pilot, the scenario has also highlighted the importance of iterative development, inter-disciplinary collaboration, and sustained institutional commitment. The results achieved are not only technically successful but also socially meaningful, reusable, and scalable. In this way, the Girona pilot provides a solid foundation for future extensions at local level and a transferable model for similar heritage contexts across Europe.

2.4.2. THE AR NARRATIVE OF THE HIDDEN SIDE OF THE BIBRACTE ARCHAEOLOGICAL SITE

Located in central France, in the Morvan mountains, the Gallic town of Bibracte, dating back to the 1st century BC, was mainly made up of wooden buildings, of which only a few traces remain today: postholes, pits, circulation levels, hearths, and similar features. The process of Romanisation, following the Gallic Wars (58-51 BC), introduced new architectural techniques that left more substantial and enduring remains.

Added to this are the following realities, common to all archae-ological sites:

- Archaeology destroys its object of study because each archaeological layer can only be excavated once before being destroyed when the layer below is excavated in turn.
- At the end of the work, the last layer excavated, if not preserved, is backfilled to protect the remains (which is the case for wooden building remains whose structure has disappeared).
- Even when remains are preserved in situ, this only reflects the state of occupation of the site, as more recent remains have been dismantled to achieve this, while the oldest remains remain hidden beneath the preserved state.

Fig. 18. The archaeological site of Bibracte on Mont Beuvray (A. Maillier, Bibracte)

More broadly speaking, what escapes immediate perception at an archaeological site, and more generally at heritage sites of all kinds, can be divided into four categories (detailed below): what is no longer there, what is present but not visible, what is not or no longer perceptible by the senses or the intellect, and finally what remains outside the scope of visitors' experience, such as the technical processes involved in archaeology and heritage restoration.

What is missing

- What has disappeared:
  - Past landscapes and ecosystems, which generations have constantly adapted to their needs.
- What has been destroyed:
  - Buildings, structures, objects, and decorations destroyed by time.
  - Structures, objects, and decorations destroyed by humans (war, vandalism, plowing, construction, exterior and interior renovations, etc.).
- What has been moved:
  - Reused materials.

- Looted architectural decor elements and objects.
- Objects and materials taken for study, conservation, and exhibition in other places (museums).

What is present but not visible

- Remains visible only during excavations or restoration work.
- What is covered or hidden:
  - Archaeological layers backfilled after excavation or preserved under more recent remains.
  - Traces of developments hidden during restoration and repair work.
- What is inaccessible:
  - Elements of heritage with restricted or prohibited access for reasons of personal safety (dangerous site) or property safety (fragile site), or for legal reasons (private property, etc.).

What is not perceptible

- To the senses:
  - Because it is too degraded (remains of wooden architecture, etc.).
  - Because it has been too extensively altered/restored (loss of authenticity).
  - Because it is too incomplete (loss of integrity).
  - Because it is too tenuous (micro-reliefs, micro-remains: seeds, pollen, etc.).
- To the intellect:
  - Because the original function of the site and the practices that took place there are no longer present and/or have been forgotten (religious spaces corresponding to rites that have fallen into disuse, for example).
  - Because the historical, cultural, and socioeconomic context of the site and practices is unknown to visitors.

What is behind the scenes

- The stages of archaeological research (preparation of the excavation, fieldwork, data analysis) and the restoration project.

Fig. 19. The remains of the PC15 public space, now backfilled (A. Maillier, Bibracte, 2017 and 2025)

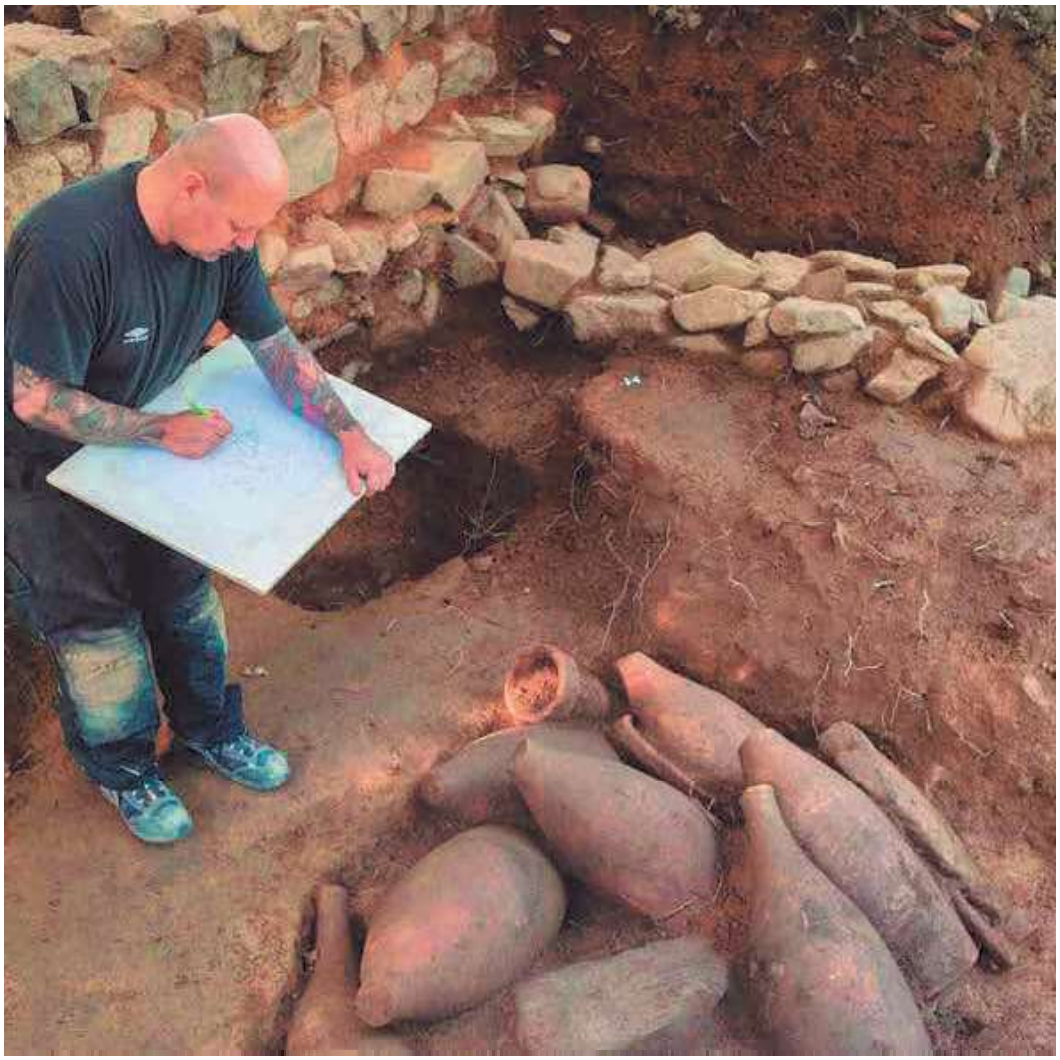

Fig. 20. Excavation drawing of a pit filled with amphorae before their removal and the backfilling of the pit (A. Maillier, Bibracte, 2024)

Fig. 21. The large Roman house PC1, of which only the foundations and the first courses of the walls remain (A. Maillier, Bibracte, 2019)

Fig. 22. Seed, pollen and charcoal analysis by flotation, and pollen study using an electron microscope (A. Maillier, Bibracte, 2019 and 2024)

Local scope of the scenario

The main challenge in mediating with visitors to the Bibracte archaeological site is, therefore, to enable them to see and understand these remains and the archaeological realities that are invisible or virtually invisible on the site. Until now, their promotion has mainly relied on:

- the museographic elements of the permanent exhibition: models, iconography, videos and texts,

- explanatory panels on the archaeological site with the same type of iconography, accompanied by some restitutions on a reduced scale or on a scale of 1,
- the 'La Boussole de Bibracte' geolocated tour application, including iconography and 360° views of hypothetical 3D reconstructions of the elevations of three buildings. However, this tool does not allow for an easy, dynamic response to this challenge as research progresses, because the integration of new media (video, audio, and especially 3D augmented reality) requires new development by the service provider and therefore incurs costs for the site manager.

The EUreka3D-XR project offers a more comprehensive and immersive response to this challenge, directly at the archaeological site. The two tools developed by NTUA enable the creation of a geolocated tour of the archaeological site, accessible via a mobile app. Thanks to augmented reality, visitors will be able to view 3D models of terrain and objects linked to their context of discovery and enriched with additional content. This tour will allow them to discover *The Hidden Face of Bibracte* by giving them access to elements that have disappeared, are not visible in situ, or are not directly accessible to the senses and intellect (see above).

This scenario will thus make it possible to:

- Strengthen the links between the archaeological site and the museum.
- Encourage visitors to the site to come to the museum to see the "real" objects whose 3D models they have seen.
- Better promote research to visitors.
- Increase visitor numbers to the site.

Overall scope of the scenario / Field of application of the device:

The device designed as part of EUreka3D-XR can be useful in a wide variety of heritage sites, from leveled archaeological sites to architectural and urban complexes that are still inhabited, which face similar issues (see table above).

Given this scope of application, the device tested at Bibracte:

- explores to the fullest extent possible the possibilities for revealing and understanding different types of invisible realities,
- utilises the full potential of the tools developed by NTUA in order to highlight them for their future users.

Target audiences / stakeholders

The pilot project, as a demonstrator, targets heritage professionals likely to use AR Tour Builder, while the augmented reality tour, created using this tool and accessible via the mobile AR Tour Experience app, aims to engage site visitors and other local stakeholders.

The specific characteristics of these two audiences are provided in the subsections below:

Target audience for the use of the AR Tour Builder

The target audiences for the AR Tour Builder are primarily:

- Heritage institutions that manage outdoor heritage sites (the system developed does not allow visits to enclosed spaces, such as the interiors of historic monuments or museums).
- Public and private operators of archaeological excavations.
- Local authorities and tourist offices in areas rich in heritage.

and secondarily:

- Schools and universities, particularly in the fields of history, archaeology, art history, architecture, and urban planning.
- Independent tour guides and mediators.
- Architects, urban planners, and urban project operators, particularly in the context of consultation processes and project presentations to residents.
- Cultural and Creative Industries: 3D design studios, designers, digital artists, scenographers, producers of immersive content,
- Local authorities and cultural operators wishing to develop innovative mediation initiatives in public spaces (cultural events, temporary art trails, neighborhood enhancement).

Some of these audiences are already accustomed to using no-code tools to design heritage discovery experiences: Genially[8] for light escape games, and especially PlaysVisit and GuidiGO[9] for geolocated tours. The first need is in fact common to these audiences (with the possible exception of the Cultural and Creative Industries): to have a no-code and open source tool, therefore free, to easily design geolocated tours that make 3D models and other types of cultural heritage content accessible via a mobile application, thus offering an AR experience to the on-site visitor.

In fact, currently, there is no completely free and accessible solution without mastering coding that allows the creation of geolocated tours that can accommodate AR experiences using 3D models. Existing solutions, such as GuidiGO or PlayVisit, are proprietary platforms that require a paid subscription for 3D and AR, and remain limited to marker-based AR. Development tools, such as Unity or Unreal Engine[10], although open source or with free licenses, require programming skills and are not specifically designed for the creation of geolocated tours for non-developers. In addition, the ARKit and ARCore[11] frameworks, although offering advanced markerless spatial AR functions, also require specific development to combine geolocation and AR using 3D models. Finally, these solutions are not interoperable with open platforms that provide access to cultural heritage items, such as Europeana and the EUreka3D Data Hub. Thus, the creation of free, easy-to-use tools specifically designed to meet the needs of heritage sites and other stakeholders constitutes a major challenge in democratising the creation of geolocated tours in AR, while allowing complete autonomy for end users in the design and editing of content.

These tools can also meet specific needs that are not entirely present in Bibracte but for which appropriate technical solutions

8 https://www.genial.ly/en

9 https://www.guidigo.com/en. For example, of the 151 GuidiGO tours listed in Bourgogne-Franche-Comté (France), 52% were carried out by classes (from CP to Terminale, often in partnership with heritage institutions), 20.5% by tourist offices, 8.5% by heritage institutions (museums and castles) and 10.5% by other stakeholders (mainly independent guides, followed by students and heritage enthusiasts).

10 https://unity.com/ and https://www.unrealengine.com/en-US

11 https://developer.apple.com/augmented-reality/arkit/ and https://developers.google.com/ar

have been identified. Specific needs also make it possible to consider adapting the tools to other heritage situations and then to related fields of application:

- Links to 360° videos, particularly to enable exploration of the interior of monuments that are closed to the public.
- Use of QR codes to more precisely locate 3Ds in AR (not relevant on the archaeological site of Bibracte due to the small number of supports to fix them).
- Materialisation of in situ POIs by physical marking, this is because not everyone knows how to read and use a map in order to find the POI, in addition, a phone vibration is triggered.
- Setting the trigger radius for POIs, i.e., the distance from which their content is displayed on the mobile application: Shorten this distance when POIs are close or in an urban context and areas with heavy vehicle traffic. Lengthen it when a POI is not physically accessible (remains under brambles, construction site under excavation, etc.) or temporarily in the event of a visit by a large group.
- Presentation of underwater remains from the surface. The effect of AR will be a little different, however, since the 3D models will appear on the surface of the water, but it is an interesting solution to allow a wider audience to discover these remains in a less expensive and more secure way. There are two such devices, MeDryDive AR App and VISAS[12], but whose design tools are not open source.
- Presentation of buildings, or developments, that have not yet been constructed as part of architectural and urban projects, particularly during consultation and presentation phases with future residents, in order to facilitate understanding of the project's scale, integration into the landscape, and impact.
- Recreational and educational uses of artistic mediation, consisting of temporarily "enchanting" an urban or rural space through augmented reality visualisation of 3D models of works of art, allowing for stylistic and historical comparisons in situ. This type of use is of particular interest for teaching art history, art schools, and cultural mediation activities outside the classroom.

12 https://medrydive.eu/medrydive-ar-app/ and https://link.springer.com/chapter/10.1007/978-3-319-48496-9_22

Target audience of the AR Tour Experience, to visit the Bibracte site

In the case of Bibracte, the users of the mobile app are all of the visitors to the archaeological site, particularly those who do not visit the museum or take a guided tour.

This scenario meets several needs of this audience in its diversity:

- For all visitors: it aims to alleviate their frustration at the lack of visible remains on the site, while satisfying their natural desire to see, understand, and explore. The scenario promotes an active approach to discovery: it allows everyone to become an active participant in their visit, revealing “the hidden face of Bibracte” through an immersive and interactive experience that stimulates the imagination and enriches understanding of the site.
- For visitors who are keen on archaeology: they can deepen their knowledge, in particular with the possibility of downloading content that can be consulted in detail after the visit.
- For teachers and students, whether guided or visiting independently, the scenario illustrates several aspects of the school curriculum, in particular “What came before France? What traces of ancient occupation remain?” (History - 4th/5th grade) and “Arts and societies (Antiquity and the Middle Ages): cities, architecture, myths, and representations” (History of the Arts, 7th grade).

Content used in the scenario

The scenario is structured around 3D models, complemented by 2D content, texts, videos, audio files as well as interactive online content.

3D Content

- 3D ‘terrain’ models (remains of structures and excavation areas): pit filled with amphorae from PC14 terrace and mine shaft from Theurot de la Roche, to which will be added the masonry cellar from PC2.

- 3D models of archaeological artefacts: amphora stamp, maple cup, piece of harness, plumb line, helmet reused as a foundry ladle, figurine of a draped woman, chest key with sliding keyhole cover.
- 3D restoration of the missing elevations (addition): PC1 domus and PC15 public building.

Fig. 23. 3D model of the masonry cellar of Roman house PC2

Fig. 24. 3D model of a turned maplewood bowl

Other file types

- 2D+: geolocated and oriented photographs of the landscape from the Pierre de la Wivre in 1873-1874 and of the mosaic of the PC1 *domus*.
- 2D: three pairs of before/after photographs of landscapes, five photographs of excavation process, a dozen photographs of archaeological objects, and several scans of ancient documents such as 19th-century excavation notebooks.
- PDF: six editorial files on the archaeological sites (Rock de la Wivre, PC1 *Domus*, PC2, *Domus*, PC14 *Terrace*, PC15 *Public building* and Theurot de la Roche), extracts from excavation reports (in particular for the well on the edge of PC14 Terrace), educational content on archaeological methods, maps.
- Video: videos presenting archaeological sites (PC2 *Domus*, PC15 Public building and Teurot de la Roche mine shafts) and thematic videos on archaeological methods (palynology, dendrochronology and dendroclimatology) as well as on the routes taken by amphorae from Roman Italy to Bibracte.
- Audio: 14 audio presentations of each 3D model and two georeferenced and oriented photographs, allowing them to be viewed in full screen without text overlay or interface changes.

Fig. 25. Orthophotograph of the large Roman house PC1 mosaic during excavation

Fig. 26. Editorialised dossier on the large Roman house PC1

External online content:

- 360° videos
- Editorialised hypertext content
- Quiz on Historiana[13]

Narrative and storyboard

Two visit scenarios are proposed to illustrate the AR Tour Builder's ability to design tours on the same site, depending on the themes covered, the target audiences, or the distribution contexts. This approach demonstrates the tool's editorial flexibility and its ability to adapt to a variety of uses.

The main narrative: The hidden side of Bibracte

The main scenario offers a visitor experience focused on revealing the invisible, providing access to archaeological realities that usually escape visitors' direct perception. The aim is to reveal

13 Example of a Quiz in Historiana: https://hi.st/B66

what is no longer visible, what is buried, what can no longer be perceived by the senses or the intellect, as well as what remains outside the scope of the traditional visitor experience.

The points of interest that make up this narrative have been selected according to three complementary criteria:

- their ability to show and explain remains and realities that are not directly visible on the site, in order to illustrate this staging of the invisible;
- the availability of 3D models of terrain or objects, with each POI centred around a main 3D model (with the exception of a geolocated and oriented photograph of an ancient landscape);
- the possibility of associating these models with varied and engaging complementary content, highlighting the full potential offered by the AR Tour Builder and AR Tour Experience tools.

Each 3D model thus serves as the anchor point for the narrative specific to each POI and guides the selection of associated content. This approach promotes the construction of a coherent narrative while highlighting the diversity of the formats used.

The narrative consists of seven POIs, all of which, with the exception of Theurot de la Roche, which is dedicated to lost landscapes, are located in the Parc aux Chevaux area.

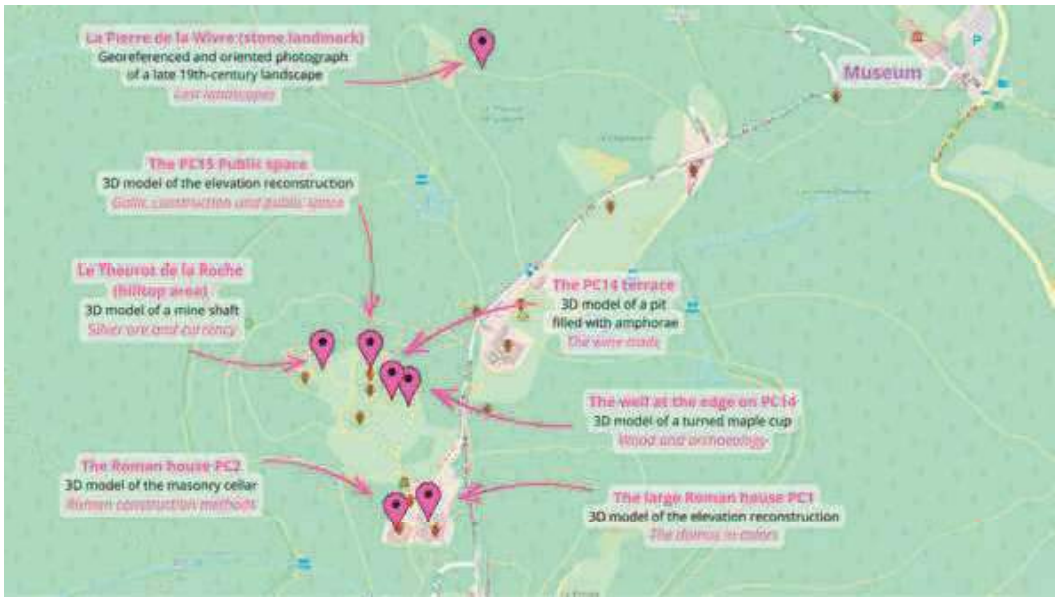

Fig. 27. Location of the seven POIs, with their main media and associated narratives

The content and the narrative that links it together reveal the four types of invisible realities identified above:

- What is missing: the vanished landscapes visible from the Pierre de la Wivre, the vanished elevations of the public building PC15 and the domus PC1, the remains of the pit filled with amphorae destroyed during the excavation process, as well as the objects now preserved and exhibited in the museum.
- What is not visible: the backfilled remains of the post holes of PC15, the buried structures of the well at the edge of the PC14 terrace, the cellar of the PC2 domus, and the pit of the Theurot de la Roche silver mine.
- What cannot be perceived, either by the senses or by the intellect: micro-remains and pollen, the former functions of PC15 and certain areas of the domus PC1, the skills and know-how of craftsmen and builders, trade networks, changes in the landscape, and the degradation and preservation of certain materials, such as wood.
- What is outside the scope: the areas currently being excavated and, more broadly, the post-excavation study work, particularly through the ancillary sciences of archaeology such as palynology, dendrochronology, and chemical analysis of materials.

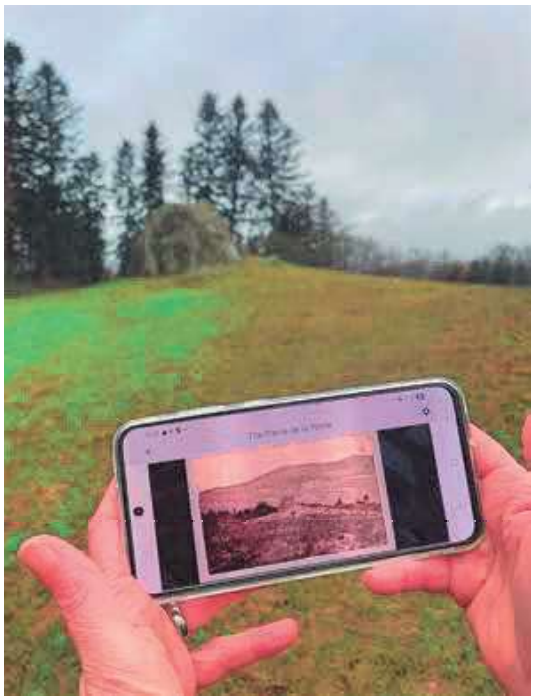

Fig. 28. Facing La Pierre de la Wivre and looking towards the north-west, appearance of a georeferenced and oriented photograph of the late 19th-century landscape

Fig. 29. Augmented reality view of the amphora-filled pit at the north-east corner of the PC14 terrace

Fig. 30. Photographs of a bronze coin die and a silver coin of the Aedui

Fig. 31. Photograph of the extraction of a peat core and video introducing palynology

VIDEO INTRODUCING PALYNOLOGY

https://api.nakala.fr/data/10.34847nkl.8555d6qg/5059b2d448ec442bd1c89db16201651452c38462

The secondary narrative

The proposed demonstrator takes the form of a short tour on archaeological looting, designed for the International Day Against Illicit Trafficking in Cultural Property (November 14). It is based on the content of two Open Educational Resources produced as part of the PITCHER[14] project (Preventing Illicit Trafficking of Cultural Heritage: Educational Resources – Erasmus+ 2021-2024).

As the Bibracte site has not, to our knowledge, been subject to large-scale looting, this secondary narrative aims to raise visitors' awareness of the inseparable link between an object and the

14 https://www.pitcher-project.eu/

context in which it was discovered, as well as the information that they convey to each other and which disappears when objects are illegally removed. Three POIs thus illustrate the importance of geographical, spatial, and stratigraphic context in archaeological interpretation.

These two stories are available in French and English, ensuring their linguistic accessibility to as many people as possible. In addition, the application's user interface incorporates some digital accessibility features such as enhanced contrast in line with the common UI features designed for all EUreka3D-XR tools.

Consideration for users with disabilities, particularly visual, auditory, cognitive or motor impairments, is an integral part of the ongoing review process. This was a particular focus during the testing phase, with a view to identifying shortcomings and possible future extensions of the tool with respect to various types of disabilities, to develop potential improvements in terms of ergonomics, navigation and content accessibility.

Interaction with end users

On-site

- Interactions with the physical environment: move from one POI to another, locate remains and take a fresh look at the site thanks to the app's content; position 3D models in the real environment to display them in augmented reality, then move around the locations to explore all sides of the models, move closer to observe details or move further away to see the whole.
- Interactions with the app: interact with the touch interface (buttons, menus) to navigate between the different content available; manipulate 3D models in the 3D viewer (rotation, zoom); complete quizzes like positioning elements in their correct category or location.
- Social interactions: share discoveries and amazement, discuss the content presented and cooperate to answer quizzes, particularly in the context of educational interactions between pupils or between parents and children.

Fig. 32. Display of the map used to orient oneself on the site

Fig. 33. Positioning of the 3D model of the mine shaft within the physical environment

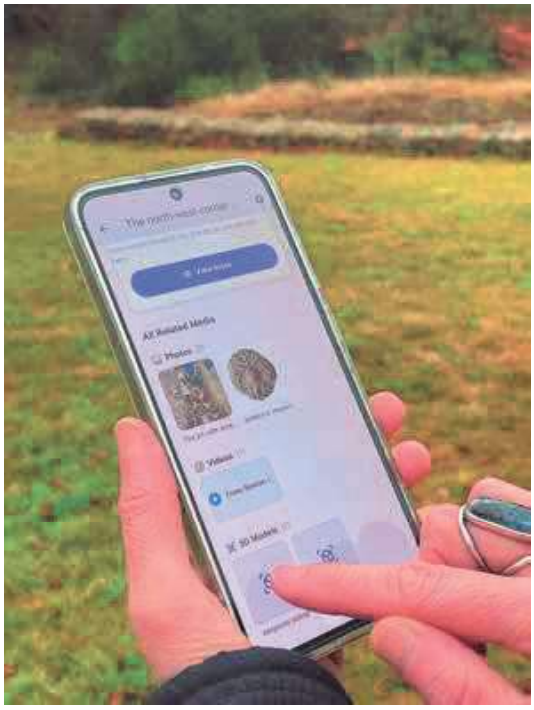

Fig. 34. Discovery and selection of complementary content within the application

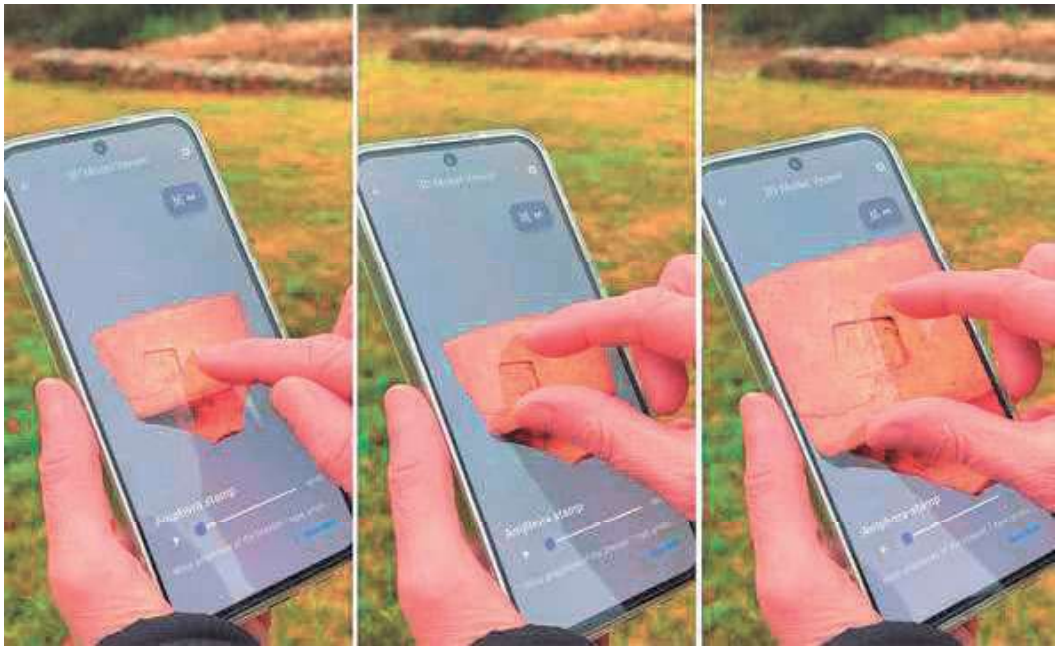

Fig. 35. Manipulation of a 3D model of an amphora stamp in the 3D viewer

Online

The application relies mainly on content that is accessible online. Some of this content, particularly editorialised reference resources, has stable and permanent addresses (DOI, ARK or institutional URLs). Other content, which is interactive in nature (quizzes,

active pages, 360° videos), is accessible via dynamic web pages incorporating HTML links and internal navigation mechanisms.

Provided there is sufficient network coverage, the content can be viewed dynamically via the telephone network. For downloadable content (3D models, 2D files, video, audio and PDF), the system offers a default option to download in advance, in order to ensure continuity of use on-site[15]. Particular attention has been paid to the size of the files used, in order to ensure smooth and economical use of the system.

Workflow for the curator

The site curator accesses the tool and has a range of functionalities, as described below.

Shape the scenario

The AR Tour Builder tool was developed to support the creation of the geolocated tours at Bibracte and is offered as an open tool for future use by any interested stakeholder. The AR Tour Builder provides a map interface which allows users to create and position Points Of Interest (POI) on certain locations. A POI can be associated with multiple cultural heritage objects of various formats (3D objects, images, text) and includes specific metadata such as its GPS coordinates, a title and a general description, etc. A map enriched with POIs constitutes a tour. Several tours can be organised under the concept of a 'site', which represents a heritage site or a geographical area in which one or more tours are offered.

The possibility of offering several tours on the same site is particularly interesting. It allows curators to create different tours based on their themes, the type of audience (e.g., a family and children's tour), or even the time of year, especially for recurring events.

15 Since several areas of Mont Beuvray are not covered by all four French mobile phone operators, content must be downloaded directly to the application to allow offline use.

This opportunity opens up a particularly rich field of possibilities that invites detailed planning over several years.

The AR Tour Experience tool allows creators to test the scenario on-site in order to correct and adapt it, depending on on-site particularities (e.g., network coverage) and the evaluation of the overall experience.

Access/retrieve content

Access to content is supported via a 'Library' interface (one per site).

Content can be directly uploaded manually via a form, linking a media url to it, or can be imported from external sources like Europeana and then letting the user fill in additional metadata useful for the user experience.

- Manual upload: A sidebar from the right opens with a form for the user to fill in content metadata as well as a url field for its media with preview capability.
- Import from external sources: A modal opens showcasing external sources (e.g., Europeana) allowing the user to select between them. Once selected, the right sidebar opens with the form fields pre-populated with the content's metadata and url, allowing the user to fill in more information if needed.

Once the asset is created, the sidebar on the right turns to a view of the asset information, such as a file preview, title, description, file name (imported or manually filled information)

Embed the contents in the application

The contents are embedded at the level of each POI.

Once a POI is created, part of the content can be inserted directly via the tool: title, thumbnail and descriptive text.

Other content can be added from the Library. E.g., 2D images, 3D models, videos, audios, PDFs and interactive online content.

Challenges

In addition to the technical challenges associated with the AR Tour Builder and AR Tour Experience tools, the specific difficulties with the Bibracte scenario mainly concerned content to be used and the importance of taking into account the diverse needs of future users.

In terms of content, while the majority of 3D models could be identified quickly, the same was not true for a significant portion of additional supporting content of other formats proved more challenging, due to the vast wealth of iconographic, documentary and multimedia resources available on Bibracte. The choice of points of interest (POIs) based on 3D models that tell a story and reveal an invisible aspect of Bibracte proved decisive in targeting the most relevant additional media more precisely. This approach made it possible, on the one hand, to construct a coherent narrative and, on the other hand, to highlight the full potential of the two tools.

Beyond the final selection of content, another challenge was the translation of some of it (texts and videos) into English. While not a major challenge, this step nevertheless required a significant amount of work. Furthermore, although the team already had expertise in designing interactive activities via the online educational platform Historiana[16] (notably through the use of the E-activity Builder), the adaptation of these activities to simple formats suitable for mobile use had to be specifically taken into account.

The needs of future users, beyond the specific case of Bibracte and more broadly in the field of archaeology, gradually became apparent during the project, particularly through exchanges with various external partners. This openness, to other contexts of use, in regards to the developed tools, represents a strong potential for stakeholder growth.

However, it was not possible to conduct practical trials of these expanded uses at Bibracte, as the site has specific constraints and objectives. Nevertheless, initial testing was carried out in a few

16 https://historiana.eu/

cases during the public event in Girona at the end of January 2026. Nevertheless, initial testing was carried out at project's events in Girona (January 2026) and Cyprus (May 2026), and with evaluation and validation activities implemented by Bibracte, and presented in the project's final documentation.

Future developments

The sustainability and future development prospects of the scenario and tools can be considered on two scales: that of the archaeological site itself on Mount Beuvray, and that of the potential uses of the tools developed outside this pilot site.

At the Mount Beuvray Archaeological Site

The presence of an existing geolocation-based visitor tool, La Boussole, whose content is managed by Bibracte via a CMS, is both an asset and a challenge. It allows Bibracte to contribute valuable expertise in the development of tools and scenario design, but also raises the question of how and when to replace the existing system with the one developed as part of EUreka3D-XR.

The AR Tour Builder and AR Tour Experience tools offer significant technological advantages:

- Direct and easy integration of multimedia content (videos, audio and web resources subject to network coverage);
- Visualisation of 3D models in augmented reality;
- Easy to use.

However, other features are essential before considering its deployment:

- Allow users to choose between several map backgrounds (topographic or historical map, Lidar, aerial view);
- Allow the display of specific pictograms for ongoing excavation-sites and services available on the site (museum, restaurant, car parks, shuttle bus), with management of periods, days and opening hours in AR Tour Builder;
- Provide an intuitive graphical interface and a smooth user experience;

- Be available on the main operating systems, including iOS, in addition to Android.

Above all, the guarantee of corrective and upgradeable maintenance over the long term, as well as accessible technical support when needed, are essential conditions for considering any effective deployment to the public.

On the outskirts of Bibracte

One of the major advantages of AR Tour Builder is its ability to create tour itineraries covering several geographical areas. One of the first identified use cases is the archaeological site of the sources of the Yonne, located in the immediate vicinity of Mont Beuvray, in the commune of Glux-en-Glenne. More broadly, the application offers significant strategic potential for promoting the entire Grand Site de France 'Bibracte – Morvan des Sommets' area, which encompasses twelve municipalities around Mont Beuvray.

This area has a dense network of footpaths and a particularly rich rural heritage, which is evident both in the landscape and in the villages, through a wide variety of architectural and vernacular features: churches, castles, mills, wash houses, dry stone walls, etc. This tangible heritage is complemented by an equally valuable intangible repertoire: stories, music, dances and oral traditions have been better preserved here than in many other regions.

The AR Tour Builder and AR Tour Experience tools could thus contribute to the emergence of new mediation circuits rooted in this heritage diversity, by mobilising local actors around participatory projects. It is important to note that the implementation of such projects would be the responsibility of a different team from the one in charge of archaeological mediation at the Bibracte site and museum. This distinction would allow the two initiatives to run in parallel, according to their own schedules, without creating competition or delays between the two projects.

2.4.3. THE CREATION OF A NEW LIFE OF SAINT NEOPHYTOS' ENKLEISTRA IN CYPRUS IN THE VIRTUAL SPACE

The hermitage of St. Neophytos, known as his *Enkleistra*, meaning in Greek "place of seclusion", is a small but extremely significant Byzantine monument associated with the Monastery of St. Neophytos in Tala, Cyprus. It is a cave located by St. Neophytos in 1159 and the place where he spent the rest of his life. The monument consists of three interconnected caves, hand-cut into a sheer limestone cliff face over a period of four decades by St. Neophytos, also known as Neophytos of Cyprus and Neophytos the Recluse. With a total length of ~12m and depth of ~3m, the caves are decorated with exquisite 12th century Byzantine frescoes (and some later) comparable to the UNESCO World Heritage Site listed Painted Churches of the Troodos Mountains. The monument contains the bed, desk and tomb of the saint in the cell, his private chamber, all carved in the cliff. The altar, which is in the middle room that is the sanctuary, is carved in the same way. The third room is the nave and it includes the iconostasis and a wooden cross that formally held a relic of the True Cross, making it particularly significant to the faithful.

The site has been designated as a 'monument at risk' for four main factors:

1. Increased ambient moisture content due to climate change affecting the structural stability of the frescoes and pigmentation;
2. The entire monument (and cliff) is subject to erosion and seismic activity and moving;
3. The continuing drought conditions that have occurred in Cyprus over the past few years;
4. The site has a significant number of tourists/pilgrims posing a real threat of damage (accidental or otherwise) to the interior of the caves due to the confined space.

The site has poor accessibility requiring the climbing of steps to access the caves, narrow doors and confined spaces making it particularly inaccessible to those with mobility issues.

The pilot seeks to provide an alternative to the physical experience of visiting the *Enkleistra* should it be necessary to close the monument to the public for repairs, conservation, protection or safety, and to provide access to those who may not be able to physically access the space due to distance or physical constraints.

The vision of the pilot is to produce a faithful digital representation of the *Enkleistra* based on previous and ongoing research to allow the primary stakeholder, the Monastery of St. Neophytos, to tell the story of the saint's life and times through his digital 'avatar', who will appear in 3D and explain his story to the visitor. The stakeholder has also expressed the need to highlight the values expounded by St. Neophytos in his writings, which they consider to include important and relevant messages to the present day. Two versions of the scenario are envisioned, one a MR version on-site and the other, a purely virtual experience suitable for distribution to schools.

The MR use case addresses the need to expose the meaning, symbolism and importance of the frescoes. Due to the smallness and configuration of the space, this is not possible with traditional methods such as information signs.

In the second scenario, based on VR, the user can be potentially anywhere. Through the use of a headset, the *Enkleistra* will be able to be explored in full stereo vision in real time.

The scenario seeks to inform the visitor about the history of the site, the challenges it faces and how technology is being used to monitor, protect and preserve cultural heritage in a novel approach to the circular economy, drawing on the saint's meditations on life applied to the modern world and on the practical application of science and technology to the problems of environmental change and sustainable tourism.

Fig. 36. The Hermitage (*enkleistra*) of Saint Neophytos. UNESCO and ERA Chairs on Digital Cultural Heritage - Digital Heritage Research Lab Cyprus University of Technology

Fig. 37. Frescoes at the Hermitage (*enkleistra*) of Saint Neophytos. UNESCO and ERA Chairs on Digital Cultural Heritage - Digital Heritage Research Lab Cyprus University of Technology

Target audiences / stakeholders

While the Avatar Builder and the use case of the St. Neophytos avatar are of interest to any CHI, who wants to explore this form of user engagement and storytelling, the primary stakeholder for the pilot scenario in Cyprus is the Monastery of St. Neophytos, and the main target audiences that are addressed with the XR experience are:

1. Cultural and religious tourists on-site
2. School children aged 13+

The scenario is intended to address the following issues facing those audiences

- Physical access to the *Enkleistra* (virtual implementation)
- Heightened engagement with visitors
- Visitor language localisation
- Access to monument information that cannot be displayed on-site.

Content used in the scenario

Resources that will be used/are available to the scenario include

- 2150 images of the three main rooms (sequenced for photogrammetry)
- Terrestrial Laser Scanning of the three main rooms
- Spherical maps from the Terrestrial Laser Scanning
- Historical documentation on the life and times of the saint: the biography of St. Neophytos as written by him and relevant literature regarding both his autobiography and the frescoes of the *Enkleistra*
- St. Neophytos is studied and used in the pilot scenario, also accompanied with a report
- Recording of part of the liturgy of St. Neophytos: September 28th marks the discovery of the saint's holy relics in 1750. On that day there is a special service taking place at the Monastery, which was recorded in audio/video and used in the pilot's documentation.

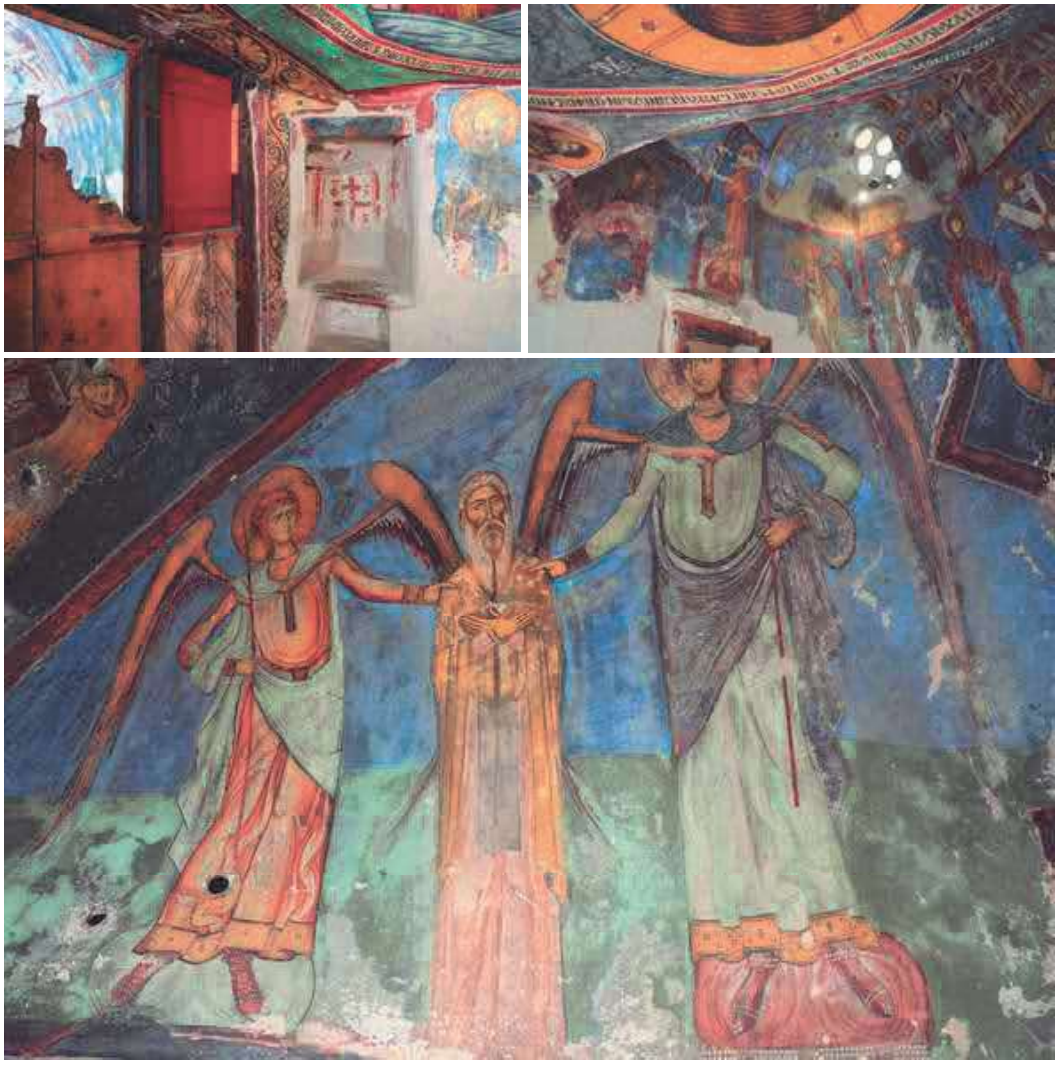

Fig. 38. Frescoes at the Hermitage (*enkleistra*) of Saint Neophytos. UNESCO and ERA Chairs on Digital Cultural Heritage - Digital Heritage Research Lab Cyprus University of Technology

Narrative and storyboard

The scenario narrative is based on the concept of the visitor being guided around the space (real or virtual) by a digital representation ('avatar') of the saint himself. During the visit the avatar will explain aspects of the space in which he lived, the values of Orthodoxy that he taught, the symbolisms of the frescoes and walk the visitor through time and space. The premise is that the saint has returned to the world after an absence of some 800 years (his death being around 1214) and can comment on the changes to the monument from the time he was alive. It is hoped that by using this concept

the following points can be introduced through speech to the visitor (this is not a definitive list)

- The construction of the *Enkleistra*
- The decoration of the *Enkleistra*
- How the monastery came to be
- The changes observable since his death highlighting the monument at risk

The encounter with the avatar will start once the visitor enters the space with the saint stepping out of the frescoes, inviting him to listen to his story and guide him throughout the space. The visitor may be able to preselect their language of preference for the avatars dialogue generated from a predefined corpus of material through generative AI.

There is the potential for non-linear/branching narrative though generative AI, however this will need to be carefully considered and sensitive to the stakeholders wishes. By necessity the on-site experience will not be exhaustive but supplemented by the VR implementation, which has more scope for interactive narrative.

Here the premise of the saint returning to the present day helps to restrict the potential for inaccurate or inappropriate answers. Simply put, the saint only 'knows' what has happened up until his death allowing predefined questions to be posed, or even appealing to the visitor to 'find out what has happened' since his passing, providing the opportunity for the interested visitor to explore further.

Interaction with end users

On-site using the application tool

This interactive experience is designed to support both VR and MR, utilising the same core assets, virtual elements, and user interface across both modes. The character and Graphical User Interface (GUI) will be reused, ensuring consistency and efficiency in development. The difference between the two experiences lies in the environment: in VR, the user is fully immersed in a virtual world, while in MR, the user remains in their real physical surroundings,

with the virtual character integrated into the real environment through the *MetaQuest 3*[17] headset.

The section below provides an overview of the scenario within the AR/VR setup, highlighting key elements of user interaction. It outlines how users could engage with the virtual environment.

Scene Setting (VR/AR)

Visitors wear the Meta Quest 3 headset inside the actual *Enkleistra* cave. As they look around, monastic chants echo faintly in the background.

- **St. Neophytos fades into view**, he pauses and looks toward the user.
- **Dialogue Choices (interactive)**:
  - **UI Elements**: Could be a choice of different situations such as: 'My Life in Seclusion' –Neophytos describes his decision to become a recluse; 'Why I Wrote'– He explains his texts and theological motivations; 'The Spirit of the *Enkleistra*' –A guided spiritual reflection on monastic life.
  - **Dynamic Responses** (Example: 'My Life in Seclusion')
  - **Audio (St. Neophytos speaks)**: *"Dear visitors, thank you for traveling from near and far to visit my Enkleistra. It is my pleasure to navigate with you throughout this hallowed place and introduce you to my life here, the frescoes that decorate the walls of this cave and their symbolisms."*
- **Saint's Departure (end of the experience)**: St. Neophytos stands, fades out.
- **Final Words (subtitle overlay)**: *"I hope your visit here has been enjoyable and rewarding, and one that has opened a window for you into Orthodoxy, the Byzantine Cyprus of my time, and its legacy to the world."*

Duration of the experience

The experience lasts a couple of minutes, a target session length is set based on physical comfort (headset). To prevent long animated sequences that demand significant computational resources, the

17 Meta Platforms, Inc. MetaQuest 3Technical specification https://www.meta.com/quest/quest-3/

experience is divided into separate modules or scenes. This also offers users greater flexibility to navigate between scenes.

Fig. 39. Mixed Reality experience with headset featuring St. Neophytos

This image illustrates how users interact with a 3D animated representation of St. Neophytos, integrated into the real-world environment of the *Enkleistra* through passthrough-enabled MR technology. Developed in Unity for Android-based devices (e.g., Meta Quest 3), the experience supports live interaction and includes an interactive user interface allowing participants to control dialogues and actions within the immersive storytelling scenario.

Workflow of the curator

The Avatar Builder workflow developed within the EUreka3D-XR project provides a structured yet flexible pathway for curators and Cultural Heritage professionals to create and adapt animated virtual human characters for immersive storytelling. The workflow is specifically designed to be accessible to non-technical users and promotes reusability of assets through clear guidelines, modular datasets, and standardised formats.

The process (depicted in Figure 40) begins with the curator accessing a set of open-source tools, predefined datasets, and documentation, which will be made available via a dedicated GitHub

repository, the EUreka3D Data Hub, and the common European data space for cultural heritage. These resources include:

- Predefined rigged 3D character models in GLB and FBX[18] formats,
- Animation clips (e.g., idle, walking, speaking) that can be reused or retargeted,
- Voice tracks generated from historical texts and synchronised with facial and body animation,
- Clear guidelines for adapting characters to different historical contexts or narratives.

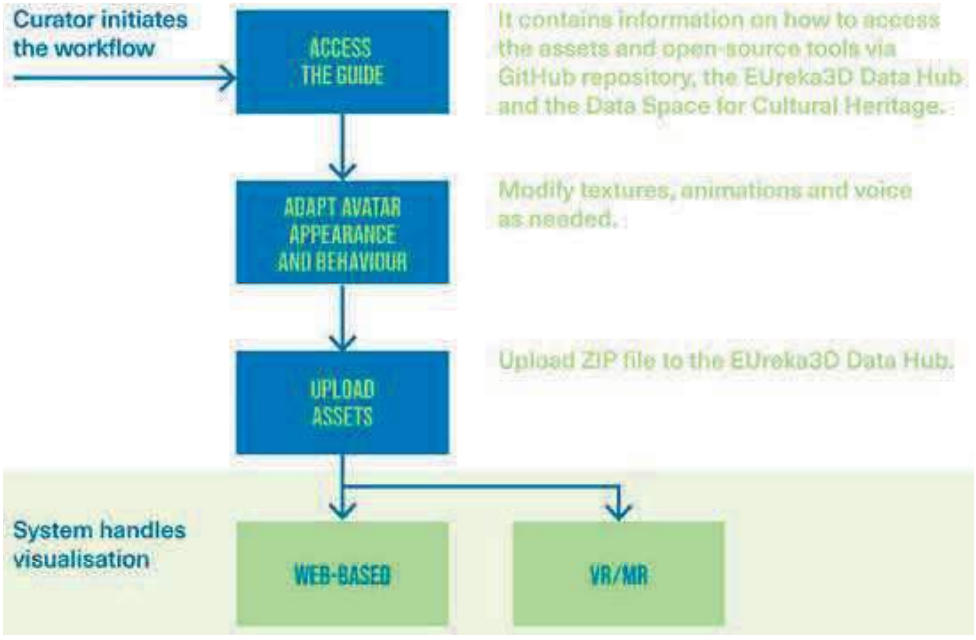

Fig. 40. Workflow of the curator using the Avatar Builder Workflow developed by MIRALab in the EUreka3D-XR project.

Using these materials, the curator can select a base avatar and adapt its appearance, behaviour, and narrative alignment to suit the intended story or cultural context. This may involve replacing textures (e.g. clothing styles), choosing or reordering existing animation clips, or uploading new voice tracks that correspond to the specific content being presented.

These adaptations can be made without requiring advanced technical skills, thanks to the accompanying step-by-step guide, which explains how to work with the predefined assets using

18 Autodesk Inc https://www.autodesk.com/products/fbx/overview

open-source tools such as Blender[19] (for visual editing) and basic file management tools (for organising assets).

Once the character is customised, the curator can upload the final assets, typically packaged as a ZIP file containing the model, animation, and audio, to the EUreka3D Data Hub. From there, the character can be visualised using the web-based 3D viewer, which supports synchronised playback of animated 3D avatars with accompanying audio. This step enables previewing and validating the avatar directly in a browser, and makes the content suitable for publication on Europeana, following the required metadata and licensing standards.

Finally, the curated avatar package can also be exported for deployment in immersive environments, such as MR or VR headsets (e.g., Meta Quest 3). The workflow supports standard export formats like FBX and GLB, ensuring compatibility with widely used engines such as Unity and Unreal, making it easy to integrate the curated avatar into on-site installations, virtual exhibitions, or educational XR experiences.

This workflow empowers curators to actively participate in the creation of engaging, culturally contextualised digital characters, extending their role beyond content selection into interactive narrative design, while still operating within a user-friendly, non-technical environment.

The diagram illustrates how curators engage with the process of creating and adapting animated virtual human avatars. Starting with a guide that links to tools, datasets, and examples, the curator customises the avatar's appearance and behaviour. Once the assets are prepared, they are uploaded to the EUreka3D Data Hub. The system then handles visualisation, enabling publication across both web-based platforms and VR/MR environments.

Challenges

Throughout the development process, several challenges were encountered, including balancing feature complexity with ease of use, addressing performance constraints, and ensuring

19 Blender Foundation Blender Studio https://www.blender.org/

compatibility across devices. To respond to these challenges, iterative evaluation and assessment activities were conducted at multiple stages of development, incorporating user feedback, usability testing, and design reviews by internal teams and with external stakeholders, such as the experts of the EUreka3D-XR Advisory Board and participants in the project's events, such as the Brussels Capacity Building event on 26 September 2025, where an early version of the VR experience was offered in a booth, at the Girona demonstration event on 29 January 2026 and in other occasions. The software was assessed against key criteria such as usability, accessibility, responsiveness, and overall functionality for the recreation, use, and reuse of the content. These evaluations informed continuous refinements, resulting in an app that is intuitive, accessible, and aligned with user needs.

The project faced interconnected technical, developmental, narrative, and research challenges in creating a virtual reality experience of the *Enkleistra* of St Neophytos. These challenges stemmed from the physical constraints of the site, the limits of current digital technologies, ethical and religious considerations, and gaps in accessible scholarly research.

Asset Development Challenges

The three caves that form the *Enkleistra* present a challenge not only for data acquisition but also for the repurposing of the dataset for use within the scenario. The spaces are irregular and densely decorated with frescoes, the lighting is poor, and the organic nature of the hand-carved wall and multiple niches provides inconsistent shadows and contrast levels. Transforming high-fidelity digitised data into a usable virtual environment confirmed the opinion that digital assets cannot be easily repurposed without compromise, requiring a careful balancing of visual authenticity with technical requirements and limitations. The virtual environment was therefore curated using theatrical and game-design techniques to guide visitors through a focused narrative experience by the avatar, rather than allowing unrestricted exploration.

VR Scene and Performance Challenges

High-resolution 3D models derived from point cloud data proved too demanding for smooth VR performance. Lowering resolution caused visual artefacts, leading to a hybrid solution combining 3D geometry with 360° panoramic imagery. While effective in conveying atmosphere and depth, this approach remains performance-intensive, highlighting the need for a purpose-built, optimised VR model.

Avatar Design Challenges

Originally, the scenario had envisioned the digitisation of one of the monastic community members to represent the saint, but the public and religious sensitivity surrounding representations of St Neophytos precluded this course of action. Historical accuracy was considered essential, requiring the avatar's appearance to be based on contemporary frescoes painted during the saint's lifetime and textual evidence describing his ascetic lifestyle. Clothing was designed to reflect humble materials and natural colours consistent with Orthodox practices of the period. The final representation was reviewed by Byzantine historians and iconography specialists to ensure historically accurate representations, improving both scholarly reliability and visual authenticity. Unexpectedly, replacing a scanned real person with an avatar based on historical depictions of the saint reduced visual dissonance and reducing the "uncanny valley" effect[20] , improving narrative coherence.

Narrative Construction Challenges

An initial plan to utilise a generative AI "ask me anything" avatar was abandoned due to risks such as long visitor engagement times, inconsistent experiences, ethical concerns, and potential misrepresentation/misinterpretation of religious teachings. A tightly scripted narrative was adopted instead, ensuring clarity, respect for religious context, and alignment with the monastery's educational mission.

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20 Mori, Masahiro, MacDorman, K., & Kageki, N. (2012). The Uncanny Valley [From the Field]. IEEE Robotics & Automation Magazine, 19(2), 98-100. https://doi.org/10.1109/mra.2012.2192811

Research Challenges

Producing valid and compelling narrative content necessitated profound research, complicated by the limitations of (and difficulty in accessing) scholarly literature. Much foundational work dates to the early-mid 20th century, with no comprehensive modern study of the *Enkleistra*'s art surpassing the 1966 Dumbarton Oaks publication[21]. Crucial progress depended on direct support from the monastery, access to private libraries, and guided site visits that contextualised historical sources within the physical landscape.

Fig. 41. Mock-up image of the VR Saint Neophytos VR experience. By MIRALab

Future developments

The development of generative AI avatars able to interactively impart knowledge to an audience in their own language will be a significant advance in cultural heritage dissemination into the educational and tourist sector. It is however not without its problems as discussed in the project report *D1.6 Ethics Issues mitigation measures*.[22]

21 Mango, C., & Hawkins, E. J. W. (1966). The Hermitage of St. Neophytos and Its Wall Paintings. Dumbarton Oaks Papers, 20, 119-206

22 https://eureka3d.eu/wp-content/uploads/2025/05/EUreka3D-XR-D1.6-Ethics-issues-mitigation-measures.pdf

Providing virtual access to heritage sites, especially those in remote areas, offers educators the opportunity to enrich their teaching portfolio and engage pupils on different levels. Logistically and financially planning a school trip to a site is an expensive commitment. Cultural heritage destinations may not be willing (or able) to accommodate large parties of students, monitor their activities or cope with associated disruption to their regular visitor baselines. Moreover concerns about health and safety and accessibility aspects within sites present challenges that CHIs may not be able to undertake, either financially or by virtue of the fact that alterations may compromise the nature of the site or monument. In both cases VR has a role to play offering a simulacra of the site that can be used to impart the essence of the place but more importantly where lessons can be taught.

The multilingual aspect holds significant potential for nations hosting large migrant communities (whether economic or social). Engaging with the culture of a host nation is one pathway to increase the assimilation process, however language may be a significant barrier to accessing information about the host culture. In the Republic of Cyprus around 20% of the population do not speak Greek as their mother tongue and about 10% of the population are migrants, with a positive net migration profile predominantly with a younger demographic.

2.5. BEYOND THE PROJECT CONSORTIUM

The EUreka3D initiative has raised the interests and the diversity of stakeholders since its inception in 2023, highlighting needs of cultural institutions challenged with the push towards 3D digitisation for which they lacked the capacity to address fully. Either constrained with budget, staff, or a lack of knowledge, smaller institutions looked at the EUreka3D Data Hub as a solution for managing and sharing their 3D assets, while the training and capacity building action of the project provided opportunities for upgrading their competences in 3D digitisation.