D3.1 Technical Requirements

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Executive summary

This deliverable outlines the technical requirements for the five tools developed within the EUreka3D-XR project. These tools address different aspects of content authoring, user interaction, and immersive experience delivery. While they are demonstrated through three distinct pilot scenarios, the tools themselves are designed to be generic and adaptable across a wide range of use cases. Their integration with the EUreka3D Data Hub ensures alignment with broader data infrastructures and contributes to long-term sustainability and interoperability.

This deliverable is structured as follow:

- **Section 1 - Introduction:** provides a general introduction and outlines the broader context within the project.
- **Section 2 - The EUreka3D-XR tools:** introduces the five tools developed within the project.
- **Section 3 - The EUreka3D-XR scenarios:** gives a brief overview of the three pilot scenarios in which the tools will be demonstrated.
- **Section 4 - Technical requirements:** details the technical requirements of each tool, shaped by the needs and constraints of the pilot scenarios.
- **Section 5 - EUreka3D-XR Cloud Infrastructure:** focuses on the EUreka3D Data Hub and the infrastructure extensions required within the EUreka3D-XR project.
- **Section 6 - Additional considerations:** offers forward-looking considerations, including integration with the common European data space for cultural heritage and initial reflections on the project's expected impact.
- **Section 7 - Conclusions**: general conclusions and closing.

1. Introduction

This deliverable defines the technical requirements for the tools and infrastructure developed within WP3 of the EUreka3D-XR project. These requirements are based on the needs emerging from the three pilot scenarios (see D2.1) and are aligned with the broader objectives and data workflows established in WP2 and WP4.

The focus of this document is on five tools that support immersive and interactive cultural heritage experiences. These are:

- AR TOUR BUILDER (NTUA)
- AR TOUR EXPERIENCE (NTUA)
- AI 3D BUILDER (Swing:It)
- 3D XR STUDIO (Swing:It)
- AVATAR BUILDER (MIRALab)

In the parenthesis the name of the developer partner is provided.

Each tool supports one or more pilot scenarios, while remaining sufficiently generic to be reused in other cultural heritage contexts. The tools have been planned and designed in close collaboration with pilot partners, and are being developed iteratively based on functional needs and technical constraints.

1.1 Role of this deliverable in the project

This deliverable defines the technical requirements for the tools and infrastructure developed in Work Package 3 (WP3), based on the pilot scenarios defined in WP2. These requirements serve as a foundation for the implementation of the five tools that will support immersive, interoperable and user-oriented applications for cultural heritage. The relation with WP2 is further detailed in Section 1.2.

D3.1 is closely linked to *D2.1 Pilot specification and planning* and provides the technical input necessary for the development, integration and testing of the tools within the data hub infrastructure which is also further developed in WP3. It plays a key role in ensuring coherence between user needs, scenario design and technical implementation. This D3.1 deliverable is a means of verification for the project's milestone 8 "Delivery of the technical requirements".

1.2 Relationship with the re-usable scenarios (WP2)

The development of technical requirements in T3.1 is closely connected to the pilot planning and needs developed in T2.1. The five tools described in this deliverable are not developed in isolation, but are driven by concrete use cases across the three pilot scenarios, namely the Girona pilot (led by CRDI), the Bibracte pilot (led by BIBRACTE) and the Paphos pilot (led by CUT) as described in deliverable D2.1. These pilots serve as validation environments that influence design choices, feature priorities and integration workflows.

At the same time, the tools are designed as generic components, intended for broader applicability beyond the primary scenario in which each is first deployed. This general-purpose approach is aligned with the project's goal to create sustainable and reusable solutions that can support a wider range of cultural heritage contexts across Europe.

For that reason, we also foresee demonstrations of tools in secondary scenarios in addition to their primary one. This cross-validation strategy ensures that technical requirements are not narrowly scenario-specific, but respond to a more diverse and representative set of needs.

Deliverables D2.1 and D3.1 have been developed in close collaboration, through joint planning and consistent terminology. WP2 defines the pilot objectives and planning; WP3 responds with the design and implementation of the supporting tools and infrastructure. The iterative exchange between both work packages has been instrumental in shaping the functional and non-functional requirements presented in this deliverable.

1.3 Methodology

The definition of the technical requirements for the tools developed in EUreka3D-XR has followed an iterative and collaborative process. The project delivers five tools, all integrated with the EUreka3D Data Hub infrastructure, and deployed in three real-life pilot scenarios. These scenarios demonstrate how digital cultural assets can be reused to create XR experiences that engage site visitors and wider audiences. In doing so, they function as testbeds for the tools, supporting prototype validation, incremental development, and user evaluation.

While the tools are designed to be broadly reusable, not limited to the scenarios in the project, the interplay between WP2 (pilot planning) and WP3 (tool development) has been essential. Scenario needs and tool capabilities have co-evolved through ongoing alignment between Cultural Heritage Institutions (CHIs) and technology partners. This dual track was part of the original project vision and actively shaped during the proposal phase in 2023/2024 through joint brainstorming.

Since the project started on February 1st 2025, regular coordination meetings were organised by the WP2 leader (Photoconsortium) and WP3 leader (imec) to ensure continued alignment. Key preparatory calls were held on 8 and 19 February 2025, followed by a dedicated session at the kick-off meeting in Pisa (27 February 2025). It was agreed to continue joint discussions in biweekly 2 hour calls, focusing in parallel on the technical requirements and pilot planning. The results are reported in the present deliverable (D3.1) and in the complementary deliverable D2.1.

These discussions extended beyond functional design. They also addressed two critical areas: (1) the requirements for integrating the new tools with the EUreka3D Data Hub, ensuring technical interoperability and closing identified gaps; and (2) the representation of tools, collections and XR experiences in the common European data space for cultural heritage. This includes alignment with ongoing extensions to the Europeana Data Model to provide a better representation of 3D objects and their visualization on the Europeana website.

In M6 of the project, on the 8th of July 2025, the tools and scenarios were presented in their early stage to the experts composing the EUreka3D-XR Advisory Board, to collect first impressions and preliminary feedback. This is part of the iterative evaluation and development process for the tools, which includes both internal partners and external stakeholders. The next occasion to meet again with the Advisory Board will be in October 2025 in the project's focus group, which will evaluate the 5 tools in sight of the delivery of the first prototype with beta versions operational (corresponding to deliverable D3.4 *EUreka3D-XR toolbox beta version* due at M9).

1.4 List of Acronyms

For clarity and ease of reference, Table 1.1 provides an overview of acronyms used throughout this document.

Table 1.1: List of Acronyms.

Acronym	Description
AAI	Authentication and Authorisation Infrastructure
AARC	Authentication and Authorisation for Research and Collaboration
AARC BPA	AARC Blueprint Architecture
API	Application Programming Interface
AR	Augmented Realty
CHI	Cultural Heritage Institution
CI/CD	Continuous Integration / Continuous Delivery
DDNS	Dynamic DNS
DNS	Domain Name System
ECCCH	European Collaborative Cloud for Cultural Heritage
EDM	Europeana Data Model
EOSC	European Open Science Cloud
GPU	Graphics Processing Unit
GUI	Graphical User Interface
IM	Infrastructure Manager
MR	Mixed Reality
OAI-PMH	Open Archives Initiative Protocol for Metadata Harvesting
OIDC	OpenID Connect
PID	Persistent Identifier
TLS	Transport Layer Security
VCS	Version Control System
VR	Virtual Reality
XR	Extended Reality

2. The EUreka3D-XR tools

EUreka3D-XR, five tools are being developed to enable the creation and delivery of engaging XR experiences using digital cultural heritage assets. These tools are:

1. **AR Tour Builder**: online tool for creating custom AR tours, retrieving 3D objects from CH repositories such as Europeana and associating them with locations on a map (NTUA).
2. **AR Tour Experience**: mobile app that allows visitors to experience phygital tours by superimposing 3D digital objects onto the physical world (AR) and providing other types of accompanying digital information (NTUA).
3. **AI 3D Builder**: 3D Modelling software pipeline based on AI and using digital photo archives (Swing:It)
4. **3D XR Studio**: Web tool for creating XR/AR experiences, also using a range of predefined layouts for UX and UI (Swing:It).
5. **Avatar Builder**: Reusable datasets and guidelines for creating virtual human characters in cultural heritage experiences (MIRALab).

The following subsections provide a descriptive overview of each tool, including its purpose and intended users. The technical requirements for each tool are detailed separately in Section 4.

2.1 AR Tour Builder (NTUA)

The AR Tour Builder, developed by NTUA, is an online tool designed to create and manage location-based augmented reality (AR) tours, which are delivered through the AR Tour Experience mobile application. Together, these two tools offer CHIs and other stakeholders a complete solution for authoring and deploying custom AR tours.

The AR Tour Builder allows CH professionals to design phygital tours by linking 3D objects and other types of content (e.g. images, audio, text) to specific outdoor locations on a map. The platform includes robust asset management capabilities through an integrated library system that is interoperable with established platforms such as Europeana and the EUreka3D Data Hub. The tool operates through project-based workflows, where teams can specify multiple tours (e.g. short and longer tours, tours addressed to children etc) for the same geographical area, organised under Projects. Each tour consists of a set of georeferenced Points of Interests, each of which can encompass a set of various types of media assets and be associated with contextual information particular to the specific tour. The information accompanying each PoI can be multilingual by design. The tours can then 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. The relation between both tools and the EUreka3D Data Hub is illustrated in Figure 2.1.

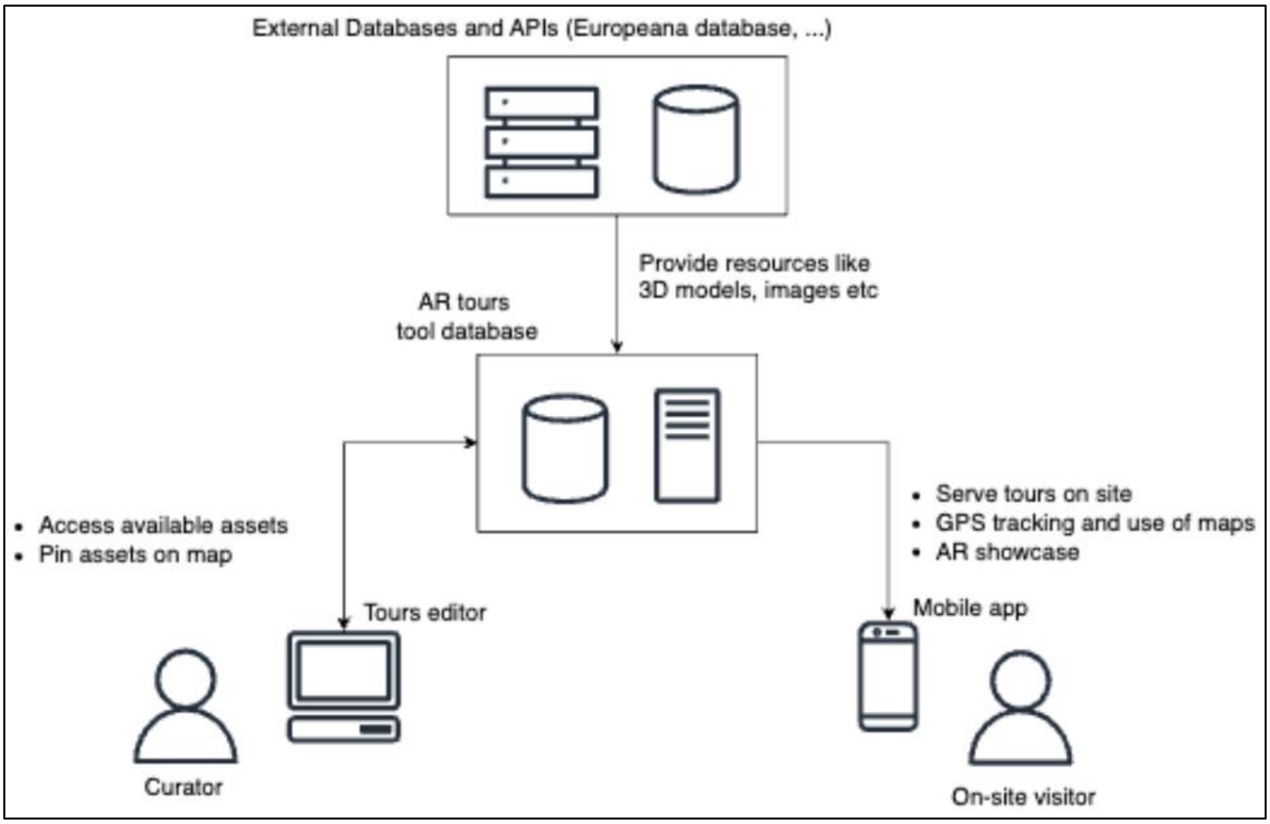

Fig. 2.1: Overview of how the web application for creating on-site tours interacts with the mobile app to the tour to the visitor.

2.2 AR Tour Experience (NTUA)

The AR Tour Experience complements the AR Tour Builder tool and serves the tours designed by the CH professionals to the on-site visitor. Through a clean and intuitive interface, visitors can browse and select tours available on their location based on their preferences.

The app uses GPS to provide real-time navigation, detecting when users approach PoIs and surfacing contextual content through a notification system. Each PoI delivers rich multimedia experiences, including text, images, video, audio and 3D models, which can be displayed either in a dedicated 3D viewer or as overlays on the physical environment, as captured by the mobile camera. This enhances physical environments with virtual reconstructions, objects that are no longer present in the environment where they were discovered (e.g. museum exhibits) and educational content. The app also supports tour progression tracking and offers practical features such as pre-downloadable content for low-connectivity environments.

2.3 AI 3D Builder (Swing:It)

The AI 3D Builder is a semi-automated 3D modelling pipeline designed to generate high-quality 3D objects from photographic sources. Developed by Swing:It, the tool leverages artificial intelligence and photogrammetry techniques to convert 2D images, often sourced from digital photo archives, into clean, optimised 3D mesh models suitable for use in XR applications. The process is designed to be accessible to cultural heritage professionals who may not have prior experience in 3D modelling, lowering the barrier to entry for digitisation and reuse of heritage content.

The pipeline consists of a web-based user interface where users upload collections of 2D images, define parameters, and trigger the generation process. Once submitted, the pipeline performs several automated steps, including background removal, image alignment, structure-from-motion processing, and mesh reconstruction. Post-processing steps such as texture refinement and simplification are also applied to ensure that the resulting 3D models are lightweight and compatible with web-based and AR/XR experiences. The generated assets can then be exported and uploaded to the EUreka3D Datahub and integrated for use in the EUreka3D tools or for other purposes.

The pipeline supports several input formats and is optimised for photographic sets capturing cultural artefacts, sculptures, or architecture. While primarily designed to work with newly captured image sets, the tool also supports repurposing of historical photo collections, offering new life to digitised materials that were not originally intended for 3D reconstruction.

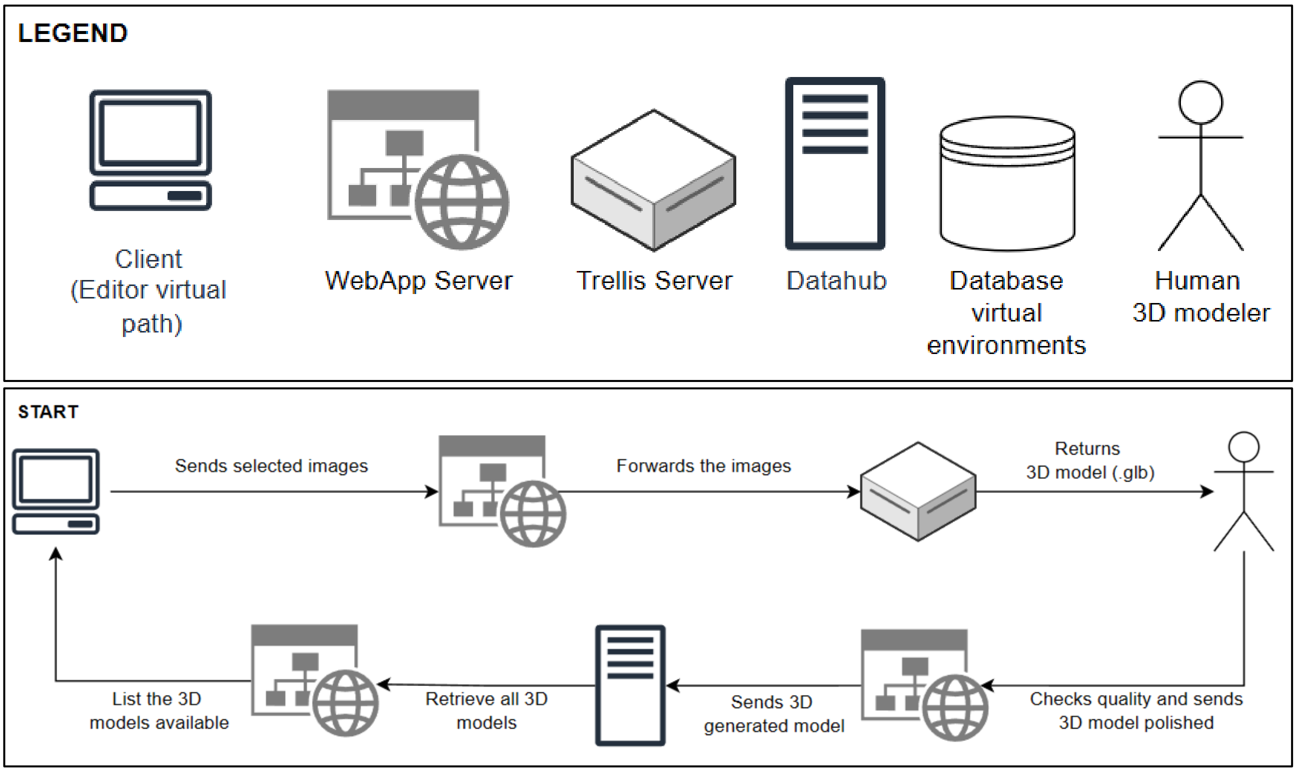

Fig. 2.2: Overview of how AI 3D Builder works by creating the 3D models.

As illustrated in Figure 2.2, users interact with the Client Interface selecting a set of 2D images to use for 3D reconstruction by sending them to the WebApp Server. The server uses Trellis and processes the request to create the model. After the transformation process ends (typically in a few minutes), the pipeline provides a downloadable .GLB model. A model whose quality is considered inadequate, can be polished by a human 3D modeler. A model whose quality is evaluated good enough then can then be sent to the Data Hub which will store and manage the model data. The connection between the Data Hub and the WebApp server allows users to retrieve a list of the 3D models associated with their account, available for download.

2.4 3D XR Studio (Swing:It)

The 3D XR Studio is a web-based authoring tool that enables users to create immersive XR and AR experiences by combining a variety of digital assets, such as 3D models, images, video, audio, and text. Designed with cultural heritage professionals in mind, the platform offers a user-friendly environment that requires no coding skills and focuses on visual storytelling, accessibility, and intuitive interaction.

The tool features a flexible layout system based on predefined templates that support a range of narrative structures and interaction flows. Users can select from various presentation styles to best fit the needs of their content and audiences, whether for on-site installations or remote digital experiences. Experiences are assembled through a graphical user interface where content blocks can be combined, previewed, and adjusted for different display formats.

The 3D XR Studio includes options for multilingual content, ensuring accessibility to diverse audiences. In addition, it supports the reuse of digital cultural heritage assets, aligning with the broader objectives of the EUreka3D-XR project to enhance discoverability and engagement with Europe's digital heritage.

By focusing on ease of use and visual coherence, the 3D XR Studio lowers the technical threshold for creating XR content, enabling institutions of varying sizes and capacities to participate in immersive storytelling and experimentation with new forms of audience engagement.

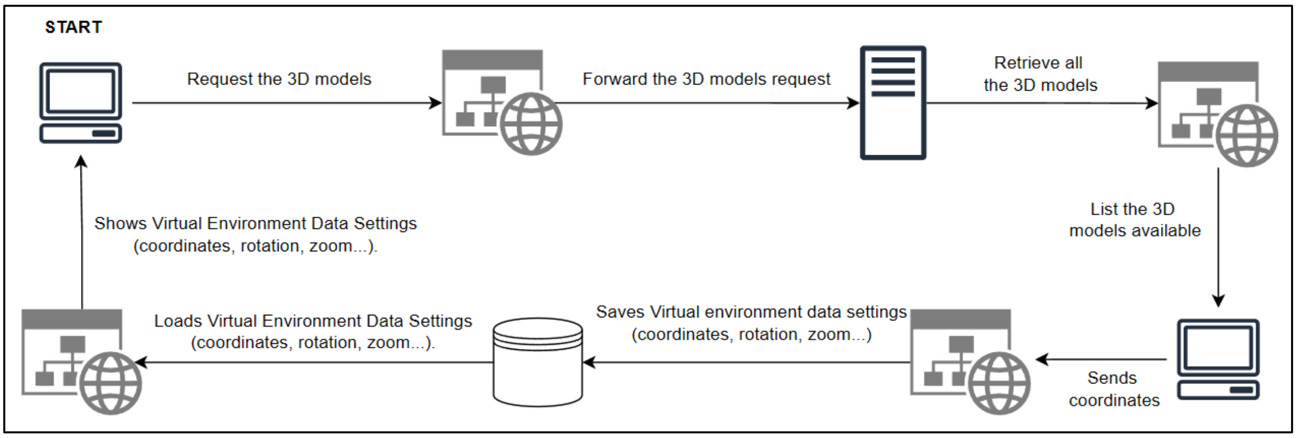

Fig. 2.4: Overview of how the 3D XR Studio manages storing/retrieving data made by curators.

As illustrated in Figure 2.4, curators use the WebApp Client Interface to log-in and manage the 3D models to use in their location. The request is sent to the Data Hub, providing a list of all the 3D models available for them directly to the curator's device. The curator can specify the desired coordinates and transformation options (such as placement.) to apply to each selected model. After the editing process ends, curators can save such data and send them to the Database Virtual Environments. These data can then be loaded for future editing sessions by curators.

After loading an already saved set of such data, using the mobile component of 3D XR Studio both curators and end users will be able to see through their devices the placed and edited models at the established set of coordinates in Augmented Reality.

2.5 Avatar Builder (MIRALab)

The Avatar Builder developed by MIRALab provides a structured methodology for creating animated virtual human characters both for web visualisation and for VR/MR storytelling. Rather than a software tool, it consists of a curated set of assets, guidelines, and best practices for using open-source tools to support the development of culturally and historically grounded avatars for immersive experiences.

This workflow is demonstrated within the EUreka3D-XR project through the creation of virtual monks for the Saint Neophytos scenario. It includes a reusable dataset of 3D character models, animation files, and synchronised voice tracks, designed to be adaptable across platforms and transferable to similar narrative contexts. Assets are exported in standardised formats, GLB for web visualisation and FBX for VR/MR environments, ensuring compatibility with commonly used 3D engines such as Unity and Babylon.js (see Figure 2.5).

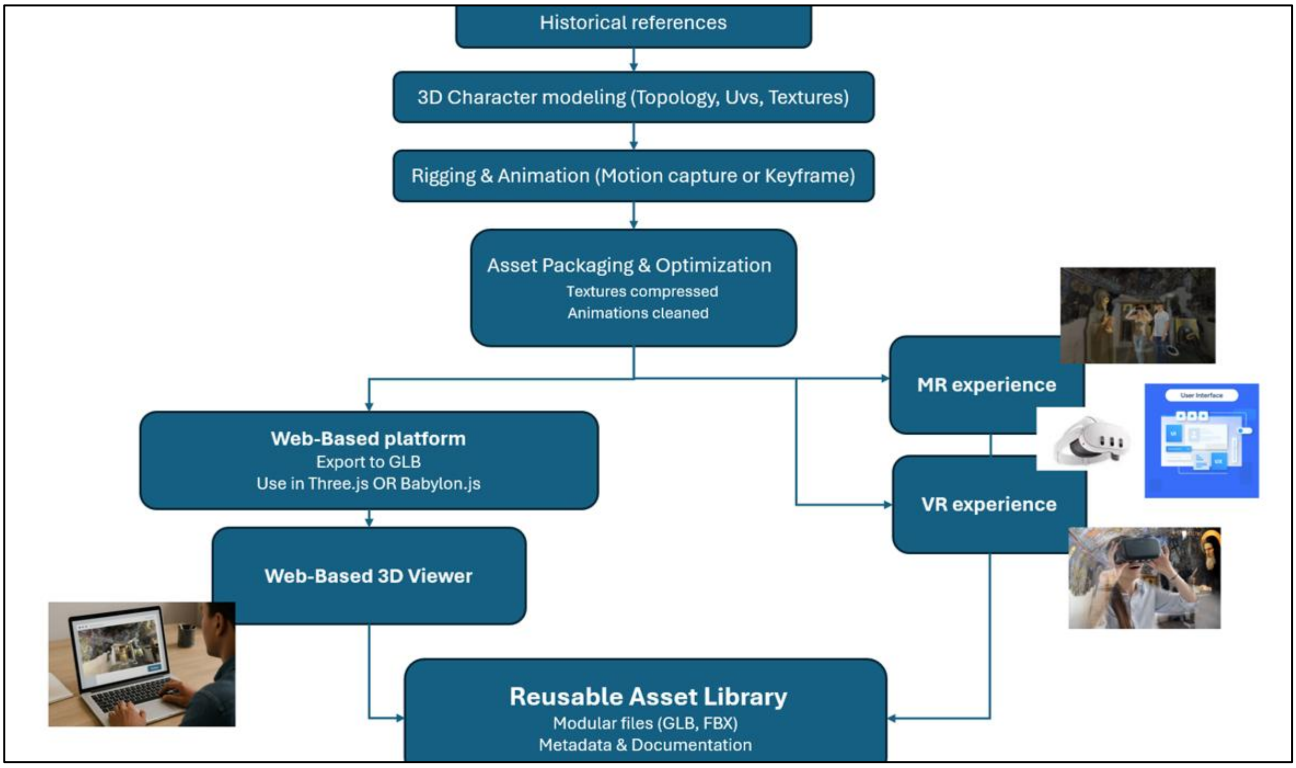

Figure 2.5: Overview of the Avatar Builder Workflow.

The workflow illustrates the process of creating culturally grounded animated virtual humans, beginning with historical references and progressing through 3D modelling, rigging, animation, and asset optimisation. This process can be carried out using open-source tools, ensuring accessibility and adaptability for a wide range of users and institutions. Final outputs are exported in standardised formats (GLB, FBX) and deployed across web-based viewers, VR, and MR platforms. A reusable asset library supports modularity and cross-platform compatibility.

A key feature of the Avatar Builder workflow is its modular architecture. Each component, models, animations, and audio, can be reused, replaced, or adapted for other similar avatars or similar contexts. Animation clips are provided in both precomputed and rig-based formats, allowing for flexible retargeting to new similar characters. Additionally, each asset is accompanied by structured metadata, detailing its technical specifications, usage context, and relevant historical or cultural background.

While current EUreka3D viewers do not yet fully support animated characters, the Avatar Builder workflow anticipates integration in future updates of the platform. It thus serves not only as a dataset, but as a reproducible and extensible workflow that lays the foundation for broader adoption of virtual human representations in cultural heritage storytelling.

2.6 Closing remarks

Please note that both the 3D XR Studio and the AR Tour Experience deliver immersive content to end users, they serve different purposes and rely on distinct workflows.

The 3D XR Studio is based on two components: a web and a mobile one, tightly connected to each other. The web component allows planning a path, managing 3D models, managing point of interests and editing augmented information (such as text, audios, pictures, videos, hyperlinks, etc.) that the end users will be able to access via the mobile component. By accessing the mobile component—which includes a subset of the web component's features—curators and creators can check the outcomes of the path creation process, verify whether the chosen settings are correct and appropriate for the real environment (via XR visualization), and proceed to fine-tune the path and 3D models (e.g., using app tools that serve as reference points to better understand the correct placement of the 3D models). Among its features, there is the chance to set occlusion points (such trees or real walls) to the final user's view. The web component ensures 3D models download from Eureka 3D Data Hub and builds a basket (Inventory) which is made available to curators both on web and mobile components. During the tour no internet connection is needed. 3D XR Studio does not need either a third party API for implementing its AR features nor programming capabilities. A mobile device natively supporting Google AR Core library is needed (very common features in modern mobile devices, except for very entry level ones). 3D XR Studio is a demonstration on how mobile and web can collaborate to effectively address the task to support CH organisations and tourists in producing and consuming innovative experiences, which can be optimized by combining remote and onsite "development".

The AR Tour Experience is a mobile application tightly coupled with the AR Tour Builder. The latter is a web-based tool that can be used by CH organisations who wish to associate various types of digital objects (3D objects, images, text, audio) with certain locations on a map, thus defining a tour. The tour is then delivered via the mobile app as a lightweight, location-based AR experience to visitors on site, using GPS to trigger content related to physical points of interest. Its focus is on guiding visitors through cultural heritage sites by augmenting the physical world with contextual digital content.

In short, the 3D XR Studio creates structured immersive scenes for general XR viewing, while the AR Tour Experience offers phygital exploration tied to specific geolocations via a mobile interface.

3. The EUreka3D-XR pilot scenarios

The EUreka3D-XR project defines three pilot scenarios that demonstrate how the EUreka3D-XR tools can be used to create immersive XR experiences based on digital cultural heritage assets. While the scenarios are described in detail in Deliverable *D2.1 Pilots Specifications and Planning*, this section provides a concise summary to contextualise the tools' intended use and associated technical requirements.

The pilots serve to validate the tools, test their integration with the EUreka3D Data Hub, and assess their applicability in diverse real-world settings. Sections 3.1 to 3.3 describe the three pilot scenarios in further detail, while section 3.4 introduces the mapping between the tools and the scenarios.

3.1 Girona pilot

This pilot led by partner CRDI is focused on using available archival records about the structure and history of the now lost mediaeval walls of the city of Girona to produce the most scientifically accurate 3D reconstruction of such city heritage. To do this, the AI 3D Builder by partner Swing:It is used to generate 3D models of the towers, the bastions and a portion of the western walls from 2D image collection. 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 by Swing:It, which can be accessed as a virtual tour online and as an Extended Reality experience in a guided pathway in the city of Girona. Figure shows a mock-up by Swing:It, illustrating the user experience with the 3D models of the Girona walls.

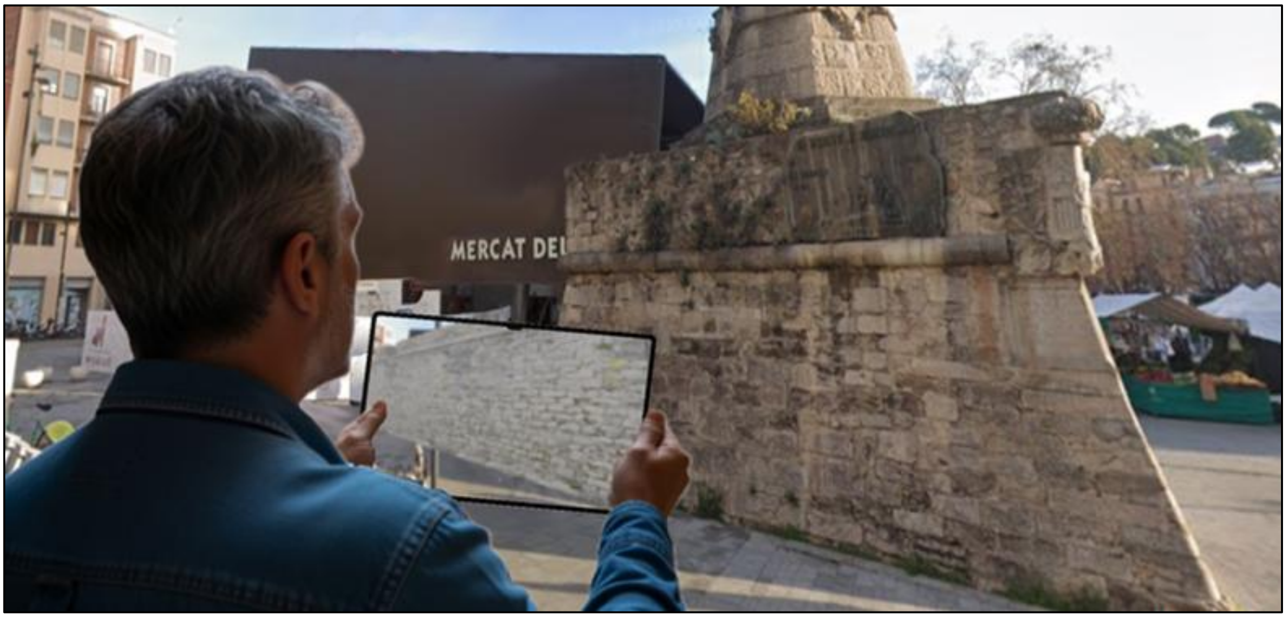

Fig. 3.1: Mock-up by Swing:It, illustrating the user experience with the 3D models of the Girona walls.

3.2 Bibracte pilot

The Celtic city of Bibracte was mainly made up, until the mid-1st century BC, of wooden buildings of which today only few remains are still available: post holes, circulation levels, hearths… Nevertheless, the site's topography is highly evocative, with irregularities of the terrain revealing the location of fortifications and numerous buildings, also allowing visitors to appreciate the vast extent of the ancient city.

The main challenge for interpretation aimed at visitors is therefore to help them see and understand these nearly invisible remains on the site. Until now, the site's interpretation has mainly relied on elements from the permanent exhibition, full-scale reconstructions and iconography, which are also occasionally used on explanatory panels placed at various points on the site.

Today, XR technologies offer a more complete and immersive solution to this challenge, directly on the archaeological site. In the pilot led by BIBRACTE, the two tools developed by NTUA will 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 visualise 3D models of terrains and objects linked to their discovery context and enhanced with additional media. This tour will allow them to uncover the hidden side of Bibracte by accessing elements that have disappeared, are not visible on site, or are not directly accessible to the senses or intellect, such as:

- The topography explaining the distribution of buildings,
- The backfilled remains and details of earlier excavations,
- The evolution of buildings, especially stone ones whose final state alone has been preserved,
- The hypotheses for some building elevations,
- The objects, now housed in the museum, presented in the context of their discovery.

The selection of Points of Interest (POIs) will be based on three criteria: their relevance in illustrating this "staging of the invisible," the availability of 3D models, and the existence of a variety of complementary media (text, 2D images, video, as well as audio, online content, or even quizzes) to showcase the full potential of these tools to future users. Figure 3.2 shows a simulation of an AR layover on top of the current scene.

Fig. 3.2: Simulation of an AR layover.

3.3 Cyprus pilot

In this scenario set in Paphos, visitors to the ancient Monastery of Saint Neophytos encounter a digital representation of the Saint who once lived in the Englystra. 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 Englystra 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 Englystra, 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.

Fig. 3.3: 3D digitisation of the Englystra, which will be used in the pilot

Upon entering the Englystra, 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 as a guide, culminating in a short re-enactment of part of the liturgy, performed by other fresco-inspired avatars. 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.

3.4 Mapping between tools and scenarios

All tools are fully exploited in one primary scenario, as outlined in the grant agreement. In some cases, tools are also demonstrated in a secondary scenario to highlight their adaptability and cross-scenario relevance. However, not all tools are applicable in every context due to specific technical or contextual constraints. For example, the NTUA tools require internet connectivity and geolocation, which are not feasible at the remote Cyprus location. Similarly, the MIRALab dataset tool depends on a closed and controllable environment for the mixed reality experience.

Table 3.1 below provides an overview of the current mappings between the five tools and the three pilot scenarios.

Table 3.1: Mapping of the tools and scenarios.

Tool	Bibracte	Girona	Cyprus
AR Tour Builder (NTUA)	primary	optional secondary	n.a.
AR Tour Experience (NTUA)	primary	optional secondary	n.a.
AI 3D Builder (Swing:It)	optional secondary	primary	-
3D XR Studio (Swing:It)	secondary	primary	optional secondary
Avatar Builder (MIRALab)	n.a.	secondary	primary
EUreka3D Data Hub	used	used	used
Europeana	used	used	used

Note that optional secondary demonstrations are subject to change, and that additional test cases may be explored later in the project that are not yet reflected in the table above.

4. Technical requirements

4.1 General Considerations

The aim of this section is to establish a shared understanding of technical requirements to steer both the further development of the EUreka3D-XR tools and their contextual implementation in the pilot scenarios. The tools each address specific functionalities, such as content authoring, avatar interaction, or immersive experience delivery, but also share common integration goals, including interoperability with the EUreka3D Data Hub, high quality content delivery and adoption of standards to enable interoperability and reuse.

Importantly, the definition of technical requirements in this project is bi-directional. On the one hand, the technical capabilities and constraints of each tool determine what is feasible in a given pilot scenario. On the other hand, the contextual and experiential goals of the scenarios impose specific requirements on the tools, for instance regarding usability, deployment environment, or user interaction models. This mutual dependency has guided both the characteristics of tools and the shaping of each pilot.

To provide a structured overview, the Table 4.1 below summarises the general capabilities, deployment modes and integration features for each of the five tools. It highlights, for example, whether a tool can be used offline or requires geolocation, whether it offers web or app-based interfaces for visitors or curators, and to what extent it supports self-guided versus guided experiences. This overview serves as a point of reference for the more detailed descriptions in the following subsections (4.2 to 4.6), where each tool's specific requirements are discussed in context.

Table 4.1: Tools capability matrix.

Capability	AR Tour Builder	AR Tour Experience	AI 3D Builder	3D XR Studio	Avatar Builder
Interaction with EUreka3D Data Hub	✓	✓	✓	✓	✓
Enables SSO authentication with EUreka3D user profiles (Integration with Check-in)	✓			✓	
Allows anonymous navigation for Visitor		✓		✓	
Use onsite - indoor				✓	✓
Use onsite - outdoor		✓		✓	✓
Use online/remotely	✓		✓	✓	✓
Use offline		✓(partially)		✓	✓
Geolocation		✓		✓	
Curator/Admin interface - web	✓		✓	✓	✓
Curator/Admin interface - app				✓	✓

Visitor interface - web					
Visitor interface - app		✓		✓	
Self-use onsite (visitor walks at their pace and path)		✓		✓	✓
Guided-use onsite (predetermined path)		✓		✓	
Self-guided onsite (visitor selects their path)		✓			
AI-based			✓		✓
Positioning of 3D object based on GPS coordinates		✓			
Positioning of 3D object based on local system of coordinates				✓	
Presentation views for audio, videos, images and text		✓		✓	✓
Integrates ARCore		✓		✓	
Uses maps APIs (such as Google maps or Open Street maps) for Geolocation		✓			

It is important to note that not all features are relevant or equally applicable across the three pilots. For example, the Avatar Builder is optimised for indoor, location-based MR experiences in controlled environments, whereas the AR Tour Experience targets outdoor navigation with geolocation-based content delivery. Similarly, some tools are designed for self-paced exploration by visitors, while others enable structured storytelling or curator-led interpretation.

4.2 AR Tour Builder

The AR Tour Builder operates as an online service accessible through a standard web browser (it will be particularly tested on Chrome and Safari). All assets associated with Points of Interest in a tour should be openly accessible, so that they can be accessed by the on-site visitor. For 3D objects to be presented properly via the AR Tour Experience, these should be provided in the following standardised 3D formats: GLB and GLTF. For other types of 3D objects (e.g., glTF, OBJ, PLY), it is the responsibility of the user to transform them to one of the supported formats.

The web app will support user registration and login. I will support access management with respect to the rights of each user with respect to the different types of data objects (Projects, Tours, Assets, POIs etc) supported by the tool. Registration and login via the Check-in service of the EUreka3D Hub will be supported.

4.3 AR Tour Experience

The AR Tour Experience mobile app will be supported on Android devices. Its proper functioning assumes a reliable GPS signal throughout the whole tour and a reasonable internet connection at least at some of the locations of the tour, to enable the downloading of the online material curated via the Builder. To support a good experience with the AR Tour Experience application, the Android phone should support AR capabilities as described in this Android developer specification. The devices included in the list have been certified with respect to a number of important features that ensure good performance and effective real-time calculations, such as the quality of the camera, motion sensors, the design architecture, and a powerful-enough CPU that integrates with the hardware design. These features are important especially for sensitive motion tracking, which is done by combining the camera image and the motion sensor input to determine how the user's device moves through the real world. If the visitor does not have a phone that supports AR, then they will still be able to experience the tour and view 3D models in a 3D viewer, but not the AR viewer mode.

4.4 AI 3D Builder

The AI 3D Builder tool relies on advanced hardware and software configurations to support the efficient processing of high-resolution images into 3D assets using AI-based photogrammetry techniques. The following outlines the key technical hardware requirements for local deployment and operation.

4.4.1 Hardware requirements

GPU: A dedicated GPU with at least 16 GB of VRAM is required; more VRAM is recommended for batch processing or 4K images. The GPU must support NVIDIA drivers and be CUDA-compatible with the versions of PyTorch or TensorFlow used by the Trellis framework.

Model: NVIDIA RTX 3090 / RTX 4080 / RTX 5000 Ada / A6000

> ***Rationale****: Dedicated GPU acceleration is critical to support the conversion of images to 3D models. GPUs with relevant (>=12 GB) VRAM are recommended for high-resolution or complex models.*

CPU: A minimum of 12 cores / 24 threads (multithreading required for pre/post processing).

Type: AMD Ryzen 9 7950X / Intel i9-13900K / modern Xeon

> ***Rationale****: some parts of 3D pipeline (like mesh structure, optimisation, web serving) are CPU-bound*

RAM: At least 32 GB of system memory.

> ***Rationale****: simultaneous handling of high-resolution images, 3D data, and AI models requires a lot of RAM.*

Storage: 1TB NVMe SSD (PCIe 4.0 preferred)

***Rationale**: Speed needed both for dataset and for temporary savings/cache of models.*

Motherboard and power supply: a motherboard compatible with PCIe 4.0 or 5.0, supporting the selected GPU, and paired with a power supply of at least 850W (Platinum-rated).

***Rationale**: stable operation of high-performance components (in particular the GPU) demands a robust infrastructure.*

Cooling system: proper airflow is required, with optional AIO (All-in-One) or custom liquid cooling for CPU-intensive tasks.

***Rationale**: heat management is critical during continuous or large-scale processing.*

Network connection: Minimum 100 Mbps wired Ethernet connection.

***Rationale**: ensures timely upload or integration of results with cloud services or remote repositories when required.*

4.4.2 Software requirements

Table 4.2 gives an overview of the software requirements for the AI 3D Builder.

Table 4.2: AI 3D Builder software requirements.

Category	Minimum / Tested Configuration	Notes
Operating system	64-bit Linux (Ubuntu 20.04/22.04 LTS or equivalent)	Official repo is validated only on Linux; Windows works via an unofficial fork. (GitHub)
NVIDIA driver	Proprietary driver compatible with CUDA 11.8 or 12.2 (≥ 535.xx)	Must expose nvidia-smi and match the CUDA toolkit in use.
CUDA Toolkit	11.8 **or** 12.2 (both tested)	Toolkit must be on $PATH at build & run time. (GitHub)
Python	3.8 – 3.11 (3.8 officially tested)	Install via **Conda/Mamba** in an isolated env (e.g., trellis). (GitHub)
Core Python libs	• PyTorch ≥ 2.4 (CUDA build) • xformers **or** flash-attn • spconv, diffoctreerast, nvdiffrast, kaolin, mip-gaussian	All installed/compiled by the repo's setup.sh. GCC 9+, CMake 3.18+ and Linux headers are needed for compilation. (GitHub)

Package manager	Conda/Miniconda (or Mamba)	Recommended by the maintainers for dependency isolation. (GitHub)
Developer tools	git (v2.40+) with LFS, make, gcc, cmake	Git-LFS is required to fetch large weight files.
Optional runtime	Gradio (bundled) for web UI on port 7860	Enable with python app.py --port 7860.
Disk & network	20 GB for code/env + 10–30 GB for models; outbound HTTPS to Hugging Face	Weights can be mirrored locally if outbound traffic is restricted.
Web UI	Node.js 18 LTS or 20 LTS with npm ≥ 10; Express 4 (or any HTTP framework); Build chain: Webpack 5 / Vite	Provides a browser-based dashboard that authenticates users, uploads image sets & parameters, and forwards requests to Trellis' Python APIs.

4.4.3 Data format and quality requirements

Data Format: Images in .png or .jpg format are accepted, no specific resolution nor aspect ratio required.

Quality Requirement: It is highly recommended providing input images that cut out the main subject that the users want to obtain as a model, removing its background (see comparison between the Figures 4.1 and 4.2).

Fig. 4.1: Starting image with background and other objects.

Fig. 4.2: Edited image: no background for better results.

Such passages will imply as an intermediate (implicit) step within Trellis converting the image in a .png format (as it allows managing the alpha channel, affecting transparency), therefore it is suggested to use this format directly. Even though every resolution is accepted, a resolution of at least 5-Megapixels (2560 x 1920 pixels) is suggested for better results.

The next two images show the different 3D model output obtained by providing in input the same image with different resolution: a 100x100 resolution for the former (Figure 4.3), a 2500x2500 resolution for the latter (Figure 4.4).

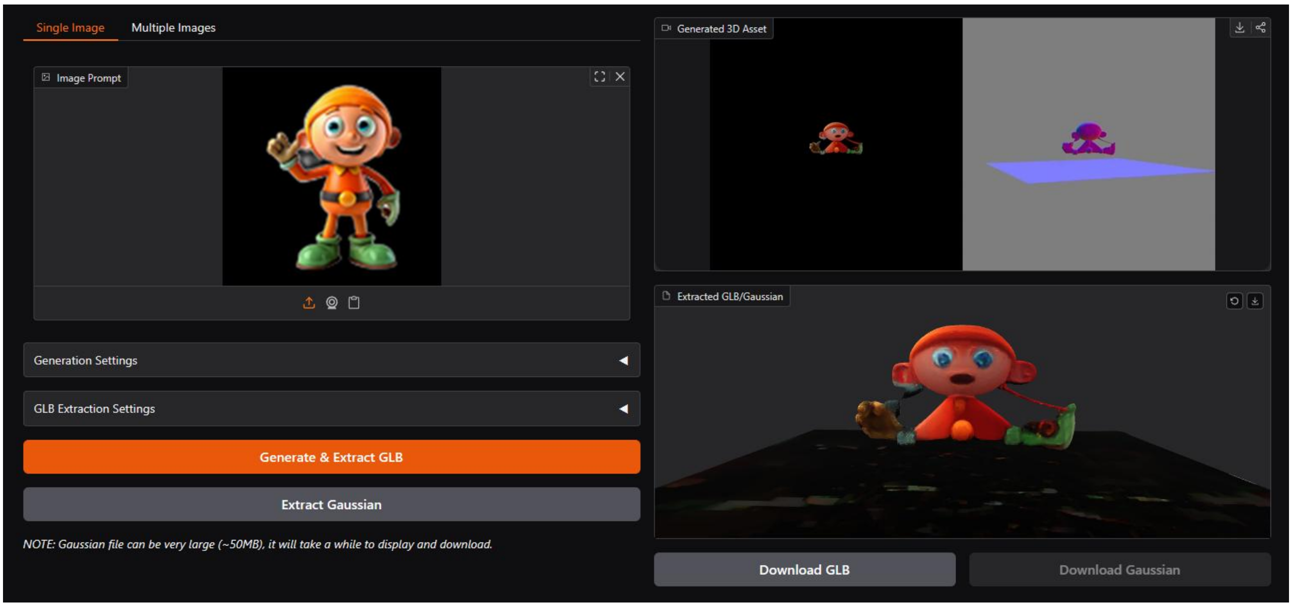

Fig. 4.3: Model produced with a 100x100 resolution image in input.

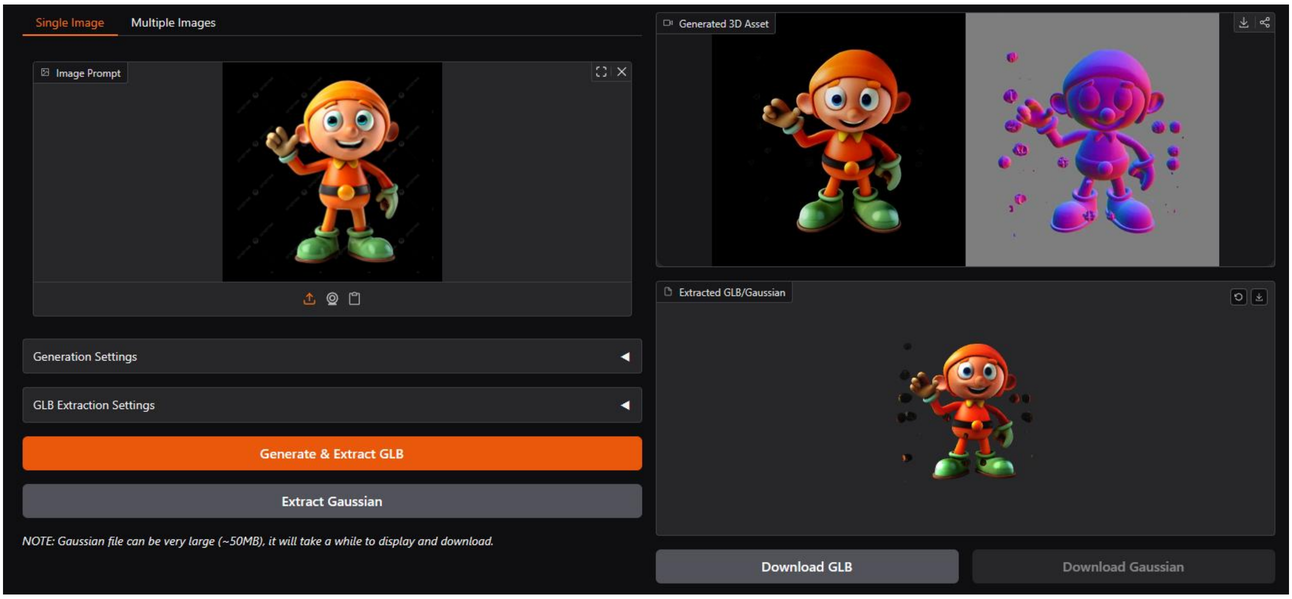

Fig. 4.4: Model produced with a 2500x2500 resolution image in input.

A specific guide suggesting best practices will be provided by Swing:It (e.g. images in a bird-view perspective, showing both front view and depth, are highly recommended).

An extract of such quality requirements is given in Table 4.2.

Table 4.2 Overview of quality requirements.

Requirement #	Title	Short Description
1	Object Coverage Percentage	Object should occupy at least 70% of the image.
2	No Backlight	Sun must be in the back or on top of the object.
3	No Panorama	Photos must be taken from a distance where the main subject is visible in its whole height.
4	No Wide Perspective	Photos must be taken with a regular lens, no wide lenses.
5	Light Conditions	Homogeneous light conditions, photos must be taken preferably in cloudy weather.
6	Front or in Perspective POV	Photos must be taken in front view or slightly in perspective.
7	Objects and People in the Foreground	Photos should not include neither objects nor people in the foreground.
8	Target Composition	Photos must catch portions of the main subject that are well lit and regular in composition.
9	High Resolution	Photos must have the highest resolution possible.
10	Exposure Value	Photos should have a proper exposure value.

4.5 3D XR Studio

The 3D XR Studio pipeline defines key infrastructural, environmental, and integration requirements for reliable server-based deployment and cloud operation. This section outlines the necessary server-side, network, and integration specifications to ensure stability, compliance, and performance.

4.5.1 Software and environment requirements

Operating System: The 3D XR Studio has to be deployed on a Linux-based server environment that has been specifically optimised for high stability and performance. CentOS or Rocky Linux are preferable.

API Integration: A robust RESTful API framework is incorporated to ensure seamless integration with existing digital systems.

User Interface: The user interface is built using modern web technologies, providing a responsive and intuitive experience for end users. This configuration ensures that the 3D XR Studio meets the necessary operational standards for processing and delivering high-quality 3D models.

4.5.2 Data Storage and Access Framework Requirements

The pipeline is designed to comply with policy restrictions by not storing 3D models or related metadata locally. Instead, it relies on its integration with the EUreka3D Data Hub, leveraging the infrastructure provided by the EGI Federation. The key components of this framework are outlined below:

External Storage Integration: The 3D XR Studio accesses 3D assets from the EUreka3D Data Hub, which utilises the robust and scalable infrastructure. Local storage is not used, ensuring compliance with policy constraints.

Secure API Interaction: Communication with the external storage infrastructure is managed through a secure RESTful API. This API not only enables the retrieval and processing of 3D assets but also ensures that the models can be returned to the user without being stored locally.

Metadata and Paradata Enrichment: The 3D XR Studio retrieves metadata and paradata from Europeana. This additional information—covering aspects such as provenance, creation details, and historical context—enriches the 3D models, providing users with comprehensive contextual data.

Processing Layer Role: By focusing on the processing and enrichment of 3D models rather than replicating storage functions, The 3D XR Studio effectively acts as a processing layer between existing Europeana digital repositories. This approach eliminates redundancy and leverages existing digital assets.

Controlled Access through Secure Authentication: The framework employs secure authentication mechanisms through the EUreka3D Data Hub to ensure controlled access. As such, a high level of data security and compliance is maintained.

4.5.3 Deployment Infrastructure Requirements

Network Performance: A robust network infrastructure is essential to support large-scale image uploads and 3D model downloads. Low-latency connections are critical to maintain responsive web performance, particularly during interactive sessions and metadata retrieval. Furthermore, all data transfers are encrypted to safeguard sensitive content.

Temporary Local Storage: Although the pipeline does not store long-term data, it requires temporary local storage for active processing tasks. This includes handling high-resolution image batches and intermediate 3D data. Once processing is complete, results are returned to the EUreka 3D Data Hub via the RESTful API, and all temporary files are securely deleted.

4.5.4 Integration Capabilities

Seamless System Integration: The tool is designed to integrate advanced workflows with both Europeana and the EUreka3D Data Hub. This is achieved through its robust RESTful API, which facilitates efficient metadata handling and supports the seamless use of new and pre-existing 3D assets.

4.5.5 Performance Considerations

Processing Efficiency: Processing times vary based on the complexity of input data and prevailing network conditions. Administrators are provided with configurable settings to balance processing speed and output quality.

Scalability: The tool supports horizontal scaling and dynamic resource management, which ensures consistent performance even under fluctuating workload demands.

4.5.6 Compatibility

Input Formats: The pipeline supports standard image formats including JPG and PNG for input.

Output Formats: The pipeline outputs models in the GLB format—a widely adopted standard in 3D asset exchange that is fully compatible with the EUreka 3D Data Hub.

This configuration lays the foundation for the reliable deployment and efficient operation of the 3D XR Studio ensuring seamless integration with existing infrastructures and high-quality processing outcomes.

4.6 Avatar Builder

To create the animated 3D Virtual Human (VH) models, we use 3D modelling and animation software such as Blender (Open source). Once the models are completed, the export format is selected based on the intended visualisation platform. For web-based visualisation, the models are exported in **GLB** format, which is optimised for efficient streaming and compatibility with WebGL and web viewers. For Virtual Reality (VR) or Mixed Reality (MR) experiences, the **FBX** format is used, which supports complex animations and is widely supported in game engines like Unity and Unreal Engine.

A collection of input datasets comprising a few rigged virtual character models, some animation files, and audio tracks will be provided and exported on the EUreka3D platform.

4.6.1 Scenario Specification

- **Historical Visual Integration:** The Cyprus scenario will feature a fresco-inspired visual style, creating a seamless continuation between the real site and the digital experience. As visitors explore the actual location and view the frescoes through the headset, a character will eventually appear to emerge from the frescoes themselves, blending the physical and virtual worlds in a fluid, immersive way.
- **3D Engine Compatibility**: The 3D character models and animations will be fully compatible with any standard 3D engine, ensuring flexibility across platforms and technologies.
- **AI-Generated Voice Synchronisation:** Character voices will be generated using AI based on historical texts and synchronised precisely with both facial expressions and body animations.

4.6.2 Experiencing the Scenario: Immersive Headset and Web-Based 3D Access

4.6.2a: VR/MR Immersion Requirements:

To experience the scenario in full immersion, users will need a Meta Quest 3 headset. The application will be developed as an Android-compatible APK file, which can be installed directly onto the headset. This standalone configuration eliminates the need for an internet connection, ensuring high portability and ease of use across diverse environments.

1. **Technical Requirements**
    a. Hardware Requirements
        - Headset: Meta Quest 3 (standalone VR/MR headset).
        - Controllers: Optional use of Meta Quest Touch controllers or hand tracking.
    b. Platform & OS
        - Operating System: Android-based OS (Meta Quest 3 runs a customised Android OS).
        - Display: High refresh rate display (up to 120Hz) with sufficient resolution for immersive MR/VR experiences.
    c. Software & Development Tools
        - Development Platform: Unity 3D or Unreal Engine with Meta Quest SDK/ OpenXR support.
        - SDKs/Frameworks: Meta XR SDK, OpenXR, Unity XR Toolkit.
        - Build Format: Android-compatible APK file.
    d. Deployment & Installation
        - APK Deployment: Application deployed as a standalone APK, sideloaded or direct installation from EUreka3D-XR.
        - No Internet Dependency: The app functions entirely offline after installation.
        - Storage: Sufficient free space on the headset (approx. 500 MB - 2 GB depending on content size).
    e. Portability & Autonomy
        - Battery Usage: Optimised to minimise power consumption and maximise session duration.
        - Offline Operation: All assets and logic self-contained within the APK.
2. **Functional Requirements**
    a. Immersive Scenario Launch
        - Users should be able to launch the scenario directly from the Meta Quest 3 main menu.
    b. Mixed Reality & VR Integration
        - Support for both VR and MR modes:
            - MR: Blended virtual objects with the real environment using passthrough.
            - VR: Fully immersive virtual environments.
    c. Scenario Content
        - Interactive 3D objects/scenes relevant to the use-case, in FBX format
        - Audio feedback and spatial sound in mp3 format
    d. User Interface (UI)
        - Simple, intuitive menu system for navigating through the different storytelling, starting, pausing, and exiting the scenario.
    e. Accessibility & Usability
        - Easy setup without complex calibration.
        - Minimal steps to launch and run the application.
        - Designed for use in varying lighting and space conditions.

4.6.2b: Web-Based Visualisation Requirements:

To enable web-based access to the immersive scenario, the following technical and functional requirements must be met:

3. **Technical Requirements**
    a. The experience must be accessible via a modern web browser.
    b. The viewer is implemented using the Babylon.js WebGL framework for compatibility and performance.
    c. The solution must integrate smoothly with the EUreka3D-XR platform.
    d. The viewer must support the following formats:
        - Animated 3D formats: **.glb**, **.gltf** (with embedded animation data such as skeletal rigging and node transformations).
        - Static 3D formats: **.obj**, **.stl**, **.ply**, **.splat** (non-animated geometries).
        - Audio format: **.mp3** files for voice or sound synchronisation.
    e. In collaboration with the EGI partner, the file formats must be evaluated to ensure compatibility with the EUreka3D-XR infrastructure.
4. **Functional Requirements**
    a. **Remote ZIP Handling:** The viewer must be capable of fetching ZIP files from a remote URL (supplied dynamically by the system or user), unpacking them in-browser using JSZip, and identifying supported 3D and audio files.
    b. **Format-Aware Loading:** Based on file extension, the viewer should dynamically select the appropriate plugin.
    c. **Audio Synchronisation**: The system must play **.mp3** audio in sync with animations when available. For static content, the audio should be played independently.
    d. **Viewer Controls**:
        - For animated content: play, pause, resume, and reset (both animation and audio).
        - For static content: audio play/pause controls only.
    e. **Camera Framing**: The viewer should automatically frame and center the 3D object to ensure full visibility, adapting to varying object sizes and orientations.

4.7 Data quality, formats, standards and interoperability

From the early stages of the EUreka3D-XR project, data quality and interoperability have been considered foundational principles guiding the development and integration of the various tools. High-quality content, aligned with recognised standards and exchange formats, is essential for ensuring reusability, long-term sustainability, and integration within broader data ecosystems such as the Europeana Data Space.

All five tools are being developed with the intention to produce and consume interoperable content. Wherever possible, open and widely adopted formats are being adopted. Building on the strategy and reputation of the EUreka3D project, EUreka3D-XR also takes into account best practices regarding paradata, provenance information, to facilitate transparent and trustworthy reuse of the generated assets.

While this deliverable introduces the baseline considerations, three additional deliverables will provide a more detailed and systematic framework on these aspects:

- **D3.6 Quality Assessment Report** will further detail the steps taken to ensure quality of data and user experiences throughout the project.
- **D3.7 Formats and Quality Guidelines Report** will document formats and quality measures.

- **D3.8 Paradata and Sustainability Report** will document practices related to managing paradata and provenance information to ensure sustainability and long-term preservation.

4.8 Cloud infrastructure considerations

Integration with the EUreka3D Data Hub is a key requirement for all tools, both in terms of technical integration and in terms of conceptual alignment. These principles are project-wide incorporated, ensuring that content generated or consumed through the pilot scenarios meets these high standards of quality and compatibility. Section 5 describes the Data Hub in detail and outlines the requirements identified in the EUreka3D-XR project.

5. EUreka3D-XR Cloud Infrastructure

This section focuses on the requirements of the EUreka3D-XR Cloud Infrastructure. Section 5.1 briefly describes the EUreka3D Data Hub, a system established during the previous project, EUreka3D, which will be used for the storage, management and use of 3D data in EUreka3D-XR. It also offers a channel to publish objects in Europeana. For this, the models must meet some requirements, described in Section 5.2.

Section 5.3 explains how the work conducted in EUreka3D-XR fits in the overall picture of the EUreka3D ecosystem. The project delivers new infrastructures and tools, to complement the EUreka3D Data Hub. Section 5.4 summarises some of the requirements for the Authentication and Authorisation Infrastructure. The needs of the tools in terms of infrastructure resources (CPU, RAM, Storage, GPU, etc) are described in Section 5.5. Finally, the deployment process to install the tools in the infrastructure is discussed in Section 5.6.

5.1 EUreka3D Data Hub

EUreka3D Data Hub is the system created during the EUreka3D project to contribute to the digital transformation of CHIs by supporting the management, storage, sharing and publishing of Cultural Heritage data.

The system is made of the main three components shown in Figure 5.1:

- **EGI Check-in** (represented by "Authentication and Authorisation" in the figure), which is in charge of authenticating users and providing the user attributes necessary to make authorisation decisions. This AAI component also organises the user community in different groups according to the user's role in the infrastructure or in the data.
- **EGI DataHub** (represented by "Data Management" in the figure), which is the main core of EUreka3D Data Hub and is responsible for the data storage, management, sharing and publishing. It manages the underlying storage hardware and provides a GUI and API to interact with the system. Apart from 3D models, users can store all kinds of related data and organise them as preferred. Any data file or directory can be shared with different audiences. Additional features include the support for the metadata ingestion in EDM format[1], the management of PIDs delivered by B2HANDLE[2], and the publishing in Europeana through the OAI-PMH protocol[3].
- A **bespoke application**, deployed on the EGI Cloud and running on virtual servers (represented by "Compute power" in the figure), which supports the visualisation of 3D objects

[1] https://pro.europeana.eu/page/edm-documentation
[2] https://eudat.eu/service-catalogue/b2handle
[3] https://www.openarchives.org/pmh/

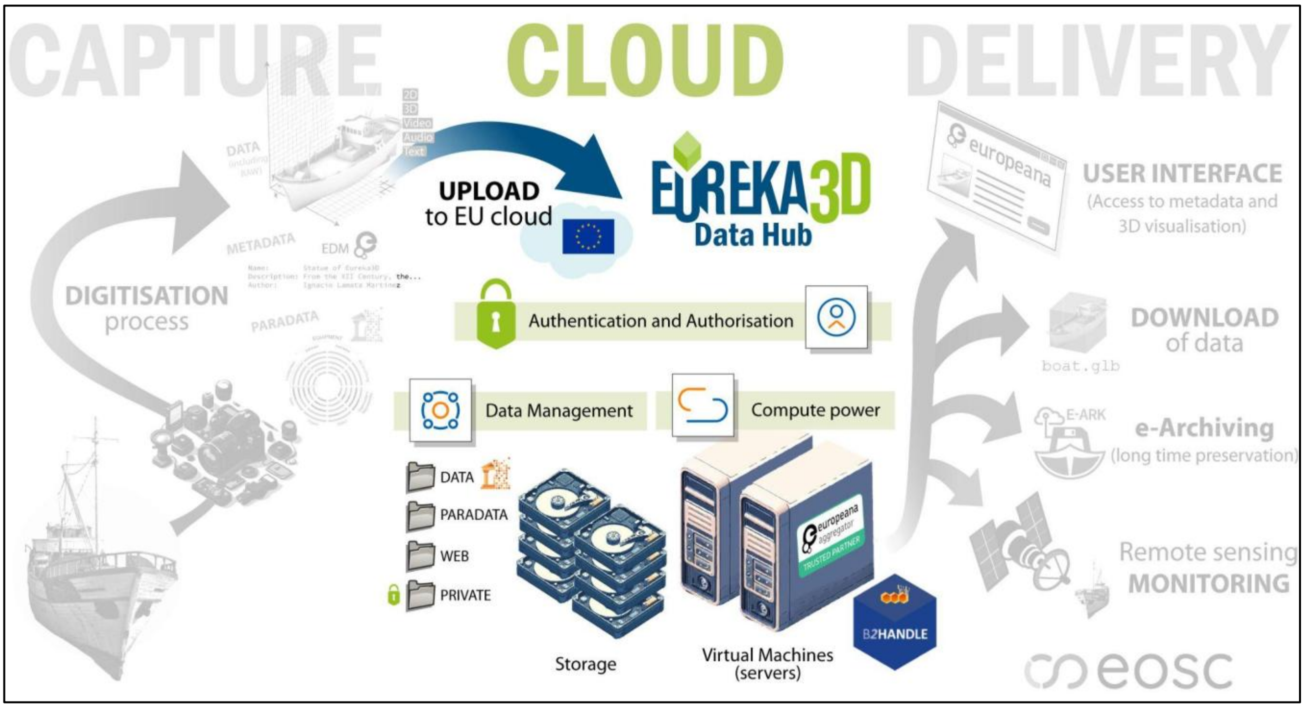

Fig. 5.1: Overview of the EUreka3D Data Hub within the EUreka3D workflow.

EUreka3D Data Hub contributes to the delivery of 3D content by supporting the publication in Europeana and the downloading of data files, which can then be manipulated and further studied by the end user in a local computer.

A more detailed perspective of the system can be found in Figure 5.2, where four types of actors can be identified:

- **Content Providers**, representing the CHIs that provide data to the EUreka3D Data Hub.
- **Cloud Operators**, who are the technical personnel in charge of developing and maintaining the cloud systems that are specific for EUreka3D.
- **The CH community**, representing the general users in the CH community (CH professionals, architects, tourism professionals, casual citizens, etc)
- **External Systems**, illustrated in this case by a single system: **Europeana**. These are the systems that interact with the EUreka3D Data Hub in one way or another (collecting metadata, accessing 3D models, etc).

Two big boxes group together the main functionalities of the system:

- The **Data Management**, mainly supported by **EGI Data Hub**, which offers access through a *Web GUI* and an *API* for content providers, and an *OAI-PMH* endpoint for external systems. Data are stored in the cloud, and eventually on physical hard disks.
- The **Compute Power**, offering the servers in the cloud to run applications. This part is deployed with the help of the Infrastructure Manager (see Section 5.6 for a brief description) and EGI Dynamic DNS (DDNS). Inside these servers, the 3D viewer and the oEmbed endpoint are implemented.

Finally, the locks in the figure represent the authentication/authorisation process implemented by EGI Check-in, to ensure that only authorised users are able to access the different systems. The access to public data does not require any authorisation mechanism.

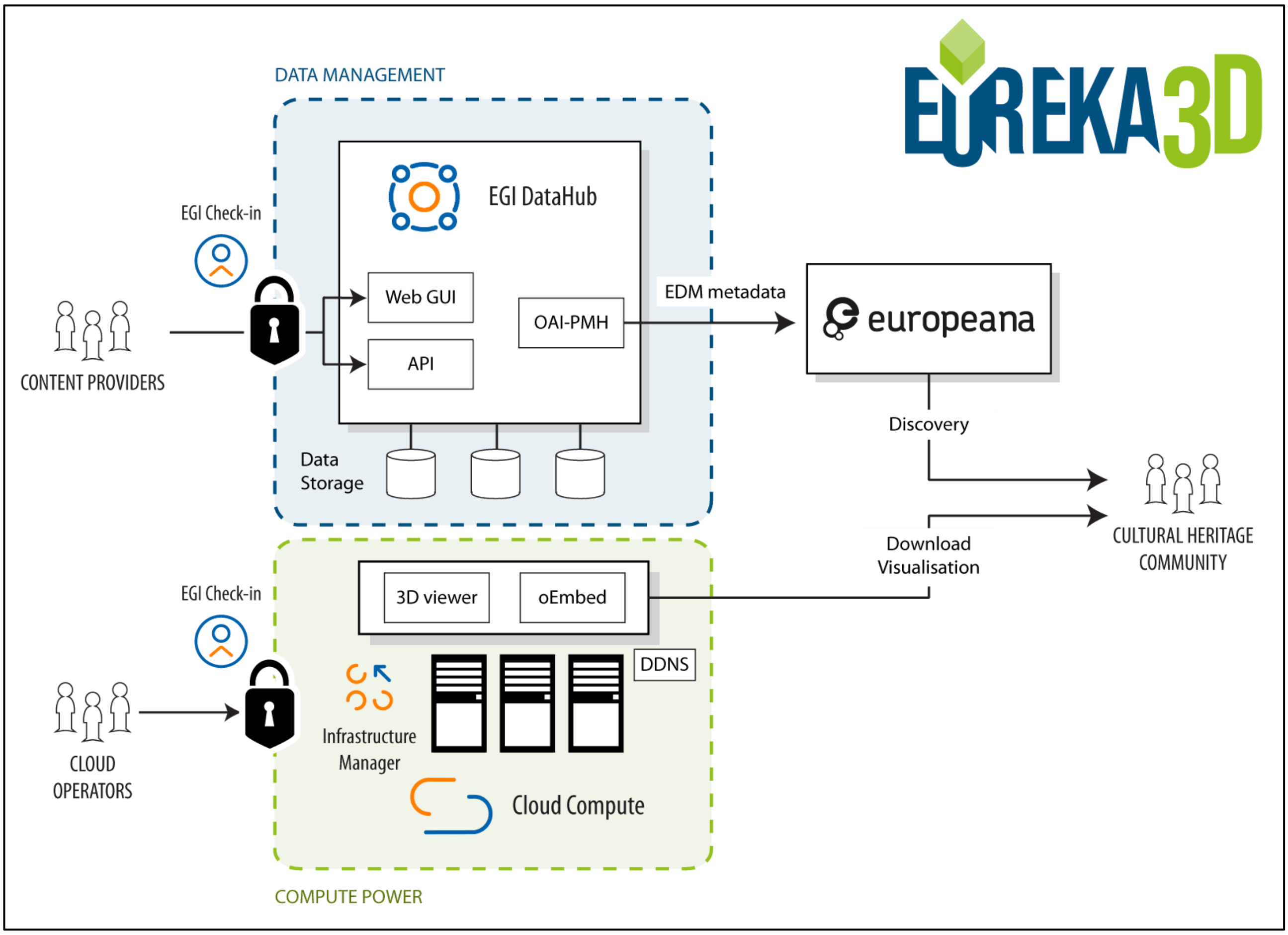

Fig. 5.2: Main components of the EUreka3D Data Hub.

5.2 Publication requirements for Europeana via EUreka3D Data Hub

In order to publish 3D content in Europeana through EUreka3D Data Hub, the user must act as a **Content Provider**. To do so, it is necessary to meet certain requirements, as summarised in Table 5.1. For more details, refer to the EUreka3D's Content Provider Handbook[4].

Table 5.1: EUreka3D Data Hub publishing requirements.

ID	Requirement	Comments
E3D-01	The user must be registered in Check-in	
E3D-02	The user must belong to the EUreka3D community and be part of a group	A new group can be created for new institutions joining the EUreka3D community

[4] https://go.egi.eu/eureka3d_handbook

E3D-03	The published 3D model must be encoded in an accepted format	Currently accepted: 3dm 3ds 3mf amf bim brep dae fbx fcstd gltf ifc iges step stl obj off ply wrl
E3D-04	The published 3D model and all associated files must be grouped in a ZIP file	
E3D-05	The published 3D model must have valid associated metadata in EDM format	A PID will be automatically assigned to the dataset

5.3 The use of EUreka3D Data Hub in EUreka3D-XR

The EUreka3D Data Hub was designed to serve as the foundation for different applications in the Cultural Heritage discipline. Figure 5.3 shows the layered architecture of the system, in which there is an Applications layer that, at the end of the EUreka3D project, included the EUreka3D viewer and Europeana.

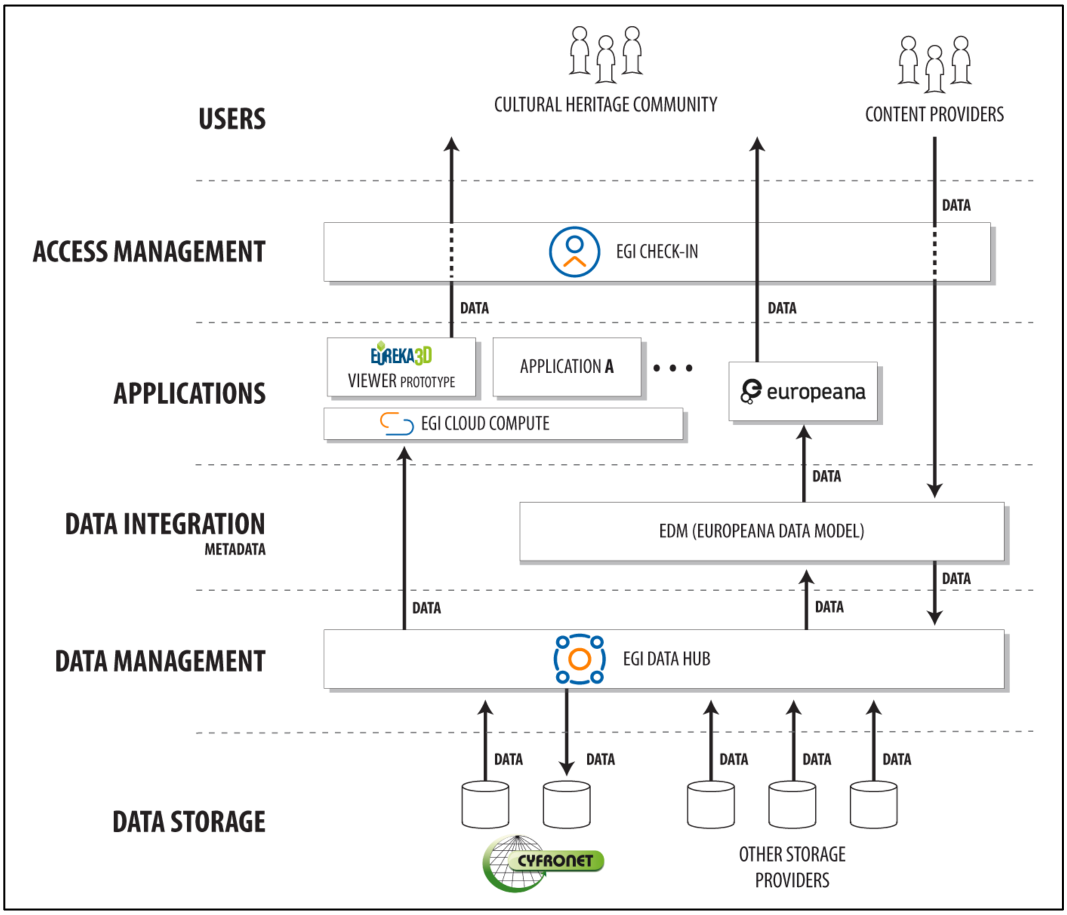

Fig. 5.3: Layered architecture of EUreka3D Data Hub.

EUreka3D-XR brings new tools that will be part of this layer and the ones with a backend will run on top of the EGI Cloud Compute. Therefore, the EUreka3D Data Hub provides the data foundation layer, which is the basis for building more complex and specialised applications on top of it. Europeana is just an example of an external system using this Data Hub, and EUreka3D-XR's tools are a clear example of advanced applications making use of the 3D data in a specialised environment.

EUreka3D-XR's tools will also make use of the EUreka3D Data Hub capabilities for 3D asset management. At the bottom of Figure 5.4 we find the EUreka3D-XR developers (which includes the Content Provider role) acting in two aspects:

- In the app deployment, developing the tools and installing them in the new EUreka3D-XR cloud infrastructure.
- Uploading the 3D models and auxiliary files needed by the tools to operate, either by using EGI DataHub's API or GUI.

The figure depicts three main boxes with systems:

- A Kubernetes cluster managed with Rancher, containing multiple nodes to run the specific tools of EUreka3D-XR.
- EGI DataHub, which manages the data, the metadata, all the storage, the oEmbed and OAI-PMH endpoints, the download of data and many others.
- The Cloud Compute infrastructure of EUreka3D, which runs the EUreka3D viewer as a container in Docker. Occasionally, this infrastructure can run specific XR tools (as depicted by "App E" in the figure).

The digitised 3D models needed by EUreka3D-XR are stored and published in EUreka3D DataHub as usual, and are exposed publicly or privately. The tools can discover and use these data either by using Europeana or through the OAI-PMH information exposed by EGI DataHub, and can retrieve the 3D model through an API. Finally, these data are used to provide the XR experience for the end users (data consumers).

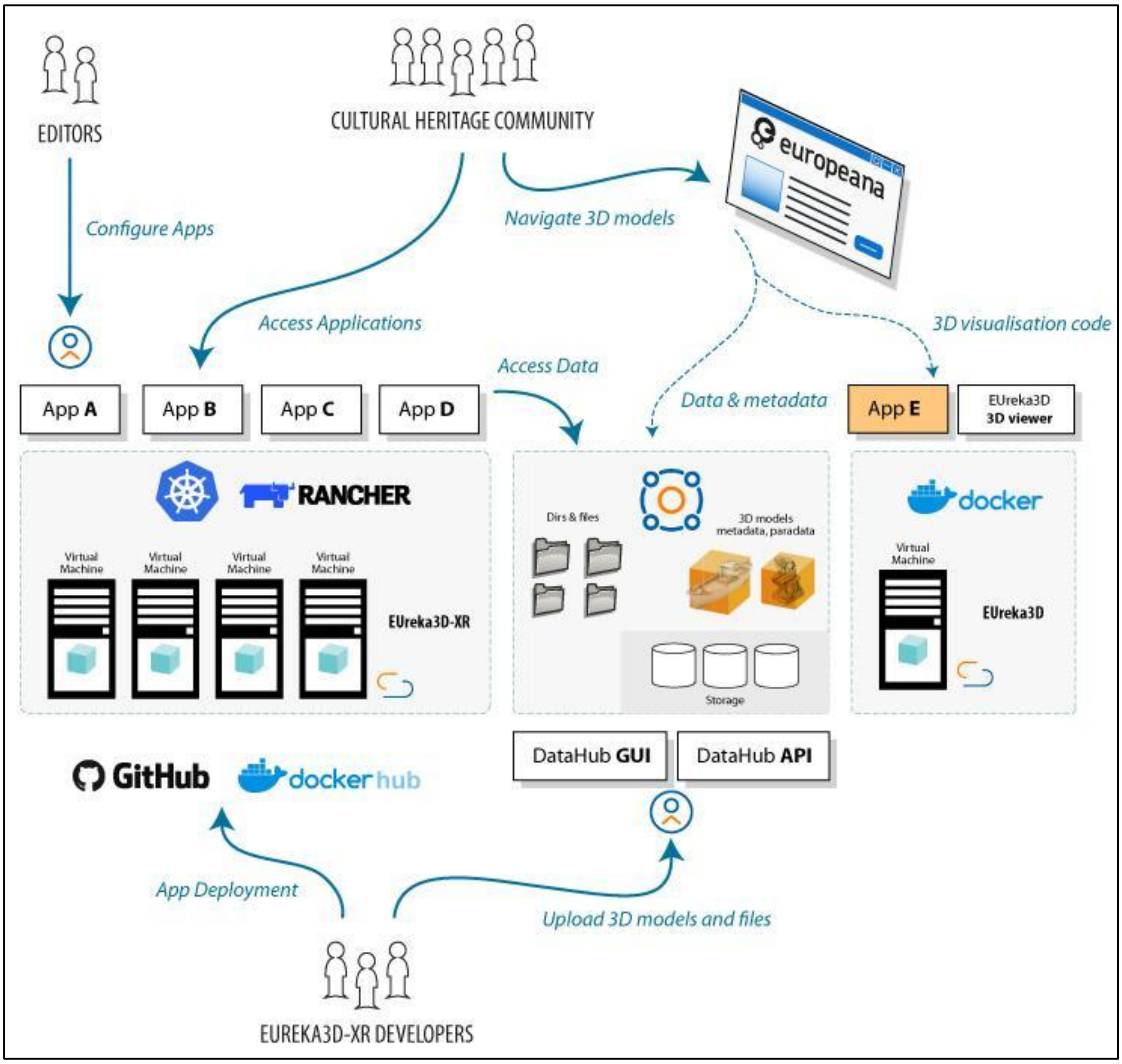

Fig. 5.4: EUreka3D-XR simplified workflow.

The end users are depicted at the top of Figure 5.4. On the left side we find the "**Editors**", a type of user that has some special permissions to interact with the tools and therefore needs to be authenticated and authorised. This is the case of users configuring the tools or creating some data to enrich the XR experience, so they will need to authenticate through Check-in. The "**Cultural Heritage Community**" refers to the rest of end users that simply access the tools or navigate 3D models in Europeana.

5.4 AAI requirements

Whether to use EGI DataHub, manage the cloud infrastructure or operate as an editor or an admin in one of the EUreka3D-XR tools, users need to identify themselves and to receive appropriate permissions. The process of demonstrating who the user is is called ***authentication***, whereas the process to determine what the user can do in the system (if the user is allowed to perform an action in the system) is called ***authorisation***. Both are supported by Check-in.

Table 5.2 describes the main requirements needed in terms of authentication and authorisation. The requirements for the system (*AAI-01* to *AAI-04*) are covered by Check-in, and the others must be implemented by the tools.

Table 5.2: AAI requirements.

ID	Requirement	Comments
AAI-01	The system must allow the authentication of users	
AAI-02	The system must provide enough attributes to support the authorisation of users	This can be made via group membership or role assignment
AAI-03	There must be clearly defined permissions for Content Providers (who upload 3D models) and operators of infrastructure (who create and manage servers and other computing resources)	
AAI-04	The system must comply with AARC BPA and be integrated in the EOSC AAI	
AAI-05	EUreka3D-XR Tools that need to authenticate or authorise users, must use only the AAI system selected in the project, adapting to the accepted standards and protocols	The OIDC[5] protocol is suggested

In terms of authentication, Check-in acts as a proxy, allowing users to perform the login through their work institutions, which are the organisations that they naturally trust. Thus, a researcher at the University of Oxford, for example, will be able to login through their university and access EUreka3D-XR systems, if they are authorised to do so.

For authorisation, and to organise the community of the project, the concept of **Virtual Organisation** (VO) is used[6]. A Virtual Organisation represents a research community and, in practice, it is just a group of users. VOs are created to organise a community of researchers, who can share resources across the EGI Federation and other services to achieve a common goal, as part of a scientific collaboration.

EUreka3D-XR will make use of two different Virtual Organisations, as graphically shown in Figure 5.5:

- **culturalheritage.vo.egi.eu**, which is the VO used in EUreka3D to organise the different CHIs. This is still used for the data management conducted in DataHub.
- **eureka3d-xr.vo.egi.eu**, which is a VO specific for the project that is mainly focused on permissions related to the infrastructure.

[5] https://openid.net/developers/how-connect-works

[6] https://docs.egi.eu/users/aai/check-in/vos/

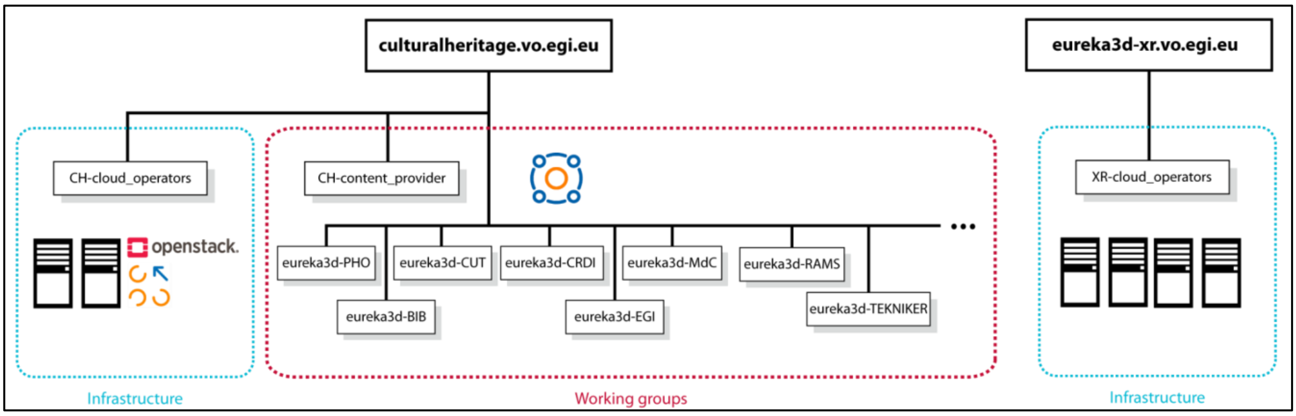

Fig. 5.5: Group configuration for authorisation.

EGI Check-in complies with the AARC Blueprint Architecture and is also part of the EOSC AAI ecosystem, so this effectively prepares EUreka3D-XR for future integrations with other initiatives such as the ECCCH or the EOSC EU Nodes.

Finally, Check-in accepts a variety of protocols and standards. In the project, the use of OIDC is suggested, which is an authentication protocol that works with Web protocols and has become the *de facto* standard for modern Web authentication. The tools that need to perform any authorisation decision from users (as identified in Table 4.1), must integrate with Check-in to authenticate users and collect attributes for their authorisation.

For more information on AAI, Check-in, and how it is used in the EUreka3D Data Hub, refer to Deliverable *D3.2 The EUreka3D AAI architecture*[7] of the EUreka3D project.

5.5 Cloud infrastructure requirements

The tools are expected to run in containers, which is a technology that allows developers to run and pack software together with all their dependencies. These containers will be managed through Kubernetes[8], an application to manage containers in a cluster of machines.

All tools will be assigned resources according to their specific needs, as identified in Section 4, considering the following parameters:

- Number of vCPUs
- Amount of RAM
- Amount of Storage
- The need for and specific requirements of a GPU
- The need for a Domain Name to address the tool
- The need for a TLS certificate for HTTPS access
- The need for persistent volumes, and amount of storage needed

[7] https://eureka3d.eu/wp-content/uploads/2024/11/EUreka3D-D3.2-V1.0.pdf
[8] https://kubernetes.io/

- Networking needs, especially in terms of open ports

Please note that exact requirements are expected to change over the course of the project. Kubernetes works on a flexible architecture that facilitates scalability, where nodes in the cluster can be added or removed dynamically to satisfy the demand of the running applications.

5.6 Technical requirements for application deployment

The deployment of tools in EUreka3D-XR follows the two paths depicted in Figure 5.6:

- **Smartphone applications** are published in an official market, allowing users to install the application in their phones.
- **Backend applications** are deployed in the EGI Cloud infrastructure.

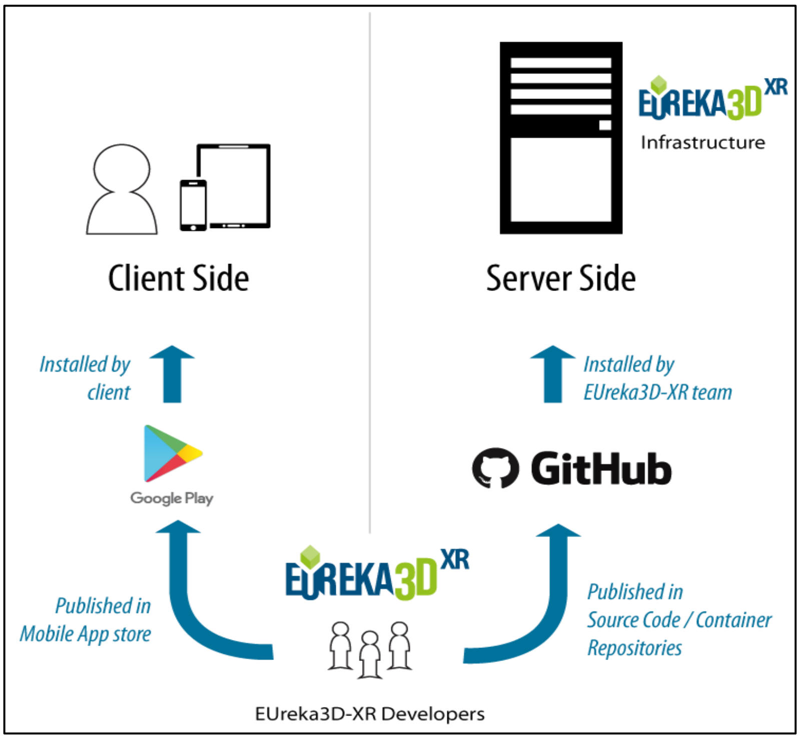

Fig. 5.6: Deployment of smartphone apps and server tools

Smartphone applications use the official market for Android applications, using Google Play to publish the apps, from which users can install them through their usual channels. There is no specific project infrastructure used in this case. The applications then run from the user device, making specific connections to Check-in or DataHub when and if necessary.

For the backend applications that run on the server side, the use of a cloud infrastructure is needed. This infrastructure is dedicated to EUreka3D-XR and will support the requirements described in Section 5.5. Figure 5.7 represents an overview of how this infrastructure is created and how the tools are deployed on it. The figure describes two main processes:

- **Infrastructure creation**: This initial step can be done either manually or with the help of the **Infrastructure Manager**[9] (IM), a service that supports the creation of infrastructure and the installation of applications. The benefit of using IM is that it facilitates the deployment process and allows the use of templates, which can document the deployment, avoid human errors and effectively enable managing infrastructure as software code. The most static infrastructure will be built at this stage: the different Virtual Machines (servers) will be created, the system users will be configured, the required domain name registered or configured, and the firewall rules will be set for appropriate network connectivity.
- **Software installation**: This step will be performed dynamically throughout the lifetime of the software (the tools). The EUreka3D-XR developers will make changes on the source code of the tools, and this will be stored in a Version Control System (VCS). This code is open source and publicly available. Once in the VCS, the CI/CD pipeline is triggered, creating a container image for the specific tool and publishing it in some Container Repository. This repository makes the software artefact available to the cluster of machines, which can download and run it.

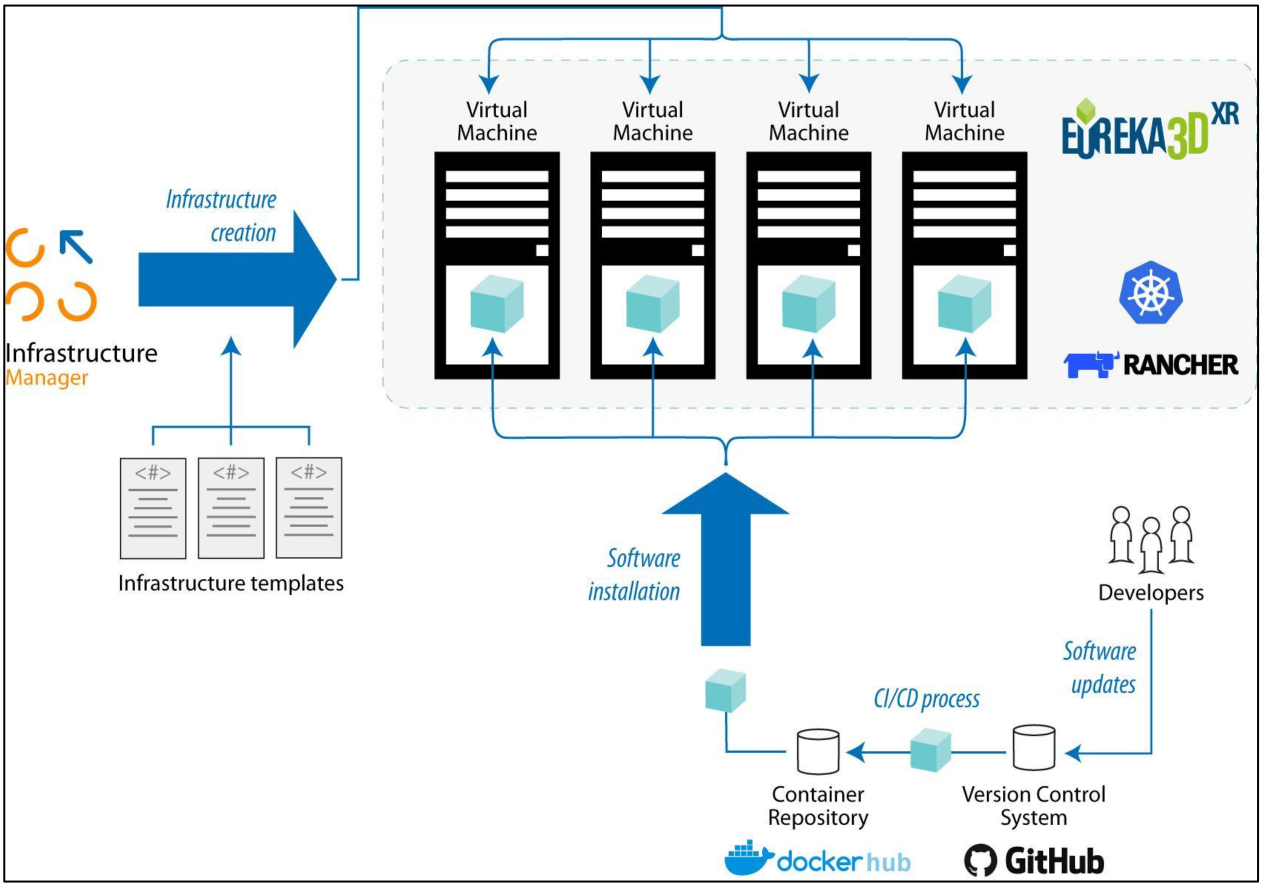

Fig. 5.7: Deployment workflow.

[9] https://www.egi.eu/service/infrastructure-manager/

Table 5.3 summarises some of the main requirements of the deployment process.

Table 5.3: Deployment requirements.

ID	Requirement	Comments
DPL-01	The tools' source code must be stored in a VCS	
DPL-02	The source code of the tools must be published under some open source licence	
DPL-03	The tools must be packed in a container image	Ideally, this should be done in an automated way
DPL-04	The container images of the tools must be published in a container repository and made available for download to the end infrastructure	Ideally, this should be done in an automated way

6. Additional considerations

In this chapter, additional considerations are provided to complement the technical aspects, functionalities, expected performance and engineering of the five tools and general architecture of the project, as presented in the previous sections.

Specifically, this chapter relates to two aspects: the integration of EUreka3D-XR project outcomes with the data space for cultural heritage, and the preliminary reflections on expected impact generated by the availability of the tools and EUreka3D-XR resources on the main stakeholder community, i.e. CHIs and other cultural / heritage professionals.

6.1 Integration with the data space for cultural heritage

One of the scopes of the EUreka3D-XR project is the enrichment of the common European data space for cultural heritage, by offering to stakeholders new services, tools and datasets for reuse. This general statement can be broken down in different actions that are planned to take place in the context of EUreka3D-XR:

- TOOLS: to provide access to new services and tools that data space stakeholders can use. In the case of EUreka3D-XR, this consists in enabling other content providers and CHIs to access the five tools and use them to enhance their digital collections, by reusing 3D and other digital resources to create new visitor experiences either onsite or online.
- COLLECTIONS: to provide access to new collections of 3D and other digital resources from the EUreka3D-XR content providers, that other content providers, CHIs, educators, creative organisations etc can reuse in their own work. In the case of EUreka3D-XR, this consists in aggregating collections to europeana.eu, via the existing pipelines in use by the Europeana accredited aggregator Photoconsortium. The collections will be also showcased via editorials published on europeana.eu and/or Europeana Pro.
- XR EXPERIENCES: to provide access to the demonstration scenarios of XR applications created with the five tools, that serve to inspire other content providers and CHIs and foster take up. This is a new concept that so far was not fully explored in the context of Europeana and the data space. Work is ongoing under the coordination of Europeana and particularly in the 3D working group of the data space to develop a position on the promotion and publication of XR experiences in the context of the data space. In the case of EUreka3D-XR, the project will certainly provide a representation of the three XR experiences to be showcased in the data space (e.g. as videos and editorials), for users to understand the possibilities.

The details of the integration actions that grant access and interoperability of EUreka3D-XR outcomes in the common European data space for cultural heritage are fully provided in the *D1.2 Initial integration report*.

6.2 Preliminary Reflections on expected impact

One of the assumptions at the basis of the strategy of the European Union as illustrated in the 2021 recommendation[10], that invites Member States to accelerate with 3D digitisation and to support share and reuse of 3D and other digital cultural resources, is that such resources can make a difference in the way stakeholder communities (such as citizens, educators, researchers, preservation operators, tourism and other creative and reuse communities) interact with cultural heritage.

In specific for the scopes of the EUreka3D-XR project, it is believed that XR experiences increase the impact of cultural collections, primarily in relation to user engagement. Therefore, once CHIs have taken the decision to digitise objects, or sites, into 3D models they are required to make a step forward to leverage their efforts and investments, for a more proactive participation in the 3D digital transformation of cultural heritage.

Interesting possibilities are offered by XR technologies for the creation of more interactive and more compelling storytelling. However, not always CHIs are able to easily implement XR experiences. While tools for creating XR experiences do exist since a long time, provided by creative enterprises in a variety of possibilities, they often present challenges for the CHI who wants to implement a XR experience:

- They often are costly services that a CHI needs to allocate budget for, therefore, it is necessary to engage a service provider, also including the set up of a competitive bidding process for public CHIs;
- With the exception of a few rare no-code, paid tools for designing geolocation-based tours incorporating 3D and AR, open source solutions or those with free licenses require IT skills, particularly in programming, that CHI staff lack, thus forcing the CHI to fully rely on professional expertise;
- They are often based on (closed) proprietary software and solutions, and are difficult to scale up;
- they may be difficult to update in time, requiring professional interventions of the creative industry who produced the service in the first place, and in general may not be very flexible in terms of functionalities and content, requiring additional technical developments;
- They are not interoperable with the European data space for CH and the respective CH data of different formats maintained on online platforms broadly used by the sector, such as Europeana and the EUreka3D Data Hub.
- Online and on-site tours and other experiences are often created on an ad-hoc basis, via setups that are specific to a particular organisation or site - usually built by tech companies outsourced with building a custom application. Thus, there is a need for generic tools that can be reused to serve different needs and circumstances.
- Many CHIs may lack hardware, network capabilities, or storage infrastructure to support XR deployments (e.g., VR headsets, powerful workstations).
- XR applications often require maintenance due to evolving operating systems, browsers, or hardware. CHIs may not have the resources or know-how to ensure the longevity of XR experiences once deployed.

The proposed tools developed in EUreka3D-XR aim at overcoming the aforementioned limitations and enabling CHIs to easily create an XR experience to serve to their target audience, enhancing the storytelling and the on-site experience. The five tools will make use of existing resources publicly available, such as the

[10] https://digital-strategy.ec.europa.eu/en/news/commission-proposes-common-european-data-space-cultural-heritage

EUreka3D Data Hub for storage and management of 3D collections, and linked to Europeana and the common European data space for cultural heritage to foster wider take up.

While EUreka3D-XR tools are not intended to replace the role of the creative industry in enhancing cultural storytelling with XR, it is expected that the availability of easy-to-use creator tools and inspiring demonstration scenarios will expand the possibilities for Cultural Heritage curators and staff in exploring novel methods of engaging with visitor communities.

The expected impact of EUreka3D-XR scenarios and tools is anticipated to shift the XR paradigm in the Cultural Heritage sector. CH staff will become more proactive in creating basic XR experiences, and they will also be better equipped to access tools and collaborate with the creative industry for more advanced implementations, regardless of their level of coding expertise or proficiency in other IT skills. To create in-house solutions for XR narratives which can be self-adapted in time to changing needs would also support the sustainability and longevity of the XR experience offered to visitors.

In summary, this approach will unlock a new landscape for creators and curators, as everyone with basic knowledge or resources can recreate 3D models of lost or inaccessible heritage, and create an AR tour to be performed on location and also adapt it to be accessed remotely (cfr. tools by Swing:It) thus supporting a dynamic and flexible approach with benefits for the whole community. It is also important to stress the openness offered by the tools for CHI professionals, that are interoperable with existing open platforms, and give the added value of using any publicly available open content (via the EUreka3D Data Hub), for example to create geolocated tours with AR capability (cfr. tools by NTUA), or to use AI for mindful 3D reconstructions (cfr. tool by Swing:It), or to access methodologies to enhance XR experiences in cultural and other types of applications (e.g. game industry) with animated, speaking avatars (cfr. tool by MIRALab).

The timeline of the project will allow for a short-term evaluation of the tools and measurement of their expected impact, also for deriving projections in the medium and longer term about the change that the availability of open access tools will have on CHI staff and professionals. The main questions that would feed the identification of change pathways for CHIs in relation to the use of the tools revolve around:

- Usability of the tools: can CHI staff easily access and use the tools?
- Retrievability of source content: can CHI staff easily upload their content for use in the various tools, or source it seamlessly from open repositories?
- Budget constraints: is it true that the tools and inspiring scenarios are sufficient for others to create an in-house prototype, without allocating specific investments?

The evaluation will happen both internally within the consortium and with external stakeholders. Measurement of the feedback will be based on qualitative indicators, collected with surveys, questionnaires and reports. More information about the planning for such stakeholders feedback collection are extensively provided in the *D2.1 Pilot specification and planning.*

7. Conclusions

This deliverable marks the first milestone of Work Package 3 (WP3) *Milestone 8 - Technical Requirements*. It lays the foundation for the technical development and integration work that follows. It defines the core technical requirements for the five EUreka3D-XR tools, as well as for their integration within the EUreka3D-XR Cloud Infrastructure. These requirements are shaped by the pilot scenarios, but reflect general ambitions in terms of usability, interoperability, and alignment with the EUreka3D Data Hub. The scenarios and the planning of the tools development in relation to the scenarios is further detailed in *D2.1 Pilots specification and planning*.

As the first deliverable of WP3, submitted in month 6, this report sets the stage for the next phases. On month 9, two beta releases will be delivered: the cloud infrastructure (D3.2) and the first version of the five tools (D3.4). These will be further developed and refined towards their final release by month 15 (D3.3 and D3.5 respectively). In parallel, three additional deliverables (D3.6–D3.8) will explore in more detail the aspects of quality assessment, format guidelines, and sustainability practices, complementing the baseline considerations reflected in this document.