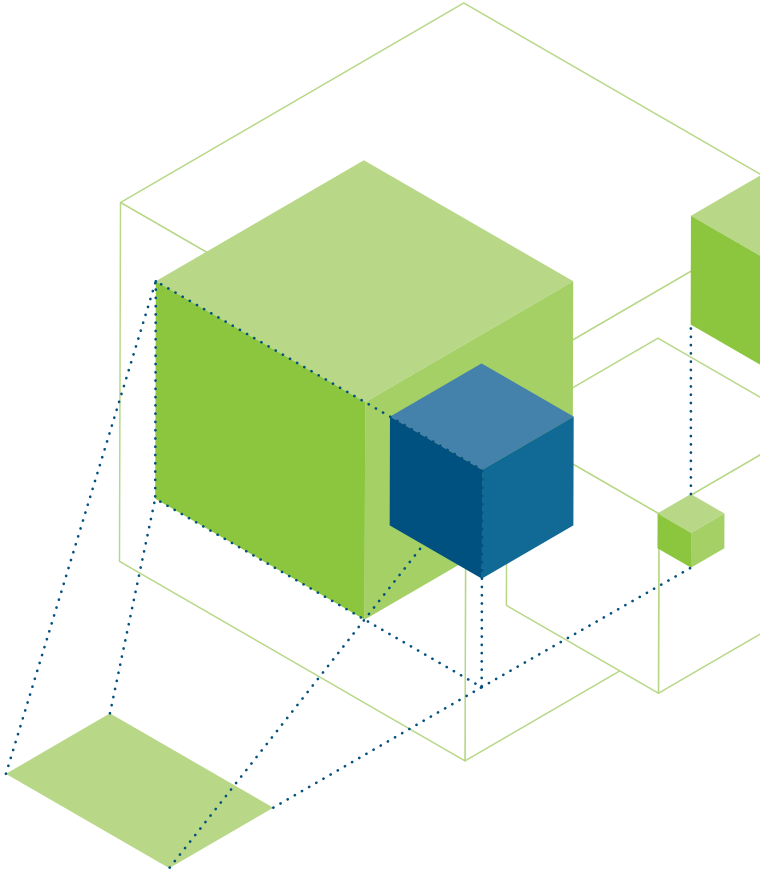
# EUreka3D-XR

## 3D AND XR IN EUROPEAN DIGITAL CULTURAL HERITAGE



EUREKA3D XR

European Union's REKonstructed content in 3D to produce XR experiences

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Co-funded by
the European Union

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# Foreword

On the 10th of November 2021, the European Commission (EC) published the *Commission Recommendation (EU) 2021/1970 on a common European data space for cultural heritage*[1], intended to accelerate the digitisation of cultural heritage assets, including monuments, sites and artefacts. Digitisation is intended as a means with a twofold objective: 1) Digitisation should help to preserve heritage at risk of degradation for the benefit of future generations. 2) Digitisation should foster the reuse of European cultural heritage –particularly in the domains of education, sustainable tourism and targeting cultural and creative enterprises. In this endeavour, Cultural Heritage Institutions (CHIs) were specifically called to explore and adopt 3D technologies as a priority in their transition path to digitalisation.

Europeana, the European digital cultural heritage platform, is at the centre of this transformation process and forms the foundation of the common European data space for cultural heritage.

The 3D digitisation of cultural heritage resources presents multiple challenges to CHIs of all sizes, particularly in smaller institutions.

The first challenge is the quality of data, metadata and paradata. The quality of data deals with the properties of the digital representation. The quality of metadata plays a fundamental role in extending the geometrical features of heritage objects to the more sophisticated concept of memory twins, where data are complemented by holistic documentation. Finally, the quality of paradata should provide a comprehensive description of the process and the technical actions taken by CHIs in their digitisation endeavour. All three are needed if the authenticity and digital provenance for reuse is to be

1 Commission Recommendation (EU) 2021/1970 of 10 November 2021 on a common European data space for cultural heritage http://data.europa.eu/eli/reco/2021/1970/oj

realised, allowing the capitalisation of cultural heritage content as an intellectual, economic and social resource, promoting Europe and European values.

The second challenge is the provision of a digital infrastructure where digital collections can be stored and processed safely. Such infrastructure must be robust and based on a European cloud, preventing the risk of losing control of precious, high-quality information generated during digitisation. It must be interoperable with other platforms and accessible to both professionals and general audiences alike, maximising the potential for the reuse of cultural content and projects.

As the European adventure into 3D digitisation progresses, our next milestone as a community is to demonstrate the benefit of digitisation, showing how 3D cultural heritage content can be used to create compelling and engaging experiences through concrete scenarios.

The EUreka3D initiative contributes to Europeana and to the common data space for cultural heritage through two projects co-funded under the Digital Europe Programme of the EC. The first project, named EUreka3D, ran from January 2023 until December 2024, successfully establishing a platform of guidelines, recommendations and digital infrastructure services. The second project, named EUreka3D-XR, ran from February 2025 until July 2026, experimenting with the reuse of 3D cultural content through extended reality (XR) experiences.

The EUreka3D-XR project is the author of this publication, which describes a set of innovative tools implemented to create three extended reality experience scenarios based on the reuse of existing digital cultural collections. The first scenario utilises the findings and collections of the Girona Municipal Archive, Catalonia, Spain, to reconstruct the missing portions of the city's historical walls, employing AI technologies. The second scenario maps points of interest for the archaeological centre of Bibracte, France, offering an enriched AR experience for visitors. This experience places 3D representations of museum artefacts and virtual reconstructions of lost buildings back into the landscape context. The third scenario mixes the 3D digitisation of the historic

hermitage (*Enkleistra*) of St Neophytos in Paphos, Cyprus, and its Byzantine frescoes together with historical documents, to deliver a range of virtual reality (VR) experiences that make it possible for the visitor to interact with a virtual avatar of the saint and listen to the story of his life in the *Enkleistra*.

We wish you a fruitful reading!

# 1. Introduction

The success of digitisation in Cultural Heritage is dependent on three main factors: competence, quality, and infrastructure. All three are strongly interrelated and urgently required if the European cultural heritage sector is to provide a meaningful response to the 2021 EC Recommendation to promote and accelerate cultural heritage digitisation. The objectives of the Recommendation are very ambitious: "to digitise by 2030 all monuments and sites that are at risk of degradation and half of those highly frequented by tourists." The Recommendation aims to foster the use and reuse of cultural collections, unlocking their full potential for societal, cultural and economic growth by diverse stakeholders. The Recommendation also endorses the common European data space for cultural heritage, the European Union's new flagship initiative, based on the Europeana ecosystem and platform, which aims to make cultural data, services, and tools openly available, interoperable, and fully accessible for reuse across multiple sectors within Europe.

The pace of 3D digitisation within Europe must be accelerated if this challenge is to be achieved, especially within smaller CHIs. 3D digitisation is a complex task that requires common shared competences, standards, methods, and tools to be developed and promoted, ensuring both high-quality digital asset creation and avoiding wasted effort and investment in creating poor-quality or unsustainable collections, which may become outdated and unusable within a few years. Additionally, to enable cultural institutions to store, share and provide their 3D data for reuse, a robust digital infrastructure is needed, ensuring cultural content produced by European institutions remains in Europe, is open, is accessible and secure, and that CHIs of any size and digital literacy level have appropriate resources and tools to engage with audiences and stakeholders.

The EUreka3D initiative started with the co-funded project EUreka3D (2023-2024) and continues with EUreka3D-XR, providing answers to these points. EUreka3D contributes to the current digital transformation of the Cultural Heritage domain with a range of competences, resources, tools, and services available for immediate use and tested in real-life environments.

EUreka3D-XR –European Union's REKonstructed content in 3D to produce XR experiences (2025-2026)– is co-funded by the European Union to continue the work of the EUreka3D project in support of CHIs that want to innovate the way they approach 3D digitisation, access, storage, sharing and re-use in compelling and engaging narratives. The main research area in EUreka3D-XR focuses on inspiring others to experiment with new and emerging extended reality technologies, transforming and enriching the corpus of online and open-access digital cultural content into new scenario-based experiences and delivering these to the common European data space for cultural heritage.

Specifically, the project has provided a set of tools for creating XR experiences with cultural content, deployed in real-world scenarios in France, Spain and Cyprus, as concrete evidence for CHIs to learn and adapt to their own unique needs. The project also offered a capacity-building and knowledge-sharing programme, including demonstrations and hands-on experiments in the use of the tools and the technical infrastructure, which reached hundreds of interested stakeholders from multiple countries globally. This commitment to support and enhance European CHIs continues beyond the project as part of the wider EUreka3D Competence Centre initiative.

## The EUreka3D Data Hub

One of the most significant achievements of the EUreka3D initiative is the provision of a fully functional, production-grade information system that serves as a virtual data space for CHIs. The EUreka3D Data Hub, developed by partner EGI with Cyfronet and WCSS, provides a comprehensive solution for CHIs involved in 3D digitisation, combined with a direct gateway to the common European data space for cultural heritage. The platform offers a suite of services and resources for management and sharing of cultural 3D assets over a European

cloud for data, metadata and paradata storage, and delivering 3D collections to aggregation platforms like Europeana. The EUreka3D Data Hub provides a framework for CHIs of all sizes to prepare their content for compatibility and ingestion into Europeana. The dataset publication process to Europeana is ensured as an integrated service by the coordinator of the EUreka3D initiative, an accredited aggregator for Europeana and partner in the common European data space for cultural heritage, PHOTOCONSORTIUM.

The EUreka3D Data Hub not only provides storage for different 3D assets but also metadata management, sharing, publication, and security to protect the data from unauthorised access. The EUreka3D Data Hub has been fully operational since 2023 and serves multiple purposes:

- It offers a solution for small CHIs that cannot afford to manage their own servers or storage.
- It contributes to the transformation of Cultural Heritage, enabling CHIs to use cloud storage and manage their assets.
- It offers a European, research-orientated alternative to commercial products.
- It serves as an enabler for the publication of cultural heritage objects in Europeana.

Over the EUreka3D-XR project, the functionalities of the EUreka3D Data Hub and its underlying cloud infrastructure have been expanded to accommodate access to the *EUreka3D-XR Toolbox*, a suite of tools developed through the project to support the creation of extended reality experiences. This includes the requirements of advanced 3D collections: a new viewer for the visualisation of animated digital assets, the inclusion of audio, and the accommodation of extended metadata and paradata profiles in the common European data space for cultural heritage for the representation of 3D objects.

## The EUreka3D-XR Toolbox

Five tools comprise the EUreka3D-XR toolbox, namely:

- **AR Tour Builder**: A web application for specifying AR tours by associating cultural heritage objects stored in online

repositories, including 3D objects, with locations on a map (developed by NTUA)
- **AR Tour Experience**: A mobile app that allows visitors to experience AR tours by visualising 3D digital objects within the physical environment and access several types of information associated with certain locations (developed by NTUA)
- **AI 3D Builder**: A 3D Modelling software pipeline that uses AI and digital photo archives (developed by Swing:It)
- **3D XR Studio**: A web tool for creating AR experiences, using a range of predefined layouts for UX and UI (developed by Swing:It)
- **Avatar Builder**: A framework that guides users in creating, animating, and preparing interactive avatars for multiple visualisation platforms (developed by MIRALab)

While each tool is tested in a specific pilot scenario within the project lifetime, all tools are designed in a generic way allowing reuse across various application scenarios. The functionality of the tools offered within the EUreka3D-XR toolbox have been co-designed through the collaboration between technical partners and partners from the Cultural Heritage sector, taking the needs of the pilot scenarios as the starting point. The tools were developed iteratively based on the outcome of testing and feedback collection, which, among other, includes advice from the EUreka3D-XR Advisory Board of experts.

## The EUreka3D-XR demonstration scenarios

The tools are tested and demonstrated in three different contexts, offering an overview of the potential of XR in enhancing cultural and heritage content. The scenarios are intended for two main purposes: first, to offer a compelling visitor experience to target audiences on-site, that reuse digital cultural heritage items; but also to provide inspiration to other institutions and sites to replicate the experience in their own contexts.

In this light, we can consider the demonstration scenarios as use-cases for others to learn from:

- In Girona, the demonstration focuses on the virtual reconstruction of the western side of the historical walls of the city

of Girona, which were partially demolished at the beginning of the 20th century due to urban development. In this pilot action, advanced 3D modelling and Extended Reality technologies are used to digitally reconstruct them, based on a wide range of historical 2D sources, including photographs, cartography, engravings, films, and textual records preserved in archives. By combining these materials with AI-driven image-to-3D technologies, the pilot enables the creation of highly realistic 3D models of the demolished walls, towers, and bastions. These models are then integrated into immersive XR experiences that allow users to explore the reconstructed walls directly on-site, reconnecting the present-day city with its historical past.

- The scenario *The Hidden Side of Bibracte* offers an immersive augmented-reality visit of the archaeological site of Bibracte, the former Gallic capital of the 1st century BCE. The users are visitors to the archaeological site (general public, families, school groups, archaeology enthusiasts), especially those who explore the site without a guide and without visiting the museum. The user moves freely around the site with their smartphone. As they approach points of interest (POIs), the application triggers digital content associated with each location. Visitors become active participants in their visit by choosing their own pace, exploring the proposed content, and interacting with it, visualising in augmented reality 3D models of archaeological structures (backfilled remains, reconstructions of vanished buildings, etc.) anchored in the real landscape, explained through audio presentations and complemented by images, videos, and PDF documents. In addition, users can manipulate 3D models of archaeological objects (rotation, zoom) while quizzes allow them to test their knowledge and enhance interaction within visiting groups.

- The third demonstration scenario is set inside the 12th century *Enkleistra* (cave hermitage) of St. Neophytos in Paphos, Cyprus, which consists of three spaces, all hand carved in the rock, connected between them via low passages and fully decorated with frescoes. According to the scenario, the visitors enter the *Enkleistra* from the main entrance of the nave. They are presented with a short narration placing their experience in

context, allowing them to familiarise themselves with the virtual environment and select their preferred language for interaction. Once the introductory narrative has concluded, the visitors encounter the digital representation of St. Neophytos (the virtual "avatar"), who takes up the narration from his personal perspective, as documented in his writings (biography) and the historical milieu of the era he lived. The visitors have the option to explore the virtual reconstruction of the *Enkleistra*, accompanied by the avatar of the saint, who guides them through the three caves, directing their attention to the frescoes, their specific details, interpretation and symbolism. Beyond the narration, the visitors can extract information through an interactive dialogue with the avatar based on call and response paradigm. The scenario concludes with the avatar thanking the visitor for their visit and inviting them to discover more about his life and the monastery's history at the museum.

## EUreka3D-XR Training Resources

A range of capacity-building actions supporting the development of XR tools and scenarios for participants at all levels of expertise was developed, to provide dissemination and demonstration of the benefits of 3D and XR in the Cultural Heritage community. By fostering collaboration across the Europeana ecosystem and the common European data space, these efforts significantly enhanced the project's outreach within the Cultural Heritage sector and other stakeholders. The training resources developed by the EUreka3D initiative are easily accessible and available in various formats (online documentation, webinars, on-site and hybrid collaborative sessions). These include hands-on guidelines, demonstrations, manuals, editorials and technical documentation focused on the use of the EUreka3D Data Hub and XR tools created in this project. The training resources also contained materials and learning resources on other relevant topics, including paradata, advanced metadata management, intellectual property, and online accessibility of content. The demonstration of the three showcase scenarios plays a key role in inspiring stakeholders and illustrating the full potential of the newly created XR tools.

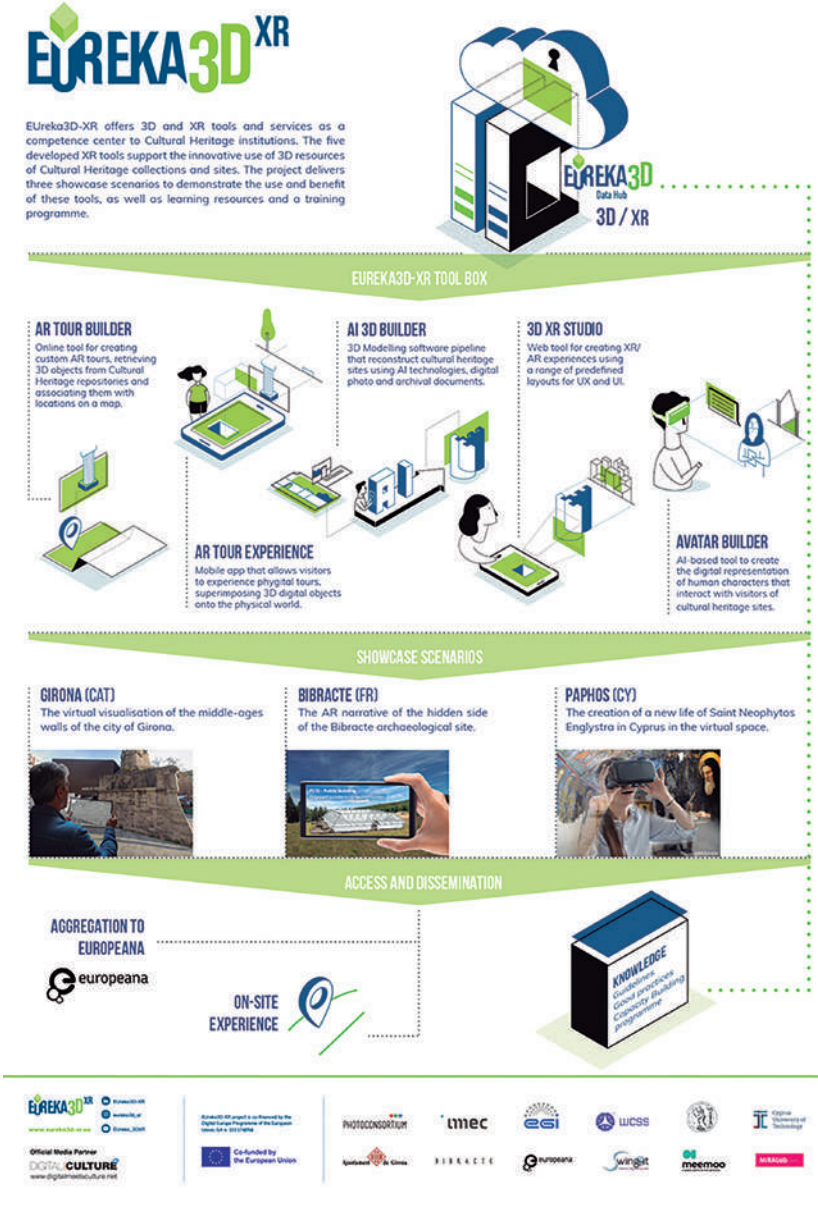



Fig. 1. Overview of EUreka3D-XR

# 2. 3D and XR for Cultural Heritage

## 2.1. THE PURSUIT OF IMMERSIVE 3D CULTURAL HERITAGE EXPERIENCES

Since the earliest stages of human history, we have shown interest in capturing, representing, and sharing our surrounding world. From prehistoric cave paintings to sculptures, paintings, photography, film, and digital media, each era has developed its own means of preserving representations of reality as perceived at the time for future generations. These representations document the world surrounding the creators and also reflect the technological capabilities, cultural values, and aesthetic choices of the time in which they were made.

As recipients of these cultural legacies, we shape our understanding of the past through interpretation, conservation, restoration practices, and the ways the past is represented. Each documentation introduces a degree of selection, abstraction, and, in many cases, idealisation. Portraits, for instance, often present a more romantic or dignified version of the subject than historical reality suggests and therefore require careful contextual interpretation.

With the advent of photography and later film, representations appeared increasingly objective and authentic. However, these technologies were also subject to aspects such as framing, resolution, lighting, and editorial decisions. The digital revolution further accelerated the ability to capture, reproduce, and disseminate cultural content at an unprecedented scale. Standardised image and video formats played a crucial role in making two-dimensional content accessible, interoperable, and suitable for long-term preservation.

The pursuit of 3D digitisation and immersive representations can be seen as a continuation of this long-standing trajectory. Rather than constituting a radical break with earlier forms of

documentation, 3D and extended reality technologies represent another step in humanity's enduring ambition to capture reality more completely. At the same time, these new technologies introduce new challenges related to interpretation, authenticity, and user experience that are particularly relevant in the context of Cultural Heritage. Admittedly, we are still in the early phases of this pursuit, with many challenges yet to be uncovered and overcome. The EUreka3D-XR project ambitiously aims to fill some of these gaps by providing a centralised cloud infrastructure and a set of tools to foster the reuse of 3D digitised assets in XR environments.

## 2.2. AUTHENTICITY, METADATA AND PARADATA

Before diving into the specific tools developed in the EUreka3D-XR project, it is important to note that our focus is not on developing reusable tools alone but also on promoting best practices in creating immersive 3D cultural heritage experiences. In this context, questions of authenticity, trust, and meaningful reuse play a central role and extend beyond purely technical considerations. Ensuring that digital representations can be correctly interpreted, compared, and reused over time requires careful attention not only to the data itself but also to the information that describes, contextualises, and explains it.

As 3D and immersive representations increasingly mediate access to Cultural Heritage, authenticity can no longer be understood solely in terms of visual realism or perceptual quality. A highly detailed or visually accurate representation does not automatically guarantee that it can be reliably interpreted or meaningfully compared with alternative representations captured over time. Authenticity in this context is closely linked to transparency: understanding what a digital representation shows, what it omits, and how it was produced. This becomes particularly important when such representations act as digital twins or proxies of artefacts, sites, or collections.

Traditional metadata has played a crucial role in the management and dissemination of digital Cultural Heritage. Descriptive, administrative, and structural metadata provide essential information about the identity, provenance, ownership, format, and relationships of digital assets. Such metadata supports discovery, interoperability, and preservation, facilitating access across institutional and technical boundaries. Established metadata frameworks, including those adopted within Europeana, have significantly improved the ability to exchange and reuse cultural content. However, while metadata effectively describes what a digital object is, it is less suited to explaining how and why it came to be represented in a particular way.

To address this gap, the concept of paradata has been introduced within the Cultural Heritage community. In the London Charter,[2] paradata is defined as "information about human processes of understanding and interpretation of data objects". Examples of paradata include descriptions stored within a structured dataset of how evidence was used to interpret an artefact or a comment on methodological premises within a research publication. It is closely related, but somewhat different in emphasis, to "contextual metadata", which tends to communicate interpretations of an artefact or collection, rather than the process through which one or more artefacts were processed or interpreted.[3] In other words, paradata provides insight not only into what is represented but also into why a particular representation was produced.

In practice, paradata can encompass a wide range of information, from high-level interpretive reasoning to detailed documentation of how digital representations were produced. From a data authenticity perspective, documentation of capture strategies, acquisition conditions, and processing choices plays a particularly important role, as these decisions directly influence the resulting representation. Recording such information supports transparency,

2 Bentkowska-Kafel, A., Denard, H., & Baker., D. (Eds). (2016). Paradata and Transparency in Virtual Heritage. Routledge. https://doi.org/10.4324/9781315599366

3 Baker, D. (2024). Paradata: The Digital Prometheus. In Lecture Notes in Computer Science (pp. 12-23). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-78590-0_2

comparability, and long-term interpretability, especially when digital representations are revisited or reused in various contexts.

The relevance of transparency becomes even more pronounced in the context of 3D digitisation and immersive experiences. Three-dimensional representations frequently involve reconstruction, interpolation, or modelling steps that go beyond direct observation. Immersive experiences may further amplify interpretive choices through rendering optimisations, dynamic viewpoint manipulation, user interactions, and narrative framing. Without explicit documentation of these choices, users may be unable to distinguish between evidence-based reconstruction and presentational enhancement. Particular attention is needed when AI-based tools are used, for example, for reconstruction or rendering. While such tools might significantly increase the perceptual quality or enhance the user experience, they introduce data that is not captured by sensors but derived from context and prior knowledge. From an interoperability perspective, it is advisable that transparency and authenticity are achieved through alignment with standardised and interoperable frameworks, such as emerging initiatives like JPEG Trust (ISO/IEC 21617)[4] or C2PA (Coalition for Content Provenance and Authenticity)[5].

Recognising the importance of authenticity, metadata, and paradata, the EUreka3D-XR project approaches tool development as part of a broader methodological framework. Rather than treating metadata and paradata as afterthoughts, the project aims to integrate their capture, management, and dissemination into digitisation and publication workflows from the outset. By doing so, the project seeks to support Cultural Heritage institutions and practitioners in producing immersive 3D experiences that are not only visually engaging but also transparent, interpretable, and trustworthy over time.

4 ISO/IEC. (2025). Information technology –JPEG Trust– Part 1: Core foundation (ISO/IEC 21617-1:2025). https://www.iso.org/standard/86831.html

5 C2PA. (2022) C2PA Technical Specification. https://spec.c2pa.org/specifications/specifications/1.0/specs/C2PA_Specification.html

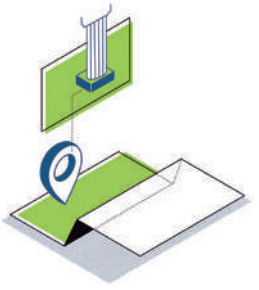
## 2.3. THE EUREKA3D-XR TOOLS

EUREKA3D-XR TOOLBOX MANUALS
https://eureka3d.eu/eureka3d-xr-toolbox/

A core action of the EUreka3D-XR project is to support CHIs in the reuse of their digital cultural content –particularly 3D content– to produce more modern and compelling storytelling, enhancing the visitor experience and engagement with cultural collections, either online or on-site. This is important not only for unlocking the potential of digital Cultural Heritage in education, entertainment and visitor engagement, but also for increasing a CHIs return on investment for digitisation by leveraging digital assets more effectively. Over the past decade or so, experimentation with XR technologies has been widely used within museums and archaeological sites to assess the potential of XR for visitor engagement. Frequently, such work has been undertaken in close collaboration with specialist creative industry partners and software houses, often with high development costs, both in terms of financing and timescales. The challenge today is to democratise access to these technologies, supporting CHIs in developing new visitor-focused narratives based on their digital collections. This approach provides CHIs the opportunity to explore these technologies in a more open way, lowering barriers to the use of tools and promoting an open-access and low-code approach that grows skills while facilitating a dialogue between cultural professionals and technology professionals.

The suite of five tools created by the EUreka3D-XR project allows CHI curators to self-create and experiment with different types of XR applications, reusing their digital collections. Each tool is openly accessible and accompanied by easy-to-understand documentation, manuals and video tutorials.

## 2.3.1. AR TOUR BUILDER



The **AR Tour Builder** is a web application that supports the design of AR tours by associating 3D objects and other types of content (e.g., images, audio, text) to specific locations on a map. The builder is intended for CH professionals and other stakeholders who wish to prepare engaging experiences for their on-site visitors. The platform offers asset management capabilities, allowing users to pin content sourced from online platforms such as Europeana, the EUreka3D Data Hub or the CHIs own repository. The user can specify multiple tours for the same geographical area, organised as individual projects (e.g., short or longer tours, tours addressed to children, etc.). Each tour consists of a set of georeferenced points of interest, each of which can be associated with a set of various media assets and contextual information. The builder supports the creation of multilingual tours, where both the content and tour-specific information can be provided in multiple languages. Tours can be accessed on-site via the companion **AR Tour Experience** mobile app, which presents the curated multimodal content based on the user's geolocation. The focus is on outdoor experiences, enabling rich engagement with cultural sites through AR overlays, images, videos, audio, and textual content.

| WHAT IS THE AR TOUR BUILDER? |
| --- |
| **AR Tour Builder** is a web-based authoring tool which allows Cultural Heritage professionals to create location-based AR tours without programming. Users of the **AR Tour Builder** can create engaging narratives by defining points of interest (POIs) on a map and attaching digital content, such as 3D models, images, audio and text. |

| WHO IS THE AR TOUR BUILDER FOR? |
| --- |
| Museums and heritage sites |
| Archives working with urban or landscape heritage |
| Educators |

| WHO IS THE AR TOUR BUILDER FOR? |
| --- |
| Tourism and local heritage stakeholders |

| KEY FEATURES |
| --- |
| Create and manage custom AR tours using a browser. |
| Define POIs for the tour on a map. |
| Attach 3D models, images, audio, video and documents to POIs. |
| Additional multilingual content support. |
| Preview tours before deployment. |
| A visitor-facing AR Tour Experience app, designed to serve tours on-site. |

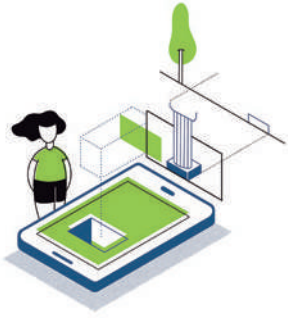
| OUTPUT |
| --- |
| A complete AR tour package ready to be experienced by visitors on-site via the **AR Tour Experience** app |

## Example User Story

A regional heritage site wishes to offer visitors an AR walk of their site. Using the ***AR Tour Builder***:

1. The curator creates a new project in AR Tour Builder.
2. Points of interest are placed on the site using a map.
3. Existing 3D models and archival images are added to each POI.
4. Short texts and audio explanations are added in the desired language(s).
5. The tour can be tested internally and prepared for public use.

## 2.3.2. AR TOUR EXPERIENCE



The **AR Tour Experience** is a mobile app which serves as the on-site visitor interface for tours designed with the **AR Tour Builder** tool. Through a clean and intuitive interface, visitors can browse and select tours available based on their preferences and location. The app

uses GPS to provide real-time navigation, detecting when the visitor approaches a specified POI and prompting the user to access the curated content associated with the location (3D models, images, video, audio and text). The 3D models can be displayed either in a dedicated 3D viewer or using the device's camera overlaid on the physical environment. These AR views can be used to enhance the on-site experience, revealing hidden or missing elements at the visitor's location, such as backfilled excavations, virtual reconstructions, or artefacts currently exhibited elsewhere. The app also supports tour progression tracking and offers practical features such as pre-downloadable content for low-connectivity environments. The application is implemented for Android devices.

### WHAT IS THE AR TOUR EXPERIENCE?

**AR Tour Experience** is a mobile application that allows visitors to experience on-site AR tours created with **AR Tour Builder**.

It allows visitors to visualise 3D and other types of digital content within their physical environment, enabling immersive, guided exploration of heritage sites.

### WHO IS THE AR TOUR EXPERIENCE FOR?

- Visitors interested in exploring a location at their own pace
- Pupils, students, and other guided groups
- Site mediators and tour guides

### KEY FEATURES

- Loading of custom AR tours on a mobile device
- Designed for outdoor heritage contexts
- GPS-based activation of POIs
- View 3D models in overlay AR using the device's camera
- On-site access to images, audio and text
- Multilingual user interface
- Dynamically updated to reflect the latest edits made via the **AR Tour Builder**

### OUTPUT

An engaging, self-guided AR tour curated by the heritage site through the **AR Tour Builder**, allowing the visitor to explore the site, its locations and context on their own terms.

## Example user story

A solo tourist is visiting a heritage site. They have a mobile device with GPS enabled and wish to explore the site based on their interests and at their own pace. The visitor may have already downloaded the ***AR Tour Experience*** app and selected their desired AR tour or may do this on arrival.

1. The visitor opens the **AR Tour Experience** app and selects their desired AR tour.
2. The app starts, locating the visitor's position at the site.
3. As the visitor explores the site, they are prompted about nearby POIs.
4. Moving to a POI, the app presents relevant content to the visitor based on their preferences.
5. The visitor can choose to visualise 3D content in overlay AR mode, visualising hidden or missing elements at the location.
6. The app provides additional rich content, allowing the visitor to explore the location context more deeply.


Fig. 2. The AR Tour Experience in action in the Bibracte archaeological site

## 2.3.3. AI 3D BUILDER


The **AI 3D Builder** is designed to transform two-dimensional images into complete, usable 3D models. Its goal is to drastically reduce the time required to create 3D assets by automating a process that traditionally demands expertise in modelling, texturing, and rendering. At the heart of this pipeline lays Trellis,[6] a system based on an AI architecture that employs Structured Latents (SLAT) representation, enabling the system to capture visual characteristics and implicit spatial relationships to reconstruct 3D geometry coherently and realistically.

| WHAT IS THE AI 3D BUILDER? |
|---|
| **AI 3D Builder** is a 3D modelling pipeline that helps users create 3D models from 2D images, such as archival photographs or documentation images. |
| The tool lowers the entry barrier for creating 3D content from existing collections. |

| WHO IS THE AI 3D BUILDER FOR? |
|---|
| Cultural Heritage Professionals |
| Researchers |
| Institutions without in-house 3D infrastructure or expertise |

| KEY FEATURES |
|---|
| Upload sets of 2D images |
| AI-assisted 3D reconstruction |
| Configurable quality and processing options |
| Export to open, industry-standard binary file format for 3D models (GLB) |
| Optional refinement by advanced users |

| OUTPUT |
|---|
| A reusable 3D model in industry standard GLB/GLTF[7] format. |

6 https://microsoft.github.io/TRELLIS/

7 International Organization for Standardization. (2022). Information technology –Runtime 3D asset delivery format– Khronos glTF™ 2.0 (ISO/IEC 12113:2022) https://www.iso.org/standard/83990.html

## Example user story

A city archive has a collection of digitised images showing views of a lost building. They would like to prepare a 3D representation of the building based on the visual evidence for research and valorisation of the collection and archive.

1. Archivists select and prepare photographs (based on AI 3D Builder guidelines).
2. Images are uploaded to the AI 3D Builder image-to-3D generation model.
3. The images are processed, and the results are exported in GLB format.
4. The 3D model can be adjusted as needed in any 3D modelling application accepting GLB format files.
5. The final 3D model is exported and available for use as needed.

Fig. 3. Acquiring aerial documentation of the remains of the Girona city walls, as an optimal input to support virtual reconstruction through AI 3D Builder. July 2025. Ajuntament de Girona - CRDI

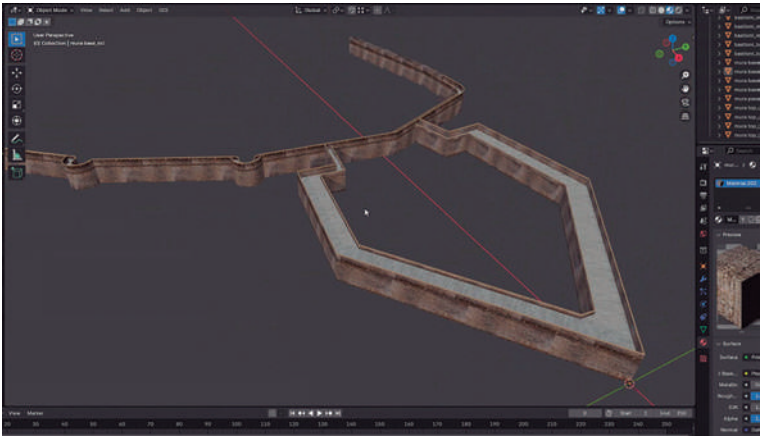


Fig. 4. Using AI 3D builder to model the bastion of Sant Francesc and the lost walls of the city of Girona

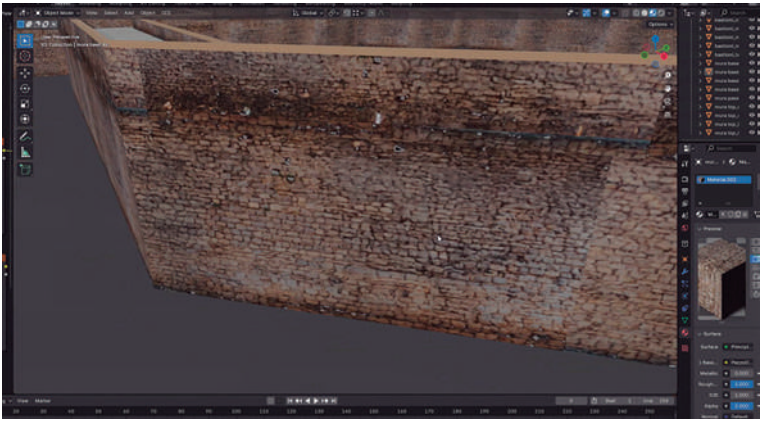
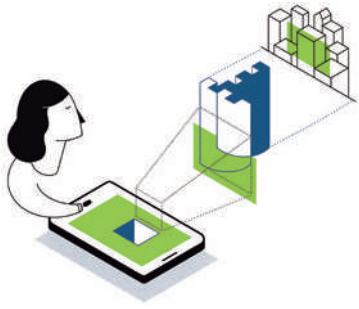


Fig. 5. Texturing (high quality) in the reconstruction model of the historical walls of Girona

## 2.3.4. 3D XR STUDIO



The **3D XR Studio** is a web-based authoring tool that allows users to create immersive experiences in XR and AR. It enables users to combine different types of multimedia content (3D models, images, videos, audio, and text) into interactive scenes, creating narrative paths and virtual environments that can be explored via mobile devices or AR/XR headsets. It is specifically designed for Cultural Heritage professionals with an intuitive, no-code interface.

The **3D XR Studio** can generate AR tours that the visitor on-site can access with their smartphone, downloading the app. In specific points of the site, the visitor finds "totems", physical references with instructions and QR codes. This allows the visitor to see the models selected and placed by the curator (potentially with rotation and scale fine tuned), see a suggested path and access the descriptions, audios and other media selected by the curator.

Except for the initial download phase, the AR tour is neither GPS not Internet based, therefore it works offline.

| WHAT IS THE 3D XR STUDIO? |
| --- |
| **3D XR Studio** is a web and mobile-based authoring environment for creating XR narratives and spatial experiences using 3D models.<br>It is designed for storytelling, education and cultural mediation. |

| WHO IS THE 3D XR STUDIO FOR? |
| --- |
| Cultural Heritage Professionals |
| Researchers |

| KEY FEATURES |
| --- |
| Place 3D models in real or virtual environments. |
| Define routes, scenes and narratives. |

| KEY FEATURES |
| --- |
| Combine maps, media and interactions. |
| Fine-tune placement on-site using mobile devices |
| Publish lightweight XR experiences. |

| OUTPUT |
| --- |
| Web-based and mobile XR experiences |

## Example user story

An archivist wishes to create a curated AR experience for a visitor to follow the route of the destroyed walls and fortifications that once surrounded the city.

1. The curator selects media to use in the scenario (3D models, video, audio, etc.).
2. The curator creates a new project in the **3D XR Studio** web app.
3. Using the provided map, the curator defines the portion of the city into which to place the 3D models.
4. The curator creates the desired route by setting a series of path points on the map.
5. The curator sets points of interest along their defined path.
6. The curator associates the selected points of interest with text, audio and video.
7. The curator defines starting points based on physical totems within the city.
8. Fine-tuning of 3D model positioning is undertaken by the curator in the field through the web app.
9. When visitors reach the physical totem, they can follow the instructions written on it in order to download the app.
10. The instructions inside the app will guide the visitors to read the QR code printed on the physical totem.
11. The app asks the visitor to place the phone next to the totem in a specific position and to wait for the initial download of the AR experience (such as 3D models and media).
12. Once the download is complete, the AR experience starts in the app of the visitors, showing 3D models, a suggested path and other media such audio or images selected by the curator (see point 1).


Fig. 6. Use of XR 3D Studio Web App for creating a touristic experience

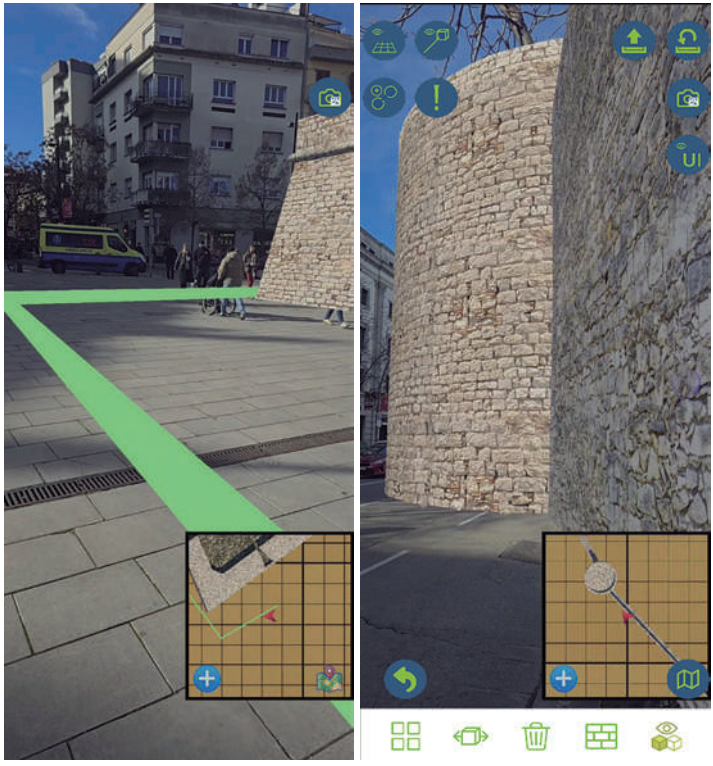


Fig. 7. Screenshots from the XR 3D Studio Mobile App for tourists (left) and curators (right)

## 2.3.5. AVATAR BUILDER

The use of virtual humans in Cultural Heritage offers significant advantages for interpretation, education, and audience engagement. By embodying historical or fictional personas, virtual humans can serve as interactive mediators bridging the gap between visitors and cultural content. To effectively support the creation and deployment of virtual humans in cultural heritage contexts, a structured and accessible production process is essential. Developing expressive and platform-compatible avatars typically requires technical expertise in 3D modelling, animation, and software integration, skills that are often beyond the reach of curators or heritage professionals. The Avatar Builder addresses this challenge providing a process framework that guides users in creating, animating, and preparing avatars for multiple visualisation platforms. By leveraging open-source, accessible software, the tool makes avatar production possible for non-experts while ensuring compatibility with immersive virtual reality/mixed reality (VR/MR) environments and web-based 3D viewers.

| WHAT IS THE AVATAR BUILDER? |
| --- |
| Avatar Builder is a **workflow and pipeline** for creating animatable **virtual characters** that can be embedded in XR experiences. |

| WHO IS THE AVATAR BUILDER FOR? |
| --- |
| Cultural Heritage Professionals |
| Creative and XR professionals |

| KEY FEATURES |
| --- |
| Create or adapt humanoid avatars |
| Animate gestures and narration |
| Combine avatars with 3D environments |
| Deploy to web-based viewers |
| Support for VR and MR pipelines |

| OUTPUT |
| --- |
| Digital avatar that can be used in multiple platforms, such as XR experiences and web-based platforms |

## Example user story

A heritage site wants to tell the story of its origin using one the main historical character.

1. A historical figure is modelled as an avatar.
2. Audio narration is recorded/created via AI.
3. The avatar is placed inside a 3D environment.
4. The experience is published via the Web Viewer.
5. Visitors can explore the experience remotely or on-site.

Fig. 8. Modelling an animated avatar to represent St. Neophytos

# 2.4. DEMONSTRATING THE TOOLS: THREE USE CASES IN EUROPE

## SUMMARY

In this section, three case studies from real life applications of the tools are presented. A brief summary is provided for each of them. In the next sub-sections 2.4.1, 2.4.2 and 2.4.3, the full case study for each pilot demonstration scenario is presented.

## 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

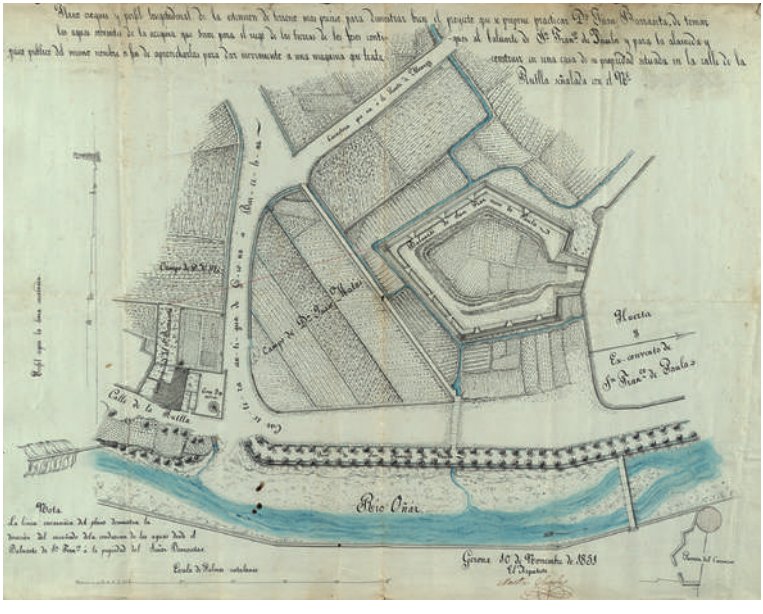



Fig. 10. Map of Sant Francesc bastion, 1851. Girona Municipal Archive

## 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

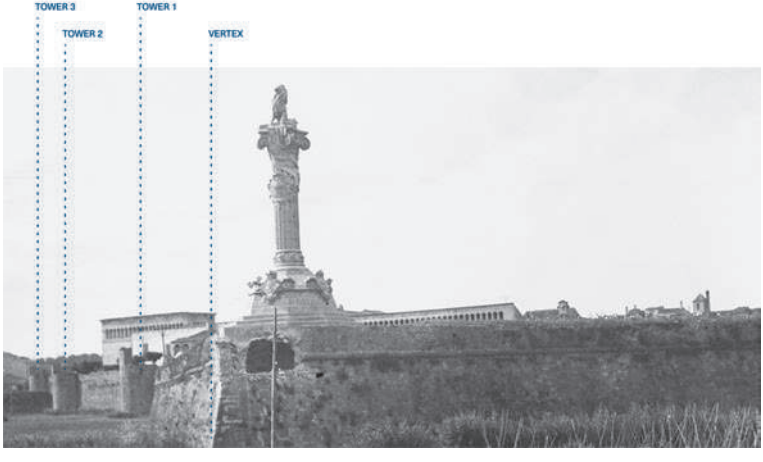



Fig. 14. Heritage photograph of the section of the wall adjacent to the bastion, with the three towers.

## 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

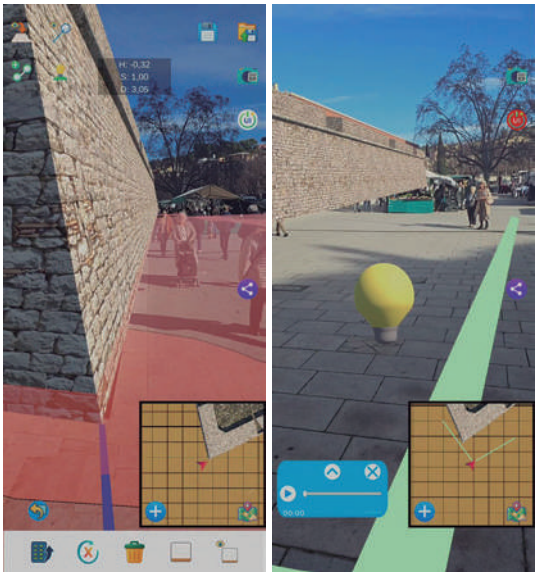


Fig. 16. Mockup for the 3D XR Studio: on the left what the curator sees when managing the 3D model of the wall (yellow indicates is selected), with tools for managing the models on the scene; on the right what the user sees when clicking on the interest point (pop-up audio)

## 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 archaeological 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.

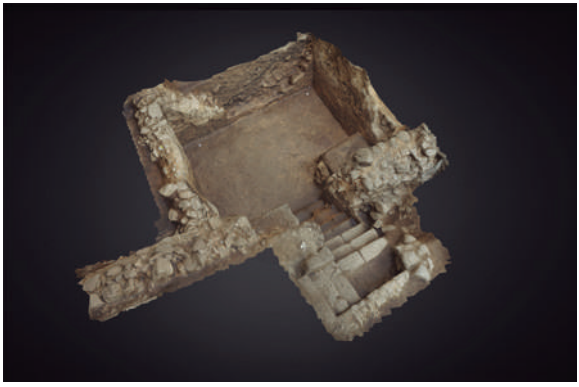


Fig. 23. 3D model of the masonry cellar of Roman house PC2

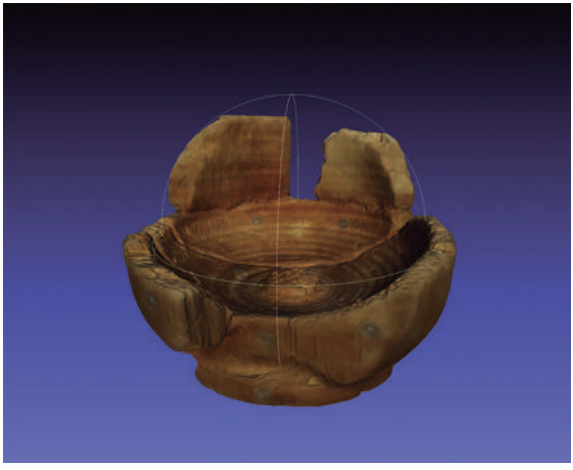


Fig. 24. 3D model of a turned maplewood bowl

## 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

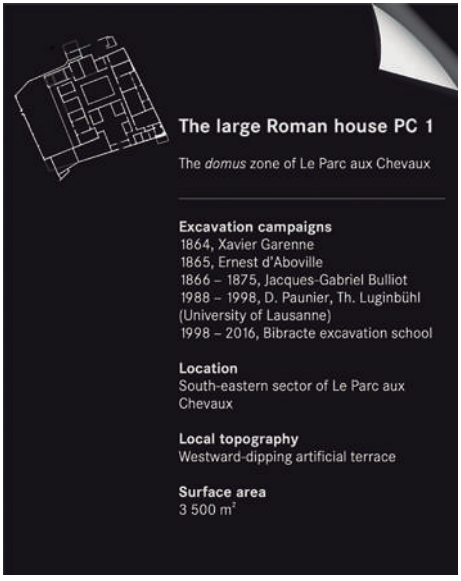



Fig. 26. Editorialised dossier on the large Roman house PC1

### 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.

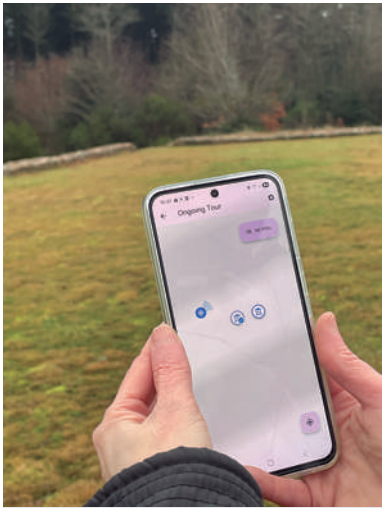


Fig. 32. Display of the map used to orient oneself on the site

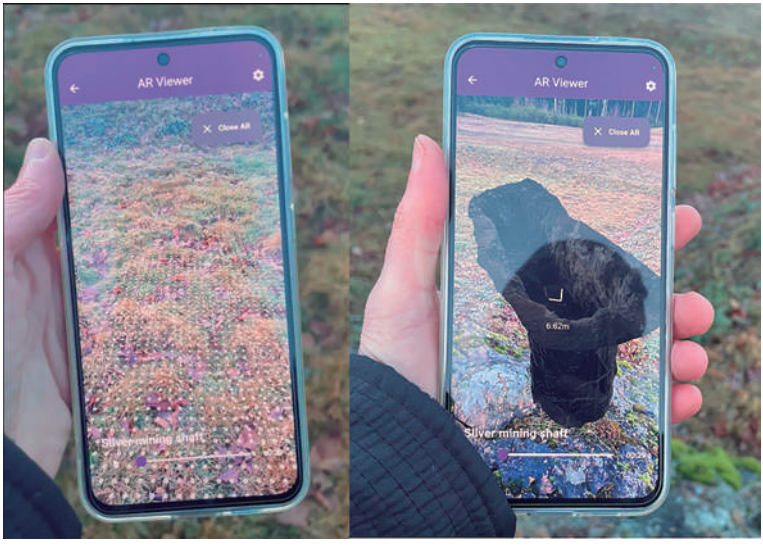



Fig. 33. Positioning of the 3D model of the mine shaft within the physical environment

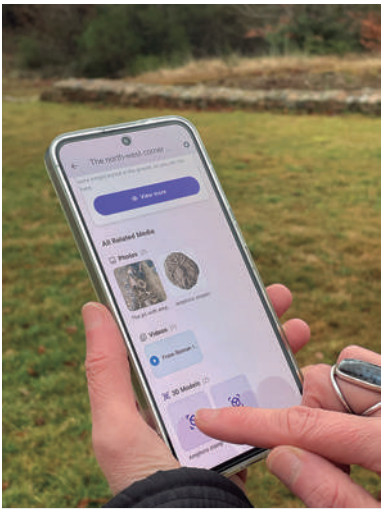


Fig. 34. Discovery and selection of complementary content within the application

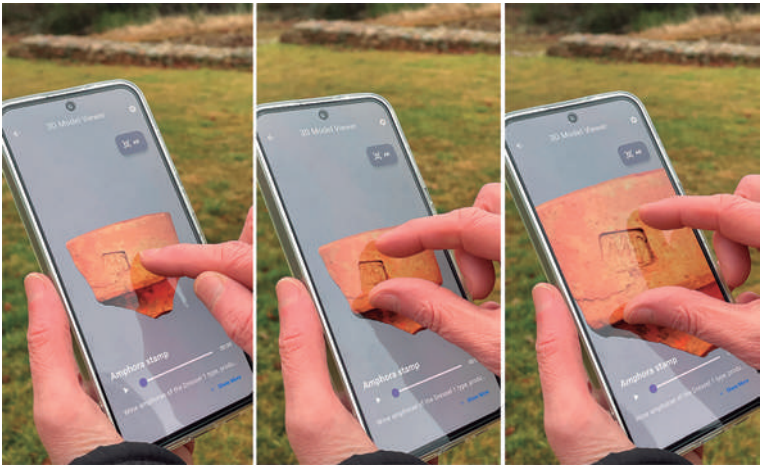



Fig. 35. Manipulation of a 3D model of an amphora stamp in the 3D viewer

## 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.

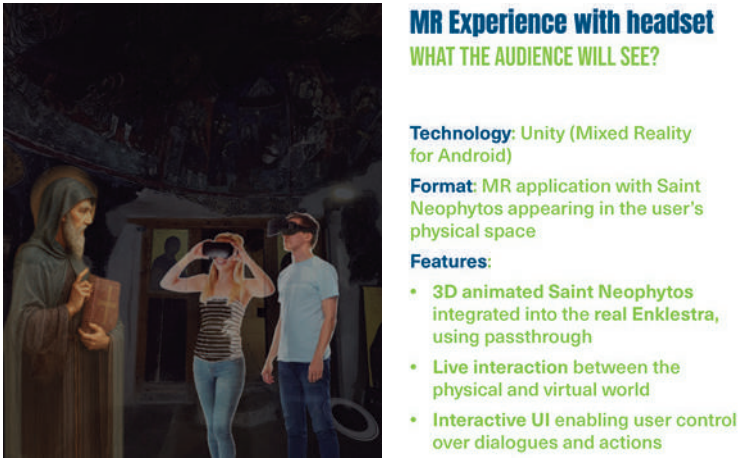



Fig. 39. Mixed Reality experience with headset featuring St. Neophytos

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.

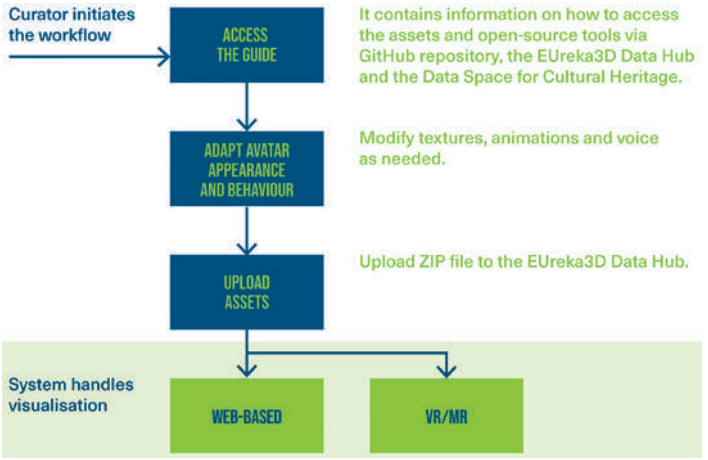



Fig. 40. Workflow of the curator using the Avatar Builder Workflow developed by MIRALab in the EUreka3D-XR project.

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.

In particular, the EUreka3D Data Hub is acknowledged as highly relevant by all stakeholder groups in the Cultural Heritage community, offering a centralised platform to institutions, of any size and capacity, to manage and share their 3D assets efficiently, without requiring advanced infrastructure or specialised skills on their end. This not only democratises access to cutting-edge technology, but also ensures that even resource-constrained entities can participate meaningfully in Europe's digital heritage ecosystem and share their data to Europeana. Since the launch of the EUreka3D Data Hub, a growing network of associated partners and interested organisations tested the platform, providing feedback that informed improvements based on users' needs. In many cases, new 3D collections have been published in Europeana, in addition to the collections provided by the project consortium.

*"We tried the platform over the past few months, and I have to say that I find it easy to use, with very low barriers. This is great because once you upload one model, it becomes simple to do the same for the rest, so you don't need much time for the data workflows. For us, this is a great opportunity to demonstrate how well-documented data and persistent identifiers can be used for multiple purposes. That's exactly the aim of this platform and what we are trying to achieve in museums. As mentioned, the data is documented under CC licenses and with the institution's name, acknowledging the people who made this dataset possible."*

Associated partner SPK Stiftung Preußischer Kulturbesitz - Staatliche Museen zu Berlin (Germany)

"*Everything is progressing very well! The management of the Basilica are very happy with the relation with EUreka3D and Europeana and we are planning creating QRs to offer the visitors the possibility of entering Europeana from the museum of the Basilica to watch the 3D models.*"

Associated partner Basílica del Pi (Catalonia, Spain)

With over 770 followers in the project newsletter up to April 2026, the EUreka3D initiative has been recognised as a primary knowledge resource for 3D by the Cultural Heritage community in Europe and beyond. A vibrant network is linked to EUreka3D-XR, comprising Cultural Heritage professionals and researchers; educators; institutions (such as archives, museums and smaller cultural

organisations); technology partners and digitisation experts; the creative industries; and other professionals and stakeholders in preservation initiatives. This network of stakeholders, built by EUreka3D, shares expertise, best practice, and standards to accelerate the 3D digital transformation, involving a knowledge base for small and big organisations alike. The efforts deployed in EUreka3D-XR to support this network include disseminating tools, learning resources and good practices for digitisation, heritage documentation, conservation and 3D modelling; sharing insights from leading professionals, partnering to support joint research or dissemination of collections; and amplifying the digitisation work of local memory institutions in the EU and neighbouring countries, breaking siloes and expanding outreach.

Continuing the effort started in EUreka3D, the current project EUreka3D-XR added a new layer to the digital transformation challenge, offering tools and resources to reuse 3D models in simple but creative XR applications. The EUreka3D-XR ecosystem thrives on cross-disciplinary collaboration where the humanities meet innovation and stakeholders can access open tools for advanced 3D management or for creation of XR/VR experiences that redefine how cultural content in 3D is experienced rather than just observed, shifting engagement with Cultural Heritage from the role of passive viewer to that of an active participant. The EUreka3D-XR case studies and XR scenarios offer a solid demonstration and inspiring examples that other institutions can replicate in their own context. The open tools proposed in the project are iteratively developed taking in the loop the requirement from potential user communities and content providers, both from consortium partners and from external users, engaged in testing and evaluation actions in the course of the project.

Beyond tools, lies another critical need addressed by EUreka3D-XR: building capacity in Cultural Heritage professionals and staff. With accessible training programs designed precisely for museums and archives staff, and by offering learning resources, competence transfer on best practices alongside hands-on sessions led by experts, all participants in the EUreka3D-XR capacity building initiatives could gain practical knowledge that they can use in their professional life, thus investing into workforce development. This

favours inclusive participation and support to digital transformation across all types and sizes of institutions across EU and beyond.

Particularly valuable in EUreka3D-XR is the role of the Advisory Board, a group of six experts in the domain of 3D digitisation, cultural heritage documentation, cultural storytelling and XR for Cultural Heritage. These professionals bring diverse expertise that helps shape project and tool development in an iterative manner, advocating for usability, scalability and strategies for fostering broader adoption of the tools across Europe's Cultural Heritage sector. Their insights, based on experience and field knowledge, ensure that EUreka3D-XR's tools address real-world needs and remain impactful beyond the project lifecycle.

## The EUreka3D-XR Advisory Board

### Dr Eleanor Fink

Expert on information policies, documentation practices and standards in Cultural Heritage organisations. She has held senior positions at the Smithsonian, J. Paul Getty Trust, the World Bank, and Museum Computer Network. She is currently leading the American Art Collaborative, a consortium of 14 museums interested in creating Linked Open Data.

### Prof. Monika Hagedorn-Saupe

Expert on museology, digitisation and museum documentation, and cultural portals. She is currently president of the German Association for Information and knowledge (DGI) and one of the German representatives in CEDCHE (Expert Group on a common European data space for cultural heritage). She is past president of ICOMs International Committee for Documentation (CIDOC).

### Prof. Isto Huvila

Researcher on digital objects documentation and paradata in the Cultural Heritage and Archaeology domains. He holds the chair in information studies at the Department of ALM (Archival Studies, Library and Information Studies and Museums and Cultural Heritage Studies) at Uppsala University.

### M. A. Dominik Lukas

Researcher on the development of databases for Social Sciences, Archaeology and Cultural Heritage at the University of Chicago. He has professional experience in archaeological fieldwork for organisations such as the German Archaeological Institute (DAI), at the Excellence Cluster Topoi (Berlin) and the Çatalhöyük Research Project at Stanford University.

### Dr Costas Papadopoulos

Researcher on 3D heritage visualisation particularly looking at digital (re)constructions for analytic and sensory studies. He is the PI of PURE3D: An Infrastructure for the Publication and Preservation of 3D Scholarship and Coordinator of the newly-founded lab: 'The Plant: Playground and Laboratory for New Technologies' at Maastricht University.

### Xavier Adraste

Project manager specialised in designing and deploying XR experiences for archaeological sites in France. Since becoming self-employed in 2021, he has been actively researching and experimenting with no-code technologies to foster digital mediation and cultural innovation, documenting this work through live sessions on his blog & YouTube.

The experts were engaged in presentation sessions and focus groups to collect their feedback and guidance, together with project partners and other user representatives. Advisory Board members provided strategic advice, tested the project prototypes, and offered valuable insights into challenges in the Cultural Heritage domain. As the main challenge, the Advisory Board members stressed the importance of systematic feedback from end users, i.e. not only from project partners and advisors. A recurring concern emerged, that EUreka3D-XR set to acknowledge, namely how to empower non-IT expert Cultural Heritage staff to use the tools, and not be scared by them: the project has addressed this with clear, step-by-step documentation in accessible language; practical tutorials and screencasts that walk through complete workflows rather than on isolated features; on-site and online workshops targeted at curators, archivists, and educators; and finally realistic guidance to cultural institutions (especially the smaller ones) about the required skills, time, and resources needed to operate the tools.

# 3. The EUreka3D Competence Centre

## 3.1. THE EUREKA3D DATA HUB


The trends of digital transformation for Cultural Heritage in Europe push towards a growing implementation of high quality 3D digitisation efforts, with the scope of preserving heritage collections and sharing them for use and reuse by different stakeholders, with a particular focus on empowering participation in the common European data space for cultural heritage.

To achieve this, CHIs need technical solutions to enable their collections to transit to the digital realm and then be offered to users. Specifically, CHIs of any size and capacity are facing various challenges:

- First, to generate high quality digitisation data that represent faithfully and accurately the cultural heritage object in question.
- Once the data file is created, to store it safely in a way that various levels of access and editing rights are granted to CHIs staff members and possible partner organisations.
- To enable the web-based visualisation of 3D models generated from raw data, allowing user communities to access them on their own devices through the Internet.
- To accompany the 3D models with accurate metadata that describe the heritage object, and with in-depth information about the digitisation process that generated the 3D model, to converge in a paradata report.
- To enable access to and reuse of raw data and 3D models, along with their accompanying documentation, for use by

user communities across domains such as heritage research, education and cultural tourism.
- To promote FAIR[18] principles in public data collections by associating Persistent Identifiers (PIDs) with public 3D models, enabling stable identification, citation, and long-term accessibility.
- To contribute to the 3D collections of the common European data space for cultural heritage, by publishing them on the Europeana website.

All these challenges are currently addressed by CHIs in an often disorganised manner, relying on in-house or outsourced services by different service providers, thus often resulting in duplication of efforts, redundancies and complex workflow management and orchestration. As a secondary but not irrelevant point, cloud-based service providers that also offer a 3D viewer are usually private companies, often based outside Europe, which raises concerns regarding data governance, regulatory compliance, and the extent to which user data protection policies can be reliably enforced. The absence of an integrated, non-profit, EU-based solution to these challenges has created a clear need in the Cultural Heritage sector.

EUreka3D fulfils this need through the development of the EUreka3D Data Hub, a pilot e-infrastructure based in Europe. It is specifically intended to facilitate the sharing of 3D cultural collections in the common European data space for cultural heritage, offering an integrated, non-profit, EU-based solution tailored to CHIs. The EUreka3D Data Hub was developed by EGI, involving EGI Foundation and associated partners Cyfronet and GRNET as service providers, bringing together e-infrastructure providers and Cultural Heritage institutions. CESNET is involved as a provider of the EGI Artefact Registry, and Rancher for EUreka3D-XR. It integrates various components to create a flexible and scalable suite of tools available on the non-profit solutions market, in accordance with

18 Wilkinson, M. D., Dumontier, M., Aalbersberg, Ij. J., Appleton, G., Axton, M., Baak, A., Blomberg, N., Boiten, J.-W., da Silva Santos, L. B., Bourne, P. E., Bouwman, J., Brookes, A. J., Clark, T., Crosas, M., Dillo, I., Dumon, O., Edmunds, S., Evelo, C. T., Finkers, R., ... Mons, B. (2016). The FAIR Guiding Principles for scientific data management and stewardship. *Scientific Data, 3*(1). https://doi.org/10.1038/sdata.2016.18

sustainable planning aimed at covering costs with competitive and affordable revenue sources and mechanisms.

The EUreka3D suite of services and resources for the management and sharing of cultural 3D assets offer solutions for data, metadata and paradata management, access, storage and publication, delivering high-quality 3D collections to users' platforms such as Europeana. The publication process of the datasets in Europeana is coordinated by PHOTOCONSORTIUM, an accredited aggregator for Europeana and partner in the common European data space for cultural heritage projects.

The value proposition identified for EUreka3D Data Hub is to offer CHIs a comprehensive EU-based solution for 3D data management and a direct entry point to the common European data space for cultural heritage. This clearly differentiates the EUreka3D platform from similar services for 3D data management, and showcases the competitive advantage of this solution, focusing more specifically on the needs of the European CHIs. Specifically, by using non-profit cloud providers based in Europe, federated under EGI, and offering secure data management mechanisms and integrated tools. All these features make the EUreka3D Data Hub not only specialised and competitive, but also more resilient in terms of scalability, adaptability and flexibility to future developments in the digital transformation of the cultural sector.

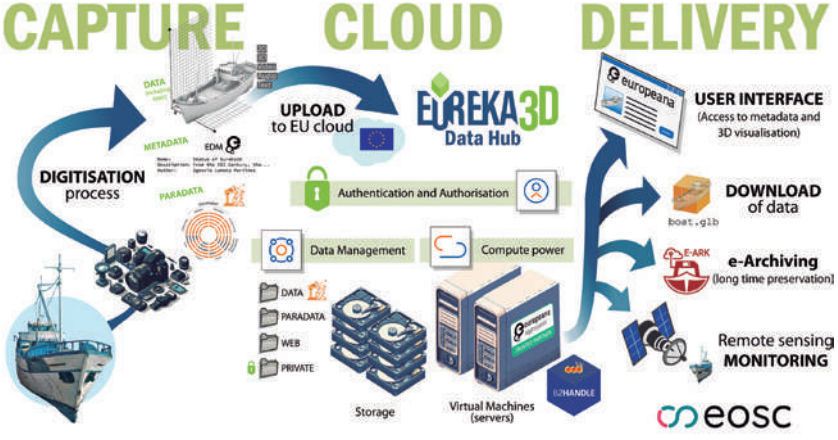


Fig. 42. EUreka3D Data Hub and workflow – general overview

## Who is the EUreka3D Data Hub for?

The main target users of the EUreka3D Data Hub are those that provide content (known as "Content Providers", mainly represented by CHIs) and, more specifically:

- Small CHIs with limited computing resources that need an infrastructure available for them to store and manage their digitised assets and associated data.
- CHIs that do not want the trouble of managing their own technical infrastructure.
- Institutions that want to publish their assets on the web, especially in Europeana.
- Dedicated CHIs that want their data securely stored in a European cloud (systems based in Europe).

These users can use the EUreka3D Data Hub to manage their data, metadata, and paradata in the system (upload, modification, deletion, etc.); to control the access to their own data and share it with a limited audience or with the wider public (for example, through publication in Europeana); to decide for each dataset whether it can be downloaded and by whom.

In simple terms, what CHIs can do in EUreka3D Data Hub is:

- Upload and store different versions/formats of 3D models.
- Share any sort of data with other CHIs and Cultural Heritage communities, establishing different access permissions for each dataset.
- Visualise 3D models in a web-based viewer that is compatible with Europeana.
- Assign metadata to any file, including the Europeana Data Model format through a user-friendly input form or an advanced XML editor.
- Upload, manage, share and publish large data sets programmatically via an API, which would otherwise be unfeasible manually.
- Link contextual information and paradata to each model, to be shared to the public.
- Assign PIDs to the public 3D models to ensure their long-term preservation online.

- Publish publicly accessible objects in the Europeana portal, containing links to raw files and paradata reports.

Additionally, the open access approach of the EUreka3D Data Hub is highly beneficial to those users who consume content (known as “data users”):

- Professionals (architects, archeologists, etc.) who want to download data to re-use it in their own practice.
- Researchers working in Cultural Heritage to access and re-use the data for their research.
- Users (both humans and machines) that want to use the data as the basis for modification and exploitation in different fields (e.g., tourism, cultural heritage experiences, promotion of cultural heritage assets, printing business, educational institutions, etc.).

Data users, who normally discover these 3D collections via the Europeana website or the common European data space for cultural heritage, can use the system to explore and view objects (3D rendered objects and their source files), metadata and paradata, and download raw data if the owner of the data allows it.

**Added value provided by the EUreka3D Data Hub**

- A European-based infrastructure, currently the only platform and viewer for 3D funded in a EU project.
- Open access to high-quality 3D assets, shared to be used for different purposes (research, industry, education etc.).
- Access control for protecting and selectively sharing the data (as a content provider, provide access to a restricted group of users).
- Interoperability with Europeana and the data space for cultural heritage.
- A user-friendly easy-to-use system (including documentation).
- Support and guidance.

## 3.2. TRAINING AND CAPACITY BUILDING IN 3D AND XR FOR CULTURAL PROFESSIONALS

The rapid adoption of 3D digitisation and extended reality technologies has opened new opportunities for Cultural Heritage institutions to preserve, enrich and share their collections. At the same time, these technologies introduce new challenges related to skills, confidence, sustainability and organisational change. The lack of knowledge, skills and resources to access relevant 3D and XR technologies and tools is a significant challenge for Cultural Heritage institutions and actors in tourism, education, research and the creative industries, which prevents them from the valorisation of 3D and other digital cultural heritage assets in innovative, immersive scenarios.

Across both EUreka3D and EUreka3D-XR, capacity building has therefore been conceived as a core project pillar. Both projects start from the awareness that access to tools and infrastructures alone is not sufficient, impactful or sustainable. For 3D and XR to be meaningfully adopted, Cultural Heritage professionals must be supported in developing:

- an understanding of digital transformation in general and 3D and XR standards, workflows and quality requirements (such as paradata);
- confidence to experiment with new data, tools and methods and knowing where to find these;
- the ability to assess when and why 3D and XR add value and how they can be practically implemented in their own organisational workflow;
- and awareness of long-term challenges such as preservation, reuse and sustainability.

Capacity building activities in EUreka3D and EUreka3D-XR focused on lowering barriers by providing inspiration and guidelines, and connecting learning to real world case studies and tools, while addressing a diverse audience ranging from beginners to more advanced practitioners.

Fig. 43. EUreka3D-XR: XR Applications for Cultural Heritage.
The first public hybrid event in Pisa, 27 February 2025

## Training and capacity building in EUreka3D

EUreka3D laid the groundwork for capacity building in the field of 3D Cultural Heritage by focusing on standards and workflows. Training activities and resources developed during EUreka3D addressed the full lifecycle of 3D data:

- The challenges and needs for creating reusable 3D content in good quality;
- The common understanding of paradata and its application to 3D documentation;
- The development of the EUreka3D Data Hub and the management of 3D cultural heritage datasets;
- The focus on formats, authenticity and preservation for 3D digitisation of cultural heritage content;
- The publication of 3D content on Europeana.

Key capacity-building actions in EUreka3D included:

- International webinars and conference sessions introducing the results of the project on 3D digitisation practices, metadata and paradata, and quality considerations. A recurring activity were the demonstrations of the EUreka3D Data Hub.

- The *3D Digitisation Guidelines: Steps to Success*[19] was one of the core activities of the dissemination and capacity building aims of the project. This publication simplified the recommended standards highlighted in the EU VIGIE Study 2020/654 on quality in 3D digitisation of tangible cultural heritage,[20] and is designed to help anyone on their 3D digitisation journey.
- Editorial content and case studies, for example Europeana Pro blog posts written by the EUreka3D Consortium to disseminate the knowledge intended for professionals in the Cultural Heritage sector, which illustrate how 3D assets can be reused for research, education and public engagement.

## From 3D to XR: Capacity building in EUreka3D-XR

EUreka3D-XR expanded the scope of capacity building from 3D data management to the reuse of 3D assets in XR experiences. Particular attention was paid to raising awareness of the opportunities of XR for Cultural Heritage, hands-on learning with the EUreka3D-XR toolkit and Data Hub, and the organisation of multilingual, cross-sectoral capacity building activities.

Following an initial needs analysis and the Europeana Guidelines for Developing and Delivering Training, a Capacity Building Implementation Plan was developed to structure activities across the project lifetime. The proposed capacity building programme combined different learning formats to address varied needs and levels of expertise. Following this method led to a standardised, structured and incremental approach based on user needs.

Key activities included:

### Hybrid and online events

- The “Reimagining Culture in 3D and XR” hybrid event in Brussels (September 2025) combined an international track

19 https://eureka3d.eu/3d-digitisation-guidelines/

20 European Commission. Directorate General for Communications Networks, Content and Technology. Study on quality in 3D digitisation of tangible cultural heritage: mapping parameters, formats, standards, benchmarks, methodologies, and guidelines : final study report. Publications Office. DOI: https://doi.org/10.2759/471776

presenting EUreka3D-XR results with a practice-oriented track in Dutch featuring local use cases and projects.

- The EUreka3D-XR Demonstration Event & Workshop in Girona (January 2026) brought together Cultural Heritage professionals, archivists and researchers for live demonstrations of XR tools and hands-on testing of workflows
- Other online and hybrid events were the kick-off event in Pisa, introducing the project and its tools and scenarios to be developed, the conference “Photography and archives: discovery, technology and innovation” in Florence and other presentations and demonstrations at sectoral conferences and in Europeana events.


Fig. 44. EUreka3D-XR hybrid Capacity Building events: “Reimagining cultural heritage in 3D and XR” (Brussels, 26/09/2025) and “EUreka3D-XR Demonstration Event and Workshop” (Girona, 29/01/2026)

## Online training programme

In collaboration with the International Council on Archives (ICA), an online training programme titled “Driving Digital Transformation in Cultural Heritage Institutions” was delivered in three sessions. Each session combined:

- live-streamed keynote presentations addressing strategic and policy perspectives, the transformative power of digital cultural heritage and good practices for creation, access and reuse;
- interactive workshops for a selected group of participants, allowing deeper engagement with tools and workflows.

This format proved very effective in balancing broad outreach with meaningful interaction and peer exchange.

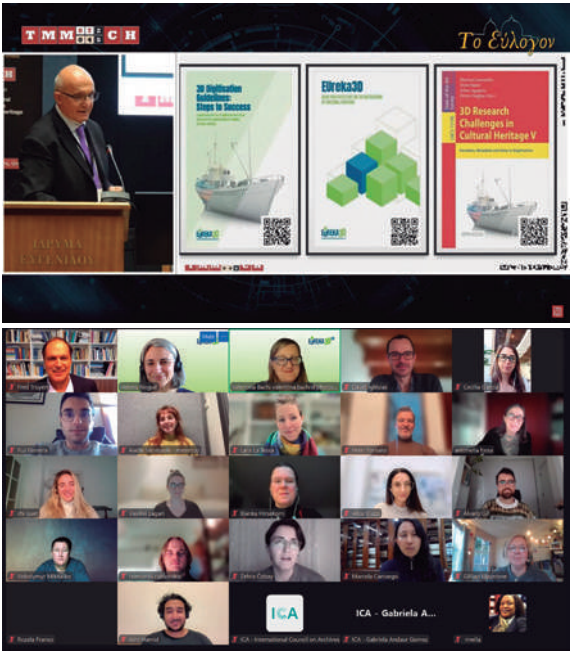


Fig. 45. EUreka3D-XR presentation and online Capacity Building event: “4th International Conference TMM-CH” (04/04/2025) and “Driving digital transformation in Cultural Heritage Institutions” (November-December 2025)

## Hands-on workshops and local initiatives

- At the French Science Festival, Bibracte hosted workshops for teachers and families, testing educational XR content and contributing to the development of Open Educational Resources (OERs).
- Local dissemination and training initiatives were organised by partners such as meemoo and Bibracte, adapting content to national and regional contexts and languages.


Fig. 46. EUreka3D-XR Capacity Building event: PRÉAC training titled “Archaeology and young people: how do you show the invisible?” (Bibracte, December 2025)

## Learning resources

Across both projects, significant effort was invested in producing reusable learning resources that remain accessible beyond the project duration.

- The translation of the EUreka3D *3D Digitisation Guidelines: Steps to success* to Dutch, Italian, Spanish, Catalan, Greek and French;
- The publication of the EUreka3D *3D Digitisation Guidelines: Steps to success* as a training course on the Europeana Training Platform[21];

21 https://europeana.moocit.fr/courses/course-v1:europeana+EUreka3D01+2024_Q3/about

- An updated version of the EUreka3D Data Hub Content Provider Handbook;
- Manuals, step-by-step guides and demonstration videos for the five EUreka3D-XR tools, designed to support non-technical users through complete workflows;
- Use cases highlighting the pilot experiences in Girona (Spain), Bibracte (France) and Paphos (Cyprus);
- Editorials, news posts and project publications, contextualising the tools and scenarios within broader sector developments and published on the project channels and Europeana Pro.

As in EUreka3D, learning outputs were disseminated through established channels such as Europeana platforms, project websites, recorded webinars and sector events, ensuring discoverability and long-term reuse.

The capacity building programme has been endorsed by a marketing and communication plan, necessary to address each target group with information tailored to its interests and through the channels suiting best the purpose of communication. It must be noted that the capacity building aims are deeply linked to communication and dissemination activities, not only for reaching the appropriate audience, but also to make all these resources available online to serve as a knowledge base providing a lasting legacy of the project.


Fig. 47. Promotion postcards: disseminating the course and Guidelines "3D Digitisation Guidelines" and promoting the training programme "Driving digital transformation in Cultural Heritage Institutions"

## Focus groups

To ensure that the XR tools developed in the project were in line with the needs and workflows of Cultural Heritage professionals, focus groups were organised to gather specific feedback.

The first two focus groups were limited to the project consortium and Advisory Board Members (July and October 2025). These sessions confirmed that the project's tools and scenarios were perceived as technically strong and conceptually valuable, but that adoption depends largely on sustainable learning support rather than functionality of the tools alone. These insights directly informed the refinement of training materials and documentation on the tools during the project. However, a continued approach after the project's deadline, for maintaining and updating the documentation, further developing other training materials and (hand-on) activities and user-centred testing remains pivotal for long-term impact and sustainability, both of the tools but also of the expertise and skills that has been gradually built in both projects.

Quote from an Advisory Board member, to the yes/no question if the scenarios and tools are in line with their expectations:

> *"I think it's not a question of no, but it exceeded expectations. So when you say yes, you do so thinking, well, actually, it was better than expected. So I don't know how you rate that. Anyway, I rated it yes. (.) Thank you."*

Other focus groups were organised with tool end users. These are stakeholders from outside the project consortium, coming from different sectors:

- During the "EUreka3D-XR Demonstration Event and Workshop" a half day workshop dedicated to archivists, was organised to test the AI 3D Builder and to show the prototype of the Girona walking tour app, collecting preliminary feedback on both the Girona wall models and the usability of the app.
- An on-site focus group event was organised in Bibracte to test the AR Tour Builder and AR Tour Experience with local stakeholders from professional communities and tourists.
- During the final event in Cyprus, an on-site demonstration at the St. Neophytos *Enkleistra* was organised with a selected

group of participants. In addition the agenda of the public event included a full demonstration of the scenarios and the presentation of the project's result. All tool developers were present to answer questions from participants.

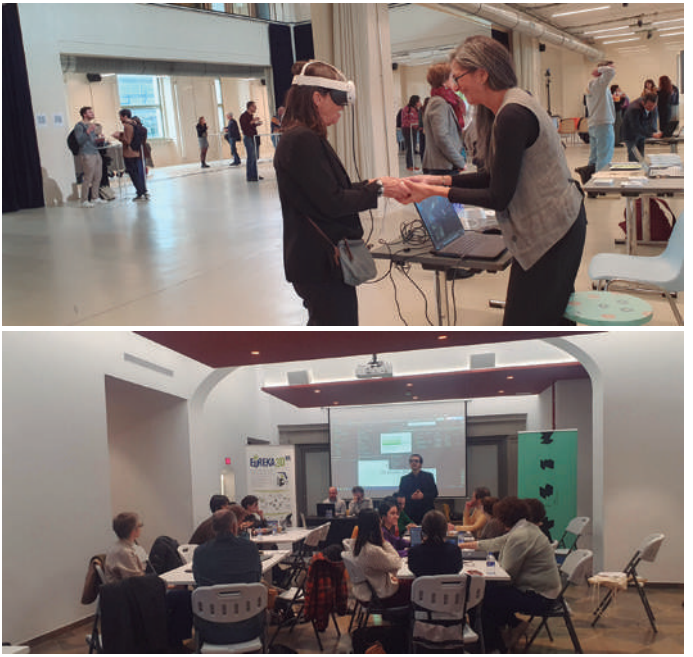

Fig. 48. EUreka3D-XR Capacity Building events: testing the Avatar Builder tool at the event "Reimagining cultural heritage in 3D and XR" (Brussels, 26/09/2025) and on-site workshop "Archives in 3D. From Records to Objects" (Girona, 29/01/2026)

## Collecting feedback

To ensure that project activities and capacity-building efforts remained aligned with user needs, EUreka3D-XR actively collected feedback through these focus groups, but also with participant surveys following events and training sessions.

The surveys indicated a high level of satisfaction and a tangible learning impact. For the Brussels capacity-building event alone, over 200 professionals from more than 30 countries registered, with survey respondents rating their overall satisfaction at a median of 4 out of 5. More importantly, a significant proportion of respondents

reported an increase in their perceived skill level after participating. Similarly, feedback from the online training programme delivered with the International Council on Archives shows consistently high satisfaction scores (predominantly 4-5/5) and strong appreciation for the balance between strategic context and practical insight.

Open-ended responses across surveys highlight increased confidence to engage with 3D and XR, a clearer understanding of digital transformation challenges, and a strong demand for follow-up, hands-on training and tool-specific guidance. Together, these findings confirm that the capacity-building actions did not only raise awareness, but contributed to meaningful competence development, while also underlining the need for continued learning opportunities beyond the project lifetime.

Three quotes from participants of the Online Training Programme "Driving digital transformation in Cultural Heritage Institutions":

*"Thank you for the opportunity to participate in the training program. I learned a great deal throughout the course. I will share all the projects and tools I acquired with my colleagues in Argentina. Thank you again, and I hope to continue sharing these kinds of opportunities."*

*"I appreciate the support and guidance of the moderators throughout the course and in each group. It was also rewarding to share the experience with colleagues from around the world, which shows that although we may be at different stages of development, we share common problems and tools for solving them. While the focus was on European projects, this program helped us build bridges."*

*"Yes, this online training programme provided both new knowledge and updated information highly relevant to my profession. The content covered recent developments, best practices, and practical techniques that I had not previously explored in depth. It also offered updated guidelines and tools that I can directly apply in my day-to-day work, enhancing both the efficiency and accuracy of my professional tasks. Additionally, the programme encouraged critical thinking and offered case studies that helped me understand how to approach complex challenges in my field more effectively. The interactive sessions and practical examples also gave me new perspectives on workflow optimization and problem-solving strategies. Overall, the programme has not only broadened my knowledge but also inspired me to implement innovative approaches and stay current with emerging trends in my profession."*

## Towards sustainable learning and competence development

Across EUreka3D and EUreka3D-XR, capacity building has evolved from foundational guidance on 3D digitisation to hands-on experimentation with XR tools and narratives. By combining events, training programmes, learning resources and participatory feedback, the projects have supported Cultural Heritage professionals in navigating a rapidly changing technological landscape.

Most importantly, these efforts have shown that user confidence, support/documentation and continuity are as crucial as technology itself. By investing in learning and capacity building, EUreka3D-XR contributes not only tools and infrastructures, but also the increased professional digital skills and shared understanding required to ensure their meaningful and sustainable use.

While EUreka3D-XR has delivered a broad and well-received capacity-building programme, the project duration inevitably limits the ability to measure long-term behavioural change. The EUreka3D-XR toolkit reached maturity towards the end of a project, while institutional adoption of tools and workflows requires time, building confidence and continued support from experts.

For this reason, learning and competence sustainability is approached in EUreka3D-XR as a long-term process:

- Learning materials and other resources, such as the recordings of presentations and the use case scenarios, will remain available as open access materials after the completion of the project (July 2026), online in the project's communication channels, in the various partner's channels, and on the existing Zenodo community[22].
- An approach will be agreed upon for the consolidation and iterative updating of training resources as the EUreka3D-XR toolkit evolves;
- Integration with the EUreka3D Data Hub, the common European data space for cultural heritage and other platforms such as Europeana;

22 EUreka3D Zenodo community. https://zenodo.org/communities/eureka3d/

- The exploration of more structural approaches, such as a Competence Centre on 3D and XR.

This last perspective is addressed in more detail in a dedicated Chapter 3.4, but it is already clear that the combined capacity-building efforts of EUreka3D and EUreka3D-XR have helped establish a shared knowledge base, a growing community of practice, and a foundation for continued skills development in the Cultural Heritage sector after the project's deadline.

## 3.3. THE PLACE OF 3D IN THE DATA SPACE FOR CULTURAL HERITAGE

The Europeana Initiative, a networked organisation uniting the Europeana Foundation, the Europeana Network Association and the Europeana Aggregators' Forum, exists to champion digital heritage as a public good, drive digital transformation in our sector, promote the ethical use of technology and trustworthy heritage data, and help shape Europe's digital heritage policies for the future.

The Europeana Foundation is a key partner of the EUreka3D-XR project, ensuring that the work and results of the project to support 3D and XR experiences in cultural heritage are integrated in the common European data space for cultural heritage.

This shall be achieved in the form of new 3D collections published as open data on the europeana.eu website, information, editorials and access to tools made easily accessible for Cultural Heritage institutions, and overall promotion of the value of high quality 3D digitisation as a pillar for the digital transformation of the sector.

3D data has become inherent to the activities of the Europeana Initiative as part of the deployment of the common European data space for cultural heritage. From increasing access to culture and improving engagement, to supporting preservation and fostering reuse, 3D offers unprecedented opportunities to advance this objective. 3D models are not just digital copies of heritage assets. They capture intricate details about the object and its story, as well

as the digital documentation process, offering new knowledge and fresh insights.

In 2019, EU Member States acknowledged the potential of 3D for digital preservation that reflects the multidimensionality of Cultural Heritage, and called for 'a pan-European initiative for 3D digitisation of cultural heritage artefacts, monuments and sites'[23]. The European Commission Recommendation[24] of 2021 on a common European data space for cultural heritage invites EU Member States to digitise in 3D all monuments and sites deemed at risk, and half of the most physically visited by 2030. It sets ambitious targets for 3D content contribution to Europeana and the data space.


Fig. 49. Twin it! campaign. The Reconstruction of the Heidentor - State Collections of Lower Austria

To contribute to these targets, the European Commission and the Europeana Initiative launched the Twin it! 3D for Europe's culture campaign[25] in June 2023, in cooperation with the Swedish, Spanish and Belgian Presidencies of the Council of the EU. Twin it! invited EU Member States to submit at least one 3D-digitised heritage asset to the data space, resulting in an exceptional collection[26] of 37 emblematic and high-quality assets. The campaign enhanced 3D commitment and capabilities across Member States, heritage institutions, the Europeana ecosystem and the professional community. It led to a Call to Action that draws inspiration from

23 Declaration of Cooperation on advancing digitisation of cultural heritage (2019).
24 https://digital-strategy.ec.europa.eu/en/news/commission-proposes-common-european-data-space-cultural-heritage
25 https://pro.europeana.eu/page/twin-it-3d-for-europe-s-culture
26 https://www.europeana.eu/en/galleries/15694-twin-it-a-pan-european-collection-of-heritage-3-d-models

the collective expertise of Twin it! Partners and leading experts to identify seven priorities for future approaches to 3D:

1. **Adopt a purpose-led and user-based approach to 3D digitisation**. The decision of what to digitise in 3D and at what quality level should be based on how the 3D content will be used and by whom. This will also define the necessary investment and the choice of technology. While 3D digitisation with the highest level of precision is a requirement for reconstruction, a lower resolution can be fit for purpose if the main goal is to increase online access. A purpose-oriented and user-based approach can provide practical guidelines for efficient and effective 3D digitisation, and complement the quantitative indicators of the 2021 Recommendation with a qualitative approach.

2. **Increase the understanding and prioritisation of the categories of the 2021 Recommendation in national 3D digitisation strategies and inventories**. The Recommendation invites Member States to prioritise and set targets for the 3D digitisation and digital preservation of cultural heritage at risk and most visited monuments and sites. It also encourages paying special attention to under-digitised cultural heritage. Increasing understanding of these categories among Member States will facilitate their incorporation into existing national heritage inventories. In turn, this will help inform decision making, align national strategies with the Recommendation targets, track progress and ensure comparable data across national databases.

3. **Increase understanding of 3D workflows in the sector**, building on studies like Basic principles and tips for 3D digitisation of cultural heritage (2019)[27] and the Study on quality in 3D digitisation of tangible cultural heritage (2022)[28]. Twin it! highlighted the need for our sector as a whole to better understand 3D processes and stressed the benefits of networking and sharing experiences across Europe. Defining

27 https://digital-strategy.ec.europa.eu/en/library/basic-principles-and-tips-3d-digitisation-cultural-heritage

28 https://digital-strategy.ec.europa.eu/en/library/study-quality-3d-digitisation-tangible-cultural-heritage

common overarching workflows is essential. Our sector must also leverage Artificial Intelligence to accelerate 3D digitisation and optimise 3D digitisation workflows.

4. **Continue to strategically fund 3D digitisation at EU, Member State and institutional levels**. The Recommendation calls for a substantial upscaling of 3D digitisation. This requires continued awareness raising on the advantages of 3D in cultural institutions throughout Europe, building on the Twin it! campaign. Increased financial support for 3D infrastructure and innovation is essential, including for the data space and data space-supporting projects within the upcoming Digital Europe Programme. The Europeana Initiative and Member States should continue investing in a robust aggregation ecosystem through national, thematic and domain Aggregators, which played a key role in Twin it!. Capacity needs to be created for aggregators to evolve and modernise their support to heritage institutions and other providers.

5. **Support the emergence of sustainable and interoperable European platforms for archiving, hosting and viewing 3D cultural heritage**. Twin it! highlighted the reliance on commercial platforms from third countries for archiving, viewing and hosting 3D models, and the need for European, open and public platforms whose sustainability and public-interest-first operations can be guaranteed. The EU must continue to financially support the development of such tools, and robust digital public infrastructures where heritage is recognised as a collective, accessible and shareable resource of public interest. Such tools and infrastructures must be interoperable and easily accessible by cultural institutions of all sizes and at any stage of their digital transformation.

6. **Align efforts and increase cooperation to boost Europe's collective capacity for 3D**. Twin it! demonstrated the potential of collaborations to provide support to Member States, as cooperation with European and international organisations will be key when it comes to 3D digitisation of heritage at risk and most visited sites. Such collaborations should continue and build upon existing efforts which lead to the development of standards in 3D.

7. **Enable, promote and build capacity on the reuse of 3D content**. The reusability of content, including 3D models and related data, contributes to the development of new knowledge and stimulates creativity and innovation. Twin it! revealed challenges around assessing copyright and communicating accurate and open reuse conditions of 3D models. The Europeana Initiative and the data space will continue to raise awareness of the positive impact of reuse, build capacity around communicating rights information, and strengthen 3D metadata and paradata standards in support of reuse. It is important that Cultural Heritage institutions comply with EU copyright law, which states that unoriginal reproductions of public domain works are not subject to copyright or related rights. Additionally, if an asset is digitised with support from public funding, the resulting data and models should not be subject to reuse limitations.

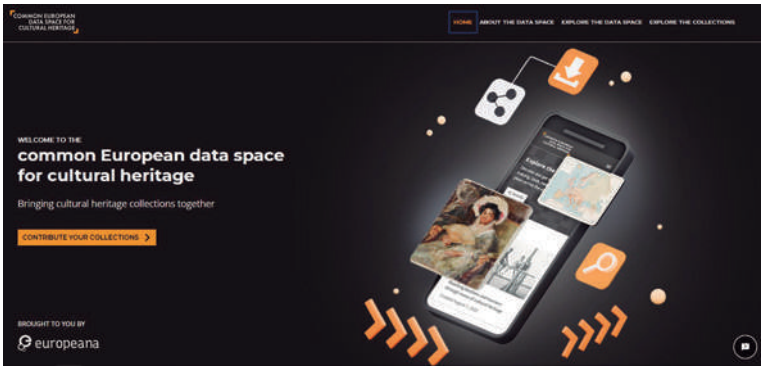


Fig. 50. Common European data space for cultural heritage homepage

Building on the momentum of the first campaign, the Europeana Initiative and the European Commission continue to empower Member States and heritage institutions to advance 3D digitisation through Twin it! Part II campaign[29], taking place during the Polish, Danish and Cypriot Rotating Presidencies of the Council of the EU. Drawing from the lessons and principles established in the first

29 https://pro.europeana.eu/post/europeana-and-partners-launch-twin-it-3d-for-europe-s-culture-part-ii

phase, the new campaign focuses on the need for a purpose-driven, user-focused approach to 3D digitisation, and the importance of promoting reuse through enablement and capacity-building.

This means that more metadata needs to be provided to increase the quality of the published 3D data and to clearly convey the intended use of each 3D object. The core Europeana frameworks, namely the Europeana Data Model[30] and the Europeana Publishing Framework[31] have been extended for this purpose. These extensions allow the inclusion of additional data, such as 2D images, detailed information about specific elements or movable objects within a site, or metadata about the 3D model itself. This approach will create richer, more dynamic and multidimensional representations of heritage assets, unlocking greater potential for reuse in applications like XR experiences.

## 3.4. IMPACT, SUSTAINABILITY AND FUTURE OF EUREKA3D AND EUREKA3D-XR

Due to emerging developments in 3D digitisation and tools for the interaction of 3D models, the EUreka3D and EUreka3D-XR were closely linked in their approach to Impact and Sustainability. Primarily, this focused on Capacity Building which was based on best practice that resulted from the research, knowledge and experience of the CHI content partners in the project.

The EUreka3D project laid the foundation of "How to digitise cultural heritage in 3D". This stemmed from the recommendations of the *VIGIE 2020/654 Study On Quality In 3D Digitisation Of Tangible Cultural Heritage*, commissioned by the EC. This highlighted a critical step, omitted by many, related to the addition of valuable paradata. The guidelines produced in the EUreka3D project[32] gave a best practice approach to 3D digitisation which was disseminated

30 https://pro.europeana.eu/page/edm-documentation
31 https://pro.europeana.eu/post/publishing-framework
32 https://eureka3d.eu/3d-digitisation-guidelines/

to identified stakeholders in webinars, workshops and more broadly via online papers and social media.

The EUreka3D-XR project aimed to progress this by looking at the "use" of optimal 3D models, with particular focus on extended reality (XR) increasing the engagement by users and reducing costs and development for CHIs, by creating and providing some easily accessible XR tools along with the best practice case studies, that can be found in more detail in this booklet.

## Identified Impact and Sustainability Areas in EUreka3D-XR

The Capacity Building Implementation Plan of EUreka3D-XR identified already in the early stage of the project the expected change pathways connected to the impact areas of the project, that were likely to change the workflow behaviours of stakeholders in both the short and long term. These areas were refined into 4 core elements within EUreka3D-XR:

### 1. Content

The CHI content partners of EUreka3D-XR produced high quality 3D models that have been published in Europeana through the EUreka3D Data Hub, as open access collections for use and reuse by a variety of professional and amateur stakeholders.

The 3D models were digitised in high quality using the guidelines of the VIGIE Study 2020/654 recommendation, producing the current best practice standard available for 3D models. As a result, the 3D models are now available for use by the broadest range of user stakeholders from public through to professionals who need a high level of detail and information, metadata and paradata.

These 3D models also formed the basis of the XR experiences of the CHI sites that were created by the IT service provider partners in three pilots of different kinds, set in Girona, Bibracte and Cyprus.

The XR experiences developed from these high quality 3D models use the latest innovation in XR technology. This maximises the engagement potential to users as well as acting as a best practice

scenario to inspire external CHIs who may wish to attain similar results using their own 3D models with the option to use the available XR Tools developed during the EUreka3D-XR project. One of the main drivers for creating XR experiences was from evidence that showed that 3D models in isolation were less engaging. By creating XR experiences of 3D models it not only actively engages users into the initial interest of specific cultural heritage objects or sites but it also acts as a gateway to more lasting impact of further discovery following the experience of XR.

These XR experiences are, by themselves, additional tangible cultural content, made available as AR/VR experiences on mobile devices for users on-site as well being discoverable via Europeana for interested institutions to be inspired from.

### 2. XR Tools

The XR Tools developed during the project by the IT service providers, under the guidance of the pilot leader CHIs, are an additional tangible result of EUreka3D-XR. A key aim and impact area of this project was to inspire and encourage CHIs, particularly smaller organisations, to try and create XR experiences without burdensome costs and development time. By having the tools that were used to build the three XR experiences in this project easily accessible, we very much hope that CHIs will experiment with their own 3D models which can then be a stepping stone into producing fully functional XR-experiences of their own. Indeed, feedback from the workshop events and the scenarios themselves have shown that the XR Tools have the potential to build fully functioning experiences without significant extra custom development.

### 3. Infrastructure

The EUreka3D Data Hub was developed in the EUreka3D project and is critical to the storage and display of high quality 3D models, metadata, and paradata. In EUreka3D-XR, this data hub has also been used to host the XR Tools that are available to CHIs for ongoing use.

There are a number of key points regarding the importance of the EUreka3D Data Hub for CHIs, particularly those based in the EU.

1. The common European data space for cultural heritage requires an EU hosted solution to shift the current reliance on US corporate platforms. Not only is the EUreka3D Data Hub an EU based cloud infrastructure but it is also administered by a not for profit EU Foundation (EGI).
2. The EUreka3D Data Hub is dedicated to Cultural Heritage. Again this is important to promote quality, authenticity and to distinguish itself from the wide variety of 3D models that are available on other platforms.
3. The EUreka3D Data Hub understands the importance of interoperability and is disseminating models, metadata and paradata to aggregators dedicated to Cultural Heritage such as Europeana.
4. Security, flexibility and scalability are built into the EUreka3D Data Hub. This includes a secure authentication mechanism with single-sign-on using established corporate identities, the ability to host very large 3D "raw" models as well as optimised models for visualisation and a federated network of European (and global) Data Centres allowing for dedicated hosting in a specific country or distributed hosting for increased speed and backup.
5. During the EUreka3D-XR project an importance has been placed on competitive costs and sustainability of the EUreka3D Data Hub.

The impact of the infrastructure lies mostly in these points for CHIs, particularly smaller ones with less budget and IT capability. The EUreka3D Data Hub provides a lower cost alternative to hosting in-house via a platform that is not under foreign corporate control. CHIs now have less of a barrier to begin their digital transformation by hosting their digitised data, specifically 3D models in the EUreka3D Data Hub.

## 4. Knowledge transfer

Knowledge transfer is a key area of both EUreka3D and EUreka3D-XR. 3D digitisation is still a nascent area for many, and to make informed decisions about their 3D digital journey they need to be aware of the developments and best practices that are being demonstrated by the leading professionals in the sector. During both projects a large amount of information has been written,

gathered and recorded from online and published articles, professional blogs (such as Europeana Pro Blogs), webinars, workshops and dedicated sessions, including those with the EUreka3D-XR Advisory Board. The discussions have been taken further by connecting with partner networks of Cultural Heritage professionals such as the International Council of Archives and the networks of the Europeana Aggregators Forum. The case studies that have been produced by the XR scenarios in the project serve as a lasting example of best practice that have been published here in this booklet, as well as online at the project website[33] and many other dissemination channels.

EUreka3D is committed to maintaining this information as a valuable resource for the 3D digital transformation and as a foundation to build and develop ideas and innovation. To widen access, many of the publications have been translated to several EU languages.

In an extension of the EUreka3D, the XR project produced an open online training course[34] in partnership with the Europeana Academy.

Over all the knowledge that has been shared, and will continue to be shared, will have a positive impact on all of the stakeholders of 3D for many years to come, to innovate methodologies and workflows, and to support the implementation of standards to improve the preservation and use of cultural heritage digital memory twins.

## Resulting Sustainability

EUreka3D-XR has assigned the Impact areas above, with a sustainability plan.

### 1. Content

The 3D models produced in the project will remain interoperable with Europeana from now until 5+ years and the quality produced

33 http://eureka3d.eu

34 https://europeana.moocit.fr/courses/course-v1:europeana+EUreka3D01+2024_Q3/about

from following the VIGIE Study 2020/654 guidelines means that they will have a usable life well beyond this.

The XR Experiences created in the project will be launched to users at the content parts sites and via apps before the end of the project, with links from the models aggregated by Europeana. The expected life of these experiences is also 5+ years, inline with alternative IT user engagement developments, but with the rapid technological change with the advancement of AI leaves some uncertainty to the level of redundancy these experiences may suffer in the longer term.

### 2. XR Tools

As with the content, the XR Tools will be available after the end of the project for CHIs to experiment with. Although the XR Tools will be available for a minimum of 5 years it is more speculative to guarantee they will not be superseded by developing technologies before this time. It is expected the use and interest of XR Tools will decline over time and it is hoped they will be a catalyst for an ongoing development of openly accessible XR Tools that CHIs and other stakeholders can use.

### 3. Infrastructure

The sustainability of the EUreka3D Data Hub is heavily dependent on the continued interest of CHIs to host their models in accordance with the key points mentioned above. The Data Hub needs the support of the Digital Europe Programme to serve and be promoted as a viable solution which can significantly contribute to the common European data space for cultural heritage. With this support, the EUreka3D Data Hub will be able to gather the seed investment to ensure self-sustainable well beyond 5 years.

### 4. Knowledge transfer and competence centre for 3D Cultural Heritage

As mentioned above, the knowledge gained in the project will be made available in the project website, as well as external websites such as Europeana, for 5+ years. To build on this knowledge, progress research, foster ideas and assess and adopt new technologies and standards, requires a commitment by all

partners and a coordination of responsibilities beyond the end of the funding period. EUreka3D and XR has continued to discuss and recommend a dedicated competence centre on 3D in order to facilitate the ongoing knowledge transfer of 3D Cultural Heritage practices and to support the EUreka3D Data Hub.

# 4. Conclusions

The EUreka3D initiative has been a multi-year collaborative effort that has significantly advanced Europe's capacity to create, manage, preserve and reuse high-quality 3D cultural heritage content. This conclusion synthesises the project's achievements, reflects on the insights gained across the pilots, tools and training activities, and positions EUreka3D-XR within the broader momentum of 3D digitisation in the common European data space for Cultural Heritage. It also provides a forward-looking vision, informed by the project's sustainability planning and the emerging prospects for a Competence Centre for 3D Cultural Heritage.

EUreka3D-XR has an evolving ecosystem from the foundational guidelines and methodologies for 3D digitisation; the technological innovations behind the EUreka3D Data Hub; the five tools that make up the XR Toolbox; the three demonstration scenarios that tested these tools in real-life environments; and the broad capacity-building programme that sought to empower Cultural Heritage institutions of all sizes to engage with 3D and XR. These areas have produced sector-wide perspectives on impact, sustainability and future opportunities.

## 4.1. FROM 3D DIGITISATION TO MEANINGFUL REUSE

The starting point for EUreka3D-XR was clear: European Cultural Heritage institutions, especially the many small and medium-sized ones, face barriers in adopting 3D technologies to engage with the digital transformation and meet the goals recommended by the EU. EUreka3D and XR demonstrated how 3D digitisation requires more than equipment and software. It demands skills, infrastructure, quality standards, clarity of purpose, and structured workflows. We

are all well aware that the 2021 EC Recommendation on a common European data space for cultural heritage has accelerated the urgency to address these challenges.

The first EUreka3D project responded by offering guidelines, paradata frameworks, and a dedicated infrastructure. EUreka3D-XR progressed this agenda by answering a further question: *how can 3D content be activated through compelling, scalable and accessible XR experiences?* The three pilot scenarios, Girona, Bibracte, and the *Enkleistra* of St. Neophytos in Cyprus, serve as concrete illustrations of what re-use looks like in practice. Each addressed a different heritage challenge: reconstructing lost structures, making invisible archaeology visible, and allowing safe and accessible visitation to fragile heritage spaces.

These pilot scenarios did more than test tools, they validated the central premise of EUreka3D-XR: 3D content only reaches its full cultural, social and educational potential when activated through meaningful interpretation. High-quality 3D digitisation remains fundamental, but it is the combination of narratives, location-based context, XR visualisation, and, in some cases, virtual humans, that transforms the content from a digital asset into an experience that can inform, engage and inspire audiences.

## 4.2. REFLECTIONS ON THE XR TOOLS: REUSABILITY, OPENNESS AND ACCESSIBILITY

EUreka3D-XR explored five tools that compose the EUreka3D-XR Toolbox:

- AR Tour Builder
- AR Tour Experience
- AI 3D Builder
- 3D XR Studio
- Avatar Builder

Throughout the scenario pilot cases, each tool demonstrated its capacity to support CHIs in different parts of the 3D-to-XR value chain. The AR Tour Builder and AR Tour Experience empowered Bibracte to design and deploy an interpretive route that uses location-based AR to reveal what is absent or hidden on the archaeological site. The AI 3D Builder enabled CRDI in Girona to generate new 3D models from archival photography, amplifying the value of historical records and enhancing the reconstruction of lost walls. The 3D XR Studio allowed curators in Girona to craft a mobile AR walking tour combining models, media, and spatial storytelling. The Avatar Builder allowed CUT to create a guided mixed-reality encounter with the historical figure of St. Neophytos, addressing a scenario where access, fragility and site risk call for virtual mediation.

Across all these examples, reusability emerged as a guiding principle. The tools were developed generically from the outset so that Cultural Heritage institutions, regardless of country, discipline or size, can adapt them to their own needs. In Chapter 2.3, the tools' interfaces, supported formats, example user stories and output expectations were described so that external CHIs can understand not only *what the tools do*, but *how* they can be incorporated within real workflows.

The project also demonstrated that openness is key to democratising XR creation. None of these tools require advanced coding skills. Instead, they are structured as no-code or low-code environments that enable heritage professionals, curators, archivists, educators, to craft experiences directly. In addition, by integrating ingestion pathways from Europeana and the EUreka3D Data Hub, the AR Tour Builder and 3D XR Studio strengthen interoperability, allowing CHIs to easily bring existing 3D collections into new interpretive experiences.

Finally, accessibility guided tool design. The AR Tour Experience integrates multilingual capabilities, ensuring geographical and linguistic diversity are supported. The Avatar Builder, through the *Enkleistra* scenario, explored options to generate narration in multiple languages. The pilots also demonstrated that XR can provide access to fragile or physically inaccessible heritage, thus expanding equity in cultural participation.

## 4.3. THE SCENARIOS: BEST PRACTICE DEVELOPMENT AND DEPLOYMENT OF XR EXPERIENCES

The three demonstration scenarios described in Chapter 2.4 offered contrasting heritage contexts: urban archaeology in Girona, a vast archaeological landscape in Bibracte, and a confined and fragile monastic space in Cyprus. Each scenario acted as a testbed to expose practical challenges and evaluate tool functionality, data management needs, and interpretive strategies.

Girona illustrated the power of AI-assisted reconstruction. The AI 3D Builder allowed CRDI to transform archival photographs into 3D models of towers and bastions that no longer stand. As described in the pilot's narrative and content sections, the rich documentary record (plans, photographs, engravings, maps) enabled the production of carefully informed models that give citizens and visitors an enriched understanding of their lost built heritage. The scenario demonstrated the value of the 3D XR Studio in creating a walkable AR experience aligned with the city's geography and the historical narrative.

Bibracte presented a very different challenge: how to make visible what is mostly invisible. In this prehistoric city where many remains lie underground or exist only as subtle traces, the AR Tour Builder and AR Tour Experience created a geolocated circuit that reveals archaeological layers, hypotheses and contextual knowledge at the exact place where visitors stand. As outlined in the methodological and content sections, the pilot pushed the tools to accommodate varied media, multiple POIs, and complex interpretation needs. It also highlighted the importance of fine-tuning AR anchoring and georeferencing, valuable insights that will shape the tools' further development.

St. Neophytos' *Enkleistra* brought attention to conservation, accessibility and immersive narrative design. Using the Avatar Builder, CUT developed an interactive virtual encounter with the saint, supporting both an on-site mixed-reality experience and a fully virtual mode for schools or remote users. As explained in the

workflow and narrative sections, this approach demonstrates how XR can support fragile heritage that experiences intense visitor pressure or is physically difficult to access. It also shows how avatars, when used responsibly, can facilitate deeper engagement with intangible heritage, spiritual practices, pedagogy, and the contemplative dimension of monastic life.

Together, these case studies demonstrate how the XR Tools can support cultural heritage interpretation across a spectrum of scenarios: reconstructing the past, revealing the invisible, and safeguarding fragile places.

## 4.4. INFRASTRUCTURE: THE EUREKA3D DATA HUB

A recurring theme is the critical importance of a secure, inter-operable and European-based infrastructure.

The EUreka3D Data Hub, developed in EUreka3D and further adapted in EUreka3D-XR, provides CHIs with:

- single-sign-on via established European AAI infrastructures
- storage for raw 3D data and optimised formats
- metadata and paradata management
- a web-based viewer compatible with Europeana
- programmatic access via APIs
- allocation of Persistent Identifiers to support long term preservation of online content
- a direct publishing pathway to Europeana that simplifies the workflow for CHIs

The EUreka3D Data Hub addresses several structural challenges in the sector: dependence on commercial non-EU platforms, fragmentation of workflows, and difficulty in managing large 3D datasets. It also lowers barriers for smaller institutions that lack their own IT infrastructure.

EUreka3D-XR tested not only the integration of 3D datasets but also the hosting of tools themselves, showcasing the Data Hub's

potential to become a central repository for both content and XR-creation resources. This positions the EUreka3D Data Hub as a foundational pillar of a sustainable ecosystem for 3D cultural heritage in Europe.

## 4.5. KNOWLEDGE TRANSFER AND CAPACITY BUILDING: EMPOWERING STAKEHOLDERS FOR THE 3D DIGITAL TRANSFORMATION

One of the project's strongest achievements, as detailed in Chapter 3.2, is the breadth and depth of its capacity-building programme. The hybrid events, online training, webinars, focus groups, and hands-on workshops ensured that the project's tools and methodologies were not just demonstrated but truly embedded in learning processes across Europe and beyond.

The publication of step-by-step manuals, videos, the EUreka3D Guidelines, and the Europeana MOOC "3D Digitisation: Prepare for Success" created a rich suite of re-usable learning resources. Translations into multiple EU languages further supported accessibility and uptake.

The testimonies from participants, including archivists, educators, researchers and cultural managers, confirm that these activities significantly increased confidence and understanding. Participants particularly valued the combination of strategic insights (such as preservation, standards and policy frameworks) and practical hands-on sessions (using tools such as the AI 3D Builder or the AR Tour Builder).

The project's investment in capacity building is part of its lasting legacy. The 3D digital transformation requires not only tools, but people who can use them, adapt them, and share them.

## 4.6. KEY LESSONS LEARNED ACROSS THE PROJECT

A number of overarching insights have emerged:

### 1. Quality Is Foundational

Tools and XR experiences function best when built on high-quality digitisation. The VIGIE Study 2020/654 recommendations, integrated into EUreka3D's Guidelines, continue to serve as a critical standard for capturing, documenting and preserving 3D assets.

### 2. Paradata Is Essential

Without transparent documentation of methods, transformations and interpretive choices, 3D models risk losing research value and long-term credibility. EUreka3D-XR reinforced that paradata must be considered early in the digitisation workflow –not retrofitted later.

### 3. XR Must Be Purpose-Driven

All three scenarios demonstrated that XR is most impactful when addressing a real interpretive or accessibility challenge, not when used as an isolated technological showcase.

### 4. Accessibility and Inclusiveness Expand Impact

XR can make heritage accessible to audiences who cannot physically visit a site due to geography, fragility, mobility limitations or conservation needs.

### 5. Interoperability and Sustainability Require Shared Infrastructure

The EUreka3D Data Hub and Europeana provide the necessary backbone for long-term preservation, accessibility and discoverability.

### 6. Skills Development Must Accompany Technology

Without structured training and documentation, the sector cannot keep pace with rapid developments in XR and 3D digitisation.

## 4.7. TOWARDS A COMPETENCE CENTRE FOR 3D CULTURAL HERITAGE

One of the most important long-term outcomes of EUreka3D-XR is the momentum toward establishing a Competence Centre for 3D Cultural Heritage. As identified above and referenced in the sustainability planning, the Competence Centre would serve as a durable hub for:

- maintaining and evolving training materials
- coordinating standards and best practices
- supporting the stewardship of the EUreka3D Data Hub
- providing strategic guidance to CHIs
- fostering community exchange among researchers, technologists and cultural professionals

The Competence Centre is envisioned to be a collaborative entity able to gather expertise, maintain continuity and ensure that lessons from EUreka3D and EUreka3D-XR continue to shape future initiatives.

## 4.8. A VISION FOR THE FUTURE

As Europe continues its transition into the common European data space for cultural heritage, the importance of high-quality 3D content and meaningful XR experiences will only grow. EU Member States have committed to ambitious targets for digitisation, interpretation and preservation. Initiatives like Twin it!, the European Collaborative Cloud for Cultural Heritage, and the evolving Europeana framework highlight a collective momentum that is both technological and cultural.

EUreka3D-XR stands as a concrete contribution to this landscape:

- a demonstration of how standards and paradata can strengthen trust and interpretability
- an example of how EU-based infrastructure can safeguard sovereignty and long-term access

- a set of tools that democratise creative expression in XR
- a suite of scenarios that show how 3D content can be reused in ways that are socially, historically and educationally meaningful
- a rich repository of learning resources that empower the sector to grow

Above all, the project shows that 3D and XR are not ends in themselves. They are the foundations for cultural, interpretive, educational and civic engagement. They help us see what is lost, understand what is hidden, experience what is fragile, and imagine what cannot otherwise be seen.

# 5. Final Reflection

EUreka3D-XR concludes with a powerful message: Europe's Cultural Heritage sector is ready to move from experimentation to sustainable practice in 3D and XR. The tools exist. The infrastructure exists. The skills are growing. The demand for preservation, interpretation, education, accessibility and engagement is clear.

What comes next is a shared responsibility to maintain what has been built, to nurture the emerging networks and capacities, to adapt to new technologies, and to continue enriching the Cultural Heritage landscape with high-quality, trustworthy and imaginative digital content.

With the advances achieved in this project, and with the prospective foundation of a Competence Centre for 3D Cultural Heritage, Europe is well-positioned to lead the next decade of innovation in cultural heritage digitisation and immersive experience design.

The work does not end here. It evolves. And it evolves with confidence.

# Annexes

## ANNEX 1. LIST OF ACRONYMS AND ABBREVIATIONS

| ACRONYM | DESCRIPTION |
|---|---|
| 2D | Two-dimensional |
| 3D | Three-dimensional |
| AAI | Authentication and Authorisation Infrastructure |
| AARC | Authentication and Authorisation for Research and Collaboration |
| AARC BPA | AARC Blueprint Architecture |
| API | Application Programming Interface |
| AR | Augmented Reality |
| CHI | Cultural Heritage Institution |
| CI/CD | Continuous Integration / Continuous Delivery |
| CMS | Content Management System |
| DDNS | Dynamic DNS |
| DNS | Domain Name System |
| ECCH | European Collaborative Cloud for Cultural Heritage |
| EDM | Europeana Data Model |
| EOSC | European Open Science Cloud |
| GPU | Graphics Processing Unit |
| GUI | Graphical User Interface |
| ILO | Intended Learning Outcome |
| IM | Infrastructure Manager |
| MOOC | Massive Open Online Course |
| MR | Mixed Reality |
| Metadata | Structured data about identification, management, type, use and location of physical or digital resources |
| OAI-PMH | Open Archives Initiative Protocol for Metadata Harvesting |

| ACRONYM | DESCRIPTION |
|---|---|
| OER | Open Educational Resources |
| OIDC | OpenID Connect |
| PID | Persistent Identifier |
| POI | Point of Interest |
| Paradata | Information about the creation processes and the methodologies used in the creation of a digital object and its provenance |
| TLS | Transport Layer Security |
| VCS | Version Control System |
| VR | Virtual Reality |
| XR | Extended Reality |

## ANNEX 2. EDITORIALS

Creating and promoting editorials that highlights not just the activities of the EUreka3D-XR project but their relevance to the narratives of European history and culture gives cultural heritage objects value and contextualises them in new ways. These stories show us more about our shared human history and are crucial in engaging audiences and helping them to understand the value of the project.

Sharing the achievements of the EUreka3D-XR project, including learnings, case studies and wider reflections on the possibilities 3D and XR technologies hold for cultural heritage data has been a key activity of the project. Project partners published rich and diverse editorials across Europeana's platforms, including Europeana.eu and Europeana Pro. An overview of all publications to January 2026 is provided below.

The editorials covered a range of topics from the technical (like explaining VR to a professional audience), to the actionable (such as how to join events, courses and build your skills), to the historical (opportunities to learn about the case studies of Girona, Bibracte and Cyprus).

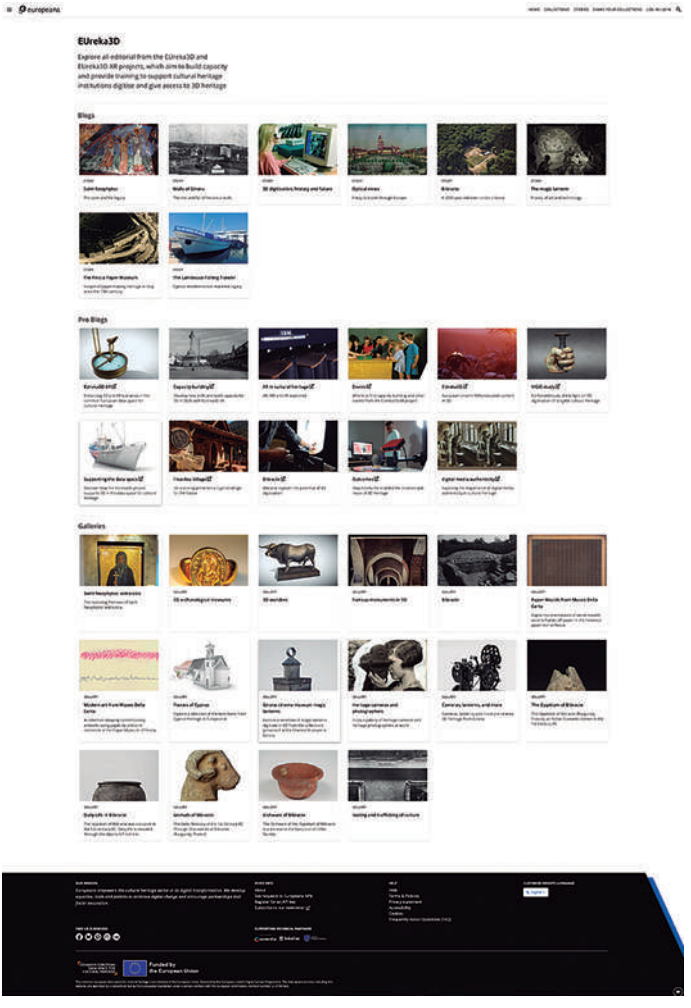


Fig. 51. Screenshot of the webpage collecting all Europeana editorial from EUreka3D and EUreka3D-XR projects

WEBPAGE COLLECTING ALL EDITORIAL FROM EUREKA3D AND EUREKA3D-XR

https://www.europeana.eu/eureka3d

# ANNEX 3. PRESENTATION OF THE PROJECT PARTNERS

## Coordinator: PHOTOCONSORTIUM, Italy

PHOTOCONSORTIUM

Photoconsortium is the Europeana accredited aggregator for photography. It has participated since 2016 in the Europeana DSI series of projects for the maintenance and improvement of the Europeana platform and successfully participated in various generic service projects of the Connecting Europe Facility (CEF) Programme, to enrich the Europeana collections. In addition to a deep knowledge of the Europeana aggregation mechanisms and strategy, and to the embedment in the various working group of the Europeana network, Photoconsortium as an association adds value to EUreka3D-XR in force of its network, comprising over 30 members representing the whole Cultural Heritage sector. Photoconsortium is the project coordinator and also leads the work package on re-usable scenarios.

## Cyprus University of Technology, Cyprus

Cyprus University of Technology

Cyprus University of Technology (CUT) is national representative of Cyprus in the newly established Commission Expert Group on the common European data space for cultural heritage (CEDCHE) expert group, as well as member of DARIAH. CUT participates in EUreka3D-XR with its Laboratory on 3D digitisation where the EU Study on quality in 3D digitisation was developed and the coordinator of ViMM and ViMM Plus projects was conducted. CUT was part of EUreka3D as a content provider, and in this project is developing one of the three XR pilot scenarios, the creation of a new life of St. Neophytos *Enkleistra* in Cyprus in the virtual space.

## CRDI Ajuntament de Girona, Catalonia (Spain)

Ajuntament de Girona

CRDI, the Centre for Image Research and Dissemination, is the image archive of the Municipality of Girona. Based on the accumulated knowledge, CRDI undertook the development of a working methodology focused on the search for image quality which, together with the preservation and digitisation policy, made it possible to contribute thousands of digitised documents to Europeana. CRDI holds expertise on metadata curation and management, and has extensive experience in participating in European projects in the cultural field over the last ten years. In EUreka3D it was one of the content providers and the leader of work package 4 (Dissemination and Communication). In EUreka3D-XR, CRDI develops one of the three XR pilot scenarios, the virtual visualisation of the middle-ages walls of the city of Girona. CRDI is also responsible for the dissemination and the communication of the project.

## Bibracte, France

BIBRACTE

Bibracte EPCC, a key actor of the French archaeological community, is the managing organisation of a permanent archaeological research program and custodian of the scientific archives produced on the eponymous site since the beginning of excavations in the 1860s. Bibracte owns a unique capital of information to explore new ways of using digital technologies throughout the archaeological process, from taking data in the field to sharing it with all the users concerned. Bibracte was one of the content providers in EUreka3D, and contributed with archaeological objects and sites, digitised in 3D and available in Europeana. In EUreka3D-XR, Bibracte develops one of the three XR pilot scenarios, the XR narrative of excavations in process in the archaeological site.

### Europeana, The Netherlands

Complementary to all the roles played by the other partners, the Europeana Foundation (EF) participates as beneficiary in EUreka3D-XR to provide its advice on a series of key aspects. On one hand, EF advice guarantees the compliance of the project's actions, and in particular the new digital environment, with the existing Europeana CSP (e.g., access to links, secure connections and in general the correct implementation of the EPF). On the other hand, EF contributes to assess the sustainability of the technical services, to identify the benefits that can derive for the European common data space for cultural heritage. EF will continue to provide the fundamental liaison with the common European data space for cultural heritage and support the project's outreach publishing editorials on its channels.

### meemoo, Belgium

meemoo is a non-profit organisation that, with help from the Flemish Government, is committed to supporting the digital archive operations of cultural, media and government organisations. Together with partners, meemoo brings the past back to life and prepares it for the future. The organisation safeguards the archive content digitally, and makes it accessible and usable. In EUreka3D-XR, meemoo is responsible for the Capacity Building programming and implementation, for participants involved in the project, the Europeana and Data Space communities, and Cultural Heritage institutions in general.

## imec, Belgium

imec's core research team ETRO (Department of Electronics and Informatics of the Vrije Universiteit Brussel) is the world-leading R&D and innovation hub in nanoelectronics and digital technologies and focuses on sensors, image and multi-dimensional signal processing. imec-ETRO-VUB has a long-standing expertise in digital imaging and video processing for medical imaging, media systems, industrial processing and digital heritage. In EUreka3D-XR, imec is the leader of the Supporting Technologies work package, providing the supervision of the technological articulation between the cloud resources, the 3D requirements and the XR applications, maintaining a constant dialogue with the Cultural Heritage institutions.

## EGI Foundation, The Netherlands

The EGI Foundation (also known as Stichting EGI and abbreviated as EGI.eu) is a non-for-profit foundation established under the Dutch law to coordinate the EGI Federation (abbreviated as EGI), an international collaboration that federates the digital capabilities, resources and expertise of national and international research communities in Europe and worldwide. The main goal is to empower researchers from all disciplines, including digital cultural heritage, to collaborate and to carry out data- and compute-intensive science and innovation. In EUreka3D, EGI developed the EUreka3D Data Hub. In the continuation project EUreka3D-XR, EGI continues to provide the cloud resources needed to store, visualise and process the cultural content provided by CHIs.

## Wroclaw Centre for Networking and Supercomputing, Poland

Wroclaw University of Science and Technology hosts the WCSS Wroclaw Centre for Networking and Supercomputing. They are part of the Polish Cloud Grid and take part in EUreka3D-XR as a member of the EGI Federation. WCSS is involved in the project as a provider of storage and computing resources.

## National Technical University of Athens, Greece

The National Technical University of Athens is structured according to the continental European system for training engineers, with an emphasis on solid background. NTUA is historical partner in the technical development of the Europeana platform and a technology partner of the common European data space for cultural heritage project as well as coordinator of the ongoing project “AI4Culture: An AI platform for the cultural heritage dataset”. In EUreka3D-XR, NTUA is the task leader of the XR Toolbox development. They also provide two of these tools, an open online application that will enable CHIs to set up custom AR tours accompanied with a mobile app that serves the tours to their visitors as a phygital experience.

## Software Engineering, Italy

Swing:It is a very skilled Italian SME founded in 2010, leader in provisioning of XR solutions, expert on the development of XR applications focusing on developing technologies that enhance User eXperience (UX) and Interfaces (UI). Member of EuroXR association, it acted as technological leader of the COSME project CHARM on innovating rural tourism through adoption of XR technologies. In the project, Swing:It aims to narrow the divide between reality and virtuality, making advanced XR technologies user-friendly and widely accessible. Swing:It provides EUreka3D-XR with high-level competencies on design and development of XR applications, integration and exploitation of AI functionalities. They develop two applications within the toolbox: an AI application for a tool for the creation of 3D models starting from 2D images and the creation of XR/AR experiences.

## MIRALab, Switzerland

MIRALab is an R&D SME based in Switzerland, a spin-off of the MIRALab of the University of Geneva. The group works in the field of Computer Graphics, Virtual Worlds and generative AI. Since 2000, MIRALab has modelled the life of ancient sites such as the Pompei site or the Roman theatre Aspendos in Turkey. From existing frescos, MIRALab has modelled 3D inhabitants in a tavern on the Pompeii cultural heritage site using AR technology. In EUreka3D-XR, MIRALab contributes one of the toolbox applications, providing the modelling and simulation of the *Enkleistra* of St. Neophytos by re-enacting the life inside the monument.

## PARTNERS

PHOTOCONSORTIUM

imec

egi

WCSS

Cyprus University of Technology

Ajuntament de Girona

BIBRACTE

europeana

wingit Software Engineering Italia

meemoo FLEMISH INSTITUTE FOR ARCHIVES

MIRALabSARL

## OFFICIAL MEDIA PARTNER

DIGITAL MEETS CULTURE .net

www.digitalmeetsculture.net

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