D3.7 Formats and quality guidelines report

Due date: 30/04/2026

Dissemination level: Public

Author:
Frederik Temmermans (imec)

HISTORY OF CHANGES			
Version	Date	Authors and editors	Comments
0.1	10/03/2026	Frederik Temmermans (imec)	First draft
0.2	23/04/2026	Frederik Temmermans (imec)	Final draft completed, ready for review
0.3	23/04/2026	Valentina Bachi (PHC), Antonella Fresa (PHC)	First review
0.4	28/04/2026	Ignacio Lamata Martinez (EGI)	Final review
0.5	28/04/2026	Frederik Temmermans (imec)	Completed
1.0	39/04/2026	Valentina Bachi (PHC)	Submitted version

TABLE OF CONTENTS

EXECUTIVE SUMMARY

This report translates the findings and insights from the EUreka3D-XR project into a set of practical **formats and quality guidelines**, formulated as recommendations for external stakeholders involved in 3D digitisation, management, and reuse of cultural heritage assets.

Building on the quality assessment framework developed in Deliverable 3.6 (*Quality Assessment Report*), this document shifts the focus from quality assessment to actionable recommendations, addressing the full lifecycle of 3D content, from acquisition and processing to presentation, access, preservation, and reuse.

The guidelines aim to support Cultural Heritage Institutions (CHIs), service providers, and technology developers in making informed decisions regarding:

- the definition and adoption of quality-oriented workflows;
- the selection and use of interoperable formats and representations for 3D and multimodal assets;
- the design of consistent and coherent user experiences across tools, services, and infrastructures;
- the integration of accessibility and user experience considerations;
- the development of effective documentation, user manuals, and dissemination practices;
- the alignment with emerging standards and best practices for authenticity, provenance, and trust.

In addition, the integration of metadata and paradata to ensure transparency, reproducibility, and long-term usability is recognised as a crucial aspect. However, as metadata relies on well-established practices (e.g. Europeana Data Model and Dublin Core) and paradata is addressed in more detail in Deliverable D3.8 *Paradata and sustainability report*, this topic is not elaborated further in this deliverable.

1. INTRODUCTION

The increasing adoption of 3D digitisation in the cultural heritage sector brings new opportunities for access, research, and reuse, but also introduces significant challenges related to data formats, consistency of experience, interoperability, and long-term sustainability.

Within the EUreka3D-XR project, a diverse set of tools, workflows, and usage scenarios has been developed to support the creation and deployment of 3D and XR applications. These activities highlighted the critical role of well-defined formats and clear quality guidelines in ensuring that digital assets remain usable, interpretable, and trustworthy across different contexts.

Deliverable 3.6 *Quality Assessment Report*[1], openly available for download from EUreka3D-XR online channels, established a comprehensive framework for assessing quality across multiple dimensions, including data fidelity, metadata completeness, user experience, and infrastructure considerations. This deliverable translates these insights into actionable recommendations, addressing the full lifecycle of 3D content, from acquisition and processing to presentation, access, and reuse.

This deliverable provides guidelines and recommended practices, organised as follows:

- **Section 2** focuses on defining quality and establishing a methodological framework;
- **Section 3** addresses data formats and rendering, including both established practices and emerging approaches;
- **Section 4** focuses on consistency of experience across tools, services, and infrastructures;
- **Section 5** discusses accessibility and user experience considerations;
- **Section 6** covers user manuals, documentation, and dissemination practices;
- **Section 7** outlines future directions related to authenticity, provenance, and trust.

While metadata and paradata are essential for ensuring high quality, transparency, reproducibility, and long-term usability, they are not the primary focus of this deliverable. Metadata relies on well-established practices (e.g. Europeana Data Model and Dublin Core), and paradata is addressed in more detail in Deliverable D3.8 (*Paradata and sustainability report*).

Together with *D3.8 Paradata and sustainability report*, this deliverable is a means of verification for Milestone 14 “Formats and quality guidelines, Paradata sustainability”.

The recommendations presented in this report are informed by the implementation and evaluation of the EUreka3D-XR Toolbox[2], EUreka3D Data Hub and infrastructure[3], and usage scenarios[4], as well as by broader developments in the field. They are intended to be applicable beyond the project itself, providing a reference for external stakeholders seeking to establish or refine their own 3D digitisation workflows.

[1] https://eureka3d.eu/wp-content/uploads/2026/03/EUreka3D-XR-D3.6-Quality-assessment-report-v1.pdf

[2] D3.4 Toolbox beta https://eureka3d.eu/wp-content/uploads/2025/11/EUreka3D-XR-D3.4-Toolbox-beta.pdf

[3] D3.2 Cloud Infrastructure beta https://eureka3d.eu/wp-content/uploads/2025/10/EUreka3D-XR-D3.2-Cloud-Infrastructure-beta.pdf

[4] D2.1 Pilot specification and planning https://eureka3d.eu/wp-content/uploads/2025/07/EUreka3D-XR-D2.1-Pilot-specification-and-planning.pdf

2. DEFINING QUALITY IN 3D DIGITISATION AND XR EXPERIENCES

2.1 CONTEXT

Deliverable D3.6 (*Quality Assessment Report*) introduces the approach adopted by the EUreka3D-XR project with respect to quality in the context of 3D digitisation and XR experiences. In this context, quality is understood as a multifaceted concept, encompassing the fidelity and integrity of 3D content, the completeness and correctness of metadata and paradata, and the overall quality of experience provided to users interacting with tools, infrastructures, and applications. Together, all these aspects contribute to the reliability, usability, and long-term value of digital assets within a broader ecosystem. A key conclusion of D3.6 is that quality cannot be assessed solely at the level of final outputs, but must be considered as an end-to-end approach, embedded across the full lifecycle of digitisation, processing, deployment, and reuse.

Building on this definition, the following provides a set of recommendations for approaching and defining quality in the context of 3D digitisation and XR projects. These recommendations focus on the overall conceptual and methodological approach to quality, rather than on specific technical aspects. More detailed guidance on topics such as data formats, application deployment strategy, user experience, and documentation are addressed in the subsequent sections.

2.2 RECOMMENDATIONS

R2.1. Define approach to quality early

The concept of quality should be defined early on in the project and aligned with the intended use case (e.g. conservation, research, dissemination, XR experience).

R2.2. Consider quality as a multifaceted concept

Quality should not be reduced to visual appearance alone. It should be considered across multiple dimensions that shape the overall experience, including data fidelity (geometry, texture, structure), technical robustness (formats, compatibility), usability and accessibility, consistency of experience, and supporting documentation.

R2.3. Integrate quality across the full lifecycle

Quality should be addressed as an end-to-end concern, spanning acquisition, processing, integration, deployment, and reuse. Decisions made in early stages have a direct impact on downstream quality and cannot be fully corrected later.

R2.4. Document trade-offs

Trade-offs between competing requirements (e.g. fidelity versus performance) are inherent to 3D and XR workflows. These should be clearly defined, documented, and consistently applied throughout the project.

R2.5. Treat quality as an evolving property

Quality requirements and expectations evolve over time. Processes should allow for iteration, user feedback, and continuous improvement, rather than remaining fixed. In this context, input from external stakeholders (e.g. advisory boards or user groups) plays a key role in avoiding a narrow or static definition of quality.

R2.6. Align quality expectations across stakeholders

Quality requirements should be defined and continuously aligned across all stakeholders involved in the project, including cultural heritage institutions, technology providers, and end-user representatives. Differences in priorities (e.g. scientific accuracy, performance constraints, or user engagement) should be explicitly identified and reconciled to ensure that quality objectives remain coherent and fit for purpose.

2.3 CONCLUSION

Quality should be understood as a multifaceted concept. As highlighted by the EUreka3D-XR experience, achieving quality in practice requires early definition, continuous alignment, and the ability to balance competing requirements through informed and documented trade-offs. This view on quality forms the foundation for the recommendations presented in the subsequent sections.

3. Data formats & rendering

3.1 Context

Data formats and rendering environments play a key role in enabling the effective representation, processing, presentation, reuse, and long-term preservation of 3D and XR content. The selection of appropriate formats directly influences interoperability, performance, visual fidelity, and long-term sustainability, while rendering environments determine how digital assets are ultimately experienced by end users.

In practice, 3D digitisation workflows must balance multiple, often competing requirements. For example, formats suitable for processing or preservation are not always optimal for presentation, particularly in web-based environments. Similarly, differences in platforms and target devices introduce constraints related to performance, compatibility, and user experience. As a result, decisions regarding formats and rendering approaches must consider the full lifecycle of digital assets, from creation to access, reuse, and long-term preservation.

The following subsection presents a concrete example from the EUreka3D-XR project, illustrating how these challenges were addressed in practice within the Avatar Builder workflow. Based on this experience, a set of recommendations is then derived to support the selection and use of data formats and rendering strategies in broader contexts. Finally, emerging data representations and formats are discussed, highlighting ongoing developments and their implications for future workflows.

3.2 Case study: Avatar Builder workflow and lessons learned

Data formats and workflow strategy

The Avatar Builder workflow relies on a combination of standardised and widely adopted data formats to support both efficient production and broad dissemination. In particular, the project adopts a dual-format strategy, using FBX for virtual and mixed reality applications and web-oriented formats such as GLB/glTF, OBJ, PLY, STL, and SPLAT for online visualisation.

The FBX format is primarily used for integration within Unity, as it provides robust support for rigged and animated characters, complex hierarchies, and interactive behaviours. This makes it particularly suitable for the development of immersive experiences in VR/MR environments, such as the animated avatar of Saint Neophytos.

For web delivery, the workflow prioritises formats such as GLB, which enable compact, single-file distribution, efficient transmission over the network (as it is a binary format), and real-time rendering in browsers. These formats are natively supported by web-based frameworks, such as Babylon.js. Additional formats (e.g. PLY or SPLAT) are supported to accommodate specific use cases, including point-based and Gaussian splatting representations, which are increasingly relevant in cultural heritage digitisation.

This dual-pipeline approach balances flexibility during production with efficiency in dissemination, ensuring that core assets can be reused across platforms while being adapted to their specific constraints.

Constraints and interoperability considerations

Several technical and conceptual constraints influenced these choices. Interoperability between formats and software environments remains a key challenge, as differences in material definitions, shaders, and texture handling may lead to inconsistencies when converting assets, for example from FBX to GLB. These discrepancies directly affect visual fidelity and often require validation and manual adjustments to ensure consistent rendering across platforms.

Performance considerations also play a central role, particularly for real-time applications. Web platforms and standalone VR devices impose constraints related to processing power, memory, and network conditions, requiring careful optimisation of assets to ensure smooth interaction and acceptable loading times.

The project also aligns with cultural heritage standards by relying on open and well-documented formats, supporting interoperability with platforms such as Europeana. This highlights the importance of adopting web-friendly, standardised formats, such as glTF, to ensure long-term accessibility, reproducibility, and interoperability within external ecosystems.

Rendering and visualisation environments

The project relies on two complementary rendering environments. Web-based visualisation is implemented using the Babylon.js library, allowing users to access the experience directly through a standard web browser without additional software installation.

In parallel, immersive visualisation is developed within Unity and deployed on devices such as Meta Quest 3, offering a fully interactive and spatially immersive experience. These approaches address different use cases: web platforms maximise accessibility and dissemination, while VR/MR environments provide deeper engagement and interaction.

Throughout the production process, tools such as Blender are used for modelling, texturing, baking, and validation of assets prior to integration into the final environments.

Trade-offs and lessons learned

The development process highlighted several important trade-offs. A key challenge concerns the balance between visual fidelity and performance. While high-resolution models and textures improve realism, they can significantly impact performance in real-time environments. As a result, optimisation techniques such as *mesh simplification* and *texture baking* must be considered from the early stages of production.

Interoperability between tools and formats also remains a recurring challenge. Transferring assets across different environments can introduce discrepancies in materials, animations, or lighting, requiring iterative testing and validation.

In addition, deploying the same content across multiple platforms, such as web and VR, introduces further complexity, as each platform imposes distinct technical constraints. This often requires compromises in asset design or the creation of multiple optimised versions.

Finally, the project underlined the importance of balancing technical complexity with user experience. While advanced interactions can enhance immersion, they may also increase development effort and reduce usability if not carefully designed. Prioritising clear, intuitive, and meaningful interactions is therefore essential to support the narrative and educational objectives of the experience.

3.3 Recommendations

R3.1. Separate formats for authoring, preservation, and presentation

Different stages in the lifecycle of 3D content have distinct requirements, and there is no single format that can efficiently satisfy all of them. Formats that support complex structures, animation, and editing are typically better suited for authoring and integration, while formats optimised for stability and completeness support long-term preservation. In contrast, lightweight, standardised formats are more appropriate for presentation, particularly in web-based and real-time environments.

R3.2. Prioritise web-friendly and widely adopted formats for presentation

For presentation and online access, formats should be selected based on their ability to support efficient transmission, real-time rendering, and broad compatibility. Unlike 2D image formats such as JPEG 1 or PNG, which are natively supported by web browsers, 3D formats rely on dedicated viewers for visualisation. In practice, this implies prioritising web-friendly formats (e.g. glTF/GLB), which are openly specified and widely adopted, and therefore provide consistent rendering behaviour across platforms.

R3.3. Validate interoperability

Interoperability between formats and tools should not be assumed but actively validated. Differences in material definitions, shaders, and texture handling can introduce inconsistencies when assets are transferred across software environments or converted between formats. Systematic validation across target tools and platforms should therefore be integrated into the workflow, with particular attention to preserving visual fidelity and functional behaviour.

R3.4. Plan for performance and optimisation

Performance constraints, particularly in real-time and web-based environments, should be considered early in the workflow. High-resolution models and textures improve visual quality but can negatively impact performance.

As highlighted by the EUreka3D-XR experience, optimisation strategies such as mesh simplification, texture baking, and efficient data representation should be applied from the early stages of production, rather than introduced as a post-processing step. This includes selecting compact and efficient data formats, such as binary representations (e.g. GLB) over textual alternatives (e.g. OBJ), which reduce file size, improve transmission efficiency, and support faster processing. Where relevant, formats and workflows should also support progressive or on-demand (lazy) loading, enabling partial data access and improving responsiveness in web-based and real-time environments.

R3.5. Consider platforms and usage scenarios

Different platforms (e.g. web, VR, mobile) impose distinct technical constraints and offer different interaction capabilities. Content and formats should therefore be selected and adapted based on the intended usage scenario, taking into account factors such as device capabilities, network conditions, and functional requirements. In some cases, this may require maintaining multiple optimised versions of the same asset.

R3.6. Prefer open, interoperable, and sustainable visualisation solutions

Visualisation tools and platforms should be selected based on their ability to support open standards, interoperability, and long-term sustainability. In particular, solutions that allow control over data, integration with existing infrastructures, and alignment with European frameworks (e.g. EOSC, Europeana, and the upcoming Collaborative Cloud for Cultural Heritage) should be prioritised.

Reliance on closed or proprietary platforms (e.g. commercial online viewers such as Sketchfab) may offer ease of use but can introduce limitations in terms of data portability, long-term access, and integration with external systems. Where possible, preference should therefore be given to open or standard-compliant solutions, including those developed within European research and innovation ecosystems, which are often better aligned with European data infrastructures and policy frameworks.

3.4 Emerging data formats

Current 3D digitisation workflows rely on several well-established representations and data formats. Mesh-based formats (e.g. OBJ, FBX, glTF) represent surfaces using polygonal geometry and textures and are well-suited for real-time rendering and dissemination. Point cloud formats (e.g. PLY, LAS) represent scenes as collections of points with associated attributes and are commonly used in acquisition and documentation workflows. In addition, scene description formats (e.g. glTF, USD) extend geometric representations by incorporating materials, lighting, and hierarchical structure, enabling more complex and interactive applications.

Recent advances in 3D reconstruction have led to the emergence of new representations that move beyond traditional geometry-based models. In particular, radiance field representations model the appearance of a scene as a function of both spatial position and viewing direction, enabling highly realistic rendering from arbitrary viewpoints. Unlike conventional 3D formats that rely on explicit geometry and textures, radiance fields encode both geometry and view-dependent appearance in a unified representation. This enables photorealistic rendering with effects such as reflections, transparency, and complex lighting interactions. Two main categories of such approaches can be identified:

- **Implicit representation**s (e.g. Neural Radiance Fields (NeRF)), where scene information is encoded in neural networks. These methods can achieve high visual fidelity but typically require significant computational resources and are less suited for direct manipulation or real-time use.
- **Explicit representations** (e.g. 3D Gaussian Splatting (3DGS)), where scenes are represented using sets of primitives with associated radiance properties. These approaches enable real-time rendering and are increasingly used in practical applications due to their balance between quality and performance.

Radiance field representations are particularly promising for XR and cultural heritage applications, as they enable more photo-realistic representations compared to traditional formats. However, they currently introduce important challenges, including:

- The lack of standardised and interoperable exchange formats, with current implementations relying on ad hoc or framework-specific data structures (e.g. extensions of point cloud formats); Currently, 3DGS representations are typically stored using extended point cloud formats such as PLY, where each Gaussian is represented as a point with additional attributes (e.g. scale, orientation, and radiance parameters). However, no standardised exchange format exists.
- Increased data complexity and storage requirements, requiring efficient compression and streaming solutions.
- The need for new quality assessment methodologies, as traditional metrics based on geometry or images are not directly applicable.

In this context, ongoing standardisation efforts such as the JPEG Radiance Field (JPEG RF) initiative aim to address these challenges by defining common frameworks for the metadata format, coding, compression, and evaluation of radiance field representations.

Given their current level of maturity, emerging representations should be considered complementary to established formats rather than direct replacements. Hybrid workflows combining meshes, point clouds, and radiance fields are likely to provide the most robust and sustainable solutions in the short to medium term.

3.5 Conclusion

The experience gained in the EUreka3D-XR project highlights the importance of selecting data formats and rendering approaches in relation to the full lifecycle of 3D content, balancing interoperability, performance, and platform-specific constraints. Practical workflows, such as the Avatar Builder, demonstrate that no single format or solution is sufficient, and that a combination of approaches is often required to support both production and presentation needs.

Given their current level of maturity, emerging representations such as radiance fields should be adopted with caution in production workflows. While they offer significant advantages in terms of visual fidelity, their lack of standardisation and interoperability limits their suitability for long-term preservation and broad reuse. In practice, they are best used in combination with established formats, ensuring that core data remains accessible, portable, and sustainable over time.

4. Consistency of experience

4.1 Context

Deliverable D3.6 (*Quality Assessment Report*) discusses consistency of experience as an important dimension of quality in 3D digitisation and XR projects, with particular attention to the role of the EUreka3D Data Hub and the underlying deployment infrastructure in providing a coherent, reliable, and trustworthy environment for users. In the EUreka3D-XR project, this was addressed through the harmonisation of core technical and operational components, including architectural alignment, unified access mechanisms, consistent data publication practices, and harmonised deployment processes. As described in D3.6, these measures were intended to reduce fragmentation across tools and services and to provide a more predictable and coherent experience for both content providers and end users. As such, the approach followed in EUreka3D-XR provides a practical example of how consistency of experience can be addressed in complex 3D and XR ecosystems, and in cultural heritage applications more broadly.

The experience gained in EUreka3D-XR highlights that consistency of experience does not emerge automatically from the integration of multiple tools and services, but requires deliberate design and coordination across technical and operational layers. Fragmentation in access mechanisms, data handling, or application behaviour can quickly lead to inconsistencies that negatively impact usability, trust, and adoption. Ensuring consistency therefore becomes a key design objective, rather than a by-product of system integration.

4.2 Recommendations

R4.1. Design for consistency as a primary objective
Consistency of experience should be treated as a core design objective, rather than as a by-product of integrating multiple tools and services. In practice, independently developed components tend to diverge in behaviour, interfaces, and assumptions unless alignment is actively enforced.

R4.2. Harmonise authentication and authorisation mechanisms
Users should interact with the ecosystem through consistent authentication and authorisation mechanisms. Differences in login procedures, access rights, or identity management can introduce friction and reduce trust, even when underlying services are technically sound. In addition, in a context of increasing security awareness and risks such as phishing, relying on a limited set of trusted and well-established authentication and authorisation solutions improves both user confidence and overall system security.

R4.3. Ensure consistency in data access and publication
Data should be exposed through standardised and interoperable access and publication mechanisms, enabling consistent discovery, retrieval, and reuse across tools and platforms. In the EUreka3D-XR project, this was achieved through the EUreka3D Data Hub, which provides a unified entry point for 3D assets and associated metadata, and ensures compatibility with external ecosystems such as Europeana through the use of established models and protocols (e.g. Europeana Data Model and OAI-PMH).

This illustrates the importance of aligning data publication practices with widely adopted standards and aggregation platforms, rather than relying on ad hoc or tool-specific interfaces. Inconsistent data models or access mechanisms can significantly hinder interoperability, limit reuse, and increase integration effort for downstream applications.

In addition, consistent data publication should support persistent identification and long-term reuse. The use of Persistent Identifiers (PIDs) and well-defined metadata frameworks ensures that digital assets remain findable, citable, and accessible over time, even as underlying storage or systems evolve, thereby supporting FAIR principles and reliable integration into broader research and cultural heritage ecosystems.

R4.4. Maintain a unified deployment strategy

Differences between development, testing, and production environments should be minimised through reproducible and controlled deployment processes. In practice, this requires a clear separation of environments (e.g. staging and production), the use of code repositories in version control systems, and automated build and deployment pipelines to ensure that applications are deployed in a consistent and traceable manner.

The EUreka3D-XR approach illustrates the importance of containerised deployments and automated CI/CD (Continuous Integration/Continuous Deployment) processes in achieving reproducibility, controlled updates, and operational reliability. Such practices ensure that application behaviour remains predictable over time and across platforms, reducing discrepancies between services and strengthening user trust.

R4.5. Reduce fragmentation through shared infrastructure and standards

Where multiple tools and services are developed within the same ecosystem, fragmentation should be actively mitigated by relying on shared infrastructure components, common standards, and aligned operational practices at the system level. In the EUreka3D-XR project, this includes the use of a shared data infrastructure (EUreka3D Data Hub), common authentication mechanisms, and harmonised deployment processes.

This approach reduces duplication, simplifies integration, and ensures that tools remain interoperable and coherent as part of a broader system. In contrast, isolated or tool-specific solutions tend to increase maintenance complexity, limit reuse, and hinder the scalability of the ecosystem.

4.3 Conclusion

While consistency of experience should be a primary design objective, the EUreka3D-XR project also highlights that it cannot always be achieved through a single, rigid strategy. In practice, trade-offs may arise between consistency and other factors such as implementation complexity, performance, flexibility, or functional requirements. For example, centralised mechanisms (e.g. for access control or data management) may improve coherence, but can also introduce additional overhead or constraints that need to be carefully evaluated.

As a result, achieving consistency of experience requires a pragmatic and adaptive approach, where initial design choices may need to be revised as new requirements, limitations, or use cases emerge. Consistency should therefore not be treated as a fixed target, but as a continuous balancing process, guided by technical feasibility, user needs, and operational constraints.

5. ACCESSIBILITY AND USER EXPERIENCE

5.1 CONTEXT

Deliverable D3.6 (*Quality Assessment Report*) addresses accessibility and user experience as another important dimension of quality in 3D digitisation and XR projects, with particular attention to the design and evaluation of the EUreka3D-XR toolbox. The project developed a set of tools targeting cultural heritage professionals, often with limited technical background, with the objective of enabling the creation and deployment of 3D and XR experiences in an accessible and usable manner. As described in D3.6, this required careful consideration of interface design, interaction workflows, and iterative refinement based on user feedback gathered through pilots and validation activities.

The experience gained in EUreka3D-XR, based on pilot activities and user feedback, indicates that usability and accessibility are critical factors for the adoption potential of tools and workflows. In practice, challenges are often not purely technical, but relate to the diversity of user profiles, including variations in expertise, technical background, and physical capabilities. Accessibility should therefore not be limited to interface design alone, but should ensure that tools remain usable across this diversity of users, allowing both non-experts and advanced users to effectively perform tasks within their respective contexts.

In addition, accessibility should be aligned with recognised standards such as the Web Content Accessibility Guidelines developed by the World Wide Web Consortium[5] and guidelines such as those provided by the European Web Accessibility Directive (WAD)[6]. These include aspects such as colour contrast, scalable typography, alternative content access, and appropriate interaction target sizes, which contribute to usability for a broad range of users, including those with visual, auditory, physical and cognitive impairments. While full compliance may not always be achievable, in particular in XR contexts, progressive alignment with these principles significantly improves inclusivity and usability.

Finally, XR environments introduce additional dimensions of accessibility and user experience that go beyond traditional web-based interaction. Factors such as device ergonomics, user fatigue, session duration, and cognitive load can significantly influence the usability and acceptance of immersive applications.

5.2 RECOMMENDATIONS

R5.1. Design for diverse user profiles

Tools and applications should be designed to accommodate a wide range of user profiles, including variations in expertise, technical background, and physical capabilities. This requires balancing simplicity and functionality, ensuring that non-expert users can perform essential tasks while allowing more advanced users to access additional capabilities when needed.

In practice, interfaces and workflows should minimise the need for specialised knowledge, avoiding unnecessary technical steps and prioritising task-oriented interaction. Where complexity cannot be avoided, it should be progressively introduced rather than exposed upfront.

R5.2. Align with recognised accessibility standards

[5] https://www.w3.org/TR/WCAG21/

[6] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32016L2102&from=EN

Accessibility considerations should be aligned with recognised standards such as the Web Content Accessibility Guidelines and the European Web Accessibility Directive (WAD). Key aspects include colour contrast, scalable typography, alternative content access, and appropriate interaction target sizes. While full compliance may not always be achievable, in particular in XR contexts, progressive alignment with these principles significantly improves usability and inclusivity.

R5.3. Harmonise the user experience across tools

When multiple tools are part of the same ecosystem, differences in interface design, interaction patterns, or visual presentation can introduce confusion for users. Efforts should therefore be made to minimise cognitive switching costs when users move between tools, ensuring a coherent and predictable user experience.

In addition, tools should exhibit consistent behaviour in how data is handled, how interactions are performed, and how performance is perceived, as inconsistencies in these aspects can negatively affect usability and user confidence.

A common experience can be achieved through the definition and application of shared design guidelines across tools. A concrete example is provided in Section 4.6 ("Harmonisation") of Deliverable D3.6, where common design principles were defined and applied to ensure visual and interaction consistency across the EUreka3D-XR toolbox.

R5.4. Address XR-specific usability and accessibility factors

In contrast to design for traditional 2D screens, usability in XR environments is influenced by additional factors such as device ergonomics, user fatigue, session duration, and cognitive load. These aspects should be considered when designing immersive experiences, as they can significantly affect user comfort and acceptance.

5.3 Conclusion

The experience gained in EUreka3D-XR highlights that accessibility and user experience are critical factors influencing the adoption potential of 3D and XR tools. While technical capabilities are essential, they are not sufficient to ensure effective use in practice. Usability is strongly shaped by real-world constraints, including limited time, varying levels of expertise, and the need to integrate tools into existing workflows.

In addition, XR environments introduce specific challenges that go beyond traditional interface design, requiring careful consideration of factors such as ergonomics, fatigue, and cognitive load. These aspects can directly impact the practical usability and acceptance of immersive applications.

As a result, accessibility and user experience should be considered as key design drivers, requiring continuous attention throughout the development process. Achieving this in practice involves balancing technical possibilities with user needs and constraints, and recognising that effective solutions must work under real-world conditions rather than idealised scenarios.

6. User manuals, documentation & dissemination

6.1 Context

Deliverable D3.6 highlights the role of user manuals, technical documentation, and dissemination activities as essential components supporting the effective use of the EUreka3D-XR toolbox and the EUreka3D Data Hub. Practical usability of tools depends on the ability of users, who might have limited technical expertise, to understand and use them in their specific contexts. As such, documentation and dissemination materials are integral elements of the project and its outcomes.

6.2 Recommendations

R6.1. Design documentation for varying levels of expertise

Documentation should be tailored to users with different levels of expertise and technical background. This requires clear language, avoidance of unnecessary technical terminology where possible, and a focus on task-oriented guidance that supports both non-expert users and more advanced users.

Documentation should be structured around concrete tasks and workflows, rather than around tool features. Step-by-step guidance and real use cases are more effective than exhaustive technical descriptions.

This can be achieved by providing layered documentation, for example by combining "getting started" guides for onboarding and basic tasks with more detailed technical specifications or reference documentation for advanced use.

R6.2. Provide documentation in multiple formats

Different users benefit from different types of documentation. In addition to written manuals, complementary formats such as video tutorials, demonstrations, interactive training materials, and example datasets can significantly improve understanding and reduce onboarding effort.

In the EUreka3D-XR project, this approach is reflected in capacity building and dissemination activities, including the use of structured training materials (e.g. tutorials, workshops, and online courses). These formats support different learning styles and enable more effective onboarding and knowledge transfer.

R6.3. Integrate documentation with the tools where possible

Documentation should not be limited to external resources, but should be integrated into the tools themselves where possible (e.g. contextual help, tooltips, or guided workflows). This reduces the need for users to switch between environments and supports more efficient task completion.

Where full integration is not feasible, clear and direct links between tools and relevant documentation can be provided to ensure smooth access to supporting information.

R6.4. Ensure consistency between tools and documentation

Terminology, workflows, and concepts used in documentation should be aligned with those implemented in the tools. Inconsistent naming or descriptions can lead to confusion, particularly in ecosystems involving multiple tools developed by different contributors.

To support this, it is recommended to establish a common glossary of terms and definitions at project level, ensuring consistent use of terminology across tools, documentation, and dissemination materials.

R6.5. Maintain and update documentation alongside tool development
Documentation should evolve together with the tools. Outdated or incomplete documentation can significantly hinder usability, even when the tools themselves are well designed.

R6.6. Support dissemination and capacity building activities
Dissemination and capacity building activities, such as workshops, training sessions, and structured learning materials, play an important role in enabling users to adopt and effectively use the tools. In the EUreka3D-XR project, such activities complement documentation by providing training and hands-on experiences, enabling users to understand the tools and identify how to integrate them within their own workflows.

R6.7. Consider open-source publication of software components
Where appropriate, software components should be made available as open source. This supports transparency, reproducibility, and reuse, and enables broader adoption by external stakeholders.

Open-source publication also contributes to long-term sustainability by reducing dependency on single vendors, facilitating community-driven maintenance, and supporting the development of an active user and developer community.

6.3 Conclusion

The experience gained in EUreka3D-XR confirms that documentation, user manuals, and dissemination activities are essential to enable the effective use of 3D and XR tools. While technical capabilities define what tools can achieve, their practical value depends on how easily users can understand, access, and apply them in their own contexts.

Documentation and capacity building should not be considered as supplementary outputs, but as core components that directly influence the usability and adoption potential of the tools. Achieving this requires a structured and user-oriented approach, combining well-structured documentation, multiple formats of learning materials, and targeted dissemination activities.

7. Future directions: authenticity, provenance and trust

7.1 Context

The development of 3D digitisation and immersive XR experiences can be seen as part of a long-standing trajectory of capturing and representing cultural heritage. While these technologies enable increasingly detailed and interactive representations, they also introduce new challenges related to interpretation, authenticity, and trust.

In this context, authenticity can no longer be understood solely in terms of visual realism or perceptual quality. Highly detailed or visually convincing representations do not necessarily guarantee that they can be reliably interpreted, compared, or reused over time. Instead, authenticity is closely linked to transparency, requiring an understanding of what a representation shows and how it was produced.

This places increased importance on metadata and paradata. While traditional metadata supports identification, discovery, and interoperability, it is less suited to capturing the processes and decisions underlying the creation of a digital representation. Paradata, in contrast, provides insight into how and why a representation was produced, including capture strategies, processing steps, and interpretative choices. As further elaborated in Deliverable D3.8 (*Paradata and sustainability report*), paradata plays a central role in documenting the lifecycle of a digital asset, enabling transparency, supporting reuse, and strengthening confidence in the quality of the resulting representations by making the underlying processes explicit and assessable.

These aspects become particularly critical in 3D and XR contexts, where representations often involve reconstruction, interpolation, and rendering processes that go beyond direct observation. The increasing use of AI-based tools further amplifies these challenges, as generated content may enhance visual quality while introducing elements that are not directly derived from captured data.

7.2 Provenance and trust frameworks

As 3D digitisation and XR technologies continue to evolve, ensuring the authenticity and trustworthiness of digital representations becomes a central challenge. In this context, provenance refers to the ability to document and trace the origin, creation, and transformation of a digital asset over time. This includes not only where the data comes from, but also how it has been processed, interpreted, and potentially modified throughout its lifecycle.

To be effective, provenance information must be securely bound to the content itself, ensuring that it remains associated with the asset across systems, formats, and usage scenarios. This requires mechanisms that go beyond traditional metadata, enabling verifiable and tamper-evident links between digital assets and their associated provenance records.

Emerging frameworks such as JPEG Trust (ISO/IEC 21617)[7] and initiatives like Coalition for Content Provenance and Authenticity (C2PA)[8] provide structured approaches to address these challenges. These frameworks enable the integration of provenance information, trust indicators, and verification mechanisms directly within or alongside digital content, supporting interoperability across platforms and ecosystems.

[7] https://jpeg.org/jpegtrust
[8] https://c2pa.org/

However, provenance alone is not sufficient. The broader objective is transparency, enabling users to understand not only the origin of a digital representation, but also the processes, assumptions, and potential limitations that shaped it. This is particularly important in the context of 3D and XR, where reconstruction, rendering, and AI-based enhancement can significantly influence the final representation.

Looking forward, the integration of provenance and trust frameworks within data infrastructures, publication workflows, and user-facing applications will be essential to support reliable interpretation, meaningful reuse, and long-term sustainability of 3D cultural heritage assets.

8. Conclusion

This report translates the experience and findings of the EUreka3D-XR project into a set of practical guidelines supporting the development, management, and reuse of 3D and XR cultural heritage assets.

Together with *D3.8 Paradata and sustainability report*, this deliverable is a means of verification for Milestone 14 "Formats and quality guidelines, Paradata sustainability".

By addressing quality as a multidimensional and lifecycle-oriented concept, the report highlights the importance of combining technical, operational, and user-oriented considerations. In particular, it emphasises the role of interoperability, documentation, accessibility, and consistency in enabling effective and sustainable use of 3D content.

Looking forward, the integration of provenance, paradata, and trust frameworks will play a key role in ensuring that digital representations remain transparent, interpretable, and trustworthy over time. Together, these elements contribute to building robust and future-proof ecosystems for 3D cultural heritage.