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Demonstrators Report 2

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| Abstract | This document provides detailed information about the deployment and implementation of the demonstrators targeted in the project, and their validation |
| Keywords | Demonstrators, Use Cases, Validation |

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Glossary

| Abbreviation | Meaning |
|--------------|-----------------------------------|
| 3DGS | 3D Gaussian Splatting |
| API | Application Programming Interface |
| AR | Augmented Reality |
| AT | Authoring Tool |
| BW | Bandwidth |
| CCDM | Class Conceptual Data Model |
| CI | Continuous Integration |
| CMS | Content Management System |
| DDD | Domain-Driven Design |
| DoA | Description of Action |
| DW | Deutsche Welle |



| Abbreviation | Meaning |
|--------------|---------------------------------------|
| EBU | European Broadcasting Union |
| FPS | Frames Per Second |
| FVV | Free Viewpoint Video |
| GDPR | General Data Protection Regulation |
| glTF | Graphics Language Transmission Format |
| GS | Gaussian Splatting |
| HDR | High Dynamic Range |
| HMD | Head-Mounted Display |
| IMU | Inertial Measurement Unit |
| JSON | JavaScript Object Notation |
| KPI | Key Performance Indicator(s) |
| MIME | Multipurpose Internet Mail Extensions |
| MOS | Mean Opinion Score |
| MVP | Minimum Viable Product |
| NeRF | Neural Radiance Field |
| NMR | Neural Media Repository |
| OS | Operating System |
| PNCC | Projected Normalized Coordinate Code |
| POI | Point of Interest |
| PSNR | Peak Signal-to-Noise Ratio |
| RF | Radio Frequency |
| SfM | Structure from Motion |
| SSIM | Structural Similarity Index Measure |
| SUS | System Usability Scale |
| VPS | Visual Positioning System |
| VR | Virtual Reality |
| WP | Work Package |
| XR | Extended Reality |
| XRC | XRCapsules |



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Executive Summary

This deliverable provides detailed information about the **deployment and implementation of six demonstrator use cases** and how they contribute to the technical validation of XReco's platform and services. Furthermore, this document delivers the final result of the project's demonstrators.

Additionally, the deliverable includes the **use case validation results**, defined according to the different key group functionalities that users can perform, and related to three different validation phases that happen across the project. The first phase to be validated is that of September 2022 (moment A) when the XReco project started, to see how the target users would have performed the production tasks of the XReco workflow before the consortium took to work, and thus establishing a baseline. The second validation phase happened around June 2024 (moment B1), about 21 months into the project, coinciding with the development of the first version of XReco's Minimum Viable Product (MVP - the first integrated version of the XReco platform). The third phase to be validated was June 2025 (moment B2), about 34 months into the project, coinciding with a refined version of the MVP after an additional year of development. The results show how the project's tools have successfully achieved an improvement in satisfaction and workflow acceptance of over 20%.



1 Introduction

In the second phase of the XReco project (M22-M38/June 2024 – Oct 2025)¹, the use case partners designed, implemented, and deployed six demonstrators: three in the domain of news media (one by RAI, two by DW), one for general virtual media production, and two in the domain(s) of Tourism and Automotive. The main objective of the demonstrators is to prove that the XReco platform and its components enable the five user types (as described in D6.2²) to perform their tasks:

- Content givers to upload content to the Neural Media Repository (NMR)
- Content searchers and transformers to search the NMR and connected external repositories
- Content transformers to transform 2D assets into 3D assets
- Content creators to create Extended Reality (XR) experiences
- Content givers and takers to sell and buy assets and/or experiences on the XReco marketplace

Section 2 of this deliverable will describe how the XReco tools were used to produce these demonstrators.

The different demonstrators have covered the tools and technologies developed in XReco as listed in the overview table below. The so-called Demonstrator Matrix (Table 1) was designed early in the project to define which technologies would be used by whom and subsequently led to forming collaboration groups comprising use case and technology partners to team up for the realisation of the Demonstrators.

Table 1: Demonstrator Matrix

| Demonstrator | Metasearch | 3D Reconstruction (NeRF) | 3D Reconstruction (SfM) | 3D Reconstruction (3DGS) | Holoportation | Free Viewpoint Video | 4D Human Reconstruction | Human Reconstruction 4DGS | XReco Authoring Tool | AR CMS | Licensing | Marketplace |
|-----------------------------------|------------|--------------------------|-------------------------|--------------------------|---------------|----------------------|-------------------------|---------------------------|----------------------|--------|-----------|-------------|
| News Media (Virtual Studio) – DW | X | | X | X | | X | | | X | | X | X |
| News Media (3D Infographics) – DW | X | | X | X | | | | | X | | | X |
| News Media - RAI | X | X | X | X | X | X | | X | | | X | X |
| Virtual Media Production - FFP | X | X | X | X | | X | X | | X | | | X |
| Tourism - ZAUBAR | X | | X | | | | X | | | X | | X |
| Automotive - CAR | X | | X | | | | | | | | | X |

¹ In this case, the second phase does not relate to the second reporting period, but to the time after the submission of D5.1.

² <https://xreco.eu/wp-content/uploads/2024/04/XReco-D6.2-Dissemination-communication-and-exploitation.pdf>



The News Media Demonstrators by Deutsche Welle (DW) and RAI show how XRco supports news media production in large broadcaster workflows as well as for integrating smaller 3D/VR representations in everyday journalism (see 0), while FFP's second Virtual Music Video Production Demonstrator shows how smaller media companies can make use of XR production technologies. All Media Demonstrators reconstructed buildings and smaller objects producing 3D models and 3D Humans in volumetric captures or avatars, integrating these 3D assets in their immersive storytelling to enable innovative media production.

ZAUBAR's Tourism Demonstrator and CAR's Automotive Demonstrator show the use case of a tour guide and tourists who explore a city using interactive Augmented Reality (AR) experiences. The tour guide has the role of content creator, and the tourists are the final content consumers. Using the reconstruction technologies that XRco provides, the tour guide can reconstruct landmarks and input them into the platform and create the experiences through the ZAUBAR App or the proprietary CAR app respectively.

While the successful production of these six demonstrators already provides proof that the XRco tools and services enable content producers to create 3D assets and Extended Reality (XR) experiences, the XRco technologies are also validated individually in a series of validation activities in June and July 2024 and later by external users providing feedback on the Minimum Viable Product (MVP) of the platform. Section 3 and the annexes to this document elaborate on the validation methodologies and procedures.

Just as the demonstrators prove the use of different potential users to carry out certain tasks, there is also a quantitative evaluation to fulfil two KPIs as mentioned in the Description of Action (DoA).

- **KPI 3.2:** Improved by at least 20% (in terms of user acceptance measured in a Likert scale) XR production workflows via the delivered platform, evaluated through **acceptance testing, subjective usability evaluation and expert interviews.**
- **KPI 4.2:** Show increased acceptance and usability rates ($\geq 20\%$), via user studies and interviews on at least three (3) different sectors (i.e., journalism and media, automotive, tourism).

Because the user groups are significantly different, the selected approach towards this validation was in dividing the platform in 5 different key group functionalities:

- XRco Platform
- 3D Reconstruction Services
- Unity Authoring Tool
- XRCapsules
- ZAUBAR CMS

Every key group functionality had a different test set associated to it.



2 The Demonstrators

The following subsections detail the six different demonstrators: two traditional broadcasting companies, RAI and Deutsche Welle (DW), and Austrian SME media production company FFP tested the use of XReco technologies in News and Media productions, while ZAUBAR and CAR implemented and demonstrated XReco technologies in the field of Tourism and Automotive entertainment. Following the project’s Description of Action (DoA), the News Media Demonstrators have been the focus of the workflow design as they serve media production companies of various sizes, whereas the Tourism and Automotive Demonstrators focus more on the use of the platform and its components in other, non-media-focused areas.³

2.1 News and Broadcasting Demonstrator – RAI

Table 2: Overview of technologies used in RAI's demonstrator

| Title | The news evolution | Lead partner | RAI |
|-----------------------------------|---|--------------|-----|
| Platform services | Metasearch, Marketplace | | |
| Reconstruction technologies | NeRF, Gaussian Splatting, Structure from Motion | | |
| Human reconstruction technologies | Holoportation, Unreal Engine (MetaHuman), GDGS: 4D Gaussian Splatting, Free Viewpoint Video | | |
| Authoring tool(s) | RAI’s studio facilities (Virtual studio, Unreal engine) | | |
| Output format(s) | 2D Video | | |

The evolving media landscape increasingly demands immersive, non-linear formats supported by innovative tools for content creation and distribution. XReco addresses this need by providing a unified, data-driven ecosystem for next generation media production. This capability was demonstrated through a short TV documentary on Guglielmo Marconi, created using historical materials assembled via the XReco platform. The Marconi documentary validates the XReco platform as a robust, end-to-end solution that effectively addresses the key technical and commercial challenges of modern Extended Reality (XR) and virtual production.

2.1.1 Demonstrator overview and expected output

To showcase a broad range of XReco's capabilities, RAI developed a demonstrator focused on the TV production of a short documentary about the life and groundbreaking work of Guglielmo Marconi, the pioneer of wireless telegraphy. Marconi's story, marked by revolutionary inventions that laid the foundation for modern communication, offers a rich tapestry of vintage electronics that can be brought to life through XReco's advanced functionalities. The project's ambition to seamlessly integrate XR content into media production and

³ “The News Media demonstrator will be the focus of the platform and of the technologies surrounding it, and it will allow the cooperation of professionals coming from research and development together with artists, journalists, and other media professionals. The Tourism & Self-Driving Cars demonstrator will prove the potential of the XReco ecosystem to be exploited in other environments where media technologies play an important role.”



consumption makes it an ideal platform for delivering educational news and entertainment TV programmes in an engaging and informative manner. The demonstrator's outcomes are showcased in the form of a video documentary⁴, which integrates the various technologies developed by the partners. This multimedia format allows the innovations to be presented in a dynamic and engaging way, as described in the following subsection.

2.1.2 Demonstrator Workflow

Table 3 presents both the core components updated from the first demonstrator and the new ones introduced in this second demonstrator.

Table 3: Workflow of creating “The news evolution” demonstrator

| WORKFLOW FUNCTIONALITY | COMPONENT NAME (RESPONSIBLE PARTNERS) | TASK | MAIN ROLE IN THE DEMONSTRATOR |
|--|---|------------|---|
| Content ingestion | Repository Connector (ATOS/i2Cat, RAI) (updated) | T3.5 | Ingestion of assets from proprietary sources and public online platforms into the XReco platform |
| Content analysis | News content tagging (RAI) (new) | T4.1 | Generation of multilingual semantic tags (e.g., named entities, concepts) from the descriptions of ingested assets |
| Content access, search, and management | Orchestrator (MOG) (updated) & Neural Media Repository (UNIBAS) (updated) | T3.1, T3.2 | Tag-based content filtering; Cross-modal content search; Configuration, execution and monitoring of content production services |
| Content production | 3D object reconstruction (CERTH, UPM, RAI) (updated) | T4.2 | Generation of 3D models from 2D video assets |
| | Blind face restoration (RAI) (new) | T4.3 | |
| | 3D face reconstruction (RAI) (new) | T4.4 | Creation of realistic, high-fidelity 3D models of human faces |
| | 3D Human (RAI) (updated) | T5.4 | Creation of photorealistic digital twins |
| | Virtual scene composition (i2CAT, RAI) (new) | T4.3 | Virtual reconstruction of real-world environments from 2D videos |
| (Real-time) Content integration | Holoportation (i2CAT) (updated) | T4.4 | Reconstruction and transmission of full human bodies |
| | Free Viewpoint Video (UPM) (new) | | Reconstruction and transmission of full human bodies |
| | GDGS: 4D Gaussian Splatting (i2CAT) (new) | | Reconstruction of full human bodies |
| Content licensing | Rights Management (FINCONS) (updated) | T3.3, T3.4 | Association of content license policies to ingested/generated assets |
| Content monetization | Marketplace (MOG) (updated) | T3.3, T4.4 | Selling or purchasing of generated assets and experiences |

⁴ Demonstrator video on YouTube: <https://www.youtube.com/watch?v=XaOlnKwhYw>

The first crucial step in building such a demonstrator involves content ingestion. XReco Connectors enable media providers to add different types of media assets, including images, 2D videos, texts and 3D models, along with standardised metadata, to the platform. In the case of the Marconi documentary, we uploaded some 2D videos of ancient electronic devices from the RAI Museum of Radio and Television in Turin, to provide a valuable visual context for successive processing. An example is shown in Figure 1.

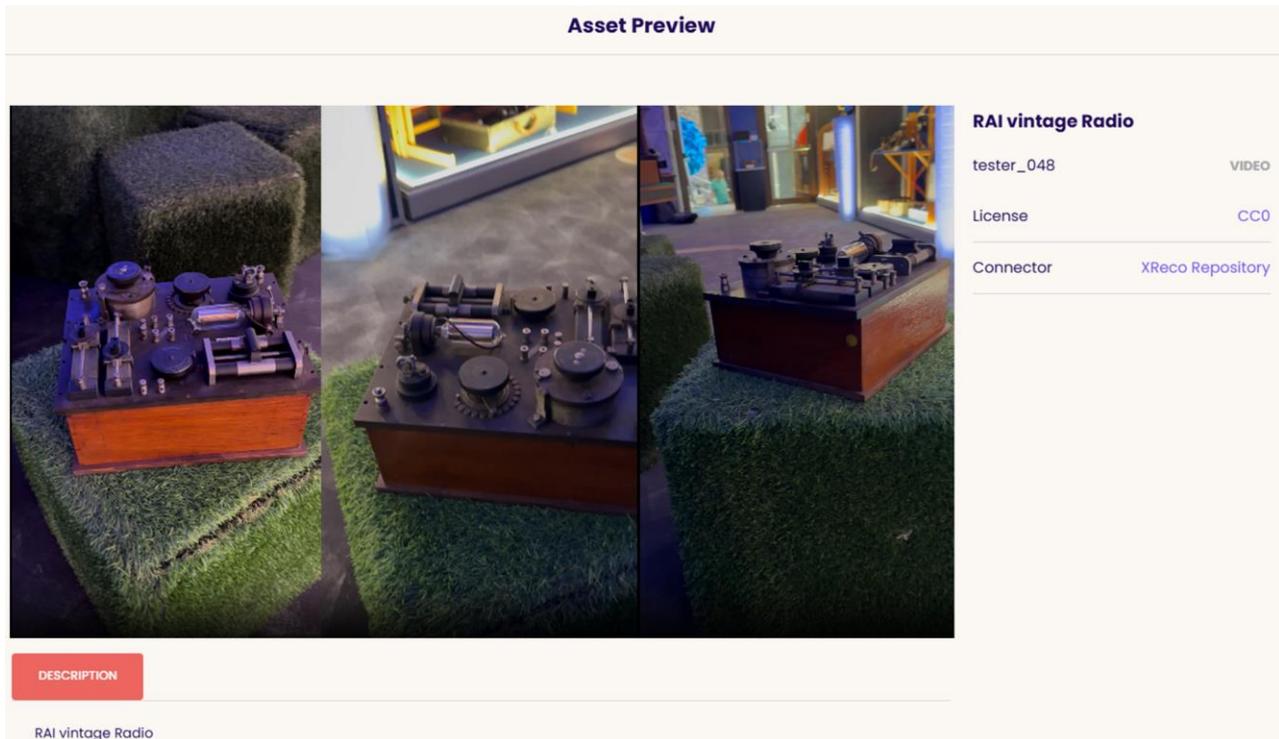


Figure 1: 2D video showing a Morse telegraph used for 3D reconstruction.

Given that contents ingested in the XReco platform originate from heterogenous providers, such as online news, broadcasters' archives, public web repositories, each distinguished by its own metadating rules and schemas, XReco's standardised approach ensures that all contents ingested are efficiently organised, interlinked and easily accessible within the platform. For instance, searching for keywords like "phonograph" or "telegraph" enabled the editorial team to retrieve images of sound and voice reproduction devices from the set of content sources available via the Metasearch service that crawls internal and external sources like Wikimedia Commons, Sketchfab, and Europeana. Building on these search results, they were able to better identify a subset of visual assets and textual descriptions of Marconi's early technological innovations by combining a reverse image search with the filtering criteria provided by the News Tagging service, two new features offered by the updated Orchestrator and Neural Media Repository (see Figure 2).

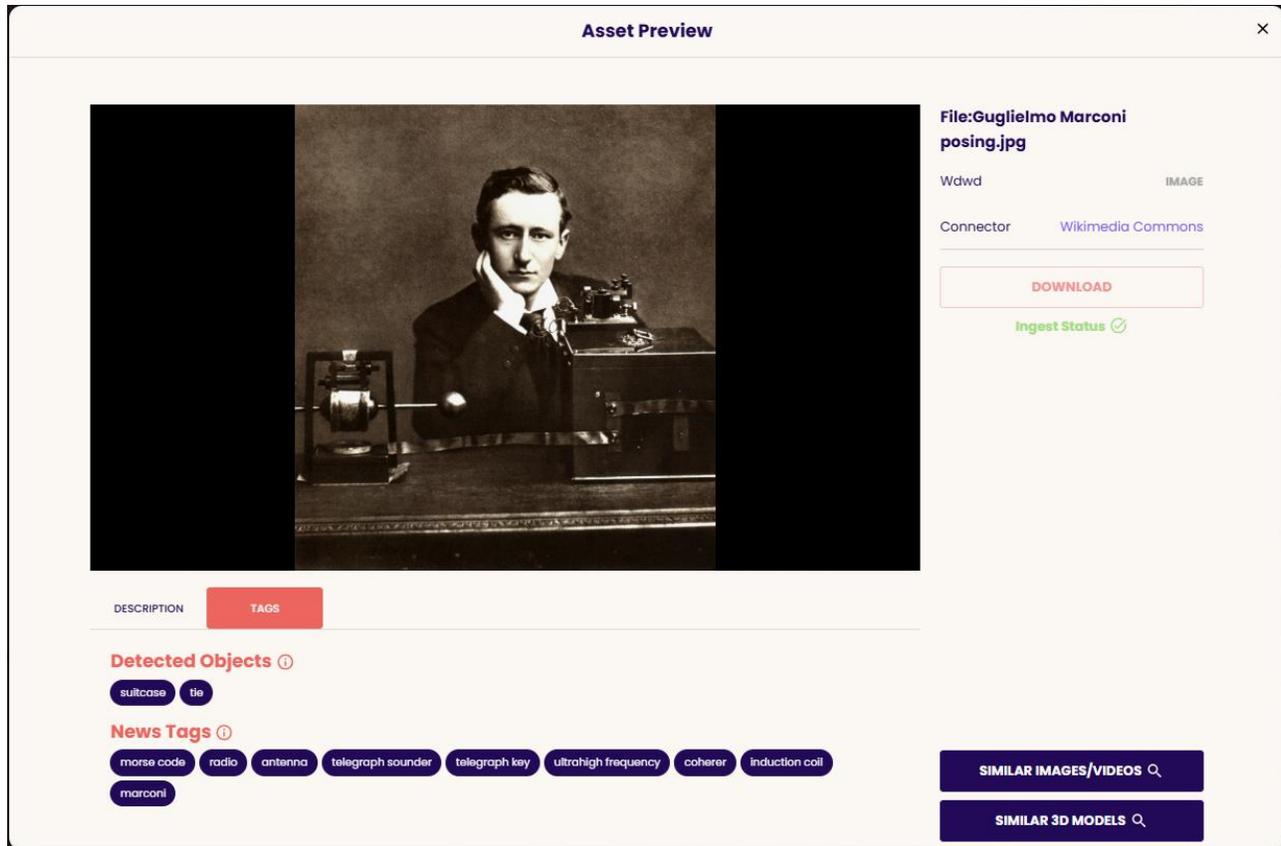


Figure 2: Example of multimodal content search refinement based on textual properties (i.e., semantic tags) or visual properties (i.e., similar images/videos/3D models).

One of XReco's most exciting features is its cutting-edge content production capabilities. The platform allows creators to transform traditional 2D footage into realistic 3D models using advanced services and no code. This goes beyond the initial demonstrator, providing an end-to-end pipeline (from 2D footage upload to 3D model building) that is accessible and tuneable via the unified interface of the XReco Orchestrator. This interface provides a streamlined user experience, hiding the complexity of the underlying technologies. For the Marconi documentary, detailed 3D models of key technological artifacts were reconstructed using Instant NGP and Structure from Motion (SfM). These models are placed in a virtual environment alongside the real presenter, allowing viewers to explore these technological marvels from every angle, fostering a deeper understanding of their complexity (see Figure 3).

For any media organisation that wants to protect, and exploit produced assets, addressing content licensing and monetization is crucial. For this purpose, the editorial team used the XReco Rights Management interface to attribute the appropriate licence to each of the generated 3D models, ensuring clear terms of use and compliance, before publishing them on the XReco Marketplace. The licences can be selected from a broad set that includes both free and non-free options. The selection process is now supported step-by-step through a visual interface, which helps users understand the peculiarities and implications of each license (see Figure 4).





Figure 3: Screenshot from the video of the Marconi documentary.

The real presenter and the 3D models are placed in a virtual environment. The presenter can interact with the models by e.g., focusing on them or zooming in.

Publish Asset

Follow the steps below to select the most suitable license for your asset and publish it to the Marketplace.

1 LICENSE EXPERTISE
1 of 6 I need help selecting a license.

2 ATTRIBUTION
2 of 6 Anyone using my work must include proper attribution.

3 DO YOU WANT TO ALLOW OTHERS TO USE YOUR WORK COMMERCIALY?
3 of 6

Yes, others can use my work for commercial purposes against remuneration.

Yes, others can use my work for commercial purposes for free.

No. Others can not use my work for commercial purposes.

PREVIOUS
NEXT

SELECTED LICENSE

CC BY

Attribution required. Free to use, modify, and distribute for any purpose, including commercial use. [REVIEW LICENSING CONDITIONS](#)

PUBLISH ASSET

Figure 4: Example of license selection.

The XReco platform is designed to be complemented with third-party tools to meet production needs. For example, we built a digital twin of Marconi with Unreal MetaHuman. Figure 5 illustrates the process. Starting



from a set of low-resolution images of the Marconi’s face from the RAI’s archive, we ran the XReco face restoration service to improve their quality (top left). We then used the face mesh stand-alone software⁵ to create the face mesh based on the restored face images (top right). After that, we imported the mesh into Unreal to refine the appearance and using a motion suit to record body movements (bottom left). Finally, we positioned the digital twin in a virtual laboratory (bottom right).

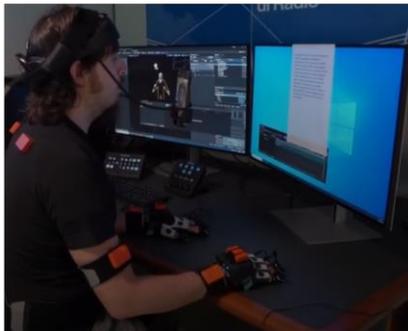
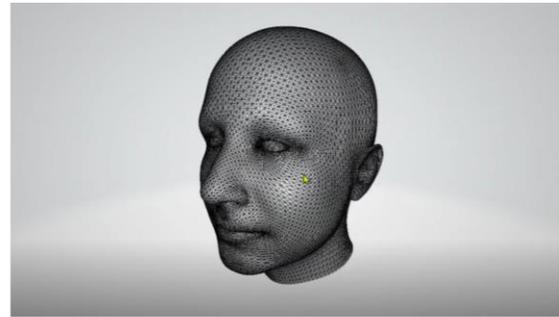
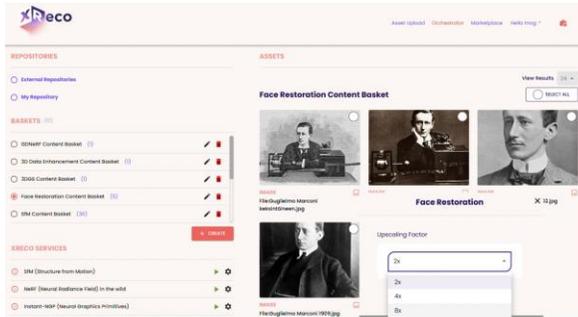


Figure 5: Illustration of the generation of the digital twin.

An interview was conducted using holoportation, which involves real-time volumetric capture, directly from i2cat premises (Figure 6 right). The three-dimensional visualisation of the interviewee provides an immersive experience that traditional video formats cannot achieve, allowing viewers to observe the subject from any angle and perceive realistic depth and spatial presence.

A combination of both XReco technologies and external tools is used in the process, with each one complementing the other.

Finally, a virtual scene was composed by UPM using a 3D Gaussian Splatting reconstruction of the Rai Museum of Radio and Television, generated from 2D footage previously recorded by i2CAT. Within this environment, two avatars representing a fan and a correspondent journalist interact with each other. The fan is created using 4D Gaussian Splatting, while the correspondent journalist is captured with a multi-view setup and rendered in real time using Free Viewpoint Video (FVV) technology (see Figure 6, left). The virtual camera path was created following RAI instructions and recommendations. The specific camera parameters were provided to i2CAT to

⁵ The face mesh was developed by RAI based on a commercial plugin for Blender called Facebuilder. [FaceBuilder for Blender | KeenTools](https://keentools.io/products/facebuilder-for-blender) at <https://keentools.io/products/facebuilder-for-blender>



generate a coherent 2D render of the 4D Gaussian Splatting fan, which was integrated with the rest of the elements of the scene.



Figure 6: Examples of the functionalities for the reconstruction, transmission and rendering of humans and real-world environments integrated in immersive XR experiences.

2.1.3 Challenges and risks

The development and deployment of the demonstrator presented a variety of technical and organisational challenges, highlighting both the innovation and the inherent complexity of immersive XR media production.⁶ One of the most prominent difficulties was the interaction between the real presenter and the inserted virtual elements, specifically, enabling meaningful interactions not only with virtual objects but also with remote participants.

Interactions with objects (Figure 3) were efficiently managed by introducing dedicated triggers, which streamlined the workflow and ensured smooth presentational dynamics. However, integrating the holoported expert from Barcelona into the virtual studio environment (Figure 6, right) proved to be considerably more demanding. Achieving natural interaction and real-time synchronisation between the presenter and the remotely transmitted avatar required advanced technical solutions and ultimately necessitated a degree of post-production correction to reach the targeted level of visual and audio fidelity.

Beyond these interactive aspects, ensuring consistent integration of differing technologies was a substantial risk. The use of multiple reconstruction techniques - such as Unreal MetaHuman, 4D Gaussian Splatting, and Free Viewpoint Video - meant that harmonising lighting, avatar scale, and audio required meticulous cross-platform coordination. Any misalignment between those elements could result in a fragmented immersive experience, reducing the effectiveness of the demonstrator. Considerable time and resources were spent on optimising these aspects, both during the initial production and the editing phase.

Despite these challenges and latent risks, the overall process resulted in a satisfactory outcome. The demonstrator successfully exemplified the capabilities of the XRReco platform, delivering an immersive, high-quality media product that demonstrates the tangible benefits of integrating innovative XR technologies and collaborative workflows in next-generation broadcasting.

⁶ As described in a dedicated conference paper: “XRReco Platform and RAI News Media Demonstrator”, Industry Demo at the 33rd ACM International Conference on Multimedia (ACMMM25) - Dublin, Ireland 27-31 October 2025.

2.2 News and Broadcasting Demonstrator – DW

In the second phase of the project, DW created two demonstrator productions, one following up on and extending the virtual studio productions of phase 1, the other introducing a completely new style of immersive interaction in news – the 3D Infographics.

2.2.1 Demonstrator #1: 3D Productions

Table 4: Overview of technologies used in DW's demonstrator #1

| | | | |
|-----------------------------------|---------------------------------------|--------------|----|
| Title | 3D Virtual Studio Productions | Lead partner | DW |
| Platform services | Metasearch, Marketplace | | |
| Reconstruction technologies | SfM, 3DGS, NeRF | | |
| Human reconstruction technologies | FVV | | |
| Authoring tool(s) | XReco Authoring Tool (based on Unity) | | |
| Output format(s) | 3D virtual studio, 2D videos | | |

In collaboration with multiple partners, DW led the creation of **three virtual studio productions** to extend the demonstration and validation of integrating XReco technologies into news media workflows. For the **first production**, which was set around Turin's Arco del Valentino, DW and UPM first recorded a Free Viewpoint Video (FVV) and then created a Unity scene to showcase the use of a 3D presenter and a 3D model within a virtual setting. The same 3D model was then used in a professional TV studio at DW's headquarters for the **second production**. This demonstrated the application of 3D assets within DW's established production workflow. **Thirdly**, a completely virtual studio was used in Unity3D. A presenter and rotating 3D models were placed inside, utilising the spatial capabilities to their full potential. This virtual presentation was demonstrated using 2D greenscreen videos, FVV, and an animated avatar from a partner project.

2.2.2 Demonstrator overview and expected output

This part of the DW News Media Demonstrator showcases the application of 3D models in virtual studio productions for media creators and journalists. The productions can be 'traditional', involving the creation of 2D videos with embedded 3D models, or they can be full 3D productions.

Three different outcomes were created:

1. A **virtual production** with UPM's **FVV Live Technology**
2. A **virtual production** in one of DW's **TV studios**
3. **Virtual 3D studio productions** in **Unity**



2.2.3 Demonstrator Workflow

Table 5: Workflow of creating the DW News Demonstrator “3D productions”

| WORKFLOW FUNCTIONALITY | COMPONENT NAME (RESPONSIBLE PARTNERS) | TASK | MAIN ROLE IN THE DEMONSTRATOR |
|--|---|---------------|--|
| Content ingestion | Repository Connector (ATOS/i2Cat, DW) | T3.5 | Ingestion of archive content through manual upload; Conversion of legacy metadata to a common data model |
| Content access, search, and management | Orchestrator (MOG) & Neural Media Repository (UNIBAS) | T3.1, T3.2 | Use of search and retrieval tools to find 3D models in internal and external repositories; Creation of content baskets; Instantiation of content processing services |
| Content production | 3D Reconstruction (UPM, i2Cat, FFP) | T4.2 | Generation of 3D models from 2D video assets |
| Content production | FVV (UPM) | T4.4 | Volumetric capture, transmission and reconstruction of full human bodies |
| Content acquisition | Marketplace (MOG) | T3.3, T4.4 | Acquisition of content that is already available in the XReco marketplace (e.g. Timisoara’s St. George Cathedral and Turin’s Basilica Superga) |
| Content licensing | Rights Management (FINCONS) | T3.3 T3.4 | Association of content license policies to ingested/generated assets |
| Content monetization | Marketplace (MOG) | T3.3 | Selling generated assets and experiences |
| Content integration | Unity Authoring Tool | T4.5 | Creation of virtual studio environment; Creation of an integrated news production in a virtual studio |

Virtual Production with FVV Live

In May 2024, DW’s Nicolas Patz went to UPM to be recorded with their FVV Live technology in front of a green screen (Figure 7). Simply put, this technology makes it possible to instantly create a 3D video using multiple cameras that are pointed at a person.





Figure 7: Behind-the-scenes-look: Presenter with VR goggles at the FVV production in Madrid.

The FVV Live Scene was then integrated into a 3D model of Turin’s Arco del Valentino in Unity3D. The reconstruction of the monument is based on several 2D photos and turned into a 3D model with the help of the SfM tool. This model was made available via the XReco platform and marketplace. The goal was to create a life-sized 3D model of the arch as a virtual set and have a presenter walk through it while talking to the viewer.

A virtual production like this – i.e., with FVV – offers a more cost-effective option to news media creators compared to using a professional journalistic studio, with results that are very satisfactory, as our demonstrator shows.



Figure 8: The goggles scene in Unity.

To make the most of the 3D aspects of both the presenter that was recorded in FVV and the 3D model, the scene covers the full spatial experience via a camera ‘flight’ of the virtual camera going around the building.

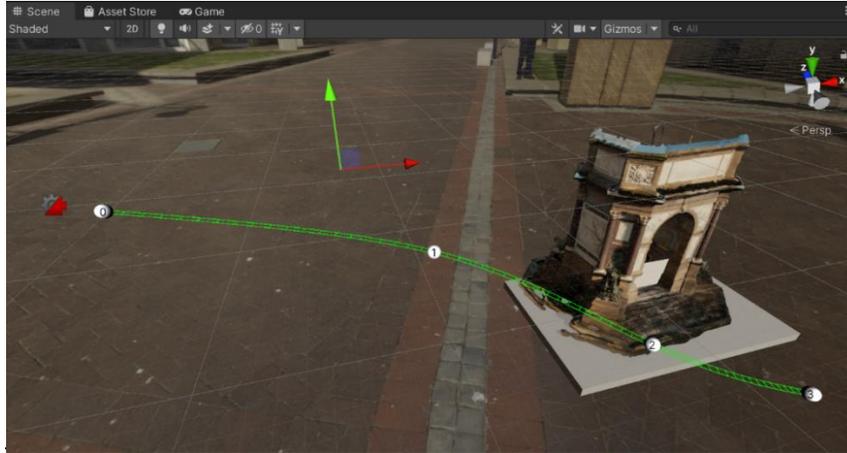


Figure 9: Screenshot of the camera path in Unity.

In the final video⁷, the presenter both stands and walks inside the monument, and speaks about the advantages of virtually visiting places and sights worldwide.

Virtual Production in a professional studio

In June 2024, the DW team met at their headquarters in Bonn to test whether putting a news presenter in a 3D model of the Valentino arch and creating a 2D output could work in one of their professional TV studios.⁸

With the help of the integrated studio VR technology, the presenter was again placed inside the 3D model of the Arco del Valentino, however, this time with only one camera pointing at him. Further options for the presenter to use the spatial aspects of the 3D model were explored. On a monitor, he could see himself in the 3D Turin arch, walk around a statue, estimate his own movements in relation to the 3D model and look at it from all sides.



Figure 10: Exploring the possibilities of 3D productions in DW's professional studio setup.

⁷ See output in XReco's YouTube channel: "XReco | Reconstructing Monuments in 3D: Turin Arch Comes Alive with FVV Live": https://www.youtube.com/watch?v=JM_3wVr2ZIU.

⁸ See output in XReco's YouTube channel: "XReco | Your Next Trip Might be Virtual – From Broadcast-Ready VR Studios to Unity3D": <https://www.youtube.com/watch?v=wy8SLFq4oP0>.



This workflow shows how XReco technologies and 3D assets can be implemented into professional journalistic processes and help DW media creators to produce high quality 2D outputs.

The virtual studio in Unity3D

After having explored the spatial options of larger models, i.e., the Arco del Valentino, DW wanted to demonstrate that smaller models can be used in 3D studio presentations just as well. In phase one of the XReco project, Visyon and Capgemini had already created a virtual studio. In the Unity virtual studio – which resembles a traditional TV studio design – they created a pedestal with a rotating platform and put 3D reconstructions made with XReco tools on top of it, namely:

- Turin’s Basilica Superga, made with NeRF
- Timisoara’s St. George Cathedral, made with SfM
- Berlin’s former Palace of the Republic, made with 3DGS

The 3D models were created and optimised with the technologies and skills of UPM, CERTH, i2Cat and FFP. The presenter is placed next to the rotating buildings.

In a traditional journalistic studio production, not much can be changed after filming is complete; camera angles, for example, remain as they were recorded. With this Unity production workflow, however, journalists and directors have the freedom to build, rebuild and use different tracking shots and angles in a scene.



Figure 11: Screenshots from the virtual studio.

Another project result that came from this virtual studio production is a collaboration with the EU project [SERMAS](#)⁹. As part of one of their use cases, SERMAS created an avatar called *Guardia* for an XR security training for journalists. Together, the XReco and SERMAS teams have successfully integrated the 3D security agent into the XReco virtual studio.



Figure 12: SERMAS Avatar “Guardia” in XReco’s virtual studio.

⁹ For a brief description of the SERMAS pilot, see <https://sermasproject.eu/pilot-1-security-agent/>

The avatar was integrated using the Unity Authoring Tool, which has a plugin that enabled ‘Guardia’s’ glTF (Graphics Language Transmission Format) version to be incorporated.¹⁰ The DW and Capgemini teams worked together to customise camera settings and angles and created “the voice” of the avatar as an audio recording with speech synthesis software *elevenlabs*. The experiment proves that news media creators can bring their own assets, including animated avatars, to the table, and integrate them in the virtual studio template in Unity. In other words, external tools and technologies can be connected to and used with existing XReco technology – just like with FVV.

In summary, the virtual productions demonstrator:

- Successfully integrated 3D architectural models into immersive studio environments
- Demonstrated versatility: The demonstrator spanned real TV studio setups and fully virtual Unity environments with rotating-platform presentations, showing XReco’s adaptability across different production scales
- Bridges the gap between traditional broadcast and immersive, flexible storytelling.

2.2.4 Challenges

Physical studios can pose limitations, as fixed cameras and restricted space reduce flexibility and can prevent presenters from moving “just anywhere”. By choosing the Arco del Valentino, the open building structure allowed a presenter to stand inside the monument and walk through it – even though the physical space “in real life”, in the studios, only allowed for a few steps. By further shifting to Unity-based virtual studios, camera angles and perspectives can be dynamically controlled.

For the production at the physical studio, the 3D model had to be cut into building blocks in advance (see Figure 13: left part of the *Arco* in red, right part green, ground plate and stairs grey, sculpture purple) to enable that the presenter would actually be hidden when behind the sculpture in the centre of the construction.



Figure 13: Segmentation of 3D Model (left); presenter behind sculpture (right).

¹⁰ See output in XReco’s YouTube channel: “XReco and SERMAS | Introducing Avatar Guardia in XReco’s Virtual Studio”; <https://www.youtube.com/watch?v=LduMVSf9VM4>

2.2.5 Demonstrator #2: 3D Infographics

Table 6: Overview of technologies used in DW's demonstrator #2

| | | | |
|-----------------------------------|-------------------------|--------------|----|
| Title | 3D Infographics | Lead partner | DW |
| Platform services | Metasearch, Marketplace | | |
| Reconstruction technologies | SfM, 3DGS | | |
| Human reconstruction technologies | n.a. | | |
| Authoring tool(s) | Unity Authoring Tool | | |
| Output format(s) | 3D infographics | | |

In search of more adaptable, smaller approaches to integrating 3D and XR experiences into everyday journalism, the DW team developed 3D infographics. These enable journalists to use 3D models in articles with minimal technical restrictions during production or consumption.

2.2.6 Demonstrator overview and expected output

The interactive 3D infographic demonstrator, developed by DW and Capgemini, introduces a Unity-based template enabling (news) media creators to embed annotated 3D models directly into web articles, without any coding expertise required. End users can then click on the 3D objects, zoom, pan and rotate around them, learning about a subject through multimedia annotations in an interactive manner.

In the course of this demonstrator eight 3D infographics of six different buildings and objects (see list under **Error! Reference source not found.** >> 3D Model Creation) were created to establish and demonstrate the workflow of creating them with the XReco templates for Unity. An overview of the 3D infographics concept and the demonstrator examples is available on YouTube.¹¹

2.2.7 Demonstrator Workflow

Table 7: Workflow of creating the DW News Demonstrator '3D Infographics'

| WORKFLOW FUNCTIONALITY | COMPONENT NAME (RESPONSIBLE PARTNERS) | TASK | MAIN ROLE IN THE DEMONSTRATOR |
|------------------------|---------------------------------------|------|---|
| Content ingestion | Repository Connector (ATOS/i2Cat) | T3.5 | Ingestion of content from WikiMedia and Europeana; Ingestion of content through manual upload; Conversion of legacy metadata to a common data model |

¹¹ "XReco I Bring Your Stories to Life with Interactive 3D Infographics" at <https://www.youtube.com/watch?v=lji9RF7wqRE>.



| WORKFLOW FUNCTIONALITY | COMPONENT NAME (RESPONSIBLE PARTNERS) | TASK | MAIN ROLE IN THE DEMONSTRATOR |
|--|---|------------|--|
| Content access, search, and management | Orchestrator (MOG) & Neural Media Repository (UNIBAS) | T3.1, T3.2 | Use of search and retrieval tools; Creation of content baskets; Instantiation of content processing services |
| Content production | 3D Reconstruction (UPM, FFP) | T4.2 | Generation of 3D models from 2D video assets |
| Content acquisition | Marketplace (MOG) | T3.3, T4.4 | Acquisition of content that is already available in the XReco marketplace |
| Content licensing | Rights Management (FINCONS) | T3.3, T3.4 | Association of content license policies to ingested/generated assets |
| Content monetization | Marketplace (MOG) | T3.3 | Selling or purchasing of generated assets and experiences |
| Content integration | Unity Authoring tool | T4.5 | Creation of 3D infographics |

Template Development

Capgemini produced a 3D infographic template in Unity, designed to be exported for WebGL and easily embedded into HTML articles. It supports interactive features such as panning, zooming and rotating as well as clickable hotspots (audio, video, text and images). Beginners and professionals can both use the template to create new 3D infographics. After learning how to navigate it, it took DW members on average 1-2 hours per infographic, including research for the hotspots.

3D Model Creation

Various artifacts and architectural sites (six in total) were converted into interactive models using XReco’s Structure-from-Motion (SfM) and Gaussian Splatting (3DGS) tools. These included:

1. Berlin’s former Palace of the Republic (3DGS)
2. Potsdam’s Einstein Tower (3DGS and SfM)
3. Berlin’s Jewish Museum (3DGS and SfM)
4. The Nebra Ark Visitor Center (SfM)
5. The Veste Wachsenburg medieval castle (SfM)
6. An antique phonograph cylinder (SfM).



Figure 14: Infographic of an old phonograph. 3D model by RAI.

Media creators who want to use the template can use XReco reconstruction tools to make their own 3D models or purchase/acquire/download them from the platform. The XReco platform is also ideal for finding hotspot

elements such as videos or photos. Otherwise, open-source platforms such as *Europeana* or *Wikimedia Commons* can also be employed for this purpose, as was done with many of the demonstrator infographics.

The 3D models were created with the help of DW’s “Daily Drone” editorial department¹². They produce a format where drone footage of famous buildings and monuments in Germany is shown to viewers. They lent some of their footage to XReco. This collaboration shows that DW departments already recognize the potential of showing certain objects/buildings from many angles and are interested in XReco's technical capabilities. The implementation of the 3D infographics at DW is currently being explored.

In addition, a joint filming day with a drone was organised to capture the Einstein Tower in collaboration with the Leibniz Institute for Astrophysics Potsdam (AIP)¹³ who are responsible for this landmark of Germany’s Science Heritage.

After being supplied with 2D footage by DW, UPM’s SfM service was used to create 3D models. FFP helped by creating the 3DGS models. The 3D model of the old phonograph was provided by RAI via the XReco marketplace.

Comparative Modelling

Einstein Tower and Jewish Museum were modelled using both SfM and 3DGS methods, illustrating visual and functional differences. While 3DGS models offer a bit more photorealistic detail, they lack physical geometry so that hotspots are always visible regardless of the viewing angle. SfM models, however, allow hotspots to “stick” to 3D “surfaces” (meaning, they *cannot* be seen from all angles). How media creators choose to reconstruct their 3D models will depend on their storytelling needs. XReco offers them different options as presented in Figure 15.



Figure 15: Screenshots of Jewish Museum infographic in 3DGS (left) and in SfM (right)

¹² <https://www.dw.com/de/dailydrone/t-19502935>

¹³ <https://www.aip.de/en/>

Customisation

The template allows media creators to adjust features of the infographics with intuitive sliders. They can:

- Set camera starting positions
- Set lighting intensity and angles
- Define hotspot behaviour: either fixed in place or facing the camera during interaction.

Other possibilities include cropping models, changing background colour and styling hotspot UI elements.



Figure 16: Screenshot of editing process in Unity with 3DGS Einstein Tower model.

Embedding/Accessibility

Final outputs are embeddable 3D viewers (HTML), requiring no redirects or downloads for end-users, and making the infographics accessible, interactive enhancements for digital storytelling. Website visitors can encounter and interact with real historical architecture or other technical topics (such as archaeology or anatomy), independent of time and location. Spatial dimensions that would be hard to convey with just text can be explored in a virtual space. For media creators, the 3D infographic templates can also be reused for VR and AR projects.

2.2.8 Challenges

Before the infographic template was ready for use, it had to go through several iterations and feedback loops between DW and Capgemini who developed it. A straight-forward way for users to import .ply files (3DGS models) instead of just .obj files (SfM) had to be found. Glitches in the infographic in ‘play mode’ were fixed as well. And since the template comes with an interactive tutorial, minor bugs also had to be fixed in the instructions, such as not being able to select a “colour picker”.



2.3 Virtual Media Production Demonstrator – FFP

Table 8: Overview of technologies used in FFP's demonstrator

| | | | |
|-----------------------------------|---|--------------|-----|
| Title | Multi-View Music Video | Lead partner | FFP |
| Platform services | Search | | |
| Reconstruction technologies | 3DGS, SfM and NeRF | | |
| Human reconstruction technologies | 3DGS/4DGS | | |
| Authoring tool(s) | Unity | | |
| Output format(s) | Multi-View interactive Video 4K 2D (Android app in Testflight mode) and immersive Apple Vision Pro XR | | |

The “Multi-View Music Video” demonstrator is an interactive experience allowing viewers to watch a 2.5-minute music video from any angle. The experience was created with the help of advanced AI reconstruction tools and services, as well as additional GenAI solutions. It is available for mobile phones (Android) and Apple Vision Pro. It was featured in a detailed YouTube video on how it was created¹⁴, and there is a downloadable & installable version for Android phones¹⁵.

2.3.1 Demonstrator overview and expected output

The starting point of the experience is a multi-camera archival in-studio recording from 2018, when neither neural rendering techniques (3DGS, NeRF) nor AI-based production tools or Generative AI were available. FFP have used XReco's complex reconstruction pipeline and Unity-based authoring tool to create and render multiple scenes from 36 different camera angles encoded in a single 4K or 8K video for the two platforms, respectively, and created interactive players for such experiences.

- On *Android*, users can rotate the content and watch from any angle by swiping their fingers over the screen. The content features traditional horizontal footage as well as vertical media.
- On *Apple Vision Pro*, the video is spatially located in 3D space, so that the viewer can walk around and thus change the viewpoint.

¹⁴ <https://www.youtube.com/watch?v=8kct6Mrgpkk>. XReco | MultiView XR Watch Music Videos from Any Angle on Your Mobile or VR Headset: <https://www.youtube.com/watch?v=8kct6Mrgpkk>.

¹⁵ Download & Installation instructions: https://panocastdownloads.s3.eu-central-1.amazonaws.com/XReco_FFP_MultiView2025_Release.zip





Figure 17: Multiple views of the singer in the interactive music video (above). Android player in use, finger-swipe motion rotating the view (last row at the bottom)

2.3.2 Demonstrator Workflow

Table 9: Workflow of creating the “Multi-View Music Video” demonstrator

| WORKFLOW FUNCTIONALITY | COMPONENT NAME (RESPONSIBLE PARTNERS) | TASK | MAIN ROLE IN THE DEMONSTRATOR |
|------------------------|---|------|---|
| Content production | n/a | n/a | Archival 36-cameras video clip originally recorded in 2018 (material used with artist's approval), 360° shootings in Seychelles, Mauritius, Zanzibar, München, and Budapest |
| Content production | 3D Reconstruction | T4.2 | Generation of 3DGS models from multi-camera 2D video assets, 360° video and mobile-phone footage |
| Content production | FVV | T4.4 | Reconstruction of full human bodies recorded from 36 camera angles and AVP, large scenes captured with 360° cameras, artifacts and objects captured with mobile phone |
| Content integration | XReco Platform and Authoring tool (Unity + FFP) | T4.5 | Creation and Rendering of an immersive video in Unity for mobile and AVP |

2.3.3 3D Reconstruction Experiments (NeRF, 3D Gaussian Splatting, SfM)

The key elements of FFP's complex production pipeline involved recovering the moving shape of the singer's body and gestures from the original studio recordings from a 36-camera studio capture, in combination with large scale 3DGS reconstructions of outdoor scenery (beaches, harbours, forest, cave), as well as smaller artifacts (seashells, flowers, African masks & statues) captured with mobile phones and consumer-grade 360° cameras (Insta360 X4). Specifically, FFP first reconstructed point clouds by recovering camera motion and estimating imaging parameters, before subsequently deploying *3D Gaussian Splatting (3DGS)*, and *SfM (Structure from*



Motion) services to create 3D spatial representation of the subjects. Source footage was recorded at multiple locations during the lifetime of the project in Seychelles, Mauritius, Zanzibar, Germany and Hungary.

To digitally create the artifacts in 3D FFP used XReco’s various reconstruction services as demonstrated in the accompanying videos and figures below. Due to the high volume of data and the extreme challenge to produce all shots from 36 angles in time, we also used a dual GTX 4090 AI machine to reconstruct and render scenes using the same algorithms.

In addition, FFP also developed a set of custom python scripts to combine individually created 3DGS models into single scenes with spatially located natural elements, into which the singer's image was placed in real-time for rendering.

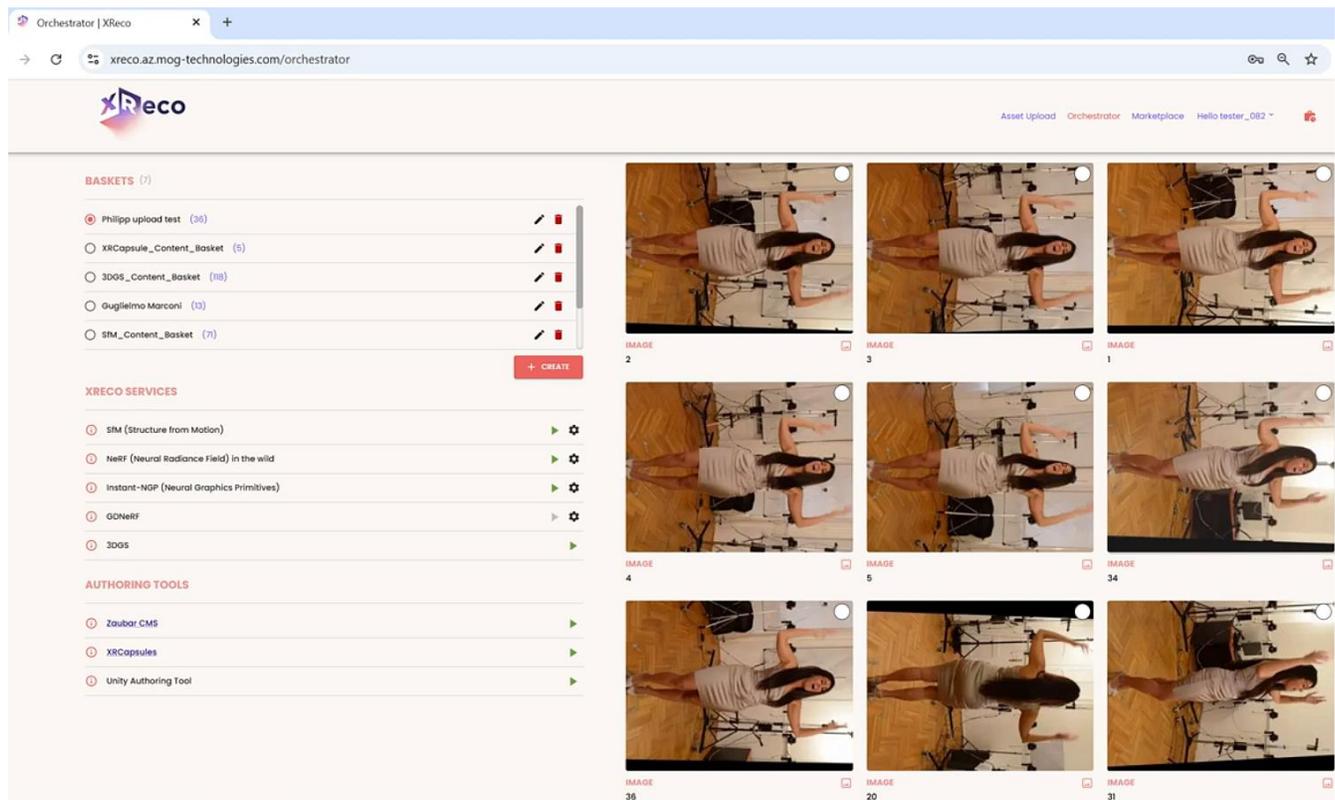


Figure 18: 36 camera data set uploaded to the XReco orchestrator for reconstruction.

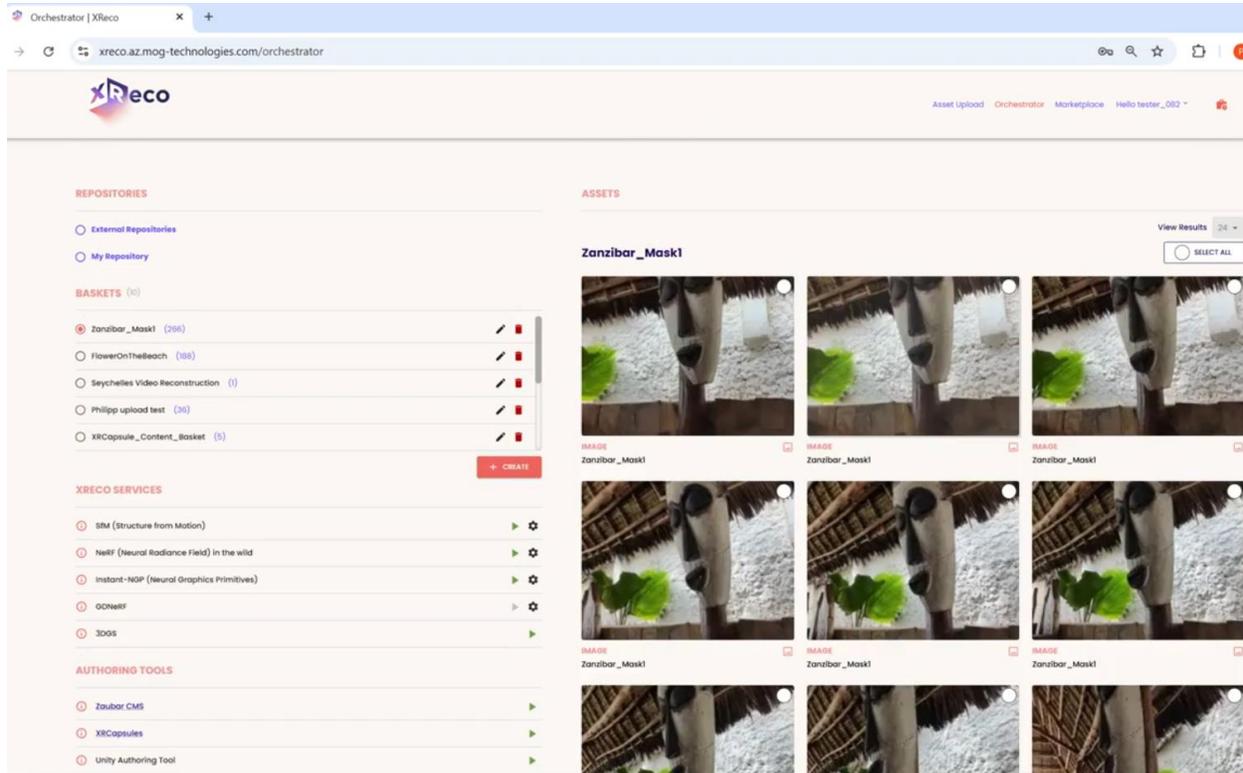


Figure 19: Mobile camera footage of an African mask uploaded for 3DGS/NeRF reconstruction, later used in the final MultiView video.

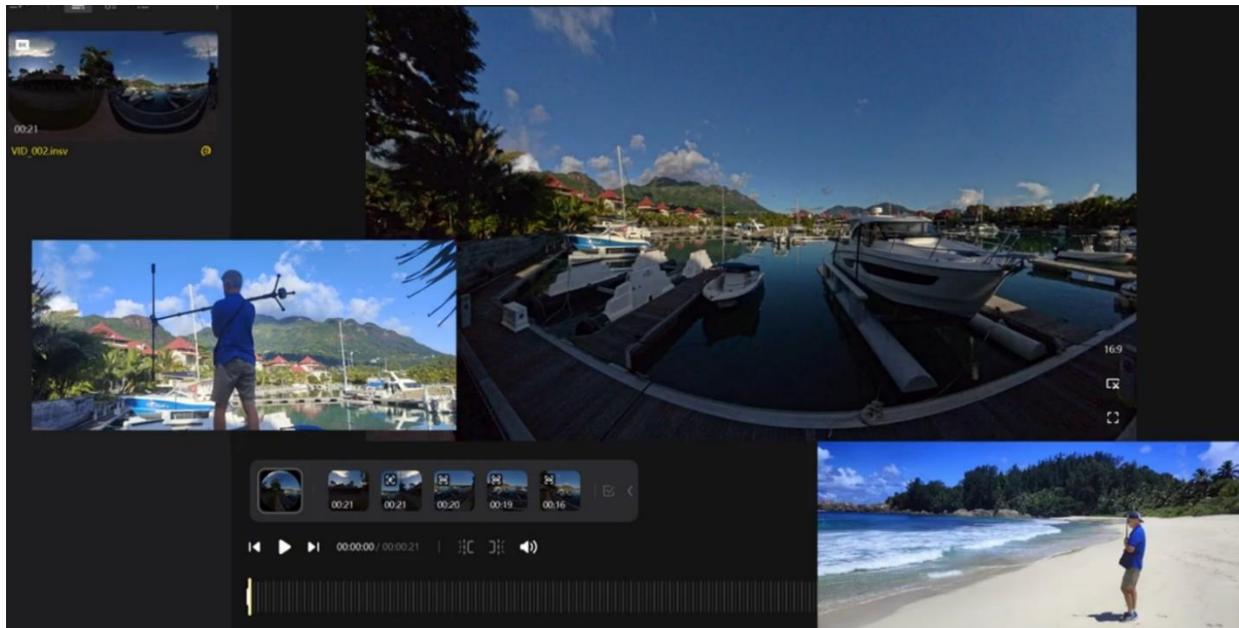


Figure 20: Capturing data for large scale 3DGS reconstruction of a harbour using a dual rig of 360 cameras. The final 3DGS model served as the background of the singer in many scenes.

2.3.4 Free Viewpoint Video

The original FVV footage was recorded in late 2018 using a 36-camera DSLR setup as part of the *Hyper360* European Research project.

For this captured studio material, however, the singer's cluttered background had to be removed in some scenes, while the quality and framing needed to be improved for others. This is called mask generation. This was done via a combination of AI-based *human-matting* and *depth-estimation* algorithms taking advantage of the 3D reconstructed 3DGS and mesh-based (SfM) representations.

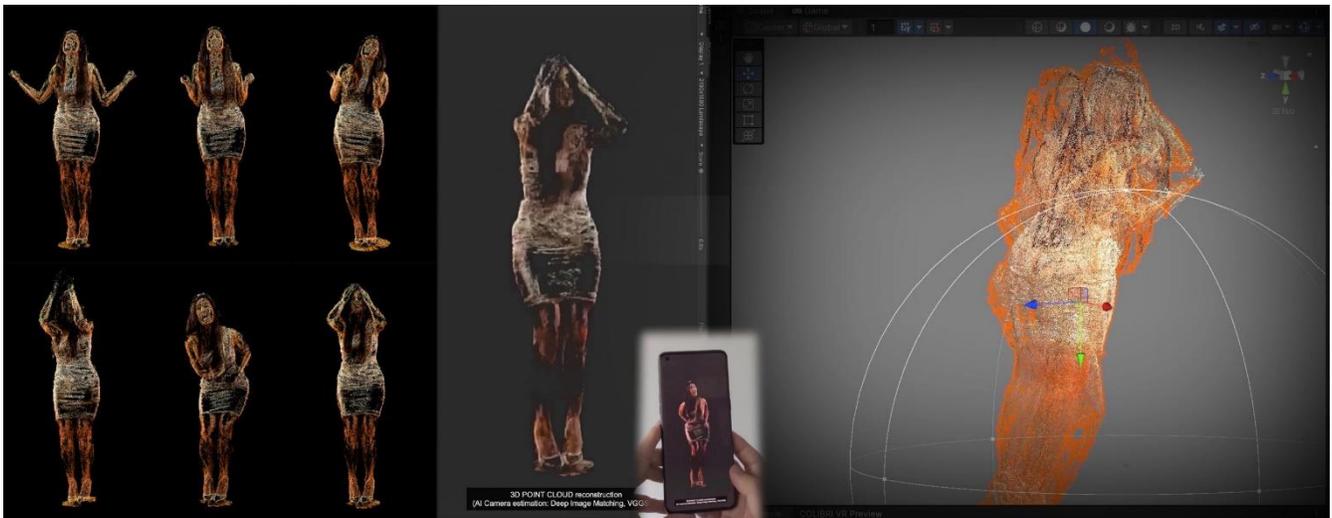


Figure 21: 4DGS reconstruction (3DGS sequence) of the singer's body in various poses showing multiple point clouds (left/right), and the same information on the mobile player (centre)

2.3.5 Authoring Tool Development

As a final step, FFP brought these data sets and image/video sources into the Unity-based XReco Authoring tool to visualise and combine them in a single unified representation for the purpose of re-rendering the scene from any angle with the help of a directed virtual camera.

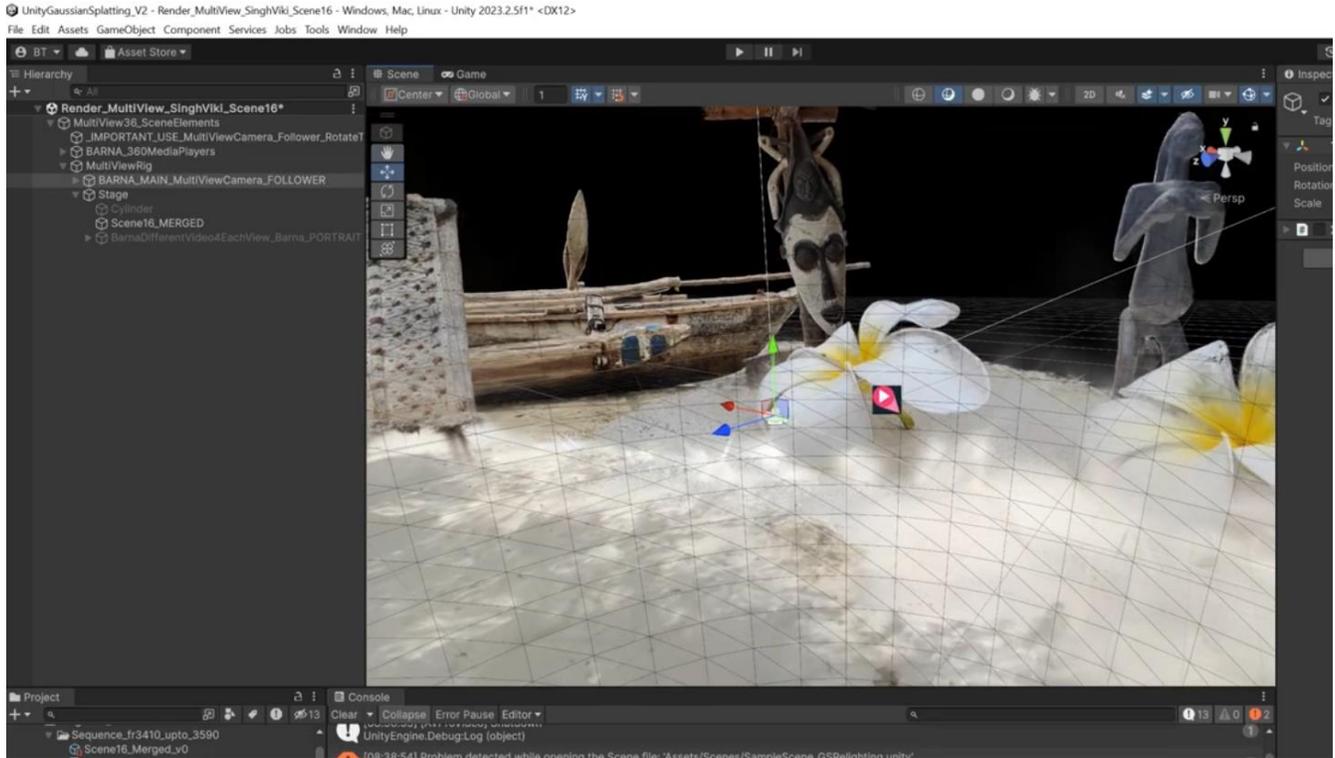


Figure 22: A complex 3DGS scene in Unity created from multiple reconstructed neural rendering elements (beaches, boat, prison door, flowers, statues, etc.) into a single.

The elements in Figure 22 were used as background in one of the scenes in the final MultiView video.

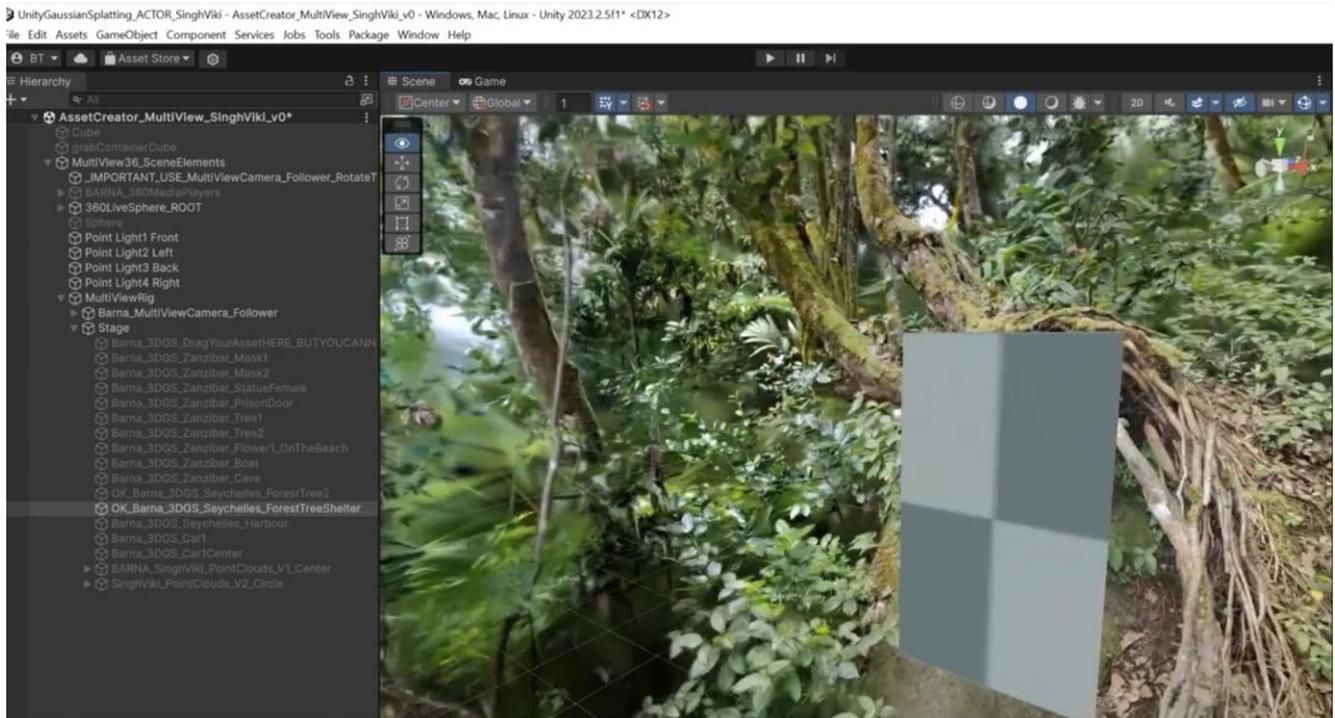


Figure 23: Combining flat (2D) AI-processed camera views with a 3DGS background in Unity for rendering 36 independent videos.

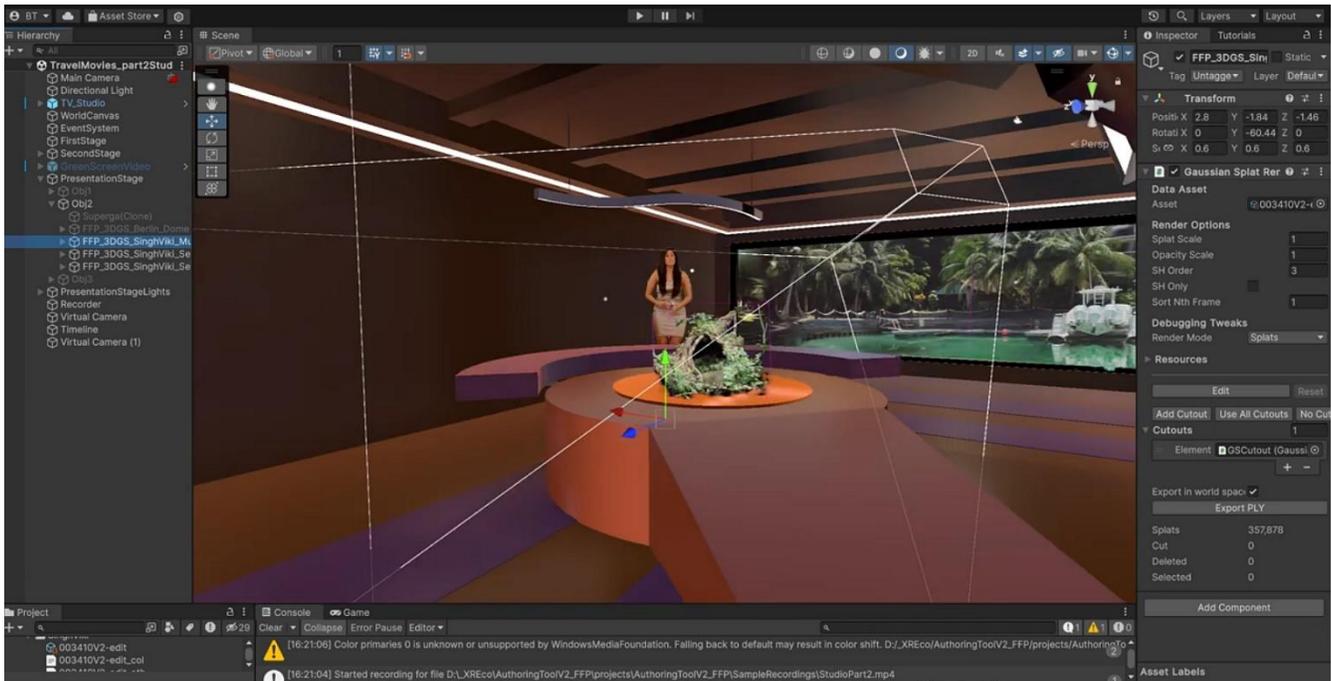


Figure 24: Free viewpoint Virtual Studio setup in Unity replacing the host with a view-dependent representation of the singer, a 3DGS forest shelter in front (same as Figure 23), and 3DGS Seychelles harbour shown in through the window as background.

2.3.6 Challenges

The key technological and production challenge was to turn a 2.5-min short video turned into 1.5-hour length full-scale video production with FFP needing to generate 36 different views for each scene. The sheer volume of captured data, the multiple neural reconstruction passes, cleanup and running additional AI-based masking and removal algorithms demanded significant effort and time. The final output was not perfect. As an example, some masking mistakes made by the automatic pipeline in the final output that can be found by viewers from certain angles only were intentionally left in.

In addition, the creative ideas and technology tests posed additional unforeseen challenges that called for

- having the singer speak a few lines that had not been in the original recording
- developing animated 3DGS models to create a singing African mask driven by the facial movements which was tracked consistently across multiple camera views,
- driving particle effects from the reconstructed moving point clouds, and
- relighting the entire 3DGS scene to match the mood of the song in each of the 18 cuts.

Finally, FFP also developed an additional playback solution to showcase how immersive personalised experiences that surround the viewer with spatially situated content can offer interactivity that had never before been possible. More specifically, FFP ported the initial MultiView playback technology to one of the latest spatial XR devices, the Apple Vision Pro, which was not available when the original proposal was submitted. This new



device, however, required us to experiment with new ways of user interaction and developing truly spatial interfaces.

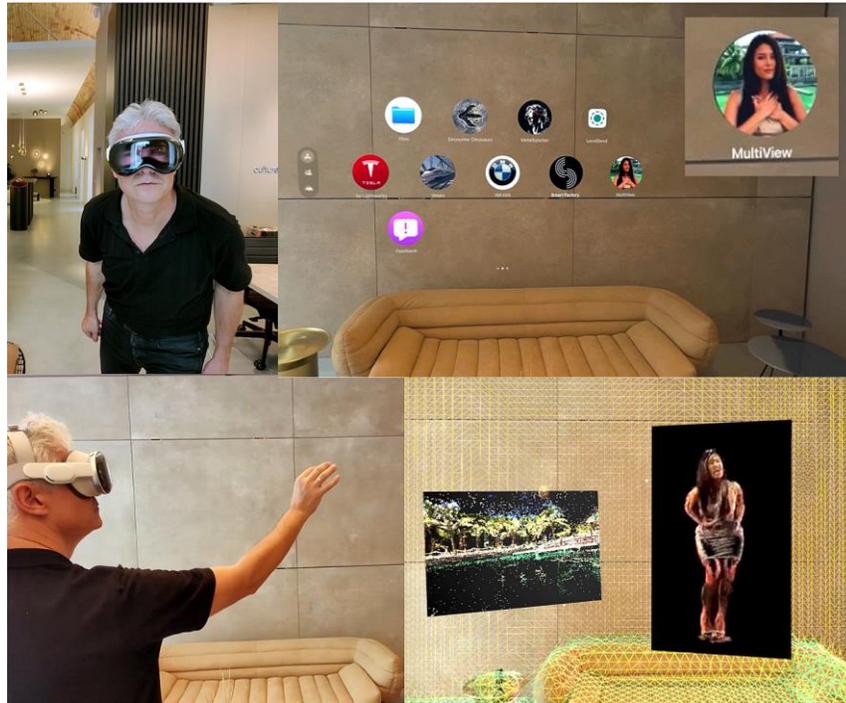


Figure 25: MultiView music video experience running on the Apple Vision Pro Mixed reality headset.

2.4 Tourism Demonstrator – ZAUBAR

Table 10: Overview of technologies used in ZAUBAR's demonstrator

| | | | |
|-----------------------------------|--------------------------------------|--------------|--------|
| Title | Tourism Demonstrator | Lead partner | ZAUBAR |
| Platform services | Metasearch, Marketplace | | |
| Reconstruction technologies | SfM | | |
| Human reconstruction technologies | 4D Human Reconstruction (in Phase 2) | | |
| Authoring tool(s) | AR CMS | | |
| Output format(s) | AR application | | |

In this Demonstrator, ZAUBAR (with support from DW on the content side) produced an application that allows tourists to explore the city with a mobile phone and view 2D representations or 3D models of the monuments

they encounter along the way and learn about their history. The user experience was documented in a Demonstrator video together with the Automotive Demonstrator: [XReco I A Ride Through History: Discover Timisoara with AR – In-Car and On-Site - YouTube](#) (see section #2.5).¹⁶

The Demonstrator was built with the ZAUBAR CMS, a browser-based, location-based AR content management system (CMS) developed, implemented, and validated in XReco. The work addressed connectivity and reliability for streamed AR on an automotive infotainment screen, introduced advanced authoring capabilities - including volumetric video avatars, mixed photo-video (“Mixie”) compositions, remote placement on a 3D map, and portal-style templates for historical imagery - and integrated zero-friction distribution to end users. The ZAUBAR CMS interoperates with the Neural Media Repository and 3D human/volumetric services.

Creating and operating location-based AR at city scale and in vehicles requires a complete authoring-to-distribution toolchain and robust delivery over heterogeneous networks. In XReco, we focused on lowering authoring friction and ensuring dependable playback in demanding conditions (urban canyons, cellular handovers, and in-car environments).

2.4.1 The ZAUBAR Web-Based, Location-Based AR CMS

ZAUBAR delivered a browser-native authoring environment where creators assemble AR experiences from multimedia assets (2D/3D/volumetric, audio, text) and place them at precise geolocations. The system supports uploads and transformations, non-destructive edits (e.g., cropping/colour adjustments), and generative AI assisted asset preparation—all accessible without local installs. Final experiences can be exported to iOS/Android and are prepared for visionOS.

Authoring model and data structures

The CMS structures its content into four hierarchical layers. At the highest level, projects act as logical containers that group work across different venues or cities. Each project is made up of multiple scenes, which are collections of content and logic tied to specific locations. Within these scenes, anchors serve as geospatial reference points, using GPS or IMU data (inertial measurement unit; an electronic device that measures a body’s motion by combining accelerometers and gyroscopes) and optionally visual hints, to bind digital content to the real world. Finally, assets and behaviours define what users actually experience: these include 3D models, 2D media, volumetric videos, and audio elements, combined with triggers, timers, and proximity gates that control interaction dynamics.

Authors use a map-centric editor to place/adjust content remotely, preview line-of-sight, and set activation radii and occlusion hints. A permissions system (roles for authors, reviewers, publishers) and versioned publishing channels (staging/production) support curatorial workflows.

To remove app download friction, App Clips (iOS) and Instant Apps (Android) were integrated. This preserved native performance and device capabilities while enabling “tap-to-launch” experiences from QR-Code, signage, or deep links - crucial in tourism and in-car contexts.

The CMS connects to XReco’s services for asset search/reuse (via NMR), 3D-object reconstruction, and NeRF-derived scene assets. It also made use of results from the 3D human reconstruction/volumetric video services.

¹⁶ <https://www.youtube.com/watch?v=EGXt1dJrxeQ>



This trimmed authoring time and enabled multimodal experiences that blended historic media with contemporary captures.

The CMS was designed as a fully browser-based solution that eliminates the need for local installations while supporting multimedia uploads, AI-assisted asset preparation, and mobile exports. By integrating App Clips and Instant Apps, it removes the friction of downloading, enabling instant AR experiences at points of interest or within vehicles. Through its connection with XReco services, it accelerates authoring by providing fast access to reconstructed 3D assets and NeRF-derived materials. The system’s end-to-end capabilities were validated through real tourism and automotive demonstrators, ensuring that authoring, distribution, and playback work seamlessly in practice.

2.4.2 Demonstrator overview and expected output

Within the XReco project, the CMS functioned as the AR authoring frontend at the end of a pipeline centred on the Neural Media Repository (NMR) for search, rights/licensing, and curated reuse. Complementary AI-based transformations included 3D reconstruction, NeRF-like methods, and 3D humans/volumetrics. It was used to create and edit an interactive location-based AR experience about the Timisoara uprising in 1989.

The XReco workflow (NMR → AI transformations → ZAUBAR CMS → zero-friction distribution) demonstrates how creator teams can produce and publish XR experiences quickly, with proper licensing and precise geolocation. The ZAUBAR Web CMS forms the last mile of the XReco ecosystem: it converts curated and transformed media from the NMR into precisely anchored, narratively structured XR experiences and distributes them to end devices with minimal friction.

2.4.3 Demonstrator Workflow

Table 11: Workflow of creating the “Timisoara Uprising (AR experience)” demonstrator

| WORKFLOW FUNCTIONALITY | COMPONENT NAME (RESPONSIBLE PARTNERS) | TASK | MAIN ROLE IN THE DEMONSTRATOR |
|--|---|--------------|--|
| Content ingestion | Repository Connector (ATOS/i2Cat, RAI) (updated) | T3.5 | Ingestion of assets from proprietary sources and public online platforms into the XReco platform |
| Content access, search, and management | Orchestrator (MOG) (updated) & Neural Media Repository (UNIBAS) (updated) | T3.1, T3.2 | Cross-modal content search; Curatorial teams discover licensed media (photos, videos, 3D objects, volumetric captures), manage carts, evaluate licensing models, and import metadata |
| Content production | 3D object reconstruction (CERTH, UPM, RAI) | T4.2 T4.3 | Generation of 3D models from 2D video assets and photos |
| | 4D Gaussian Splatting (CERTH) | T4.4 | Recording of life-size tourist presenter |
| Content licensing | Rights Management (FINCONS) (updated) | T3.3 T3.4 | Association of content license policies to ingested/generated assets |



| WORKFLOW FUNCTIONALITY | COMPONENT NAME (RESPONSIBLE PARTNERS) | TASK | MAIN ROLE IN THE DEMONSTRATOR |
|------------------------|---------------------------------------|------------|--|
| Content authoring | ZAUBAR CMS | T4.5 | 3D objects and 4D Human recordings are imported to the CMS; Scenes are composed with anchors and behaviours. Historical photos become spatial experiences through portal templates; Mixie connects archival images with cinematic sequences; volumetric avatars deliver location-aware storytelling; Scenes are positioned remotely on a 3D map (geofences, line-of-sight) and, if needed, aligned with high precision using visual localization or fine-tuned on site via the Editor app. |
| Content monetization | Marketplace (MOG) (updated) | T3.3, T4.4 | Selling or purchasing of generated assets and experiences |

The XReco ecosystem provides a data-driven media framework for XR. At its centre, the Neural Media Repository (NMR) supports search, organization, and license management; additional AI transformations include 3D reconstruction, NeRF-like methods, and 3D humans/volumetrics.

The demonstrator followed a clear production flow within the XReco ecosystem. First, curatorial teams searched the Neural Media Repository to discover licensed media, manage content collections, evaluate licensing, and import metadata. Next, the required assets were transformed using XReco services to generate reconstructed 3D models and volumetric humans. These prepared assets were then authored into scenes within the ZAUBAR Web CMS, where they were combined with anchors, portal templates, Mixie compositions, and storytelling logic.



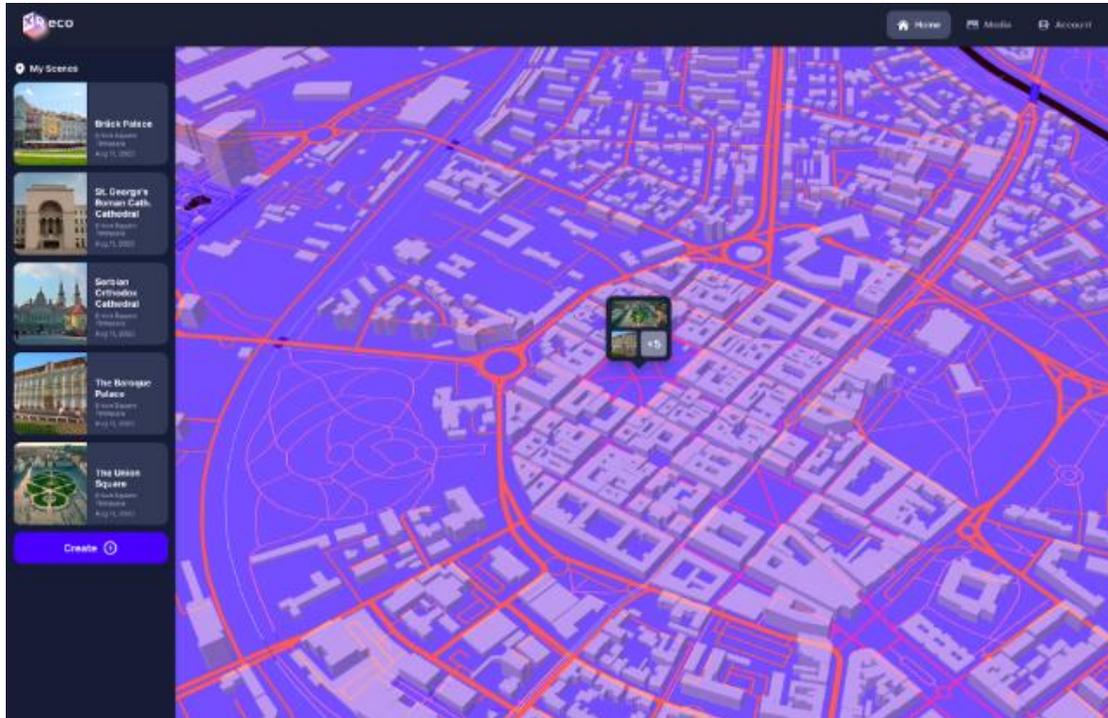


Figure 26: ZAUBAR Web CMS station overview

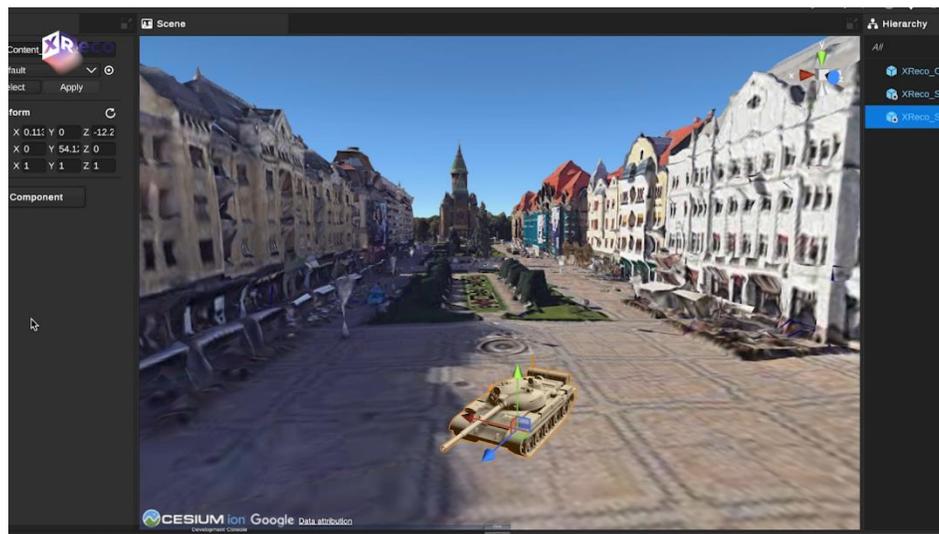


Figure 27: ZAUBAR Web CMS overview with remote placement

Remote placement on a 3D map defined initial positions, with visual localisation used to fine-tune alignments on site. End users then encountered these anchored AR scenes through zero-friction launch methods, experiencing volumetric characters, historical portals, and immersive media directly at physical locations.

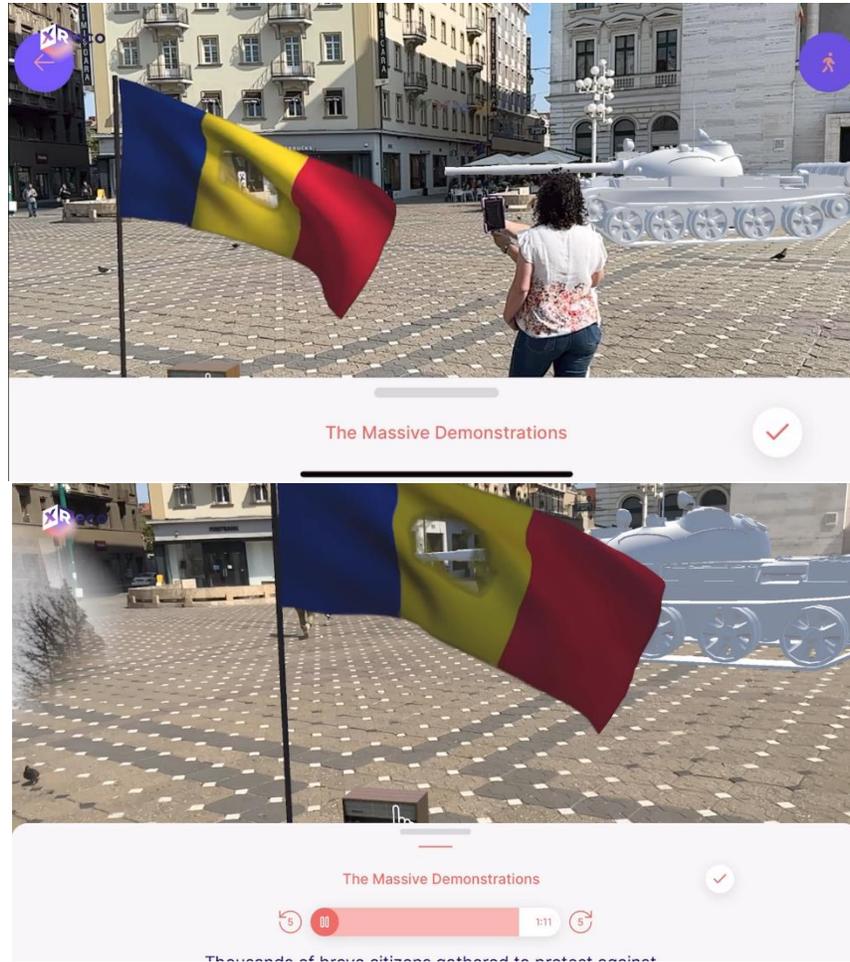


Figure 28: End-user experience in AR (l: demo reel-composition of end-users inside AR, r: end-user view)

This streamlined workflow demonstrated how XR experiences can be created and published efficiently while maintaining high spatial accuracy and licensing compliance.

2.4.4 Challenges

This section summarises the main technical, operational, and product risks we encountered while designing and validating the Tourism & Automotive demonstrator with ZAUBAR's web-based, location-based AR CMS. It also captures the experiments that did **not** work as expected, the pivots we made, and the concrete mitigations we implemented.

Alignment and Playback Robustness

Remote placement accuracy

One of the key challenges encountered during the demonstrator implementation was related to remote placement accuracy. When anchors were positioned purely through remote tools, without on-site verification, they sometimes appeared misaligned - particularly in terms of height, scale, or approach vector. To address this issue, a two-step workflow was introduced. This involved performing an initial remote pre-placement followed



by optional on-site refinement, where necessary, to fine-tune positions. Additional features such as occlusion previews and orientation helpers were also implemented to support this process. Despite these measures, sites that could not be visited before launch still carried a slightly higher risk of misalignment.

Volumetric Video & 3D Humans

Bandwidth and thermal limits for volumetric playback

The use of volumetric video and 3D humans presented both technical and operational challenges. Continuous, high-fidelity volumetric playback within a car environment created bandwidth spikes, increased device temperature, and occasionally led to dropped frames. To mitigate this, a fallback content ladder was designed, allowing the system to dynamically switch between volumetric playback, pre-rendered 3D billboards, and simple 2D video depending on bandwidth conditions. Volumetric clips were also segmented into chunks and pre-fetched for each point of interest. However, longer dialogue sequences still proved demanding, so the team prioritised short, high-impact moments and ensured pre-renders were always available as backups.

Pipeline complexity & turnaround

In addition, the pipeline for volumetric capture and processing proved more complex than initially expected. Offline processing times were longer, and minor mismatches between rig output and mobile runtime formats required additional re-encoding steps. These challenges were addressed by standardising ingest profiles, automating transcodings during the CMS build step, and strategically limiting the number of volumetric scenes in Phase 1, reserving more extensive use for Phase 2. Even so, the schedule remained sensitive to delays in capture windows, so 2D and 3D alternatives were kept on standby to avoid bottlenecks.

“Mixie” Photo-Video Compositions & Human Occlusion on Android

For “Mixie” photo-video compositions and human occlusion on Android devices, performance varied significantly across different hardware. Mixie effects performed very well on LiDAR-equipped devices but were inconsistent on mid-range Android phones and older iPhones. This was resolved through device capability detection that applied per-device templates, with automatic fallback to simpler composites without occlusion or heavy effects when needed. The team acknowledged that achieving perfect visual parity across all device types was not feasible; instead, expectations were carefully managed through quality assurance processes and clear documentation.

Automotive Integration & Streaming Path

AirPlay latency & control UX

Several challenges also arose from automotive integration and streaming paths. AirPlay mirroring occasionally introduced latency and session drops, especially in areas with high wireless interference. Mitigation strategies included adding reconnect logic, simplifying the in-car user interface to make it tolerant of brief delays, and caching points of interest ahead of time to mask short interruptions. Still, AirPlay’s performance remained non-deterministic under RF congestion, and a wired or fully native integration was identified as a potential future improvement.



Hardware variability

Hardware variability within the car setup also played a role: vibrations affecting the iPhone mount sometimes degraded VPS frame quality at driving speeds, whereas the industrial PC and camera system offered more stable performance but added complexity. To cope with this, mounting stability and exposure settings were improved, reliance on VPS during movement was reduced, and more recognition tasks were shifted to when the car had arrived at a point of interest. High-speed scenarios continued to present alignment challenges, so richer visual experiences were concentrated in stationary moments.

2.5 Automotive Demonstrator – CAR

Table 12: Overview of technologies used in CAR's demonstrator

| Title | Automotive Tour Guide Demonstrator | Lead partner | CAR |
|-----------------------------|---|--------------|-----|
| Platform services | Metasearch, Marketplace | | |
| Reconstruction technologies | SfM | | |
| Authoring tool(s) | CAR tool (originally by Atos/eviden) | | |
| Output format(s) | AR application for in-car entertainment | | |

Building on the original stand-alone application by Atos/eviden as part of the Automotive Demonstrator in Phase 1, Continental Automotive Romania (CAR) designed, implemented, and validated a native AR application and deployed it for in-car scenarios. The work also addressed connectivity reliability for streamed AR on an automotive infotainment screen.

CAR was responsible for the design and deployment of the hardware and software setup that allowed seamless visualisation and interaction with AR content while ensuring automotive-grade performance and safety. DW supported CAR with the creation of a coherent user experience and the necessary content and narrative for the Demonstrator production. The user experience was documented in a Demonstrator video together with the Tourism Demonstrator: [XReco I A Ride Through History: Discover Timisoara with AR – In-Car and On-Site - YouTube](#) (see section #2.5).¹⁷

2.5.1 Demonstrator overview and expected output

The team produced an application where tourists could explore the city through the prism of history by seeing 3D models of the landmarks they pass and learn about their history. The application gives its users a way to contact a tourist guide who would answer any questions they had in a video call. The final application was used via the dashboard in the car but could be exported to other Android or IOS devices.

The CAR AR application is a Unity-based application for location-based AR experiences. It unifies assets such as images, 3D models, audio and text with geo-location in order to create a very good tool to have as a tourist in a

¹⁷ <https://www.youtube.com/watch?v=EGXt1dJrxQ>



new place. Within the XReco project, the application functioned as the frontend at the end of a pipeline centred on the tourist’s desire to learn more about the places they visit.

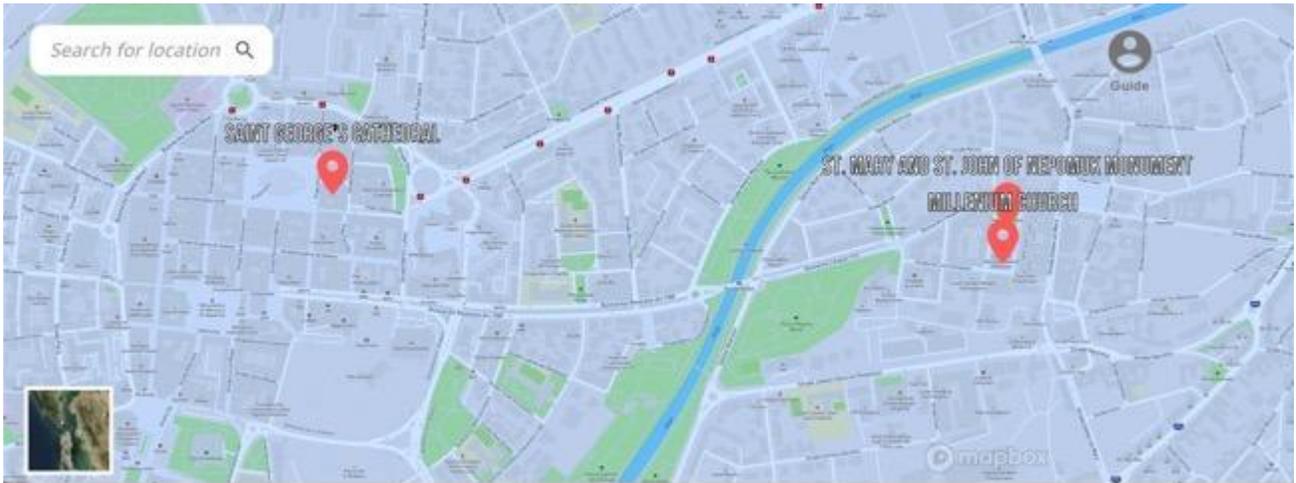


Figure 29: Points of interest on application’s main screen

The application catered for two types of end-users, tourist guides and tourists to be guided. It consists of a map-centric UI for picking landmarks and calling the tourist guide for more information (Figure 29), and a screen which displays a 3D model of the landmark, a panel with a short history of it and an audio narration which presents it (Figure 30).

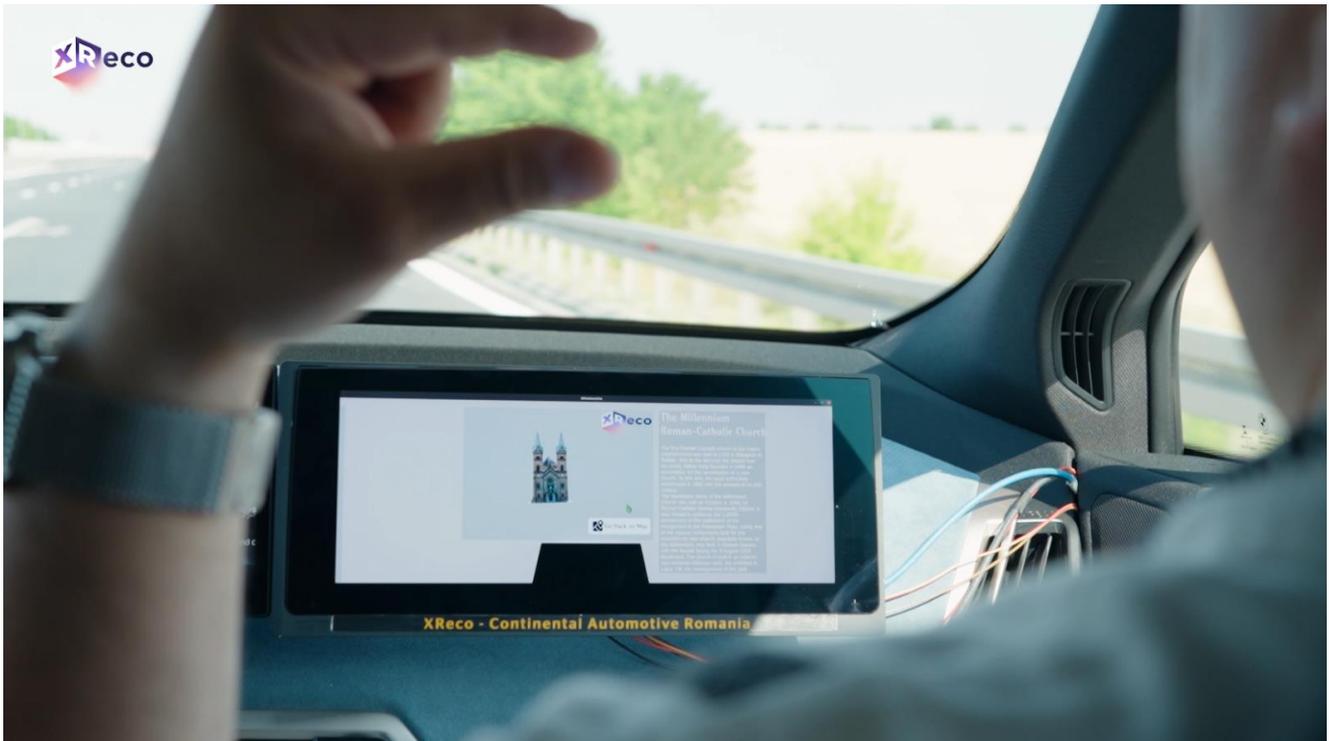


Figure 30: End-user viewing 3D model of Millenium Church and textual description on CAR display

Starting from the map, the tour guide creates a Point of Interest (POI) and adds all the necessary assets for the landmark to be added on the map. e.g. an image and the 3D model (Figure 31).



Figure 31: The Landmark Add Screen

The whole system connects tourists, guides and the XReco backend through a server connection to take care of asset storage and metadata (uploads, versioning, rights, license metadata) and the Connectors to XReco services (Metasearch).

Figure 32 shows information about a POI on the tourists’ side. Here, they can either call up the 3D model to view it full-screen in an interactive spatial viewer or connect with a tourist guide to learn more about the landmark.



Figure 32: The Popup panel

The XReco Automotive use case allows the demonstration of integrating the technology developed within the project, in WP3 and WP4, piloting a potentially final product that includes the search of assets, the creation of new ones and their monetization.

More specifically, the experiment described here validates specific tools designed to enable:



- The creation of AR applications for mobile devices
- The integration of such applications in an automotive hardware environment
- The use by the final users of the applications built with the tool.

The Tourists' Perspective

As a tourist (i.e., consumer), you start your journey by sitting in a car equipped with AR technology. As the car begins to move, the in-car screen streams content that overlays real-world landmarks. This content includes historical facts, 3D reconstructions, and interactive stories about the sites you are passing. The AR experience is designed to be immersive, turning your car ride into an informative and engaging tour. It becomes even more engaging as you control the application with gestures only, without the need to touch the screen (Figure 33).



Figure 33: Doing the click gesture (left); The application registered the click (right)

During your trip, the AR system highlights points of interest (POIs) along your route. For example, as you pass a historic building, the screen might display a 3D model of how it looked in the past (Figure 34), along with audio narration about its significance. This not only makes the journey more interesting but also allows you to learn about the city's history in a unique and engaging way.



Figure 34: 3D model on the in-car display (right)

The Creators' Perspective

As a tour guide (i.e., content creator), you use Continental Automotive Romania's AR application to create AR experiences. This application is user-friendly and allows you to place points of interest precisely in the real world, ensuring a seamless experience for tourists. You can add 3D models, upload audio narrations, and design interactive elements that will enhance the tourists' experience.

Using the application, you place anchors at specific locations which host the assets. For example, you might create a 3D model of a historic monument and place it at the exact spot where the tourists will see it from the car. The app also allows you to update and manage content dynamically. If there is new information or if you want to add a special event, you can do so easily through it. This flexibility ensures that the AR experiences remain fresh and relevant.

In summary, CAR's XReco Automotive use case demonstrates how integrating advanced AR technologies can transform the way tourists experience and interact with historical landmarks, making the journey both educational and entertaining. This project not only showcases the practical applications of AR but also highlights its potential to revolutionise the tourism and automotive industries.

Technical Specification

The AR application, within the experiments, has been deployed on a Linux computer with the following characteristics: Ubuntu 20.04 LTS, Camera, 32GB RAM.

The architecture of the AR application is focused on managing and interacting with AR content. The interface is designed for ease of use, allowing users to upload, edit, and position AR elements in a real-world context. The applications prioritise real-time interaction and efficient handling of AR data.

Continental's software is running on the mounted screen in the car. This setup ensures a smooth running of the application allowing drivers and passengers to enjoy interactive experiences without the need for complex wiring or additional hardware. The industrial PC that runs inside the car (trunk) uses an Ubuntu 20.04 LTS operating system and is interconnected to the cluster and camera that were installed.



Figure 35: The computer in the trunk of the car

2.5.2 Demonstrator Workflow

Table 13: Workflow of creating the “Automotive Tour Guide” demonstrator

| WORKFLOW FUNCTIONALITY | COMPONENT NAME (RESPONSIBLE PARTNERS) | TASK | MAIN ROLE IN THE DEMONSTRATOR |
|---|---|------------|--|
| Content ingestion, Content access, search, and management | Orchestrator (MOG) (updated) & Neural Media Repository (UNIBAS) | T3.1, T3.2 | Cross-modal content search; Curatorial teams discover licensed media (photos, videos, 3D objects, volumetric captures), manage carts, evaluate licensing models, and import metadata |
| Content production | 3D object reconstruction (UPM) | T4.2 T4.3 | Generation of 3D models from 2D video and photo assets |
| Content licensing | Rights Management (FINCONS) (updated) | T3.3 T3.4 | Association of content license policies to ingested/generated assets |
| Content authoring | CAR proprietary application | T4.5 | 2D and 3D objects are imported from the XReco platform; POIs are created with anchors and behaviours; |
| Content monetization | Marketplace (MOG) (updated) | T3.3, T4.4 | Selling or purchasing of generated assets and experiences |

To craft a comprehensive user journey for creators and tourists using Continental’s application, we need to understand the steps both user types would typically follow to achieve their goals. There are two types of users: creators (for example, tour guides) and final users (tourists). A detailed walkthrough of each journey will be given in the following sections.

The 3D objects were created from footage captured with a drone using XReco’s 3D reconstruction workflow (Figure 36). The primary objective was the digital conversion of real-world objects into structured, performant 3D mesh models suitable for immersive, real-time exploration within virtual tour environments (e.g., real estate, museum, or education applications). The workflow is defined by rigorous data capture standards and sequential processing across three specialised software tools.



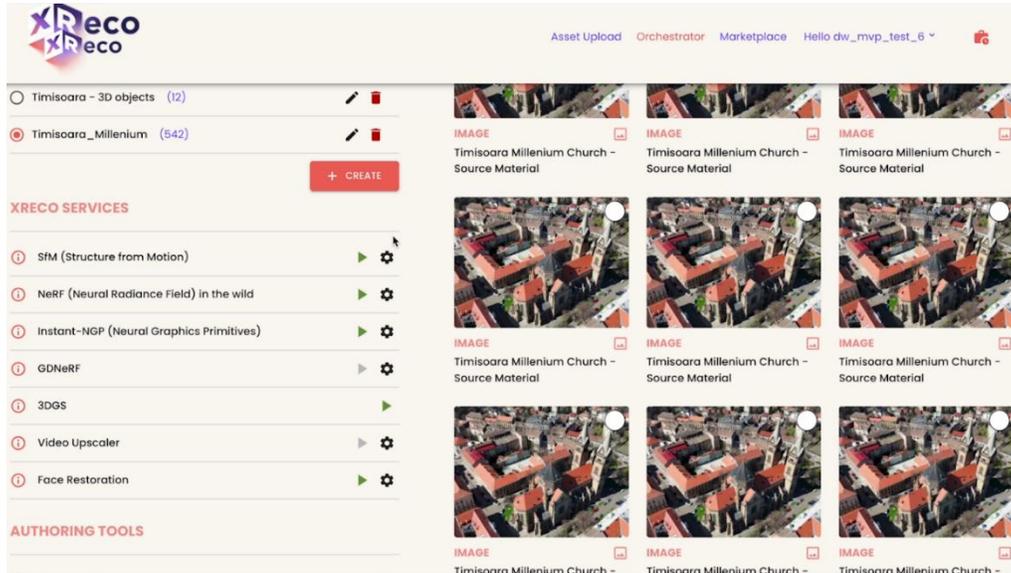


Figure 36: Creating a 3D model of Timisoara’s Millenium Church with XReco’s 3D Reconstruction workflow

When the 3D models were created, they were shared through the XReco marketplace.

Tourist guides could then add these new landmarks which includes 3D models, text descriptions and audio narration about the history of the landmark.

The application connected to XReco’s services for asset search and use. This reduced the needed time to add a landmark and enabled multi-modal experiences that blended historic media with contemporary captures.

The experience connects tourists and their guides as end-users on two different sides of the line.

POIs are placed precisely with the help of a 2D map. Later, they become visible and interactive when the car gets into a pre-defined radius. POIs can be placed easily without site visits, just with the integrated tools. Geofences combined with visual fine alignment improve robustness in the field.

The Creator Journey included:

- Content Creation and Deployment
- Content Import: Creators imported existing content from XReco marketplace or uploaded new images and videos, texts, sounds or 3D models.
- AR Content Customisation: Using the application, guides anchored the content using markers and incorporated the content.
- Preview and Edit: Before finalising, creators remotely preplaced the content for the AR experience in a web map environment and made necessary adjustments. The fine tuning was done in AR at the real location.

The Final users’ journey was all about discovery and engagement

- Accessing Content: Tourists discovered AR experiences through markers on the map
- Interactive Experience: Tourists engaged with the AR content

- Information Retrieval: Tourists access detailed historical insights and stories (Figure 37)

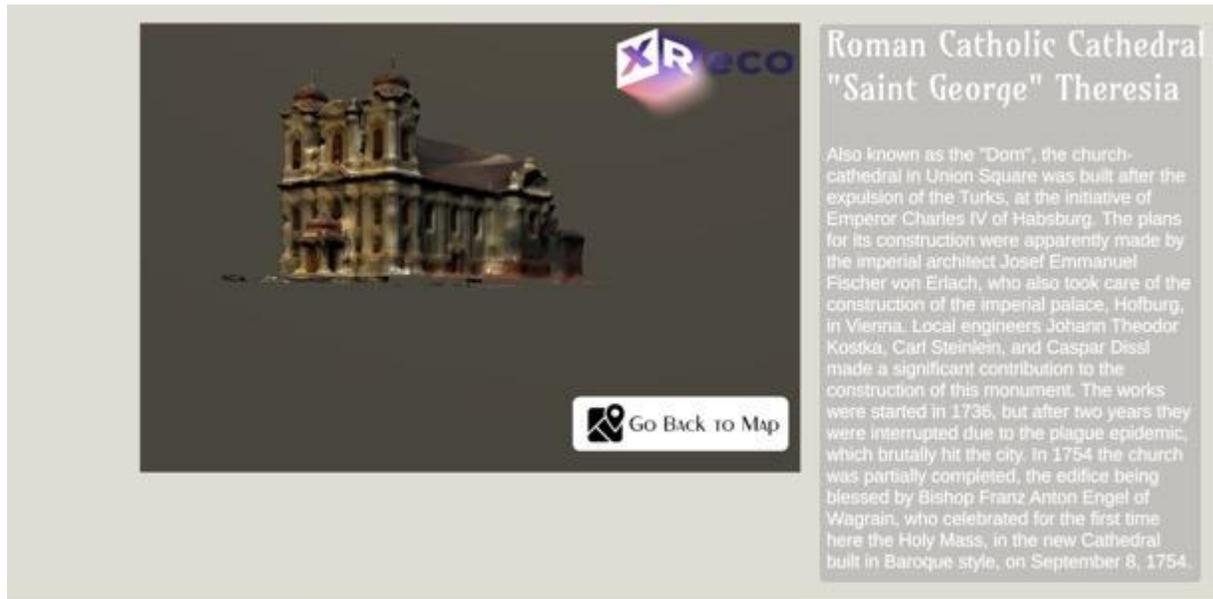


Figure 37: The Screen in which the final users interact with the object

2.5.3 Challenges, Risks, and Lessons Learned

This section summarises the main technical, operational, and product risks we encountered while designing and validating the Automotive demonstrator with CAR's AR Application.

Alignment and Playback Robustness

Cellular handovers led to buffering during the loading of the assets. Therefore, adaptive quality profiles, local caching of critical assets, and "graceful degradation" (fallback UI with text/audio only) were implemented. Rural dead zones still degrade experience; so that information is pre-fetched near upcoming POIs where possible.

Driver distraction and safety

Driver distraction and safety considerations were essential. Rich AR overlays have the potential to draw a driver's attention away from the road. To mitigate this, the application adopted a passenger-first user experience with audio-led narratives and driver-safe display modes, ensuring that interactive or visually intensive content only appeared when the vehicle was stationary or moving slowly. Even with these precautions, regional legal and regulatory interpretations varied, so compliance checklists were incorporated, and interactive elements were automatically disabled whenever the car was in motion.

3 Validation

3.1 Introduction

The demonstrators described in this document have provided first-hand experiences with the capabilities that an ecosystem like XReco provides. They are considered an essential part of validating the XReco platform, its many components, and the workflows in which they are used. If, however, we were to leave all the validation to the demonstrators, as broad as the possibilities that XReco provides, it wouldn't be sufficient to understand the improvements, challenges and reception that we bring to the state of the art of the technology and to users.

Furthermore, the XReco DoA defined two relevant, user-related comparative KPIs that were designed to prove that XReco makes the creation of XR assets and applications easier, faster, and more affordable than they have been before:

- **KPI 3.2:** Improved by at least 20% (in terms of user acceptance measured in a Likert scale) XR production workflows via the delivered platform, evaluated through **acceptance testing, subjective usability evaluation and expert interviews**.
- **KPI 4.2:** Show increased acceptance and usability rates ($\geq 20\%$), via user studies and interviews on at least three (3) different sectors (i.e., journalism and media, automotive, tourism).

In summary, the following validation seeks to measure acceptance, improvement of production workflows and added value. In addition, technical validation is done on component level, with results reported in D3.2 and D4.2 in month 34 of the project (June 2025). For the human-centred validation, tests have been originally designed to run at 3 different points in time:

- The state of the partners or equivalent technology at the beginning of the project September 2022 (A test)
- The state of the technology for the first partner prototypes and XReco platform of June 2024 (B1 test)
- The state of the technology of the MVP of the XReco project, in July 2025 (B2 test).

3.2 Methodology

Different test scenarios have been applied. As the demonstrators cover the complete workflow, the aim was to have test users who evaluate all the key functionalities. As not all demonstrators use all components or steps in this workflow and not all partners had staff involved in the respective activities, some tests focused only on subparts of the whole process, as detailed in the following subsections. All participants provided informed consent for data usage.

3.2.1 Common aspects of the Human-centred validation process: A/B Testing

Deliverable 5.1 explained the A/B testing method. In the case of XReco, it's important to note that this method has been adapted to suit the needs of the evolving project.



The most important difference in comparison to a conventional A/B testing approach is that the population used in A and B1 differs from the B2 population. Given the time span that this project covers, it was not possible to be in touch with participants who donated their time for the A and B1 testing for this next iteration.

As covered in D5.1, 3 different validation moments provide for a well-rounded view of the satisfaction in the tool and in the production workflow that we seek. A first validation moment evaluating technology available in September 2022 provides a benchmark. The B1 validation that took place in June 2024 provided insightful information from testers to whom the XReco MVP was made available. The comments were made available to our different development teams who integrated the feedback providing:

- Bug fixing.
- UX/UI Improvements.
- Improvements in the available MVP functionalities.
- New features available in the final version.
- A cohesive all-in-one platform.

For the B2 validation phase, the process was divided into two target groups. The first group consisted of so-called friendly testers - i.e. people from the partners’ organisations and/or networks who had not been involved in the project - whose feedback enabled a detailed assessment of the full set of functionalities. The second group was dedicated to external validation, recruiting potential customers from outside the consortium, i.e. people who were interested in the platform and its tools and services but had no affiliation with the consortium. This separation was introduced in consideration of the time required for each validation round: completing all tests demanded approximately more than two hours per participant, which was not feasible to ask from external contributors. Consequently, the external validation was adapted to a shorter format, including free testing time and a short online survey of around ten minutes, focusing exclusively on the core functionalities. Although this approach reduced the granularity of the collected feedback, it ensured that the effort required from external participants remained reasonable, while still generating valuable insights and serving as an instrument to engage potential stakeholders.

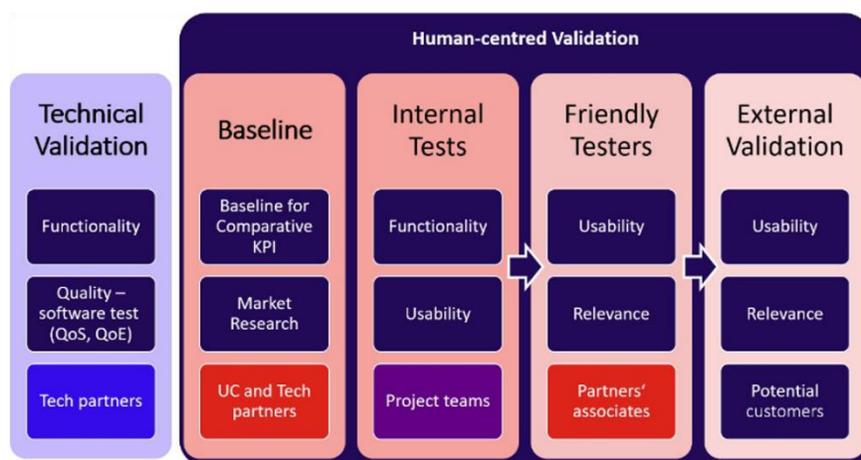


Figure 38: XReco’s validation scheme, Technical and Human-centred across multiple steps.



The actual “B2” tests can be consulted in the annexes. The “A” and “B1” tests can be consulted in the annex of D5.1¹⁸. B2 testing comprises friendly testers and external testers. The number of testers for the B2 test ranged from 5 to 20, who addressed both quantitative (SUS questionnaires) and qualitative questions.

3.2.2 Challenges in validation

We encountered several challenges during the validation process that required us to adapt and remain flexible, ensuring not only compliance with the KPIs but also that the validation process was practical and valuable in improving the tool based on user feedback.

In the previous version of this document (D5.1) it was stated that *“XReco’s ambition has been to provide affordable, fast, and easy-to-use tools and services that will enable less skilled media creators to produce 3D assets and XR experiences which had hitherto required huge budgets and/or coding skills.”* It was also stated that:

“The original idea had been to compare the complexity of the tools and workflows as they had been at the start of the project with the less complex results of the project. However, these two sets of tools have very different target users (highly skilled vs. generic user knowledge), which makes it very difficult to compare them. While it will be easy to demonstrate that the use of XReco tools requires far less technology skills than the use of the tools that were available in 2022, non-skilled users are not expected to have the knowledge or ability to go through the process of testing the more complex tools. This poses a difficulty in the A/B testing, because we cannot compare the A vs. B1 vs. B2 for non-skilled users in contrast to skilled users. To address this, the partners agreed to organise the A/B tests with more skilled users and B1-B2 tests with less skilled users. This way, there was to be feedback on the reduction of complexity from the skilled testers and a validation of usability and user satisfaction of the target groups from the tests with the less proficient users.”

In addition, we faced new challenges during the B2 validation round, particularly concerning the level of **participant engagement**. During the **friendly testing** phase, we achieved a satisfactory level of participation from potential users employed within the partner organisations supporting this project, but who had no prior exposure to it. This proved beneficial, as they were able to devote meaningful time to testing while remaining unbiased by previous knowledge.

When it came to **external testers**, the challenge proved even greater. Thanks to the efforts of our WP6 team, we were able to generate a solid number of leads for potential participants. However, we later discovered that the conversion rate from leads to actual testers was quite low. Although this issue affected only one test — the external testers round — we would have preferred to include a larger group of participants with no prior connection to the project to gain a more objective outsider perspective. To gather that kind of feedback, we conducted targeted cold-email outreach to the leads who had expressed the most interest, particularly those who had participated in one-on-one demos during the IBC event in Amsterdam. A key takeaway for future projects involving validation is the importance of establishing a dedicated budget to compensate external testers for their time.

Another challenge we encountered was the **tension between maintaining evaluation purity and delivering the most refined version of the tool** by the project’s end. In other words, there was never a completely static version for all the key group functionalities tools: during the friendly testing round held in May and June 2025, we

¹⁸ <https://xreco.eu/wp-content/uploads/2024/06/XReco-Deliverable-5.1.pdf>



occasionally used early feedback to resolve issues before other testers encountered them. This approach was necessary because some of the identified bugs were significant enough to compromise the validity of the results. In foreseeing this, in the preparation of B2 we conducted one round of internal testing in February 2025 during a consortium meeting in Torino. Many bugs were reported and fixed, but there were others that we could not anticipate until friendly testers accessed the tools. This preparation also provided the opportunity to assess the overall validation process and provide improvements to the tests. In conclusion, during B2 – friendly testers tests - the technology occasionally produced unexpected errors — as reflected in some of the testers’ comments — some of which were promptly fixed, while others proved to be one-time occurrences.

In conclusion, the validation process proved to be a dynamic and insightful phase that not only fulfilled the project’s KPIs but also played a crucial role in refining and strengthening the XReco tools. Despite challenges related to participant engagement, testing purity, and the evolving nature of the technology, the team’s flexibility and iterative approach ensured that user feedback directly informed meaningful improvements. The experience underscored the importance of early planning for tester engagement, including the allocation of dedicated resources to support external participation, as well as the value of balancing methodological rigor with practical tool enhancement. Ultimately, the validation process reinforced XReco’s core ambition — to deliver accessible, efficient, and high-quality tools that empower a broader community of media creators.

3.3 Key group functionalities

3.3.1 Functionalities Grouping

Following the B1 phase iteration, 5 tests have been performed according to the key group functionalities in the B2 phase as well.

- **XReco Platform test:** In comparison with the B1 testing, the B2 phase aggregated the media repository and search functionalities test with the rights and monetization management test into a single one, given the common paths of the user in navigating through the platform.
- **3D Reconstruction Tools test:** This test covered the usability of the reconstruction technologies, including Structure from Motion, NeRF in the Wild, Instant NGP, 3DGS, and a common validation of the reconstruction workflow. All the reconstruction tests were performed through the orchestrator platform.
- **Unity Authoring Tool test:** This test assessed whether non-Unity users can assemble a simple scene and export a working build using the Unity Authoring Tool.
- **XRcapsules test:** The same test as in the B1 phase was performed on a newer version of the tool that integrated user feedback from the B1 iteration.
- **ZAUBAR CMS test:** A test to validate whether users can upload and geolocate content in the CMS and if the smartphone AR app correctly discovers and renders the content on-site.

Because of their different nature, each of the group features have their own validation protocol as described below. We maintained the SUS questionnaire across the different phases to be able to show comparative results, while using the feedback from the B1 phase to collaborate with partners to add or refine questions that targeted the most relevant aspects identified by them.



3.3.2 Platform Maturity Across Phases

The Platform Feature Group entails the following components listed in Table 14:

Table 14: Validation of XReco's Search and Retrieval frontend components

| COMPONENT | TYPE | PARTNER(S) | VALIDATION PHASE |
|---|----------|-------------|------------------|
| Search and retrieval frontend | Frontend | UNIBAS | A |
| Neural media repository backend (vitivr based) | Backend | UNIBAS | A, B1, B2 |
| Orchestrator dashboard | Frontend | MOG | B1, B2 |
| XR marketplace | Frontend | MOG | B1, B2 |
| Monetization Management | Backend | FINCONS | B1, B2 |
| Rights Management (SLC Engine, Cicero Server, Blockchain Service Provider,) | Backend | FINCONS | B1, B2 |
| Metasearch, Ranking Agent, Connectors | Backend | ATOS, i2CAT | B1, B2 |
| Multimodal search (Cross Modal descriptors) | Backend | CERTH | B1, B2 |
| Object Detection (Landmarc classification, few shot and tracking) | Backend | JRS, i2CAT | B1, B2 |
| News Tagger | Backend | RAI | B1, B2 |

The combination of these components enables a set of innovative search functionalities for users. Beyond the capabilities of traditional text-based search engines, XReco provides:

- Multimodal search for 2D and 3D content
- Federated search across external repositories, integrated with well-known sources such as Sketchfab, Wikimedia Commons, and Europeana, as well as partner-provided archives such as DW and RAI.
- Tag-based search: leveraging automatically detected objects, landmarks, and news-related tags.

Not all components were explicitly individually tested by users; nevertheless, their functionalities contributed indirectly to the outcomes of the validation for the platform.

In general, the most relevant improvements introduced to the search functionalities across the three testing phases were as follows:

Phase A

At the start of the project, the concept of a unified platform for 3D object search and reconstruction was still at an early stage. Therefore, existing partner solutions and standalone prototypes were taken as reference points, including the vitivr media search engine developed by UNIBAS, the 3D similarity search developed by CERTH, and the first draft of the metasearch engine by ATOS. In addition, external 3D object marketplace platforms such as Sketchfab were also considered as benchmarks.



Phase B1

By Phase B1, the first integrated MVP was available, providing the following functionalities:

- Integrated reconstruction API.
- Rights management and marketplace, including Stripe integration.
- Local and federated search with connectors to Sketchfab, DW, RAI, and Wikimedia Commons.
- Object detection and landmark classification.
- Per-organisation asset spaces.

Authoring tools were available at this stage but were not yet integrated with the platform.

Based on the feedback gathered during Phase B1, the consortium streamlined subsequent integrations and user workflows.

Phase B2

Enhancements introduced in Phase B2 included:

- First-login guidance with concise text and video tutorials.
- Automatic news tagging and tag-based search.
- Multimodal search using images and 3D assets.
- Europeana connector added to the federated search.
- User groups and permissions, including per-group usability restrictions.
- Single sign-on (SSO) workflow integrated into the platform.
- UX/UI improvements like visualisations for reconstructed 3D objects, batch uploading, and refined user workflows.

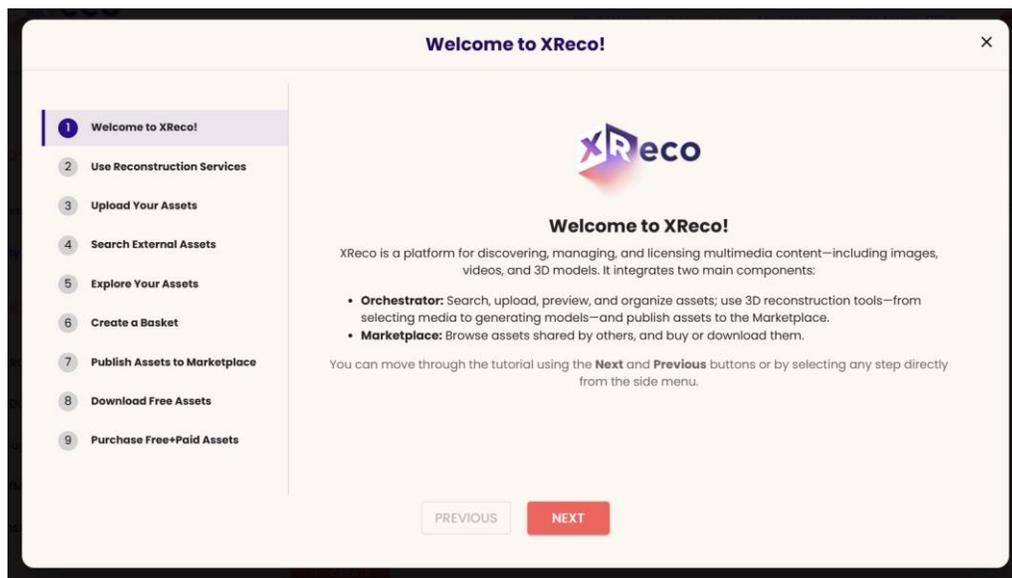


Figure 39: XReco Platform – First-login user guidance.

Improvements Beyond B2

Additional adjustments were introduced after the B2 evaluation to strengthen usability of the Orchestrator and Marketplace:

- **Transparency of Tags:** Tooltips now indicate that tags are automatically generated. This change, applied in both the Orchestrator and Marketplace, reduces confusion and sets clear expectations.
- **Enhanced License Filtering:** Marketplace search supports filtering by multiple licenses at once, giving users more flexibility when discovering and comparing assets.
- **Clarified Basket Functionality:** The Orchestrator now labels basket actions as “Add to Basket” and “Remove from Basket,” replacing the previous “Add” and “Remove” labels.
- **Repository Browsing without Keywords:** “My Repository” now displays all uploaded assets by default, allowing users to browse without entering keywords. This makes navigation easier and assets quicker to find.

These changes not only resolved the most critical issues raised during testing but also improved overall platform usability, ensuring the final release is aligned with user needs.

3.3.3 3D Reconstruction Tools (UPM, CERTH, i2Cat)

The Reconstruction Services Feature Group entails the following components listed in **Error! Reference source not found.** Table 15: Validation of XReco's Reconstruction Services components:

Table 15: Validation of XReco's Reconstruction Services components

| COMPONENT | TYPE | PARTNER(S) | VALIDATION PHASE |
|-----------------------------------|---------|------------|------------------|
| Meshroom, Colmap | SW | N/A | A |
| Structure from Motion | Backend | UPM | A, B1, B2 |
| Instant-NGP (NeRF) | Backend | CERTH | A, B1, B2 |
| NeRF-in-the-wild | Backend | CERTH | A, B1, B2 |
| Gaussian Splatting (3DGS) | Backend | i2CAT | B1, B2 |
| GDNeRF | Backend | i2CAT | A, B1, B2 |
| GDGS | Backend | i2CAT | B2 |
| 3D human-centric data enhancement | Backend | i2CAT | A, B1, B2 |

Phase A

During Phase A (baseline), the state of the art in 3D reconstruction relied on open-source photogrammetry tools such as Meshroom and COLMAP, as well as NeRF-based pipelines like Nerfstudio. While practical, these solutions typically required access to high-end GPUs and non-trivial local setup. In parallel, existing methods (e.g., Structure-from-Motion and NeRF-in-the-Wild) were installed and configured manually to establish the baseline.



At the time Phase A was conducted, 3D Gaussian Splatting had not yet been introduced and was therefore out of scope.

SfM:

During this phase, the user was required to have access to a Linux machine and possess basic familiarity with the command line. The user set up a basic development environment, downloaded, and installed the required libraries OpenMVG and Multitex; and manually gathered the footage to be used for reconstruction. Subsequently, the user created a reconstruction project and successfully generated a 3D object by executing the commands provided in the instructions via the terminal.

At this stage, the reconstruction pipeline started by extracting SIFT descriptors from the images. These features were used in the SfM process to estimate camera positions and generate a sparse point cloud. Next, the images were pre-processed and AKAZE¹⁷ descriptors were extracted. The resulting feature points were triangulated to produce a much denser point cloud, replacing the sparse one. Finally, the dense point cloud was converted into a triangular mesh, and a texture atlas was generated using UPM's obstacle-aware texturizer¹⁸. Other technical details were documented in D4.1.

The technical details of this process are documented in D4.1. It is important to highlight that, in this phase, the point cloud was initially created using SIFT¹⁹ and then densified with AKAZE.

NeRF-in-the-wild

In the first phase of the validation tests, the NeRF-in-the-wild model was re-implemented using its original codebase²⁰ and extended with a multi-resolution has-grid encoding structure²¹ (D4.1). This enhancement resulted in significantly faster training times compared to the baseline implementation. The updated pipeline was integrated into the Orchestrator, enabling users to access the service directly through it. During this phase, validation was carried out using predefined datasets. Due to the inherent challenges in achieving interoperability across different NeRF representations, as well as their computational demands, the outputs were made available to users in the form of rendered video sequences.

Depth + NeRF: GDNeRF

In the first phase, we focused on approaches leveraging NeRF and depth image sensors, analysing the state of the art and identifying the major limitations of existing algorithms. The primary challenge in achieving generalizable novel view synthesis has been obtaining real-time performance, mainly due to the computationally expensive per-ray sampling required by traditional volumetric rendering methods. To overcome this bottleneck, works such as ENeRF have introduced alternative image-based rendering paradigms. However, this method depends on a dense camera setup with numerous viewpoints, which limits its practicality in more common, sparse-view scenarios. To address these issues, we have begun developing our own approach aimed at improving performance and generalizability under sparse input conditions GDNeRF (Generalizable Depth NeRF).

3DGS

Gaussian Splatting was not yet developed during Phase A or at proposal time; it was later integrated as a new reconstruction service to align with the state of the art.



Phase B1

During this phase, the first integrated version of the platform was introduced, providing the users direct access to four reconstruction methods: Structure-from-Motion (SfM), NeRF-in-the-Wild, Instant-NGP, and 3D Gaussian Splatting (3DGS). Via the Orchestrator, users could operate from a lightweight computer to select media and remotely trigger 3D reconstructions, eliminating the need for local high-end GPUs.

Several additional reconstruction and 3D generation methods were available within the project; however, their integration had not reached sufficient maturity, and the complexity and heterogeneity of input formats precluded exposing them to users through a simple, consistent workflow.

SfM:

This phase involved mainly the design and development of the API that allows users to interact with the SfM reconstruction service using the XReco platform. The API provides tools to easily upload images from the XReco repositories to the reconstruction service, set the key parameters of the reconstruction process (number of triangles and texture resolution) and download the result in OBJ format.

The reconstruction service is designed to handle only one reconstruction at a time, which motivated the implementation of a queuing system using Celery²² to let one or many users schedule several reconstructions to be performed sequentially.

NeRF-in-the-wild

In this phase, the hash-grid structure was replaced with an Octree-based feature volume (D4.2). This approach allowed empty regions to be efficiently discarded as training progressed resulting in faster training times, albeit with a slight reduction in output quality, as well as compatibility issues with more modern version of the dependent libraries. The service was once again integrated into the Orchestrator, ensuring that users could access it seamlessly through the same interface.

Depth + NeRF - GDNeRF

During this phase, we implemented our approach GDNeRF, a novel method designed specifically to generate high-quality, real-time views from a sparse and simple camera setup. Our key innovation is to leverage depth map information to construct a probabilistic 3D feature volume. We then use a 3D CNN, supervised by GAN-based features, to intelligently process this volume, allowing it to infer information in occluded or ambiguous regions that are common with few source cameras. This approach enables GDNeRF to produce highly realistic, artifact-free results that significantly outperform previous methods in challenging, few-camera environments where they typically fail.

3DGS

In Phase B1, we adapted an alternative to the original Gaussian Splatting implementation developed by INRIA²³. The resulting pipeline extracts video keyframes when the input is not an asset, calibrates camera intrinsics and extrinsics using COLMAP, and feeds the results into GSplat²⁴, an open-source alternative offering comparable performance. The process outputs a .ply model and includes a Celery-based queuing system and a FastAPI interface for service interaction, all fully containerized with Docker for easy deployment.



Phase B2

Thanks to the feedback gathered during Phase B1, we improved the 3D reconstruction workflow in several key aspects:

- Scalability tests allowed us to establish reasonable usage limits for users according to the available hardware infrastructure.
- Batch uploading and .zip support, together with a reorganisation of the search interface, enabled the integration of more complex services (e.g., GDGS) and significantly simplified the user workflow.
- New visualisation options were added: 3D model viewers and Gaussian Splatting renderers. For results like NeRFs, which cannot be directly visualised in the browser without GPU resources, we generated video previews. Although these previews do not match the full NeRF experience, we also provided automatic conversion of NeRF outputs into 3D models to extend their usability.
- Improved feedback mechanisms were implemented across all services, including clearer error messages and progress/loading bars reporting the actual reconstruction status.

SfM:

In this phase, the pipeline was modified to improve the quality of the reconstructed 3D object. The most significant change was the point cloud densification step: the approach based on triangulating AKAZE feature points was replaced with Multi-View Stereo (MVS)¹⁹.

Motivated by user feedback, the API was extended to provide reconstruction previews in both 2D and 3D formats. Specifically, a GLTF version of the reconstructed 3D object is generated from the OBJ output, which lets users visualize the result directly within the XReco web platform without relying on external software.

Finally, a feedback mechanism was implemented to provide status updates for each stage of the reconstruction process (performing SfM, densifying point cloud, texturizing...), which is very helpful to monitor its progress and make sure that it is not stuck. Additionally, an error-handling system was integrated to notify the user when a stage fails to complete.

NeRF-in-the-wild

The core implementation remained unchanged during phase B2, with the exception of bug fixes and API adjustments made to align with the updated technical requirements and revised API structure.

Depth + NeRF - GDNeRF

During Phase B2, the core implementation was retained, with only minor revisions involving bug fixes and API updates to ensure compatibility with the revised technical specifications and API framework.

Depth + Gaussian Splatting – GDGS

In this phase, building upon our previous work, we introduce GDGS, a novel architecture that significantly enhances both rendering quality and speed by integrating the 3D Gaussian Splatting (3DGS) representation. GDGS replaces the prior rendering pipeline with a more direct model that predicts the parameters of a unique

¹⁹ S. Shen: “Accurate Multiple View 3D Reconstruction Using PatchBased Stereo for LargeScale Scenes”, *IEEE Transactions on Image Processing*, vol. 22, n° 5, pp. 1901–1914, May 2013. DOI: 10.1109/TIP.2013.2237921



3D Gaussian for each pixel of the target view. The process begins by extracting deep visual features from the nearest input view using a 2D UNet. To overcome the limitations of a single perspective and effectively handle occlusions, a critical cross-view attention module is employed to fuse these features with complementary information from other source images. From this enriched feature map, a final layer predicts the complete set of attributes for each Gaussian, including its 3D position offset, rotation, scale, opacity, and colour (represented by spherical harmonics). The final 3D position is anchored to the scene geometry by using the camera's depth map and applying the predicted offset. Finally, the entire collection of predicted Gaussians is efficiently rendered into the photorealistic final image using a specialized differentiable rasterizer.

3DGS

In the final phase, following user feedback, the Gaussian Splatting service was refined through scalability testing, enhanced error handling, and improved user feedback mechanisms during processing via the Celery framework. The output .ply files were adapted to meet Orchestrator integration requirements, enabling the inclusion of a Gaussian Splatting viewer for visualization of the reconstructed results.

Improvements beyond B2

SfM:

After phase B2, two main improvements were implemented:

- A method was developed to automatically define the region of interest in the 3D model, using the camera positions to remove outliers and partial reconstructions of background objects. More details can be found on D4.2.
- A new functionality was introduced to enable 3D reconstructions not only from still images but also from videos. For video-based reconstruction, one frame per second is extracted, allowing the generation of a sufficient set of images from which the 3D model can be reconstructed.

NeRF-in-the-wild: The B2 testing phase resulted in several targeted service refinements for NeRF-in-the-wild. These modifications addressed three primary areas:

- Core bug resolution: Critical bugs were resolved, particularly within the ray tracing pipeline, enhancing rendering stability and accuracy.
- Appearance encoding enhancement: The mechanism for appearance embedding encoding was refined, enabling more precise and higher resolution, as well as disregarding appearance encoding for scenes that do not exhibit different appearances in the uploaded datasets.
- Dataset compatibility: Support was integrated for various dataset structures, including UPM's synthetic dataset, to facilitate comprehensive objective testing of reconstruction quality.

Depth + Gaussian Splatting – GDGS

Beyond GDGS we introduced improvements to model more in-the-wild sequences where different cameras can have different lighting conditions. To address this problem, we propose to embed camera embeddings in each of the input views, which can learn each camera specific lighting conditions.



An important sidenote:

Live Broadcasting Tools (FVV, Holoportation, Live Capture or Offline Volumetric Video) are not part of the User validation. They belong to the technical testing, as users cannot test them on their own due to the advanced hardware (a camera with depth information, a studio, for instance).

3.3.4 Authoring tools Maturity Across Phases

As mentioned earlier in this document, the platform was designed to integrate three different authoring tools: the Unity Authoring Tool, the XR Capsules, and the ZAUBAR CMS and App.

Table 16: Validation of XRReco's Authoring Tools

| COMPONENT | TYPE | PARTNER(S) | VALIDATION PHASE |
|----------------------|----------|------------|------------------|
| Unity Authoring Tool | Software | Capgemini | B1, B2 |
| XR Capsules | Platform | Visyon | B1, B2 |
| ZAUBAR CMS and App | Platform | ZAUBAR | B1, B2 |

Phase A

At this stage, the only tool available for testing was the Unity real-time 3D development environment. Given its maturity and widespread adoption, **Unity was used as a baseline**. The goal was to evaluate how the workflow could be simplified for users without a strong technical background, while also gathering early feedback on specific platform functionalities to improve usability.

Phase B1

In this phase, the additional authoring tools (ZAUBAR CMS and XR Capsules) were ready for user testing. However, they were not yet directly connected to the XRReco platform. Consequently, the tools were tested independently to validate their individual functionalities and user experience.

Unity Authoring Tool

The Unity Authoring Tool was evaluated as a key component of the XRReco ecosystem, aimed at enabling users to efficiently create immersive XR experiences. It offered a streamlined and accessible workflow that allowed even those with limited technical expertise to build their own content using Unity and the XRReco tools and services. Through structured guidance, intuitive tutorials, and preconfigured templates, the tool simplified the creation process.

During the test phase, participants were guided through the creation of a virtual TV studio experience. This scenario served as a representative use case to assess whether users could independently complete the full workflow—from setup to deployment—and successfully generate a publishable immersive scene.



Overall, the results were encouraging: many users were able to complete the process and produce a functional and visually coherent TV studio experience. However, the feedback also highlighted areas for improvement, particularly regarding the clarity of guidance related to individual plugins and the general use of Unity. Enhancing support materials in these areas could further lower the entry barrier and improve the overall user experience.

XRCapsules

During the B1 validation phase, the first public MVP version of XRCapsules was launched, marking the beginning of an Authoring Tool component of the XReco ecosystem.

This milestone provided test users with access to an independent web platform for testing the XRCapsules MVP creation tool, enabling them to design and visualize interactive XR scenes without requiring programming knowledge. At this stage, the MVP consisted of the core of the tool, including:

- A single Virtual Productions template to experiment with scene creation.
- The ability to import 3D assets in common formats (GLB, GLTF, OBJ, FBX, USDZ).
- Basic position, scale, and rotation transformations for objects.
- Assignment of triggers to define simple interactions.
- Exporting scenes in JSON format for reuse in external tools like Unity.

These core features allowed users to test the fundamental workflow of creating, managing, and exporting XR scenes.

It included a proprietary login system, developed internally to provide basic user authentication without depending on the Orchestrator or Marketplace. This initial implementation ensured secure access and user session management within the platform.

A dedicated API service was created to manage 3D model optimization after import. This service automatically reduced polygon counts while preserving materials, improving performance and rendering efficiency. Developed as an independent solution, it removed the need for external tools and automated the processing of 3D assets using Blender. This feature proved essential so most users could run their creations, to adapt to the size requirements that are able to run in most home computers (and ultimately phones).

The web application was developed using modern web technologies, providing a 3D workspace where users could create projects, import assets, and manipulate them through transformations such as position, scale, and rotation. Users could also assign triggers to define basic interactions within their scenes.

Since the platform was not yet connected to the Orchestrator, asset ingestion was performed locally. Users could import their own 3D models directly from their devices, and the system supported common formats such as GLB, GLTF, OBJ, FBX, and USDZ. At this early stage, no templates were available — the platform offered only the essential core environment for building and experimenting with XR content.

Each created scene could be exported in JSON format, designed to describe all scene components — including assets, transformations, and triggers — in a structured and interoperable way. This format allowed scenes to be reproduced externally, such as in Unity, even before full integration with the Orchestrator or Marketplace was implemented.



Finally, a Unity integration package was introduced to import the JSON scenes generated by XRCapsules directly into the Unity editor. This enabled users to automatically recreate their XR environments, including asset placement, materials, and trigger configuration, providing a bridge between web-based creation and real-time visualization tools.

Overall, Phase B1 established the technical and functional foundation of XRCapsules as a standalone XR creation platform. It introduced the essential components — independent login, asset ingestion, 3D processing, scene definition, and export — laying the groundwork for the deeper integration and user-focused enhancements that would arrive in Phase B2.

ZAUBAR CMS

In B1, ZAUBAR CMS was already a browser-native, location-based AR CMS with a map-centric editor and a clear authoring hierarchy (Project → Scene → Anchor → Assets & Behaviours). Authors could remotely place content on a 3D/WebGL map, set activation radii, preview line-of-sight/occlusion, and use roles with staging/production channels for curation. Core features available included portal templates for historical photos, “Mixie” photo-video compositions (with device-dependent human occlusion), non-destructive media edits, and exports to iOS/Android with zero-friction launch via App Clips/Instant Apps (QR/NFC/deep links).

Volumetric elements existed as placeable assets with fallback to prerendered sequences, but the full “3D Humans/4D” pipeline was slated for Phase 2.

Operationally, B1 was tested independently of the platform (no SSO yet), focusing on authoring UX and dependable playback in early tourism and in-car scenarios, with remote pre-placement plus optional on-site refinement to counter misalignments.

Phase B2

By this stage, a single sign-on mechanism had been implemented, allowing users to access the different authoring tools through the platform with unified credentials. This integration redirected users seamlessly to the respective tools, effectively packaging them within the overall XRReco workflow.

Unity Authoring Tool

Following the previous test phase, it became evident that further improvements were needed in guiding users through the available plugin functionalities and the general use of Unity. In response, the documentation was significantly expanded - covering individual plugins, scripting components, and the practical use of scene templates. Additionally, the last round of user testing was supplemented with a Unity basics tutorial to better support users with limited prior experience.

As a result, the usability of the Authoring Tool improved noticeably. In the subsequent test, participants were able to create an immersive, interactive 3D infographic experience. Feedback indicated that users appreciated the intuitive workflows, the structured tutorial design, and the tool’s potential to simplify 3D content creation, even for more complex scenarios.

In addition, the integration with the XRReco platform was expanded through the introduction of a dedicated tab within the Authoring Tool. This new interface element provides direct access to key XRReco services, such as the Orchestrator, allowing users to easily browse, create and insert assets.



Overall, the Authoring Tool offers a flexible foundation for creating personalised, interactive, and immersive user experiences, supported by expanded plugin integration, improved documentation, and enhanced usability.

XRCapsules

During the B2 validation phase, a new public version of XRCapsules was released, marking its full integration into the XReco ecosystem and introducing significant advancements in authentication, interoperability, and user experience.

In this phase, XRCapsules replaced its proprietary login system from B1 with a complete Keycloak integration, providing robust user management, session handling, and secure authentication across the platform. Users could access the platform using their credentials or through the Marketplace, ensuring consistent and secure login across the ecosystem.

The connection between XReco and the Marketplace Basket was also established, allowing users to link, import, and manage digital assets seamlessly directly from within the orchestrator interface. This integration provided a more unified workflow between asset management and scene building.

The platform introduced support for external multimedia elements, which could now be imported either from a URL or from the local system. This broadened the creative possibilities for users, who could enrich their XR scenes with a variety of image, audio, and video sources.

A major user interface update enhanced the visual design and usability of the platform. New templates were introduced, allowing users to start from predefined structures and create personalized XR experiences adapted to their specific use cases. These improvements reduced the learning curve and made the creative process faster and more flexible.

Users could now save, manage, and reopen their projects directly within the platform, enabling a more continuous and efficient creation workflow.

A new XRCapsules Player allowed the visualization of video, image, and audio elements within each project, and was later updated to support the playback of previously created scenes, completing the full creative loop from concept to interactive visualization. At the same time, the user interface introduced simplified navigation to help users become familiar with the platform and start creating XR experiences more easily.

Overall, Phase B2 transformed XRCapsules from an independent prototype into an integrated component of the XReco ecosystem. With advanced authentication, Marketplace connectivity, multimedia flexibility, and improved usability, this phase solidified XRCapsules as a mature, connected, and user-oriented XR creation platform.

ZAUBAR CMS

By B2 the CMS moved from standalone to integrated: single sign-on was in place and the tool interoperated with the XReco stack (Orchestrator/NMR for search & licensing, connectors for 3D reconstruction and 3D humans/volumetrics). Authoring matured with a twostep placement workflow (remote preplace → onsite finetune), plus orientation helpers and occlusion previews to reduce misalignment. Volumetric video avatars became first-class assets with dialogue steps and an adaptive playback ladder (volumetric → 3D billboard → 2D video), including chunking and prefetch per POI to handle bandwidth/thermal limits. Mixie gained device capability detection and per-device templates to stabilize results on midrange Android/older iPhones. Distribution hardened for field use: adaptive quality profiles, local caching, graceful degradation (text/audio-only



UI), prefetching of upcoming POIs, and driver safe modes (passenger-first UX; interactivity gated when moving). The end-to-end pipeline was validated in production style demonstrators (e.g., the Timisoara Uprising AR experience), confirming authoring → distribution → onsite playback.

Improvements beyond B2

Unity Authoring Tool

In direct response to the feedback from the B2 tests, several significant improvements and new features have been implemented:



Figure 40: New UI with shortcuts (left) and Prefab list (right)

Prefab Browser: A new interface for browsing and placing prefabs, improving asset management and scene composition.

- **Top Menu Navigation:** A streamlined top menu for easier access to core functions. (see Figure 40)
- **Integrated Documentation:** A help button within the Authoring Tool now links directly to comprehensive documentation. The documentation has been restructured, expanded with new content, and refined to remove deadlocks, ensuring smoother onboarding and troubleshooting.
- **UI Improvements:** General interface enhancements for a cleaner, more user-friendly experience.
- **Bug Fixes & Code Cleanup:** Stability and performance have been improved through extensive debugging and code optimisation.
- **Import Asset Dialog:** A new dialog simplifies the process of importing external assets.
- **Updated Unity Version:** The project now supports the latest Unity version, ensuring compatibility and access to new features.
- **Text Helper Tool:** A utility to assist with annotation text creation.
- **Unity Basics Tutorials:** Introductory tutorials help new users become familiar with Unity and the tool’s workflow.



- **YouTube Instructional Video:** A step-by-step video guide is now available to support visual learners.²⁰
- **Support for 3D Gaussian Splatting Models:** Including compatibility with WebGPU, enabling advanced rendering techniques.
- **Audio and Video Support in Annotations:** Annotations can now include multimedia content, enhancing interactivity and expressiveness.

XR Capsules

Following the B2 validation phase, XR Capsules evolved into a more complete and user-friendly tool for creating immersive XR experiences. Building on feedback from previous phases, this version focused on improving usability, interactivity, visual quality, and integration with the rest of the XRReco ecosystem.

- **Interactivity and Controls**

New triggers and control systems were added, allowing users to create interactive behaviours within each capsule. These include actions such as playing a video, displaying information, or moving objects when a user clicks or enters a specific area. These features enable users to design interactive stories and experiences without any coding knowledge.

- **User Interface and Workflow**

The interface was redesigned to resemble professional 3D software. It now includes keyboard shortcuts, an information bar, and flexible editing panels for managing and previewing scenes. These improvements make the tool easier to learn, faster to use, and adaptable to different types of creators.

- **Integration and Sharing**

Integration with Unity has been enhanced so that capsules can be imported, edited, and previewed directly within Unity environments. Each capsule is defined by a structured JSON file, describing assets, transformations, and triggers, making it easier to share, reuse, and extend projects across tools.

A QR-code system allows users to generate and scan codes to open XR scenes instantly on mobile or desktop devices. Additionally, the XRPlayer now includes improved usability messages and the ability to read QR-codes directly, simplifying testing, collaboration, and access to XR experiences.

- **Visual Quality and Optimisation**

Support for HDR content and environmental lighting was added, providing more realistic illumination, reflections, and immersive quality.

The **XR Capsules Decimation Service** was introduced to automatically reduce the size of 3D models while maintaining visual fidelity. The platform includes example workflows and guides to optimize scenes for different devices, including web, mobile, and XR headsets.

²⁰ <https://www.youtube.com/watch?v=9m2LakUIEEk&t=22s>



Figure 41: The XRCapsules interface with an imported 3D model and a background

Looking ahead, Visyon is preparing the final iteration of XRCapsules, scheduled for December 2025, which will integrate the last round of usability refinements and deliver a stable, feature-rich release. This version will be released as open source, reflecting XReco’s commitment to accessibility, transparency, and sustainability. By opening the codebase, the project invites the wider community of developers, researchers, and media practitioners to extend, adapt, and evolve XRCapsules beyond the lifetime of the funded initiative.

In this way, XRCapsules become more than a project demonstrator: they are positioned as a tool for XR authoring and playback, aligned with 3D application practices, and powered by an interoperable JSON backbone. This open approach ensures that XReco’s contribution to the XR and media landscape will remain relevant, extensible, and impactful towards the future.

ZAUBAR CMS

Several changes have been inspired by the test results and the test users’ feedback:

Volumetric video avatars

Volumetric video actors (e.g., historians, guides) were integrated as first-class assets: authors can now drop them onto anchors, set facing/scale, and define dialogue steps. Playback includes fallback to prerendered sequences for constrained bandwidth. This aligned with XReco’s “3D Humans” stack (volumetric video, FVV, holoportation) and leveraged ongoing work on volumetric compression and distribution.

“Mixie” photo-video compositions

End users can take photos and videos of the AR together with themselves (human occlusion needed on user’s device) and get them automatically saved in their camera roll.

Remote placement on a 3D map and onsite

Authors can **replace and adjust content remotely** and onsite on a WebGL 3D map, previewing occlusion lines and adjusting anchor radii. This eliminated on-site setup for most scenes and accelerated multi-city rollouts.

Templates for historical photos as AR portals



Portal templates that transform flat historic photos into spatially layered “walk-in-to” vignettes with spatial audio, depth parallax, vignetting, and lighting cues were added as a functionality. Curators can now swap source images, set appropriate colour grades, and publish with a single click.

3.4 Testing Results Analysis

This section contains a summary and analysis of the following results:

- Platform results – A/B2 testing comparison
- Reconstruction results – A/B2 testing comparison
- XRCapsules Authoring Tool results – A/B2 testing comparison
- Unity Authoring Tool results – A/B2 testing comparison
- ZAUBAR CMS Authoring Tool results – A/B2 testing comparison
- External testers results – A/B2 testing comparison

The tests have in common a SUS questionnaire with 10 different categories: acceptance, confidence, learning requirement, support needed, learning curve, cumbersomeness, ease of use, complexity and consistency. Depending on the key group functionality, there are specific questions (both Likert-scale based, yes/no based or open-ended questions) tailored according to the needs of each tool.

There is also a gender comparison available, although in general the number of women testing the tool was significantly lower as of men, and the results show how differences were not significant. We had no individuals reporting to be non-binary.

For a full run-through of the testing questions and results of the Individual results for B2, you may consult the Annexes.

A common aspect of the tests is the presence of a SUS (System Usability Scale) questionnaire, given that it is a standardized tool used to measure the usability of a product, system, or service. It consists of 10 statements which participants rate on a 5-point Likert scale. 1 = Strongly Disagree and 5 = Strongly agree.

- **Acceptance:** I think that I would like to use this system frequently.
- **Complexity:** I found the system unnecessarily complex.
- **Ease of use:** I thought the system was easy to use.
- **Support Needed:** I think that I would need the support of a technical person to be able to use this system.
- **Integration:** I found the various functions in this system were well integrated.
- **Inconsistency:** I thought there was too much inconsistency in this system.
- **Learning Curve:** I would imagine that most people would learn to use this system very quickly.
- **Cumbersomeness:** I found the system very cumbersome to use.
- **Confidence:** I felt very confident using the system.
- **Learning Requirement:** I needed to learn a lot of things before I could get going with this system.

As of the scoring, each item is scored from 0–4. Odd-numbered items (1, 3, 5, 7, 9) are positive statements, so higher scores mean *better usability*. Even-numbered items (2, 4, 6, 8, 10) are negative statements, so higher scores mean *worse usability*. To make sure that all items point in the same direction (so that higher = better usability), we adjust the raw scores before summing them. For odd-numbered items (positive statements) we



subtract 1 from the user's rating. For even-numbered items (negative statements), we subtract the user's rating from 5. The total of these adjusted scores is then multiplied by 2.5, yielding a final SUS score out of 100.

Positive items $\rightarrow (\text{score} - 1) * 2.5 \rightarrow$ values in [0, 10]

Negative items $\rightarrow (5 - \text{score}) * 2.5 \rightarrow$ values in [0, 10]

Each response is mapped to 1–5 (Strongly disagree=1 ... Strongly agree=5; Neutral/Don't know=3). Positive items are transformed as $(\text{score} - 1) \times 2.5$; negative items as $(5 - \text{score}) \times 2.5$. This yields per-item scores in 0–10 where higher = better. We then average the available item scores for each participant and multiply by 10 to express the SUS on a 0-100 scale.

As of the interpretation, anything between 0-64 is poor, between 64-71 is average, and anything above 72 is above average. Keep in mind it's not a percentage: a score of 70 doesn't mean "70% usable." It's a relative measure, best interpreted through comparison to industry benchmarks.²¹

3.4.1 Platform results

Individual results

The platform test evaluated all available features, with the exception of the reconstruction services and authoring tools. Specifically, it covered the following functionalities:

- Asset upload
- Asset search
- Distinction between internal and external repositories
- Search functionalities (including tag usage and the ability to find visually similar assets)
- Asset preview
- Content basket creation
- Publishing assets to the marketplace
- License selection
- Purchase of both free and paid assets

After a guided walkthrough, testers were asked to independently complete a series of tasks - such as uploading assets, searching for specific content, grouping assets into baskets, exploring tags, and selecting appropriate licenses for defined use cases. Following each task, users were asked two main questions:

- Whether they were able to complete the task successfully
- How useful they found the feature in question

²¹ Item Benchmarks for the System Usability Scale by [James R. \(Jim\) Lewis, Ph.D.](#), [Jeff Sauro, PhD](#) Published in the Journal of Usability Studies, Vol. 13, Issue 3, May 2018 pp. 158–167

The responses have been integrated in the interpretation of the following comparisons: B1/B2 and A/B2. The reader may find the tests and further detail of their results in the annex.

B1/B2 testing

To evaluate the evolution of the XReco platform, System Usability Scale (SUS) questionnaires were administered during both the B1 and B2 testing phases.

The following subsections present results along three perspectives: (i) gender comparison across phases, (ii) overall SUS improvements, and (iii) per-category analysis. Beyond usability, the testing also generated valuable insights into the licensing framework of the Marketplace, which will be presented after the SUS evaluation.

Gender comparison in the XReco platform test:

The following two figures display the SUS questionnaire results from the B1 and B2 tests, showing mean scores by gender (Figure 42) and the change per question between phases (Figure 43).

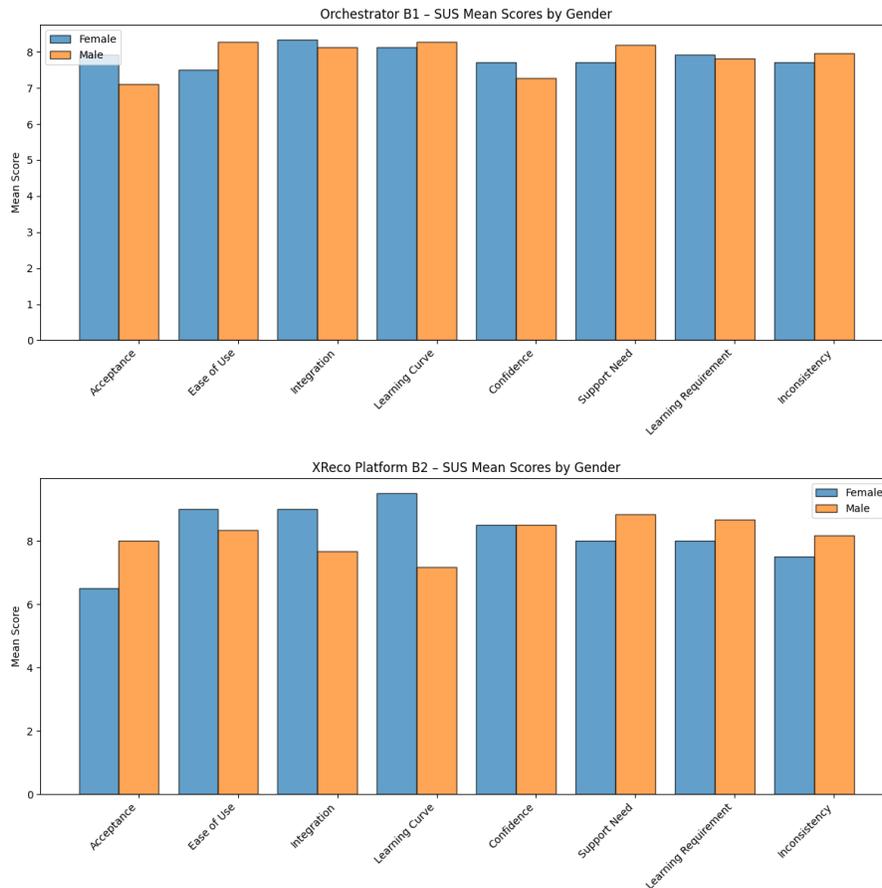


Figure 42: XReco platform test – SUS mean scores by gender in B1 phase (top) and B2 phase (bottom).



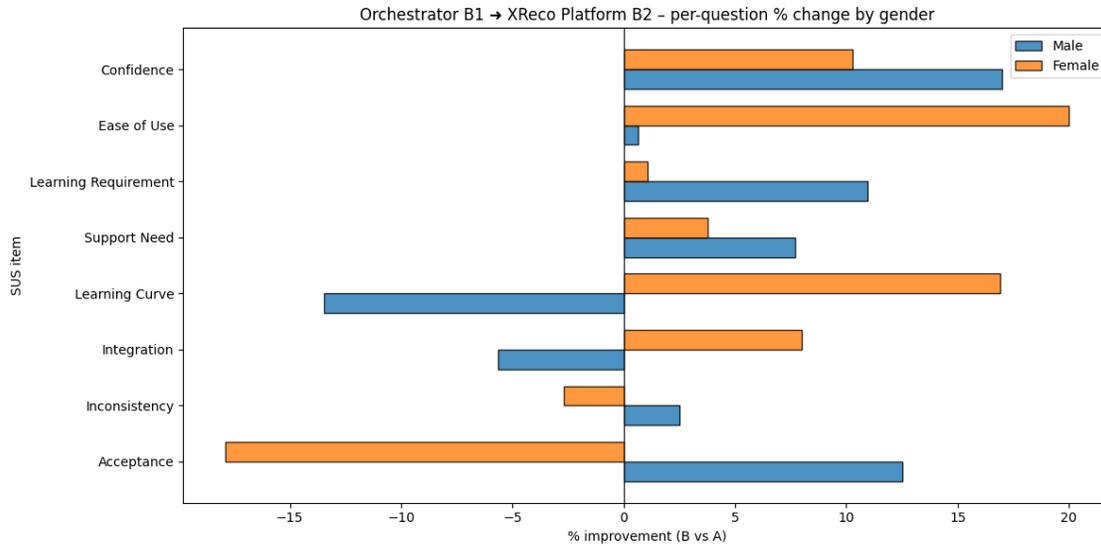


Figure 43: XReco platform test – Percentage change in SUS scores from B1 to B2 by gender.

For positively worded items (Q1, Q2, Q4, Q6, Q7; higher = better usability), both groups improved, though in different areas. Female participants recorded the strongest gains in Ease of Use (+~20%), Learning Curve (+~17%), and Confidence (+~12%), while results for male participants improved most in Confidence (+~17%) and Acceptance (+~13%). These results indicate that women experienced smoother workflows and easier learning, while men expressed stronger confidence and willingness to use the platform regularly.

For negatively worded items (Q3, Q5, Q8; higher = worse usability), changes were limited. Females showed only marginal increases in Support Need and Learning Requirement, with Inconsistency slightly reduced. Males showed somewhat larger increases in Support Need and Learning Requirement, suggesting that some adaptation effort was perceived as necessary with the expanded feature set. Nonetheless, these drawbacks were moderate and outweighed by the gains in Confidence and Ease of Use.

Overall, B2 refinements improved usability across genders, with women benefitting more in terms of learnability and men in terms of trust and acceptance.

SUS test comparison overall:

The distribution of SUS scores (Figure 44) shows a slight overall improvement from B1 to B2, with the mean increasing by ~3.9%. At the same time, the standard deviation decreased by ~15.2%, indicating that responses became more consistent across participants. The range also narrowed (-27.3%), suggesting that outlier perceptions of very low usability were reduced in B2.



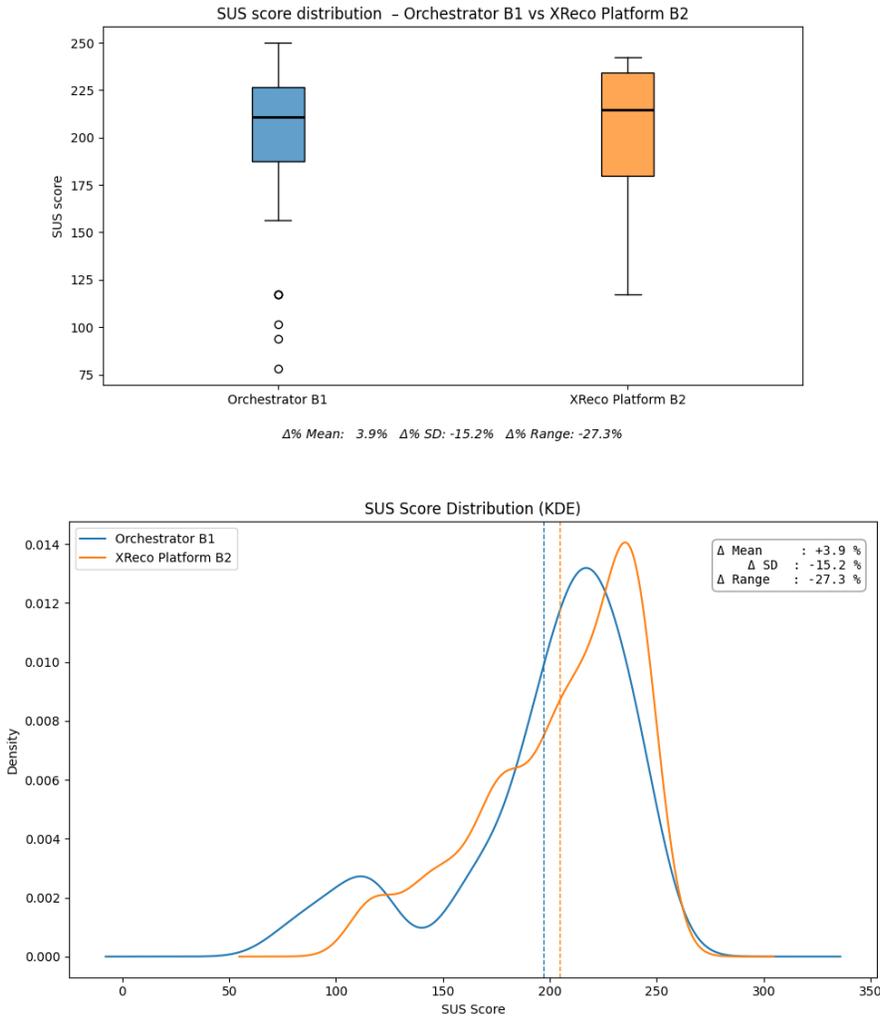


Figure 44: XReco platform test – SUS score distribution in B1 and B2 (boxplot, top; KDE, bottom)

SUS test comparison per category:

When examining per-item percentage changes (Figure 45), the largest improvement was seen in Confidence (+~15%), showing that users felt more capable and self-reliant when using the platform. Other positively worded items, such as Ease of Use and Acceptance, also showed smaller gains, indicating overall improvements in usability. Integration (~-3%) and Learning Curve (ease of learning, ~-6%) slightly decreased, suggesting that onboarding and coherence between functions became somewhat more demanding as new features were introduced.

For negatively worded items, increases in Learning Requirement (+~9%), Support Need (+~8%), and Inconsistency (+~3%) mean that users perceived these aspects as more challenging, a common outcome when systems expand in functionality and complexity.

Overall, the results show that B2 improved usability and user confidence, even if the richer feature set required additional learning and support.



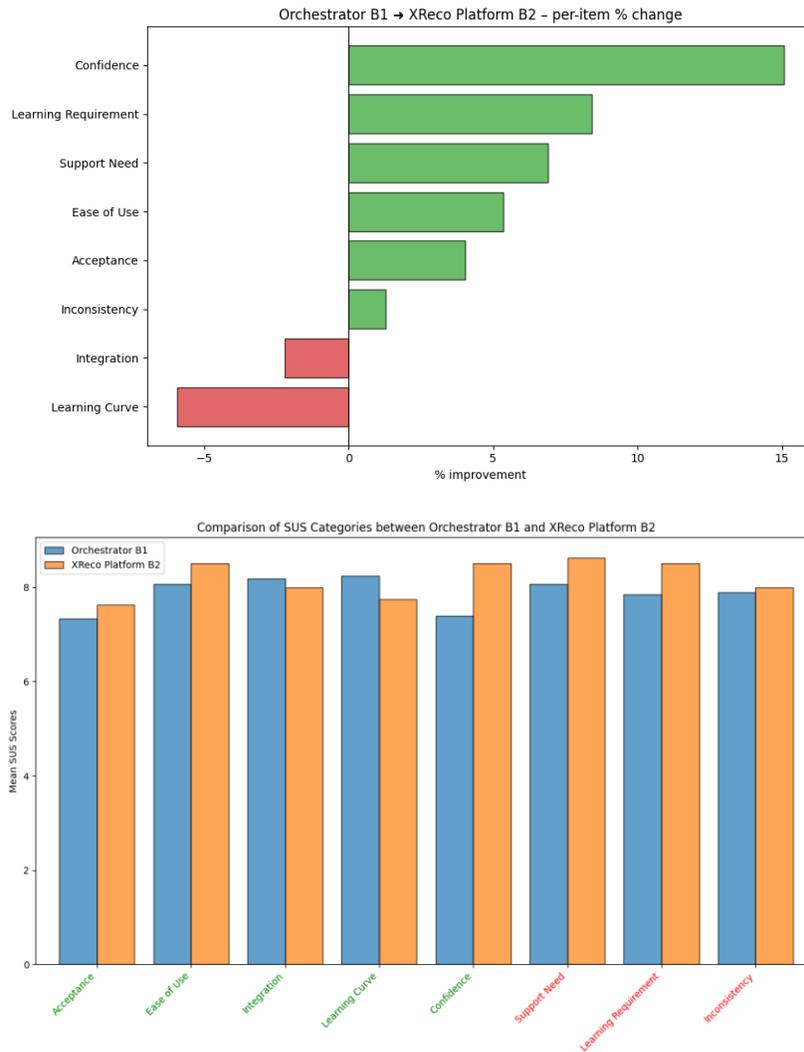


Figure 45: XReco platform test – Comparison of SUS categories in B1 and B2 (percentage change, top; bar chart; bottom)

Licensing conclusions

The B2 testing results provided valuable insights into the licensing framework of the XReco Marketplace (see Annex I for full details). Straightforward cases, such as publishing content without restrictions (CC0) or applying non-commercial, no-derivatives terms (CC BY-NC-ND), were widely understood and correctly applied. More complex conditions, particularly the CC Plus model that combines free non-commercial use with commercial unlocking, proved more challenging, as several users selected alternative licenses. This shows that while the wizard is effective for simple scenarios, clearer guidance and legal explanations are needed to support users in applying hybrid licensing models.

Responses on baseline licensing principles revealed mixed levels of clarity. While 65% of participants understood that all assets are free for non-commercial use, 35% did not, pointing to the need for better communication of



default rules. A majority of creators (55%) were comfortable with free non-commercial reuse of their assets, but a significant minority remained uncertain or uncomfortable, suggesting that adoption depends on stronger safeguards. Views on CC Plus customisation were also divided: 35% requested more flexibility beyond pricing, 20% were satisfied, and 45% were undecided, highlighting both uncertainty and a need for additional guidance, particularly for non-legal users.

In terms of additional conditions that users would like to see implemented, the most prominent concern was the prevention of AI training use, prioritised by 65% of participants, underscoring its importance in light of current copyright debates. Beyond this, balanced demand (40 - 45%) emerged for further options such as time limits, sublicensing, derivative work restrictions, and exclusivity, reflecting the desire for more precise contractual control in commercial contexts. In contrast, attribution (30%) and territorial restrictions (25%) were less emphasised, suggesting that economic and emerging digital risks are more pressing to users than traditional crediting requirements.

Together, these findings show that the XReco licensing framework is broadly usable and fit-for-purpose, but requires refinements to clarify defaults regarding free licensing of non-commercial uses, expand flexibility on commercial licensing terms, and address new challenges such as AI training.

3.4.2 Reconstruction results

Within the reconstruction test, 4 reconstruction methods were evaluated:

- Structure from Motion
- NeRF in the Wild
- Instant NGP
- 3D Gaussian Splatting

To measure satisfaction with each method, identical quality and usability statements were provided for each method, to be rated using a Likert scale (Strongly disagree, Somewhat disagree, Neutral, Somewhat agree, Strongly agree and Don't know).

Quality questions:

- The visual detail of the 3D reconstruction produced by this method is accurate and realistic.
- This method handles complex or intricate geometries, such as detailed surfaces or objects with high variation in depth, effectively.
- The 3D model generated by this method accurately represents the real-world object or scene in terms of geometry.

Usability questions:

- This method offers sufficient control to customise settings (e.g., resolution, quality) for the 3D reconstruction.
- The method result integrates well with other software tools (e.g., for editing, visualisation, or further analysis).
- The processing time required for obtaining the 3D reconstruction is reasonable.



- How much do you agree that this method is suitable in terms of speed and output quality?
- The instructions available for this method are helpful.

Additionally, to identify potential applications for each reconstruction method, testers were asked to share their opinions on how they would use them, identifying potential use cases as well as any potential problems that may have arisen throughout the reconstruction.

Since all the reconstruction methods follow the same workflow, a general 10 question SUS questionnaire was administered after the satisfaction section to gather user feedback on all methods collectively.

The analysis examines responses from 19 participants who evaluated multiple 3D reconstruction services hosted by XReco. The study achieved an 84.2% completion rate. The evaluation reveals strong overall user satisfaction with a System Usability Scale (SUS) score of 67%, indicating an average user experience. Among the four 3D reconstruction methods used, SfM demonstrated the best performance with highest quality 72.25% and usability scores 67%, while 3DGS showed the lowest error rate (rate of experimenting some problem during the operation of the service) 16% (Figure 46). The platform shows particular strength in gaming applications (36.8% of use cases) and Virtual Production (42.1% of the use cases).

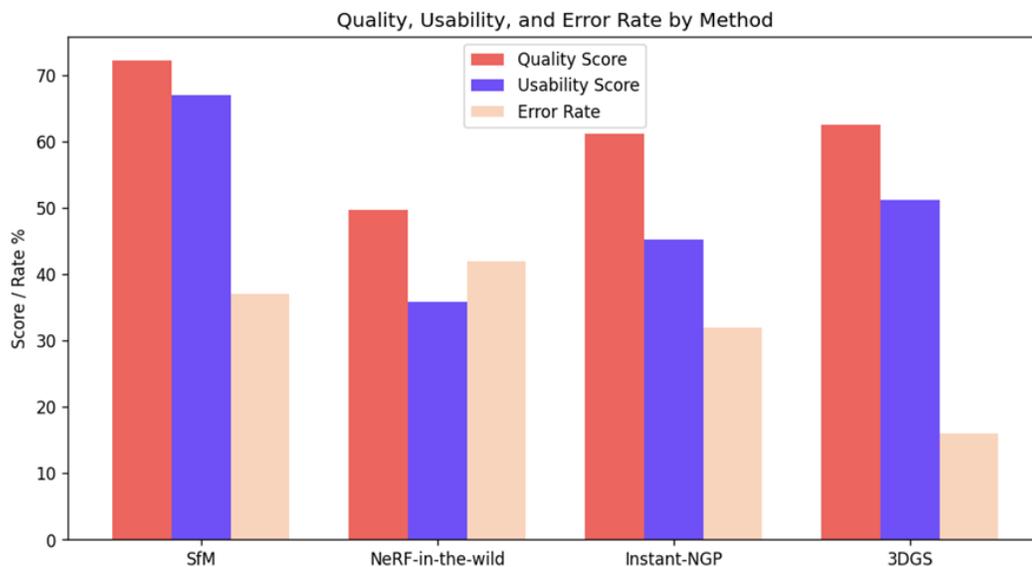


Figure 46: Quality, Usability, and Error Rate

Gender distribution

- Male participants: 79%
- Female participants: 21%
- Other: 0%

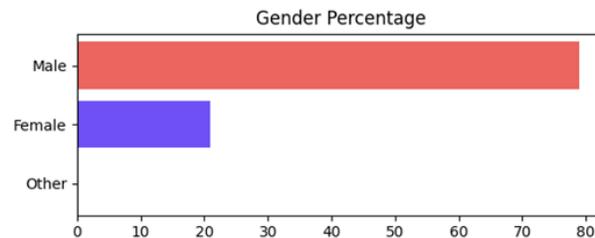


Figure 47: Gender Distribution Reconstruction Tests



Technical background

The participant pool consisted of:

- General users: 57.9%
- 3D reconstruction experts: 31.5%
- 3D modelling experts: 5.3%
- IT professionals: 5.3%

The survey revealed diverse practical applications, with immersive technologies dominating user interest (multiple answers were possible):

- Video games: 36.8%
- AR experiences: 31.5%
- XR applications: 21%
- Architecture: 10.5%
- Virtual Production: 42.1%
- XR journalism: 5.2%
- Online shopping: 10.5%

Technical challenges and pain points

Overall, user testing surfaced a mix of reliability issues and onboarding gaps, alongside clear opportunities that have already informed fixes to preview controls, service status messaging, and parameter guidance. The tone of feedback points to two broad themes: service robustness (jobs failing, empty or corrupted outputs, missing assets) and usability of the 3D viewer and workflows (rotation/tilt, upside-down models, unclear parameters or service names). These themes are common in early-stage 3D and AI-driven pipelines and align with best practices for structuring findings into actionable improvements rather than treating them as isolated incidents.

Regarding reconstruction service stability, several users reported jobs stuck on “initialising”, successful completion messages followed by empty or corrupted downloads, and assets not appearing in the repository. These symptoms are consistent with asynchronous job orchestration issues where front-end success states are not gated on storage commits, and where error propagation from workers to UI is incomplete. In response, success notifications have been tied to verified persistence, worker errors are now surfaced with clear retry guidance, and repository indexing is rechecked before exposing state. This type of gating, i.e., ensuring completion reflects actual availability, maps to standard remediation during UX audits of complex pipelines.

On previews and interaction, users had difficulties with tilts and reported upside-down models (which is a very usual issue in 3D visualization due to different camera frame conventions). To accommodate for robust viewer settings would be to normalize model orientation on load when possible (i.e., on explicit defined objects – textured meshes) or expose a “reset view” control option.

Services specifically, live interactive previews were not feasible as rendering is very computationally intensive and requires performing volumetric rendering; however, the pipelines provided rendered videos as a practical preview artifact. Given the feedback, effort should be allocated to integrate NeRF volumetric rendering with web-based 3D viewers, despite the compute-heavy procedure. Downscaling could help mitigate processing times at the cost of rendering quality.



A/B2 comparison

SUS test comparison improvement:

The distribution of SUS scores (Figure 48) reveals a substantial overall improvement from Global Reconstruction A to Global Reconstruction B2. The mean SUS score increased by approximately 58.4%, indicating a clear enhancement in perceived usability. Concurrently, the standard deviation decreased by about 15.5%, suggesting that participants’ responses became more consistent, with less variability in their evaluations. Additionally, the range contracted by roughly 48.3%, which implies that extreme negative perceptions of usability were notably reduced in the B2 condition.

The boxplot (Figure 48, top) visually highlights the upward shift in median and the reduced spread of scores for Global Reconstruction B2, while the KDE plot further confirms this trend, showing a more compact and right-shifted distribution compared to version A. Overall, the B2 reconstruction achieved higher and more stable usability ratings than the earlier version.

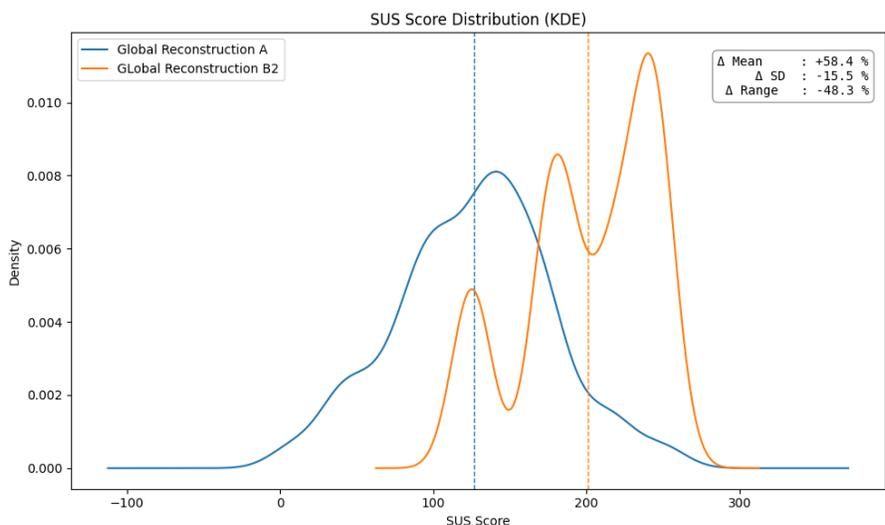
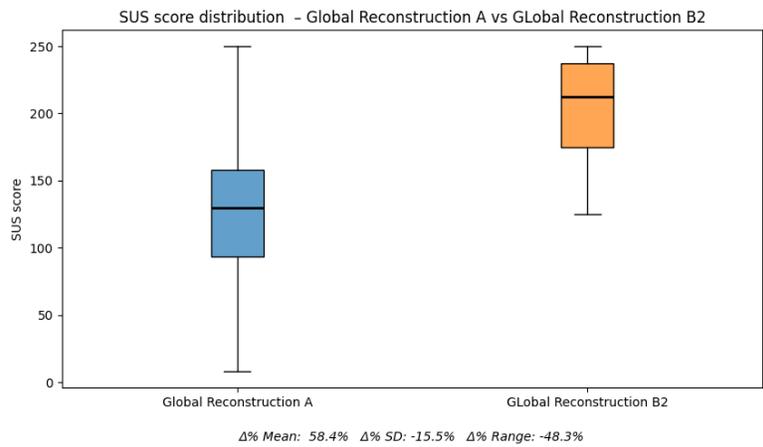


Figure 48: XReco platform test – SUS score distribution in A and B2 (boxplot, top; KDE, bottom)

SUS test comparison per category:

The category-level comparison of SUS scores (Figure 49) demonstrates consistent improvements from Global Reconstruction A to Global Reconstruction B2 across nearly all usability dimensions. The per-item percentage changes indicate that the most substantial gains occurred in Learning Curve (+~78%), Ease of Use (+~68%), and Confidence (+~63%), showing that users found the system significantly easier to learn, more intuitive to navigate, and felt more confident in its operation.

Considerable improvements were also observed in Cumbersomeness, Complexity, and Support Need, each reducing by around 55-60%, suggesting that while the platform became more powerful, users perceived interactions as smoother and less cumbersome. Meanwhile, Acceptance, Learning Requirement, Inconsistency, and Integration showed smaller but still positive changes (ranging from ~40% to ~50%), indicating broader, consistent usability enhancements across all aspects of user interaction.

The bar chart comparison reinforces these findings, showing a clear upward shift in average SUS scores for every category under B2. Overall, these results confirm that Global Reconstruction B2 delivered broad usability improvements across all assessed categories, with particularly strong gains in learning, ease of use, and confidence.

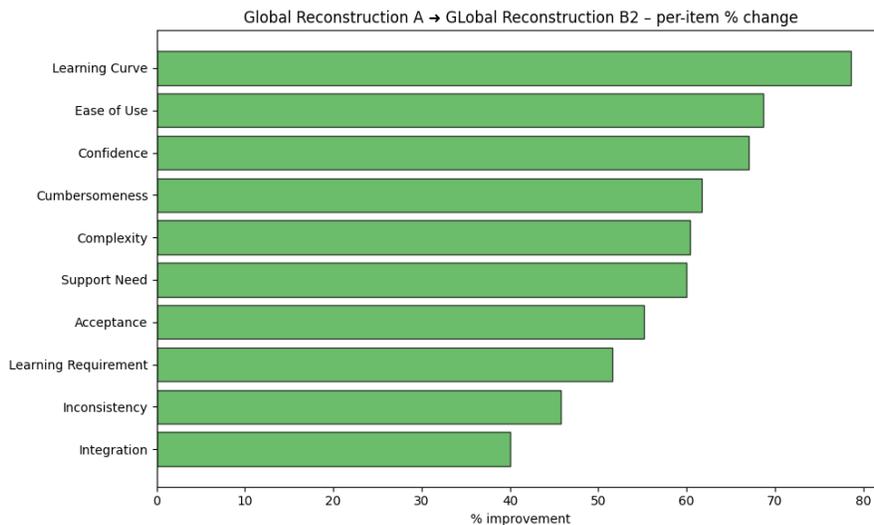


Figure 49: Changes in Results for 3D Reconstruction



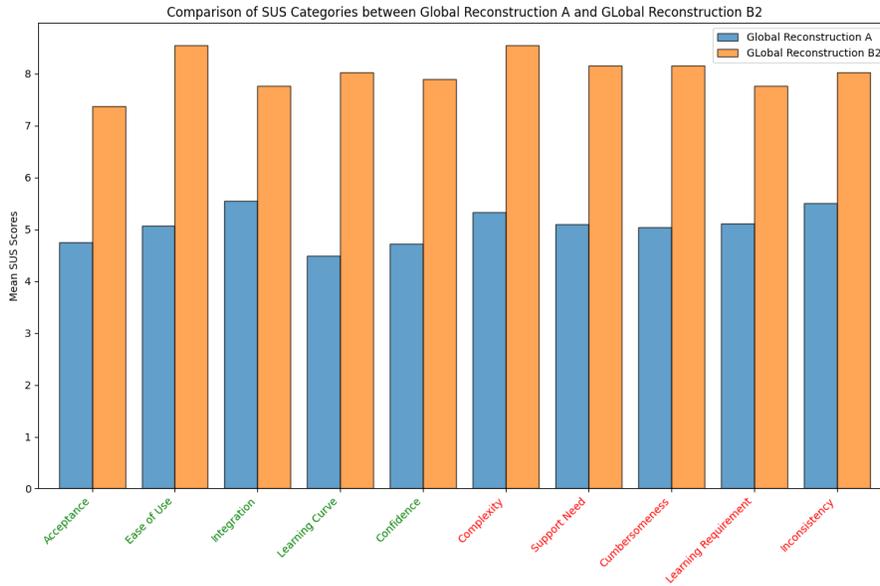


Figure 50: XReco platform test – Comparison of SUS categories in A and B2 (percentage change, top; bar chart; bottom)

3.4.3 Authoring tool results – Unity Authoring Tool

The Authoring Tool provides a series of additions to the Unity Editor that enables easier and faster creation of XReco use cases. It provides useful prefabs that encompass often needed functionality, usable scenes, interactive tutorials as well as documentation. It also makes other XReco services easier to reach via direct integration in the menu.

Result of user tests:

A user test was conducted to evaluate the usability, functionality, and user experience of the XReco Authoring Tool, the new simplified version of the Unity Authoring Tool. Participants appreciated the intuitive workflow, clear tutorial structure, and the tool’s potential for simplifying 3D content creation. However, they also highlighted areas for improvement, such as scene navigation, annotation complexity, and the need for better integration with the XReco ecosystem.

Overall, the test was well received. Users appreciated the clarity of the interface and saw a lot of potential in the tool. Many of the suggestions from the test have already been addressed through new features and improvements (see 3.3.3 Improvements beyond B2), making the experience smoother, more intuitive, and more flexible for different use cases.



A/B2 Comparison:

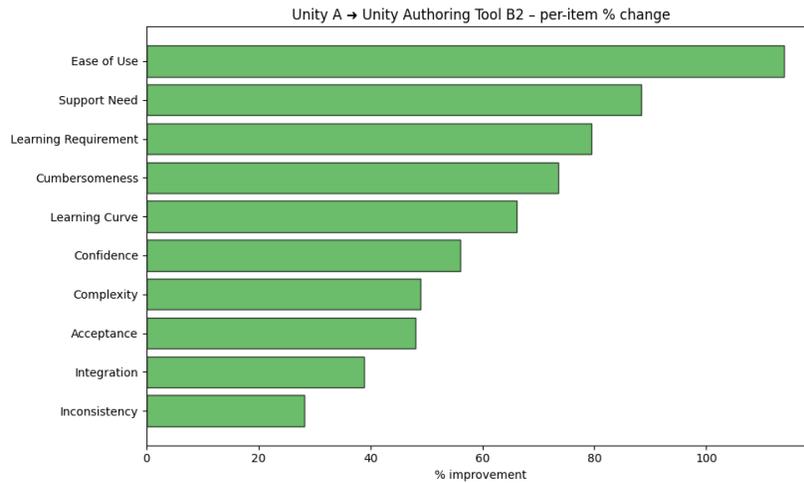


Figure 51: Changes in Results for Unity Authoring Tool (AT)

The above chart indicates the percentage improvement across various usability and functionality metrics when transitioning from Unity A to Unity Authoring Tool B2. The improvements are as follows:

Table 17: Improvements on XReco Authoring Tool (AT) calculated

| METRIC | % IMPROVEMENT |
|----------------------|---------------|
| Ease of Use | ~110% |
| Support Need | ~90% |
| Learning Requirement | ~80% |
| Cumbersomeness | ~70% |
| Learning Curve | ~60% |
| Confidence | ~50% |
| Complexity | ~40% |
| Acceptance | ~30% |
| Integration | ~20% |
| Inconsistency | ~10% |

Key Insights

- **Major Improvements:** *Ease of Use*, *Support Need*, and *Learning Requirement* show the highest gains, indicating that Tool B2 significantly enhances user experience and reduces onboarding effort.
- **Moderate Gains:** Metrics like *Confidence*, *Complexity*, and *Acceptance* show decent improvements, suggesting better usability and user satisfaction.
- **Minor Improvements:** *Integration* and *Inconsistency* show relatively low gains, possibly indicating areas where further refinement is needed.



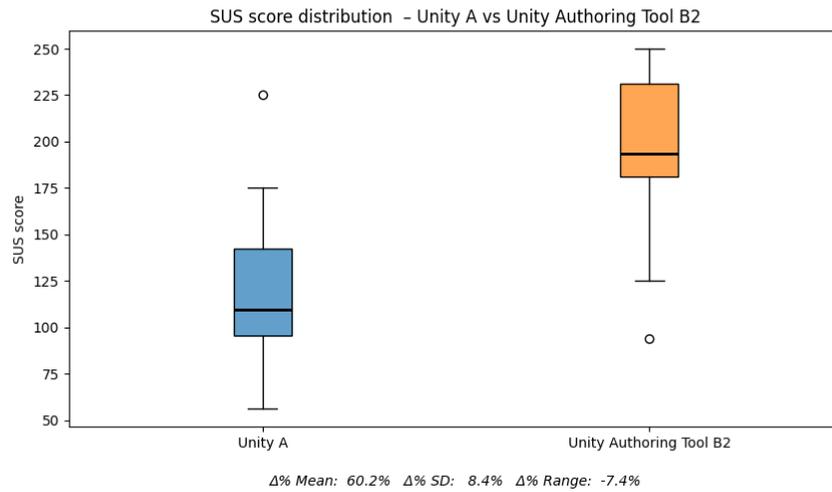
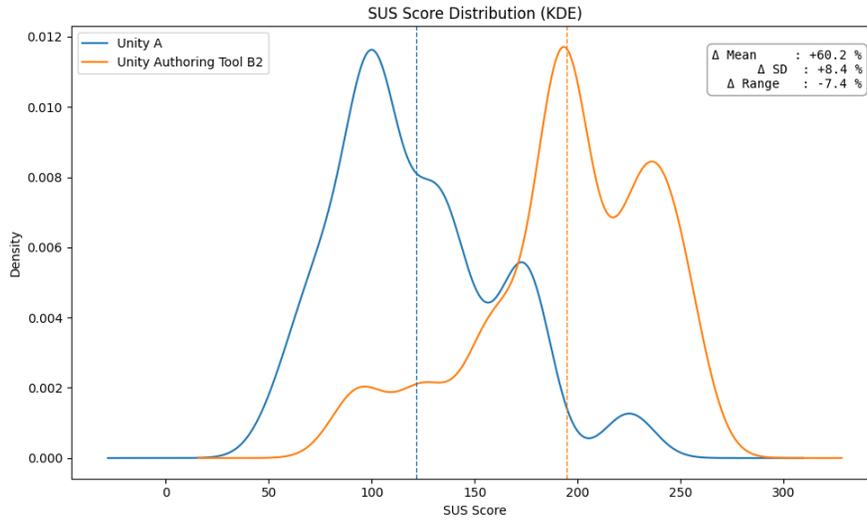


Figure 52: SUS Score Distribution AT

Unity Authoring Tool B2 shows a much higher usability score compared to Unity A, with a wider distribution around 200, indicating better and more consistent user experience.

Table 18: SUS Score Comparison Calculated

| METRIC | UNITY A | UNITY AUTHORING TOOL B2 | DIFFERENCE |
|--------------------|--------------|-------------------------|------------|
| Mean SUS | ~100 | ~200 | +60.2% |
| Standard Deviation | Concentrated | Varied | +8.4% |



| | | | |
|-------|------|--------|-------|
| Range | Wide | Narrow | -7.4% |
|-------|------|--------|-------|

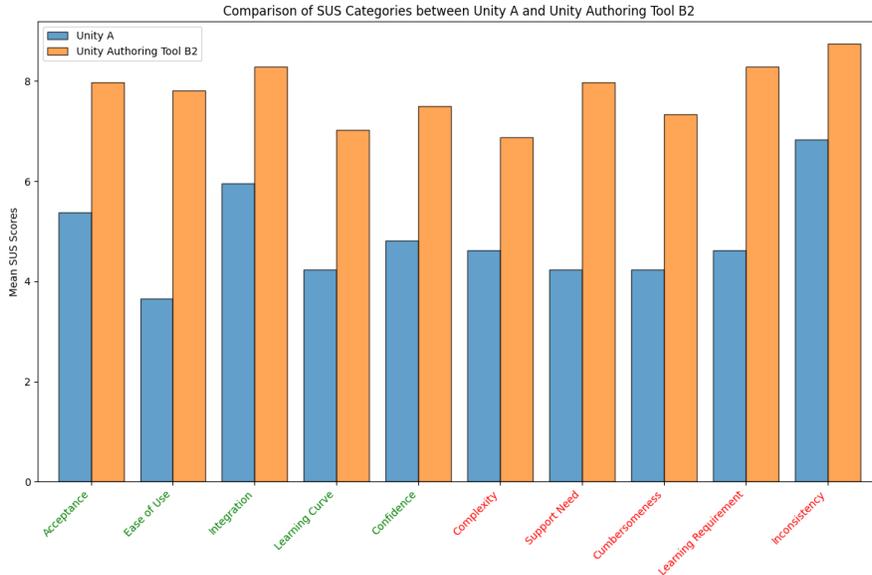


Figure 53: SUS Categories Comparison (AT)

Overall Findings

- **Unity Authoring Tool B2** outperforms **Unity A** in most usability categories.
- Both tools have similar performance in some areas, with slight variations.

Category-wise Insights

Higher for Unity Authoring Tool B2:

- **Acceptance:** Users are more willing to adopt B2.
- **Ease of Use:** B2 is perceived as easier to use.
- **Integration:** B2 integrates better with workflows.
- **Inconsistency:** B2 shows significantly fewer inconsistencies.
- **Learning Curve & Confidence:** Slight advantage for B2.

Slight Advantage for Unity A:

- **Complexity:** Unity A is perceived as slightly less complex.
- **Support Need:** Users feel they need less support with Unity A.
- **Cumbersomeness & Learning Requirement:** Marginally better for Unity A.

Key Takeaways

- **Strength of B2:** Better usability, acceptance, and integration make it more user-friendly overall.



- **Strength of Unity A:** Slightly simpler and requires less support, which may appeal to experienced users.

3.4.4 Authoring tool results – XRCapsules

The XRCapsules is a new tool aimed towards non-technical users. That is, users with no prior experience in 3D composition, 3D modelling, XR experience creation, etc. Its ambition was to provide an easy-to-use authoring tool.

To compare A and B2, we first needed to clarify their definitions. A was defined as the advanced Unity program that, in the absence of XRCapsules, users would rely on to create the XR experiences provided by XRCapsules. Naturally, Unity is a more sophisticated tool than XRCapsules, designed primarily for expert users. Based on this, we hypothesized that experienced users might not find XRCapsules particularly useful as a standalone tool, since our primary audience consists of non-experts. However, they could find it valuable when collaborating with less experienced team members—such as journalists seeking to create an augmented reality experience or a prototype to be later refined by an expert.

A/B2 test comparison:

Figure 56 indicates a clear improvement in average user satisfaction, with SUS scores increasing by nearly 20% on average. While the overall range of scores has widened, the lower end of the range in B2 is still higher than the lower end in version A.

Ease of use stands out as the category with the most significant improvement, showing an increase of over 60%. Across all categories that recorded improvements, the percentage increase exceeded the 20% KPI target.

However, three categories saw a decrease in satisfaction in B2: integration, acceptance, and inconsistency. The drop in integration can be attributed to XRCapsules being part of a larger ecosystem. The decrease in acceptance likely reflects that some users were already experienced Unity users or had prior knowledge in XR creation; advanced users may prefer their familiar, advanced tools over integrating a simpler, new option into their workflow. Finally, the decline in inconsistency is likely due to bugs encountered during testing, as B2 was still a work in progress, and several issues were resolved following user feedback. Also, some experienced users reported they missed having common industry keys available, which were later introduced.



SUS category comparison:

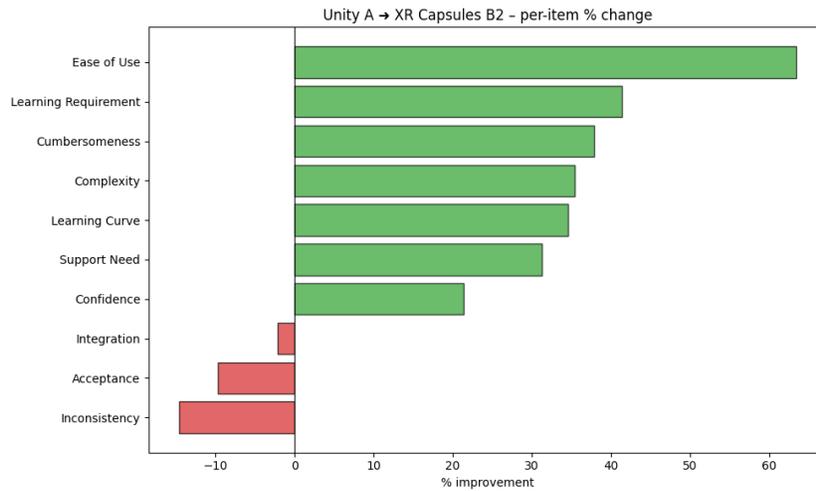


Figure 55: Per-item change XRC

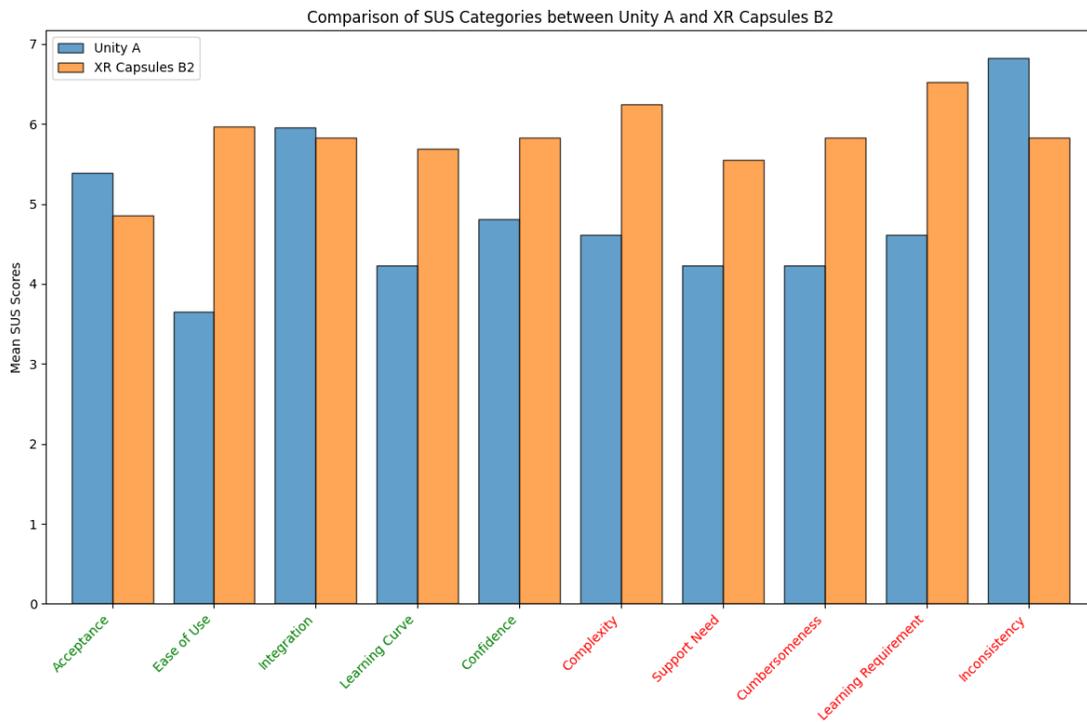


Figure 56: SUS Categories Compared (XRC)



3.4.5 Authoring tool results – ZAUBAR CMS

In a comparative usability test, the ZAUBAR CMS Creator B2 demonstrated significantly higher user satisfaction and efficiency than the Unity-based authoring workflow (Tool A). The average System Usability Scale (SUS) score for Tool B2 was 24.3% higher than for Unity A, indicating a substantial improvement in perceived usability. This uplift was accompanied by a notable decrease in score variability – the standard deviation of SUS scores fell by 18.7%, and the range of scores narrowed by 33.3%, implying a more consistent user experience across participants (see Figure 57 and Figure 58 for score distributions.) Users across diverse technical backgrounds completed tasks more easily with Tool B2, often praising its intuitive workflow and clear guidance. While a few interface issues and learning curve concerns emerged, these were relatively minor and are being addressed. Overall, the findings confirm that Tool B2 delivers a markedly improved authoring experience over the Unity baseline, especially benefitting less-technical users, without alienating expert users. This report details the methodology, quantitative results, qualitative insights, and a brief analysis of gender-based differences, followed by recommendations for further refinement.

A/B2 comparison:

The results of this user testing analysis make a compelling case for the ZAUBAR CMS Creator B2 as a superior authoring tool compared to the original Unity-based workflow. Empirically, B2 delivered a markedly higher SUS score (+24%) and smoother user experience, validating that the targeted usability improvements translated into real-world benefits. Qualitatively, users described B2 in glowing terms – “intuitive,” “easy,” “clear,” and “helpful” were recurring descriptors – and even those with minimal 3D experience were able to complete the test with confidence. This is a strong endorsement that B2 can democratize XR content creation, enabling a broader range of storytellers and developers to engage with the XReco platform.

That said, the analysis also pinpointed a few refinement opportunities. Some UI elements (like the anchor markers and annotation widgets) can be visually simplified to reduce distraction. The integration with Unity could be made more seamless, as a minority of users were unsure where the Unity interface ended and the custom tool began. Additionally, incorporating user-suggested features such as more scene templates and an asset marketplace interface would enhance B2’s value proposition for power users and at-scale production use. These improvements are relatively straightforward and are either already in development or can be scheduled in the product roadmap. Addressing them will further increase user satisfaction and eliminate the small pain points identified.

Quantitative Findings

Overall Usability Scores: Tool B2 achieved a substantially higher overall SUS score than Unity Tool A. On average, SUS increased from the equivalent of ~65 (Unity) to ~81 (B2) out of 100, a +24.3% improvement in perceived usability. This is a large gain in SUS terms, indicating that users found B2 much more user-friendly. The improvement is visually evident in the comparative box plot of SUS scores, where B2’s median is higher and the interquartile range tighter than Unity’s (Figure 57).



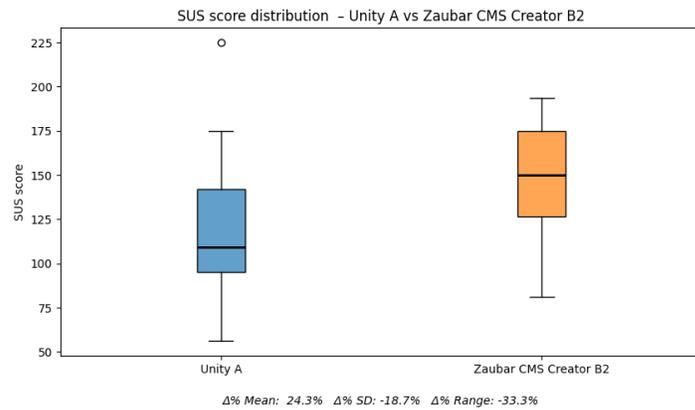


Figure 57: SUS Score Distribution ZAUBAR CMS (A vs B2), box plot

The variance in scores was lower for B2 – standard deviation dropped roughly 18.7% – meaning user ratings for B2 were not only higher but also more consistent. The range of SUS scores across participants likewise contracted by about one-third with B2 (from a widespread under Unity to a narrower, more concentrated range under B2), as illustrated by the score distribution plot (Figure 58).

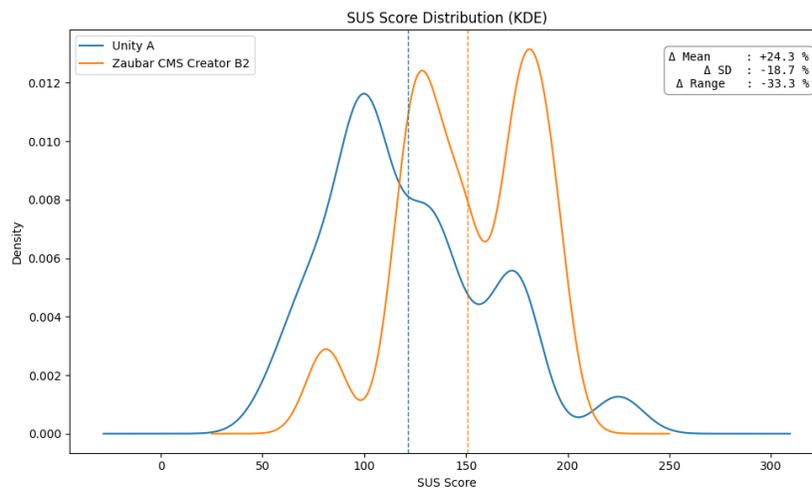


Figure 58: SUS Score Distribution ZAUBAR CMS (KDE)



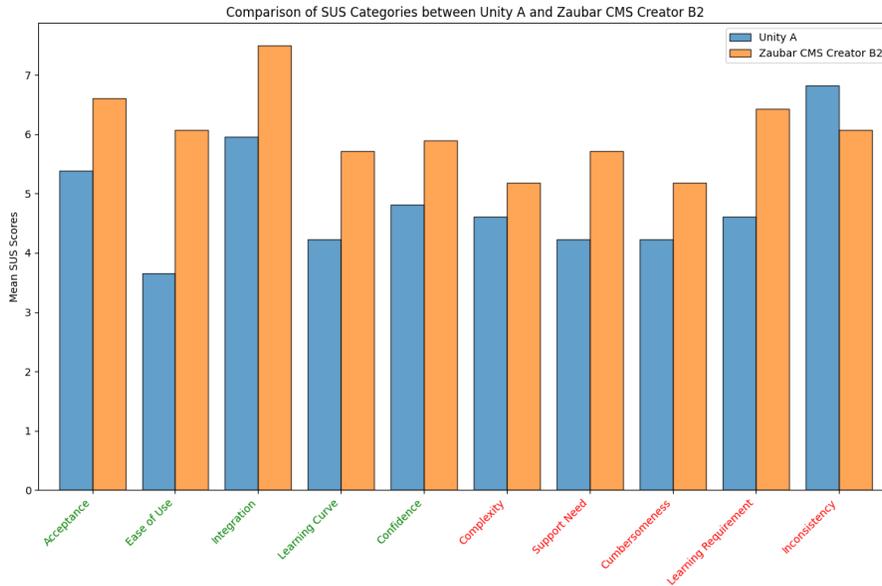


Figure 59: SUS Categories Comparison for ZAUBAR CMS (A vs B2)

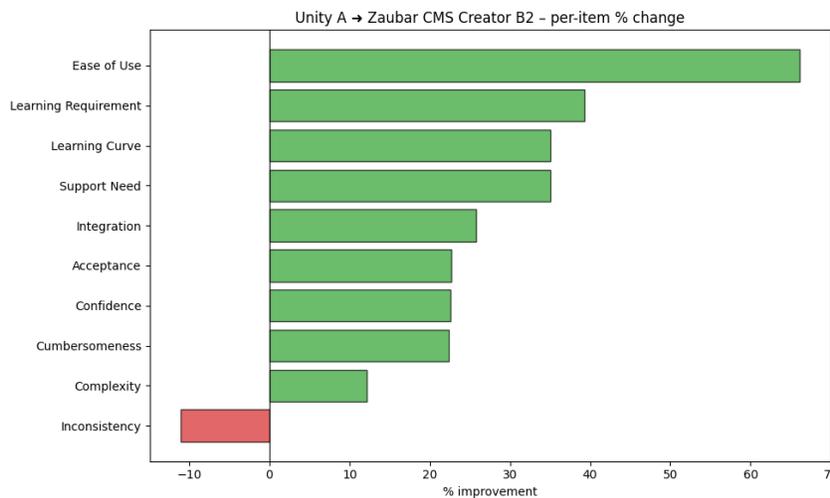


Figure 60: Per-item change ZAUBAR CMS (A vs B2)

Per-Item Improvements (see Figure 59 and Figure 60): A detailed look at individual SUS items reveals that Tool B2 outperformed Unity A on 8 out of 10 standard questions, often by a wide margin. Participants rated B2 as far easier to use, for instance: “I thought the tool was easy to use” (SUS Q3), B2 scored 6.07 vs 3.65 for Unity on a 7-point agreement scale – a 66% relative increase.

Users also felt they could learn B2 faster: “Most people would learn to use this tool very quickly” (Q7) saw a 35% higher agreement for B2. Likewise, integration of functions (Q5) was rated better (+25%), and users reported greater confidence in using B2 (+22% on “I felt very confident using the tool”; Q9). These data indicate that B2 addressed many of the usability pain points of the Unity workflow, making the experience more straightforward and assuring for users.



Notably, B2 also reduced some negative aspects present in the Unity tool. For example, participants found the Unity workflow relatively inconsistent but agreed 11% less with “There was too much inconsistency in the tool” when using B2. (Lower agreement with that negative statement implies B2 was perceived as more consistent than Unity.) In a few areas B2’s improvements were more modest – e.g. the perceived complexity of the system only improved by about 12% – suggesting there is still some complexity to streamline. However, no SUS item showed a significant degradation with B2. Even the items that are negatively worded (complexity, cumbersome, need for support, etc.) trended in the right direction or stayed roughly neutral. In summary, every quantitative indicator of usability favoured the ZAUBAR Creator B2 tool, with especially large gains in ease-of-use, learnability, and user confidence.

Task Completion and Efficiency: All participants were able to complete the required creation tasks with both tools, but they did so with fewer hurdles using B2. Self-reported completion times ranged roughly from 20 minutes to 50+ minutes, depending on the individual’s approach and whether they explored extra features. There wasn’t a clear one-to-one timing comparison between Unity and B2 (since users did different tasks sequentially), but comments suggest that B2’s guided workflow helped expedite tasks for less experienced users. For instance, one user noted they spent considerable time “playing around” in Unity, whereas with B2 they followed the steps more directly. The smoother learning curve with B2 likely contributed to more efficient task execution, although experienced users could move quickly in either tool. We did observe that error rates were low in both cases – only a few minor errors were reported (and those mostly under Unity, such as missing a step or a Unity-specific configuration issue). Overall, the quantitative evidence paints a clear picture: Tool B2 dramatically improves usability metrics relative to the Unity authoring baseline, making XR content creation more accessible and consistent.

Qualitative Insights

The qualitative feedback from participants reinforces the positive trends seen in the numbers, while also highlighting specific strengths to build on and a few areas for improvement. Below we summarize key insights from user comments, with **direct quotes to illustrate common sentiments**.

Positive Feedback – Intuitive Workflow & Clear Guidance: Users overwhelmingly appreciated the intuitive design and ease of use of the B2 authoring tool. Many described the B2 workflow as “very intuitive and easy,” reporting that they “did not have any issues” completing the tasks. The integrated tutorial was frequently praised for its clarity. A female participant noted, “The tutorial was very well written, and the steps [were] easy to follow.” Another user echoed that sentiment, saying “The tutorials were really helpful. The tool requires a bit of a learning curve but that’s okay!”. This indicates that even when users recognized there is some learning involved, the guidance provided was effective in smoothing that process. Participants also liked certain smart features of the workflow; for example, one technical user highlighted “I liked that the annotations are automatically placed close to the model” as a convenience that simplified content placement. Overall, the user sentiment was very positive – several testers explicitly commented that they “liked everything” and “didn’t dislike anything” in B2, a strong endorsement of the design.

Reduced Frustration and Support Needs: Importantly, novice users felt empowered by B2. Unlike in the Unity-based test, none of the B2 users expressed that they needed outside help to complete the task. On the contrary, a number of participants remarked on feeling self-sufficient. For example, after using B2 one general-user tester wrote, “Everything ran smoothly. I imagine it could be used as a tool to help users get familiar with 3D tools in



general.” Such feedback suggests that B2 successfully lowers the entry barrier for non-experts. Participants who had little to no Unity experience were still able to follow along with the B2 process with only minor confusion. In cases where users encountered uncertainty, the built-in cues and tutorial steps were usually sufficient to get them “unstuck” without needing to consult external support. This aligns with the SUS results where agreement with “I would need the support of a technical person” was lower for B2. In summary, qualitatively users felt more confident and less frustrated using B2, even if they were beginners in XR authoring.

Pain Points and Interface Issues: Despite the generally positive reception, the test surfaced a few usability issues and design critiques for B2. A common theme was UI clutter or distraction in the 3D scene interface. Multiple participants mentioned that the visual markers in the scene could be overwhelming. One power-user described, “The XR cubes serving as object anchors were very distracting”, and felt that the 3D annotation object had too many visual elements (text, video, image icons) making it look complex. He suggested a simplified representation – e.g. “the anchor alone would be sufficient” without the extra ornamentation. This indicates a need to streamline the annotation indicators to reduce cognitive load. Another issue raised was distinguishing Unity’s interface from the B2 tool’s functionality. As one participant put it, “I was unsure which parts were pure ‘Unity’ and which were ‘XReco’.” This confusion implies that some users couldn’t intuitively tell what the custom tool added on top of the Unity editor, which could be addressed by clearer branding or integration (or by decoupling from the Unity interface where possible). Additionally, a few technical hiccups and control challenges were reported. For instance, one non-technical user struggled with the 3D navigation controls in Unity, noting that she “did not understand how to use the WASD keys to move in the scene view...it did not work on my computer”, forcing her to rely on mouse navigation. While this was an issue with the Unity viewport control scheme rather than B2 itself, it affected her overall experience. Another user encountered a Unity versioning issue during setup (“the Unity installation process and attaching the project to a very specific Unity version [was problematic]”), underscoring the underlying complexity of the Unity environment that B2 sits upon.

Finally, there were minor tutorial/content alignment issues: one tester pointed out that some instructional screenshots didn’t perfectly match the state of their scene, causing momentary confusion. These pain points are relatively isolated, but addressing them will further polish the user experience. In particular, reducing on-screen clutter, clarifying the tool’s identity within Unity, and refining tutorial assets will help ensure new users aren’t thrown off by small snags.

Feature Requests and Suggestions: Participants provided a wealth of ideas for enhancing B2’s functionality, many of which align with making the tool more powerful and flexible for real-world use cases. **Common feature requests included:**

Additional Scene Templates: Users were excited about templates and asked for more variety. Suggestions ranged from a “live stream video with green screen” prefab, to a “news TV studio” environment, to generic scene templates like offices, classrooms, or mechanical work sites with ready objects (so that users don’t have to start from scratch). Expanding the library of templates would help both novices (by providing jump-start examples) and advanced users (by speeding up prototyping for specific scenarios).

Multiple Object Placement: Testers expressed desire to place and manipulate multiple 3D models in the scene concurrently. In the current workflow, the focus was on annotating a single model; one participant noted he’d like the tool to help in “placing several 3D models into the scene and not just one”, for example to compare objects or build a more complex scene. Enabling multi-object scenes and interactions was seen as a logical next step for the tool’s evolution.



Integrated Asset Marketplace: Several participants, especially those with content creation experience, wanted direct integration with asset libraries/marketplaces. They envisioned being able to search, import, or purchase 3D assets from within the authoring tool. One user explicitly suggested “directly integrating the marketplace, to search, purchase and place assets [directly]”. Another mentioned connecting to their XReco “baskets” of assets for one-click importing. Such integration would streamline the workflow by removing the need to manually import external assets.

Simplified Tutorial Delivery: A few participants commented on the format of the tutorial itself and offered ideas to improve it. It was proposed to “mix text and videos directly on a web page, not as part of a form”, so that instructional videos or GIFs could play in-line with the steps instead of separately. There was also a suggestion to allow the tutorial and the questionnaire to be separate, or at least not interwoven, to reduce cognitive switching. Shorter video clips targeting each micro-step were recommended to avoid any information overload. These suggestions point toward a more integrated, user-friendly onboarding experience within the tool. Beyond these, participants also gave niche suggestions (e.g. implementing undo/redo, improving gizmo explanations, offering an option to change background scene colour, etc.), which are documented in the full response log. None of the requested features contradict the core design; rather, they represent natural enhancements that could increase B2’s utility for advanced use cases. Implementing some of the most requested features – especially more templates and asset library integration – would likely further increase user satisfaction and adoption.

Mixed Reality Multimedia Retrieval iOS Application

As an additional test, the Mixed Reality Multimedia Retrieval iOS Application, developed by UNIBAS, has been further extended and integrated into the XReco technological framework and the ZAUBAR app.

Building on the earlier (MR)² prototype, the current implementation supports real-time, context-aware media retrieval within physical environments. The application helps users to capture their surroundings, execute multimodal queries, and retrieve semantically relevant digital assets to create the basis for direct reuse in immersive authoring workflows.

These outcomes demonstrate the app’s role in facilitating connections between on-site exploration, digital asset management, and XR content creation within the XReco ecosystem. Therefore, the smartphone is connected to the NMR backend. Due to licensing reasons for the different assets, the direct export of assets into the ZAUBAR Editor is deactivated.

To illustrate the operational workflow and functionality of the system, a representative use case focusing on the digital reconstruction of the Metropolitan Cathedral in Timisoara was developed. This scenario demonstrates how the app supports multimodal retrieval and integration with XReco services within a reconstructed cultural heritage environment. The available results can all be viewed in AR to see how they might look in a later usage with the ZAUBAR app.

User Story: Mixed Reality Retrieval at the Metropolitan Cathedral, Timisoara

During a simulated field scenario in Timisoara, a content creator can use the Mixed Reality Multimedia Retrieval Smartphone Application to identify and retrieve media related to the Metropolitan Cathedral. The app uses object detection to recognize the cathedrals and generate a bounding box overlay within the live camera view.



The user starts a visual similarity query, which is sent to the NMR-backend, and returns a selection of historical photographs, 3D models, and visual records associated with the query object. These results are presented in the Mixed Reality interface as a scrollable gallery and can also be visualized as spatially aligned overlays within the live view.

A following text-based query for the term "Cathedral" produces a second set of results, including additional 3D models and metadata retrieved from XReco's federated repositories, showcasing both the Timisoara Cathedral and comparable structures. In future versions, selected assets may be exported to external authoring environments, provided the user holds the appropriate usage rights. Once exported these assets can serve as linkable resources for XR experiences created by the ZAUBAR UI.

This scenario demonstrates how the MR application integrates contextual scene understanding, multimodal media retrieval, and immersive authoring within a unified workflow.

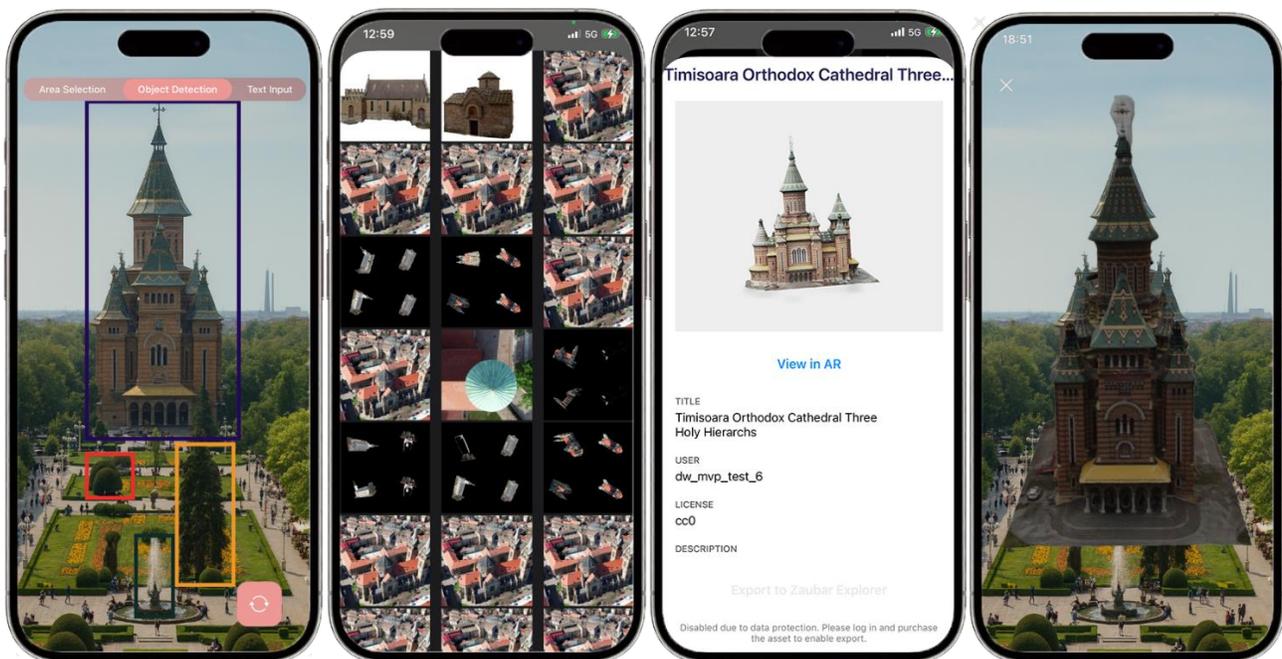


Figure 61: Screen captures depicting the user experience described above

Small User Evaluation

The Mixed Reality Multimedia Retrieval iOS Application was evaluated internally by UNIBAS and ZAUBAR as part of the XReco system integration activities. The evaluation focused on usability, responsiveness, and integration with backend search.

- The functionality of the Mixed Reality Multimedia Retrieval iOS Application behaved as expected during internal testing. Object detection performed as expected for smaller items. For buildings, the area of interest was labelled manually without issues, as it was not detected automatically.
- Visual similarity queries returned relevant results from the NMR-backend, and text-based searches provided semantically related assets using their metadata. The visualisation of results in Augmented Reality was

stable and intuitive, offering a clear demonstration of how assets could later be used within the ZAUBAR Authoring Tool.

- Minor issues were observed regarding asset scaling and slight delays in loading high-resolution assets, but overall system stability and usability were rated positively.

3.4.6 The external testers test

As had been outlined in the introduction, finding people who were interested, even eager to test the MVP of the XReco platform was relatively easy; collecting their feedback, however proved very cumbersome. Of the 65 registered MVP users – all people who had followed invitations and actively requested account credentials! – only 9 took the time to participate in our third Joint Business Clinic and another 9 took the time to fill in our user survey that had been shortened already to lower the hurdles.

Given the low turnout, the most insightful information coming from these testers is not in the metrics, but in their qualitative questions responses. Figure 63 shows that the background of these respondents is diverse. In general, they attested the platform as easy to use, with a professional and intuitive interface, and offers a strong search engine and a good range of XR tools. However, some said that the missed 3D model descriptions in more depth, including technical details like polygon count and characteristics. Users showed interest in collaboration, and would like further project organization and collaboration features, such as shared project pages and team workspaces, which is something that we had not contemplated in this stage of development of the platform. While integration with workflows is generally positive, the tutorial is necessary to get started, and users suggest clearer guidance for beginners, more advanced options for experts, and a clearer unique selling point compared to competitors.

Most respondents also acknowledged that the platform suits their workflow needs for different stages. Many of them referred to prototyping, testing prior to production, and for collaborative creative work.

Lastly, when asked about the benefits of the use of the platform, testers valued the potential to access unique 3D models not found elsewhere, valuable 3D and volumetric video tools that support quick, low-cost prototyping, time saving, improving prototype quality, and the reconstruction services which could expand their asset base.

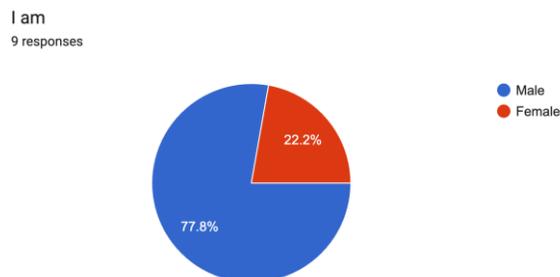


Figure 62: Gender Distribution MVP Tests



What's your background?

9 responses

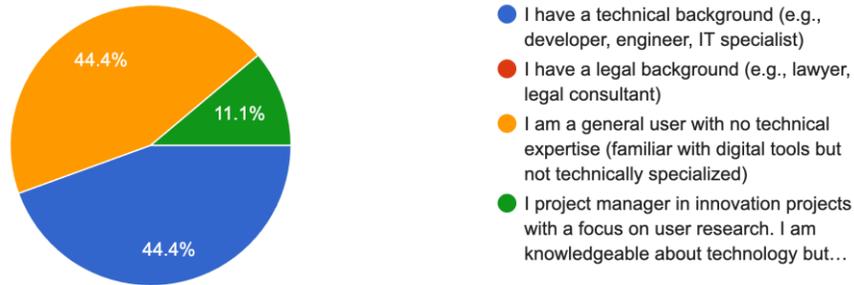


Figure 63: Background of MVP Testers

3.4.7 Global evaluation

A/B1 comparison

As a reminder, A/B1 compares the state of satisfaction of the tools available in September 2022 (state of art) with the tools developed by XReco in June 2024, which coincides with the release of the first MVP of the product.

From A to B1, there was improvement across all SUS categories. Based on the data, by B1 (June 2024), the 3.2 KPI “Improve XR production workflows by at least 20% in terms of user acceptance, as measured on a Likert scale via the delivered platform”—had already been achieved in the following areas: learning curve, cumbersomeness, complexity, support required, learning requirements, and almost the ease-of-use category.

No significant differences in gender are shown.



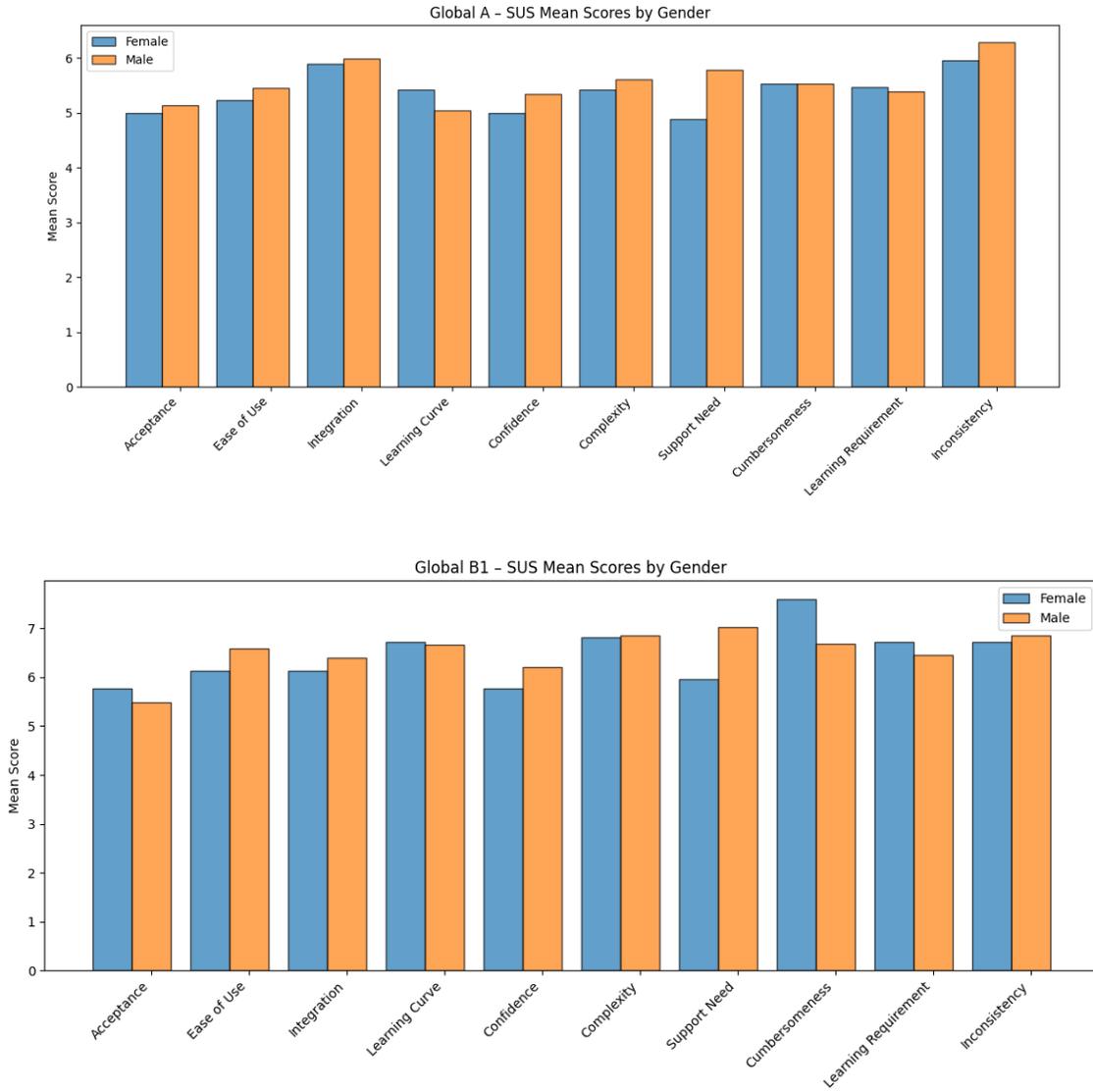


Figure 64: SUS Scores by Gender (Overall)



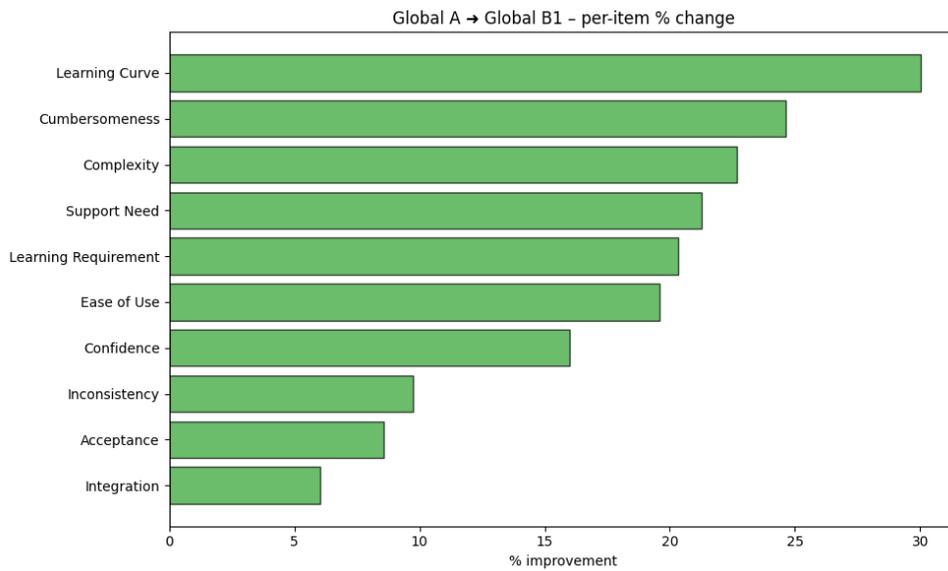
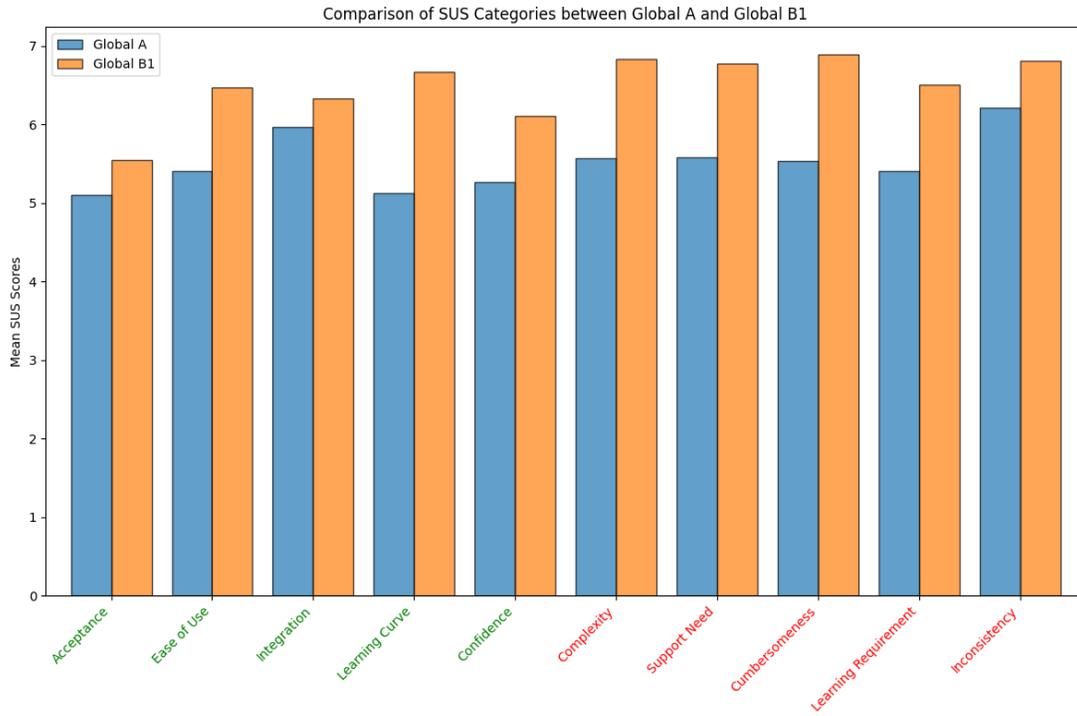


Figure 65: SUS Score Comparison (Overall A/B1)



A/B2 comparison

A/B2 compares the technology available at the beginning of the project with the technology developed by XReco by June 2025, roughly the end of the project.

In comparing A with B2, we see an improvement across every category except for integration. The acceptance category improved in over 35%, surpassing the KPI goal by almost twice what was required.

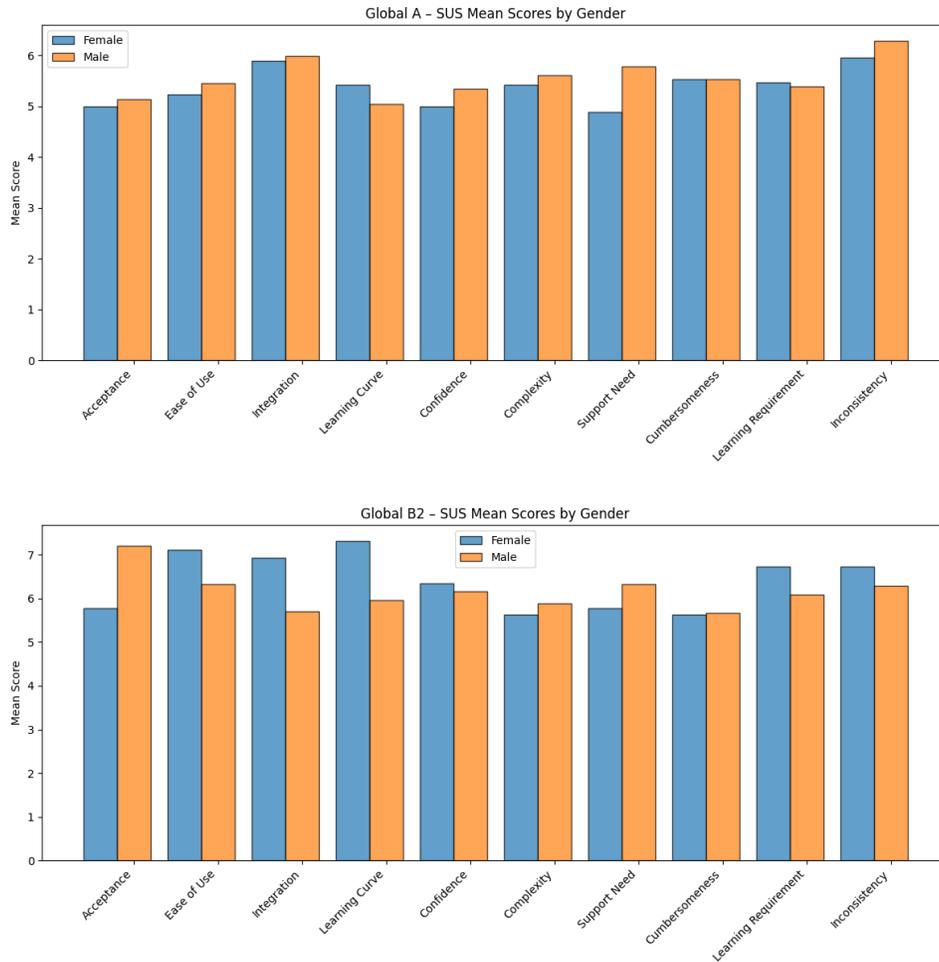


Figure 66: SUS Scores by Gender (Overall A-B2)



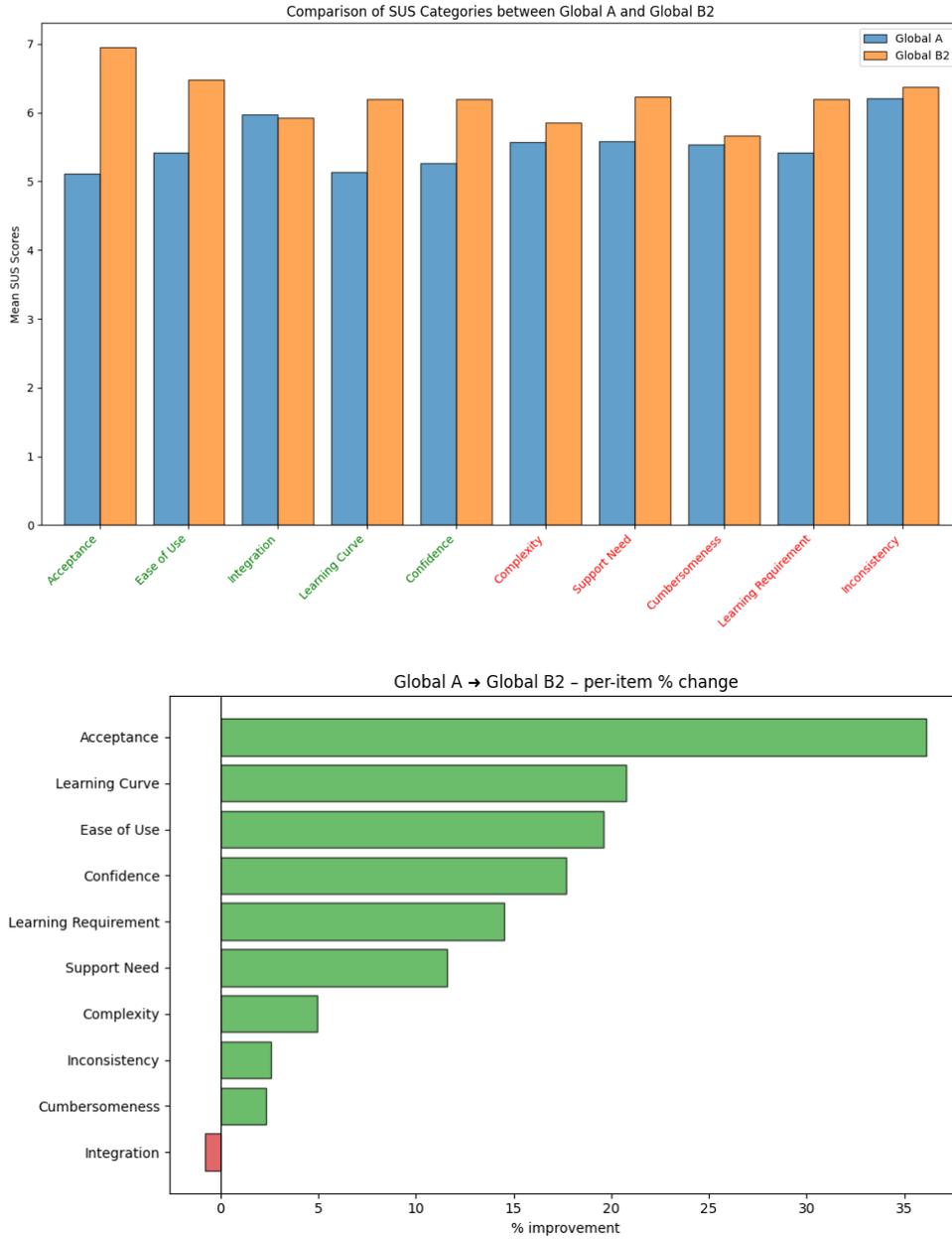


Figure 67: SUS Score Comparison (Overall A/B1)



B1/B2 comparison

B1/B2 compares the technology developed by XReco between June 2024 and June 2025 — from the initial MVP to a more mature and stable version a year later. Most categories show clear improvement, with the exception of integration and learning curve.

The lower improvement percentage is largely due to the fact that much of XReco’s added value lies in the tools it provides. In this comparison, we’re measuring progress in the development of those tools. With that in mind, it’s worth noting that even after the first MVP, we achieved meaningful advancements across nearly every category.

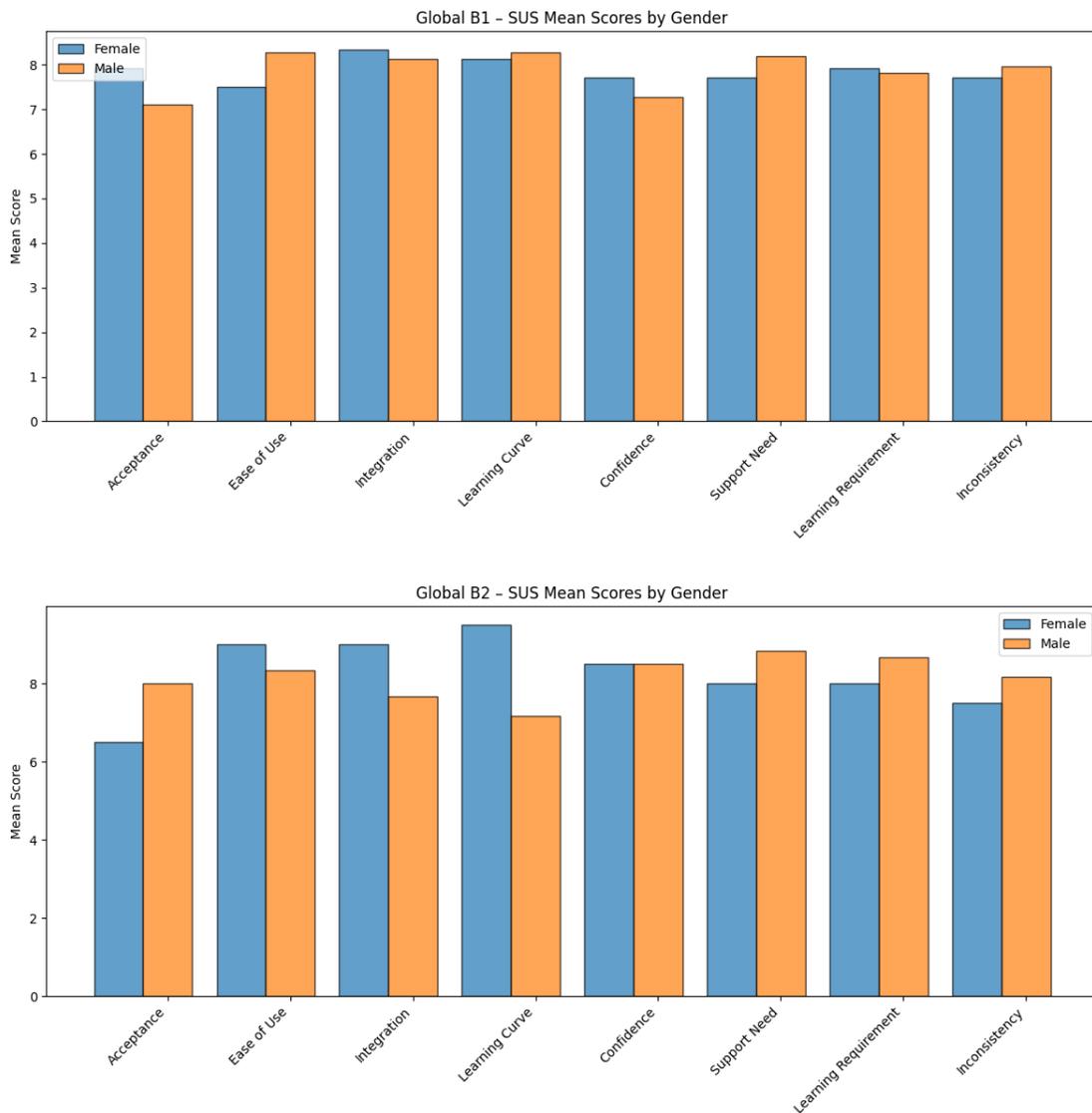


Figure 68: SUS Scores by Gender (Overall B1-B2)



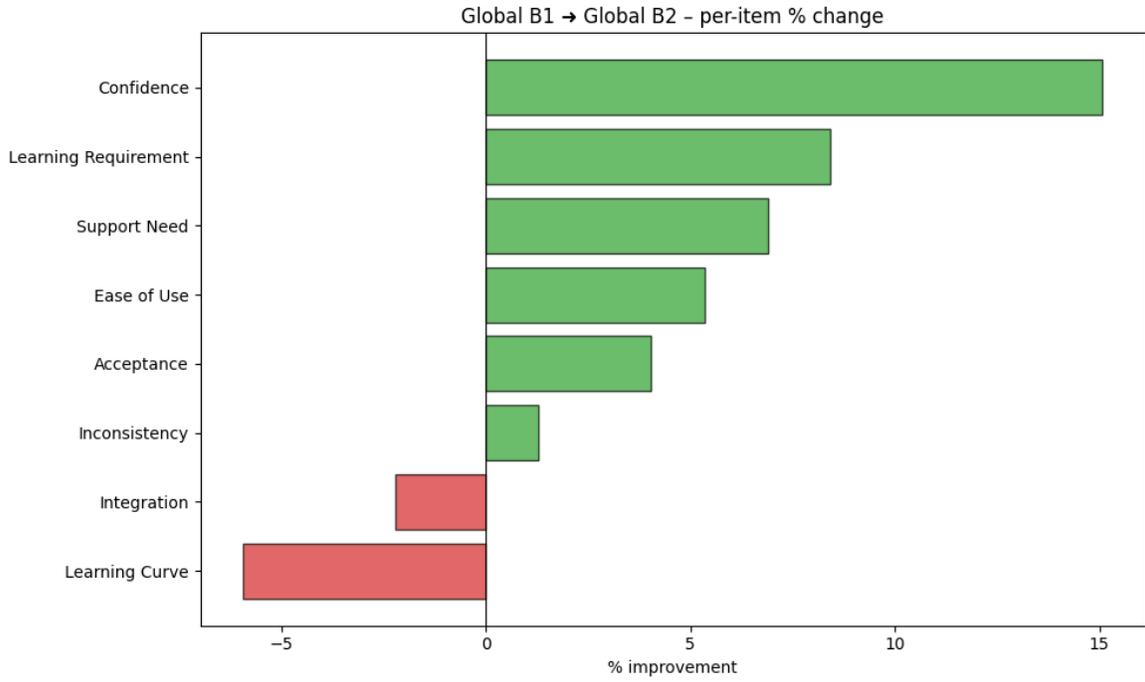
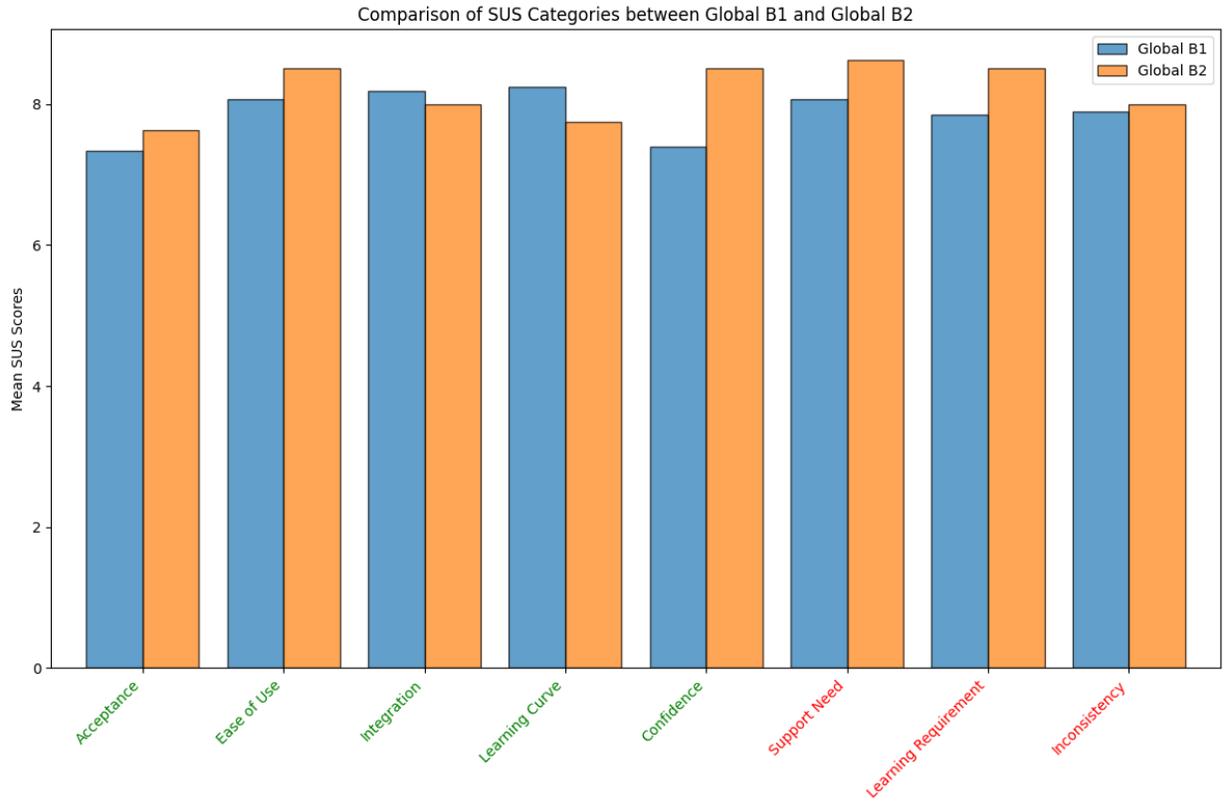


Figure 69: SUS Score Comparison (Overall B1/B1)



3.5 Update of requirements status

Some requirements were listed as pending in D2.3, as the validation of their fulfilment depended on user tests or technical validation still ongoing at the time of writing of D2.3. We provide an update of the status of these requirements in this section.

3.5.1 General

| Req. Code | Requirement | Priority | User/Technical Requirement | Responsible | Discussion |
|-----------|---|----------|----------------------------|-------------|--|
| NF.9.2 | The Neural Media Repository MUST be capable of searching in >10M assets | MUST | Technical | JRS | UNIBAS ingested 10M assets by multiplying the VBS dataset, extracting several features also used in the XReco project, and generating random queries. UNIBAS confirms that search works as expected. |
| NF.21.1 | The XR Production Workflow SHOULD be improved by at least 20% (in terms of user acceptance measured in a Likert scale) | SHOULD | User | Visyon | Global Acceptance from A to B2 show it to be over 35%, fulfilling the requirement. |
| NF.22.1 | The XR Production Workflow MUST be improved by at least 20% (in terms of user acceptance measured in a Likert scale) | MUST | User | Visyon | Global Acceptance from A to B2 show it to be over 35%, fulfilling the requirement. |
| FR.195.2 | The visual quality of the output produced by the XReco tools MUST reach a satisfactory level of 70% | MUST | User | CERTH | SfM does fulfil the requirement (72.25%). InstantNGP (61.25%), NeRF-in-the-Wild (49.75%) and 3DGS (62.50%) don't fulfil the requirement (see Figure 46). |

3.5.2 Content Sourcing

| Req. Code | Requirement | Priority | User/Technical Requirement | Responsible | Discussion |
|-----------|---|----------|----------------------------|-------------|--|
| NF.145.1 | The Repository Content Filtering functionalities MUST support a minimum accuracy of topic assignment, on closed topic set ≥ 0.7 | MUST | User | JRS | [WB 21-09-2025] Satisfied with CLIP embedding in USTORY (D3.1) |
| NF.146.1 | The Repository Content Filtering functionalities MUST support a minimum accuracy of topic assignment, on open topic set ≥ 0.5 | MUST | User | JRS | [WB 21-09-2025] Satisfied with CLIP embedding in USTORY (D3.1) |
| NF.147.1 | The Repository Content Filtering Relevance Assessment MUST provide a correlation with human assessment ≥ 0.4 | MUST | User | JRS | [WB 21-09-2025] Partially satisfied. Results on FIVR-200K dataset: up to 0.56 in cases with small length differences and 3 classes, 0.23 with large length differences and 4 classes |



3.5.3 News Media & Tourism and Automotive

| Req. Code | Requirement | Priority | User/Technical Requirement | Responsible | Discussion |
|-----------|--|----------|----------------------------|-------------|---|
| FR.27.1 | The XReco Integrated Demonstrator 1 MUST reach subjective scores for the quality of the resulting assets of at least 4 on a 5-point scale | MUST | User | DW | [NP 28-10-2025] NOT satisfied Asset quality was not tested per Demonstrator but in separate tests (see 3.4.2). |
| FR.26.2 | The XReco Integrated Demonstrator 2 SHOULD reach subjective scores for the quality of the resulting assets of at least 4 on a 5-point scale | SHOULD | User | ZAUBAR | [NP 28-10-2025] NOT satisfied Asset quality was not tested per Demonstrator but in separate tests (see 3.4.2). |

These two requirements are not satisfied, as we have already conducted five tests at three different points in time, which we believed sufficiently addressed all requirements without any overlap between demonstrators and validation activities.

4 Conclusion

Over the past 38 months, the XReco team has built a comprehensive platform featuring a marketplace, repository functionalities and licensing options. In addition, it provides access to a wide range of reconstruction methods and three authoring tools. The result is a complete extended reality ecosystem designed for broad accessibility and adaptable to numerous industries and use cases. Through the implementation and testing of multiple demonstrators, the system has validated its applicability across diverse use cases and tests, comprising over 60 testers. It has also successfully adapted to the technology advancements that have taken place over the years that the project was in effect. XReco has fulfilled the two validation KPIs it was set to. The resulting platform provides a foundation for further research, supporting continued advancement in data-driven XR content creation and deployment.



Annex I: Orchestrator Testing – Search, Repositories, Marketplace and Licensing

The following subsections summarise the results of the task execution phase.

Population:

The total number of participants was 20 (n=20), considering both gender and expertise level. Most participants were male and had a technical background (Figure 70).

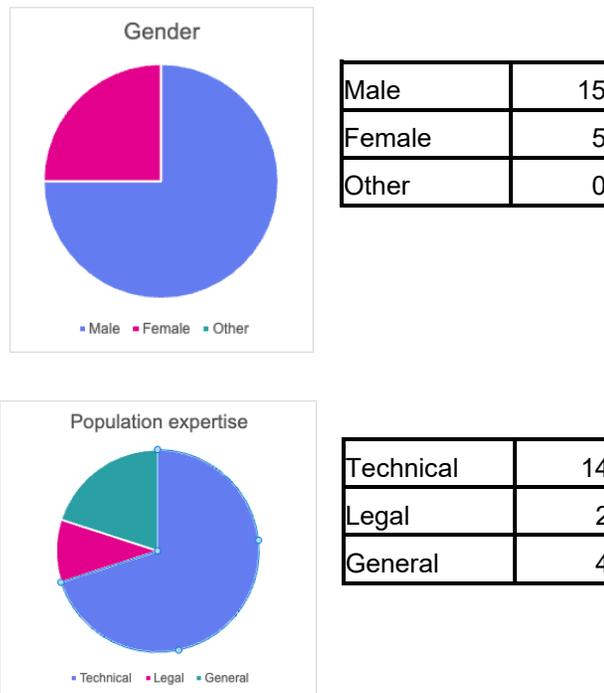
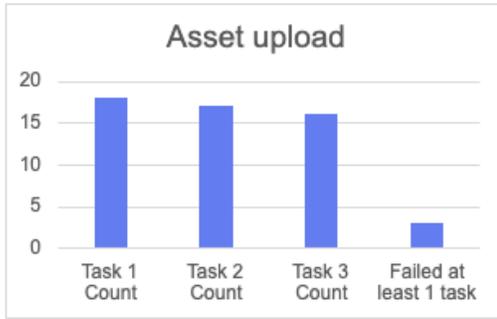


Figure 70: XReco platform test – Population results (tables and charts).

Asset upload:

Testers were asked to upload three assets. Out of 20 participants, two were unable to complete any uploads, and three failed at least one task overall (Figure 71). One inconsistent response suggests that not all participants followed the instructions to perform all three uploads. These issues appear to be linked more to test execution and instruction clarity than to the platform’s upload functionality.

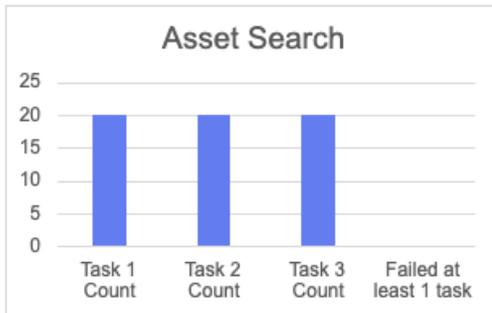


| Asset Upload to the XReco platform | Success count | Fail count |
|------------------------------------|---------------|------------|
| Task 1 Count | 18 | 2 |
| Task 2 Count | 17 | 3 |
| Task 3 Count | 16 | 4 |
| Failed at least 1 task | 3 | |

Figure 71: XReco platform test – Asset upload results (table and chart).

Asset search:

All testers succeeded in the 3 test search challenges (Figure 72).

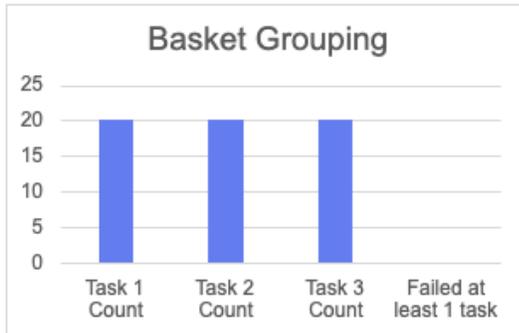


| Asset Search | Success count |
|------------------------|---------------|
| Task 1 Count | 20 |
| Task 2 Count | 20 |
| Task 3 Count | 20 |
| Failed at least 1 task | 0 |

Figure 72: XReco platform test – Asset search results (table and chart).

Grouping assets into content baskets:

All testers succeeded in the 3 basket grouping challenges (Figure 73).



| Group assets into baskets | Success count |
|---------------------------|---------------|
| Task 1 Count | 20 |
| Task 2 Count | 20 |
| Task 3 Count | 20 |
| Failed at least 1 task | 0 |

Figure 73: XReco platform test – Basket grouping results (table and chart).



Tag exploring:

Practically everyone succeeded at exploring the tags in a pre-made basket (Figure 74).

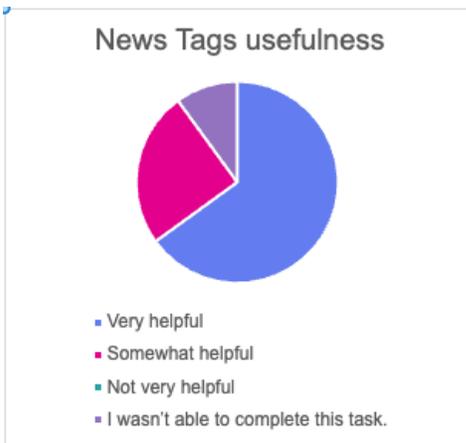


| Tag exploring | Success count |
|------------------------|---------------|
| Task 1 Count | 20 |
| Task 2 Count | 20 |
| Task 3 Count | 20 |
| Task 4 Count | 19 |
| Task 5 Count | 20 |
| Failed at least 1 task | 1 |

Figure 74: XReco platform test – Tag exploring results (table and chart).

In addition to task completion, users were asked about the usefulness of automatically generated tags for understanding and exploring retrieved assets. The questions and their corresponding results are presented below.

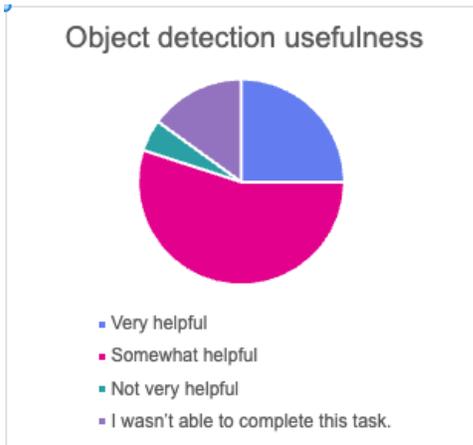
Tags Question 1: "How useful or meaningful were the News Tags for understanding and exploring the retrieved assets?"



| News tag usefulness | Count |
|--------------------------------------|-------|
| Very helpful | 13 |
| Somewhat helpful | 5 |
| Not very helpful | 0 |
| I wasn't able to complete this task. | 2 |

Figure 75: XReco platform test – News tags usefulness (table and chart).

Tags Question 2: “How useful or meaningful were the Object Detector for understanding and exploring the retrieved assets?”



| Object detection usefulness | Count |
|--------------------------------------|-------|
| Very helpful | 5 |
| Somewhat helpful | 11 |
| Not very helpful | 1 |
| I wasn't able to complete this task. | 3 |

Figure 76: XReco platform test – Object detection usefulness (table and chart).

Overall, News Tags were perceived as very useful (Figure 17), while Object Detection was considered somewhat helpful by the majority (Figure 18). This indicates that while both features are valuable, News Tags were more immediately intuitive to users than Object Detection.

Apply the appropriate licensing - Asset publishing:

Testers were requested to upload an asset to the marketplace for which they had to select the appropriate license for the assets they uploaded under 3 scenarios:

- **Scenario 1:** You're a street photographer who wants to publish your Busy Street image, with no restrictions or attribution required.
- **Scenario 2:** You filmed the Berlin TV Tower and want others to use your asset for free for non-commercial purposes with proper attribution. Commercial use should be allowed against remuneration.
- **Scenario 3:** You created a Duck 3D model for a museum collection. It should be free to share with attribution but cannot be modified or used commercially.

Each scenario described a different asset type and licensing condition. Using the platform’s licensing wizard, participants were instructed to follow the steps and select the license that best matched the scenario. This setup allowed the evaluation of the usability of the wizard in guiding users through the license selection process.

The first question regarded whether the task was completed successfully or not (Figure 19).



| Asset publishing | Count |
|--|-------|
| Scenario 1 | 16 |
| Scenario 2 | 14 |
| Scenario 3 | 15 |
| I wasn't able to perform one or more of these scenarios. | 6 |

Figure 77: XReco platform test – Marketplace asset publishing results (table and chart).

Then, the next 3 questions corresponded to the license selected by participants. We can now observe whether they selected the correct one or not.

Licensing Question 1: “Considering Scenario 1, which license was selected?”

Table 19: XReco platform test – Licensing question 1 results.

| Licensing choice - Scenario 1 | Count |
|--------------------------------------|-------|
| CC0 | 18 |
| CC BY | 0 |
| CC BY-SA | 0 |
| CC BY-NC | 0 |
| CC BY-NC-SA | 0 |
| CC BY-ND | 0 |
| CC BY-NC-ND | 0 |
| CC Plus (CC BY-NC + Unlock) | 0 |
| I wasn't able to complete this task. | 2 |

For the first scenario (Table 19), the vast majority (18) correctly selected CC0, showing that users clearly understood the simplest case of publishing without restrictions. Only 2 were unable to complete the task.



Licensing Question 2: “Considering Scenario 2, which license was selected?”

Table 20: XReco platform test – Licensing question 2 results.

| Licensing choice - Scenario 2 | Count |
|--------------------------------------|-------|
| CC0 | 0 |
| CC BY | 0 |
| CC BY-SA | 1 |
| CC BY-NC | 2 |
| CC BY-NC-SA | 1 |
| CC BY-ND | 1 |
| CC BY-NC-ND | 0 |
| CC Plus (CC BY-NC + Unlock) | 12 |
| I wasn't able to complete this task. | 3 |

For the second scenario (Table 20), while most participants (12) chose CC Plus (CC BY-NC + Unlock), which was the intended license, several selected alternative options, suggesting that the combination of “non-commercial with attribution” plus “unlock for commercial use” may not have been immediately intuitive. This indicates that some users may not be familiar with the non-lucrative nature of creative commons licenses and possibly highlights a need for clearer guidance in scenarios involving mixed conditions.

Licensing Question 3: “Considering Scenario 3, which license was selected?”

Table 21: XReco platform test – Licensing question 3 results.

| Licensing choice - Scenario 3 | Count |
|--------------------------------------|-------|
| CC0 | 0 |
| CC BY | 0 |
| CC BY-SA | 0 |
| CC BY-NC | 1 |
| CC BY-NC-SA | 0 |
| CC BY-ND | 1 |
| CC BY-NC-ND | 16 |
| CC Plus (CC BY-NC + Unlock) | 0 |
| I wasn't able to complete this task. | 2 |

The majority (16) correctly selected CC BY-NC-ND (Table 21), showing that restrictions against modification and commercial use were generally well understood.



Marketplace Asset Search:

Participants were asked to complete two Marketplace search-related tasks. Out of 20 participants, 19 successfully completed the first task and all 20 completed the second. None of the participants reported being unable to perform the tasks. One minor inconsistency was observed in the data, likely due to a participant not following the instructions as intended. Overall, the results indicate that Marketplace search and downloads were generally intuitive for users.

| Marketplace asset search | Count |
|--------------------------|-------|
| Task 1 Count | 19 |
| Task 2 Count | 20 |
| Failed at least 1 task | 0 |

Marketplace Asset Purchase:

Table 22: XReco platform test – Marketplace asset search results.



Out of 20 participants, most successfully completed the purchase flow, with 17 able to preview and buy assets. However, only 15 participants confirmed seeing their purchases in the My Purchases page. The five reported failures were linked to temporary bugs affecting the visibility of purchased assets, rather than difficulties with the purchase process itself.

Table 23: XReco platform test – Marketplace asset purchase results (table and chart).

| Marketplace asset purchase | Count |
|----------------------------|-------|
| Task 1 Count | 17 |
| Task 2 Count | 17 |
| Task 3 Count | 15 |
| Failed at least 1 task | 5 |



Beyond structured tasks, users also provided qualitative feedback.

SUS questionnaire and general satisfaction:

Asked about the usability of the system and their satisfaction, users responded in an overwhelmingly positive manner. The XReco platform was perceived as intuitive and easy to use without needing prior training or support. Willingness to use the platform frequently likely depends on whether the user sees its functions as fulfilling current needs and as such agreement was perhaps less strong than with other aspects.

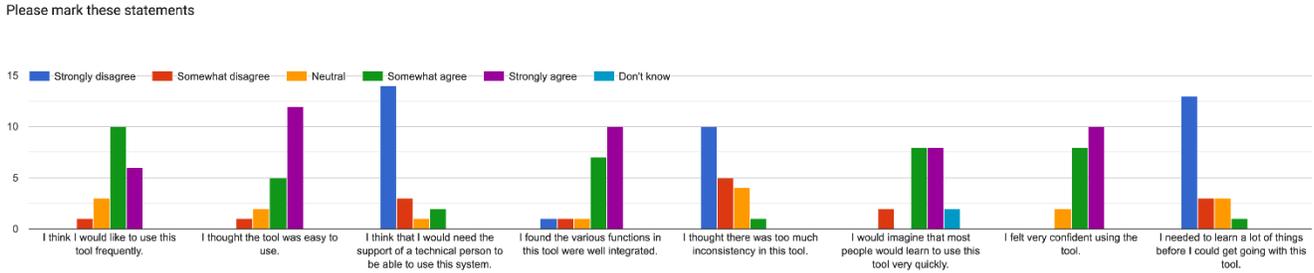


Figure 78: XReco platform test – SUS questionnaire results.

Search experience:

Users were then asked to evaluate their search experience in more detail. This included three aspects: the overall effectiveness of the search, the usefulness of available filters, and the relevance of results provided by the similarity search feature.

How would you rate your overall experience searching for assets in the platform?

20 responses

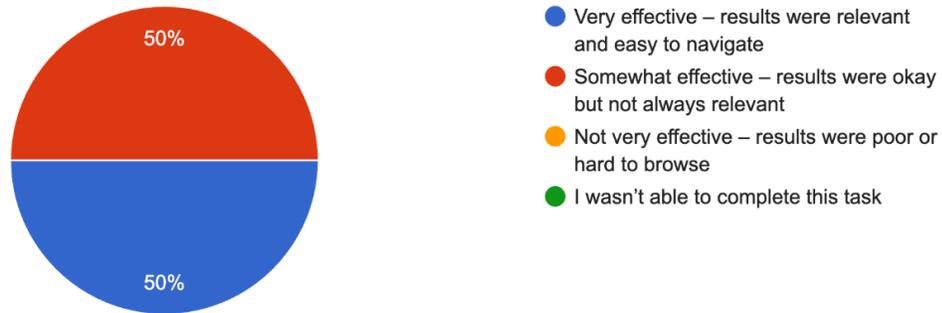


Figure 79: XReco platform test – User evaluation of search overall experience.

All users found the search to be effective, though to varying extents. Half of the users surveyed were wholly satisfied by the delivered search results and their exploration, while the other half saw issues in the relevance of the results to the query. While the platform itself was perceived as easy and intuitive to use, as seen in the previous question, in our opinion, there is a learning curve to formulating effective queries and understanding



how a search tool behaves and how to get the most accurate results. As such, we believe that over time as familiarity improves in users, search satisfaction would increase.

Were the filters (e.g., by license, type, source) useful in refining your search?

20 responses

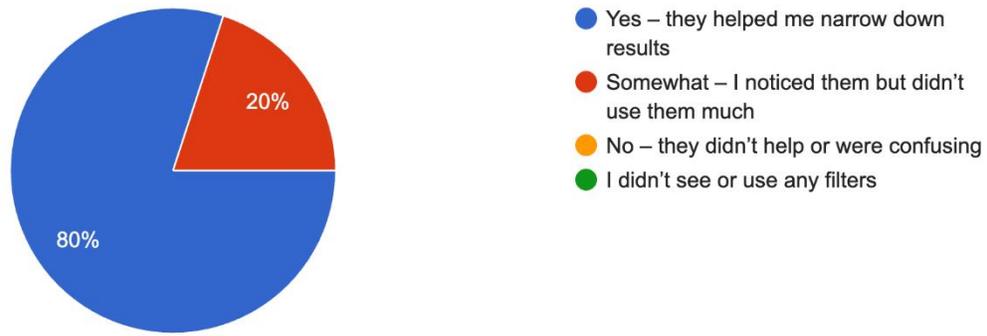


Figure 80: XReco platform test – User evaluation of search filters.

Most users found the filters to be useful, demonstrating that the chosen filter attributes match user needs while not being overwhelming. If users were immediately satisfied with the unfiltered search results, it is likely that they did not seek to filter the presented results.

How useful was the "Similar Images/Videos" feature in helping you find related content?

20 responses

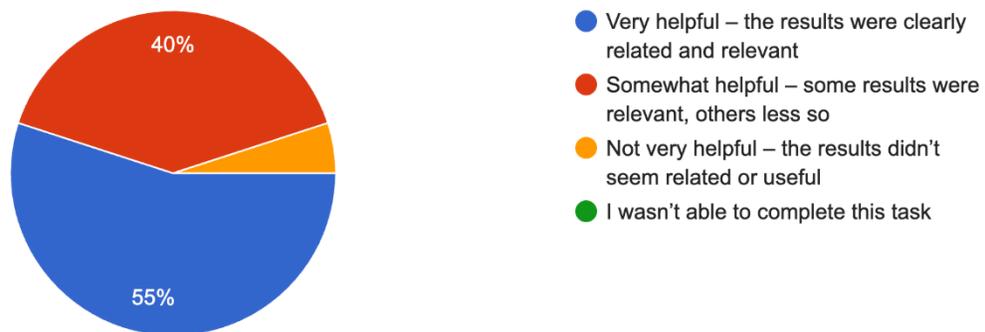


Figure 81: XReco platform test – User evaluation of similarity search experience.

While the vast majority of users found the similarity search results to be relevant, a single responder did not agree. It could possibly be the case that for the specific content viewed by that tester, no similar or related content was available on the platform, in which case the displayed content is indeed unrelated. Given that this

evaluation was performed on a limited-size dataset, we would expect the perceived usefulness to increase with additional content.

Licensing framework:

Participants were also asked a set of questions focusing on the licensing framework of the XReco platform. These questions aimed to assess whether users found the licensing principles clear, whether they were comfortable with the licensing options and the conditions those options entailed. They would also be the origin of feedback on the how the CC-plus licensing model would be received outside of a hypothetical case. Further, the questions were an opportunity to gain insights into how broader concerns regarding the use of content published on the XReco Marketplace could be addressed within the scope of licensing practices or not.

Do you think it is clear that all content published in the XReco Marketplace is free to use for at least non-commercial purposes?

20 responses

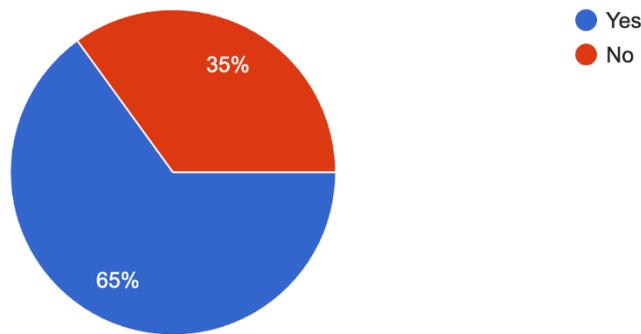


Figure 82: XReco platform test – Clarity of non-commercial use of marketplace assets.

Most participants (65%) found it clear that all assets published in the Marketplace can be used for non-commercial purposes, while 35% did not. This shows that communication on baseline licensing rules on the platform needs to be clearer to avoid misunderstandings, given that a non-negligible part of users may not be familiar with the Creative Commons licensing scheme.

As a creator, are you comfortable with the condition that all assets you publish to the marketplace can be used for free for non-commercial purposes?

20 responses

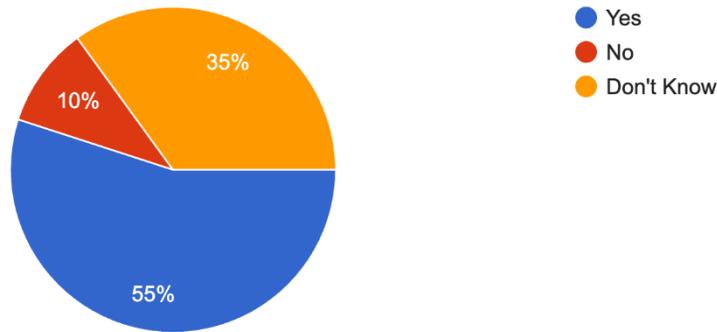


Figure 83: XReco platform test – Comfort level with non-commercial free use of published assets.

A majority (55%) were comfortable with their assets being reused non-commercially, but 10% were not and 35% were unsure. This indicates that while open use is broadly accepted, some creators still expect stronger safeguards, while others are not familiar with the Creative Commons licensing scheme.

From a licensor’s perspective, would you prefer more customization options for the "CC Plus" license applied to free+paid assets besides the price?

20 responses

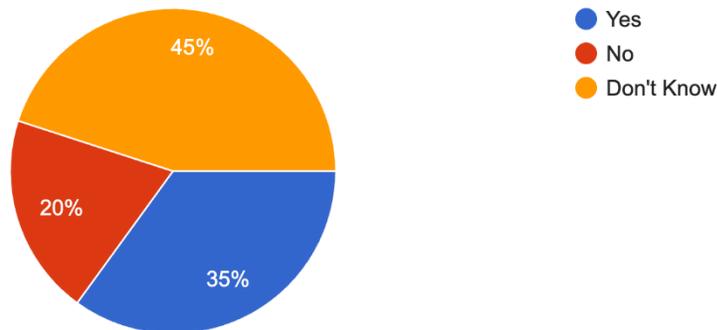


Figure 84: XReco platform test – Preference for more customisation options in CC Plus license.

Views on CC Plus customisation were mixed: 35% wanted more options beyond pricing, 20% were satisfied, and 45% were undecided. This suggests that there is uncertainty concerning customization options and could be seen as an indication of a greater need for legal guidance for the purposes of clarifying and anticipating further implementable options, including those relevant for those without a legal background.



Table 13: XReco platform test – Additional licensing conditions requested by participants.

| Additional licensing conditions for free + paid assets | Count |
|---|----------|
| Duration of Authorized Use: Length of time that licensees are authorized to use an asset. | 8 (40%) |
| Territory: Limit the usage of an asset in specific regions. | 5 (25%) |
| Derivative Works: Possibility to disallow licensees to create derivative works based on an asset. | 9 (45%) |
| Sublicensable: Possibility to disallow licensees to sublicense an asset to others. | 8 (40%) |
| Exclusivity: Possibility to offer exclusive rights to the licensee, excluding the licensor from the use of the asset. | 8 (40%) |
| Attribution: Possibility to require licensees to attribute the licensor. | 6 (30%) |
| Possibility to disallow commercial use of your asset for AI training purposes | 13 (65%) |
| Don't Know | 1 (5%) |

The top priority identified was preventing commercial AI training use (65%). This certainly reflects the ongoing discussion regarding copyright application on development of GenAI models and certainly relates with the legal question of the role (and legitimacy) of the platform in exercising the opt-out right under art. 4(3) CDSMD. Beyond this, there was fairly even demand (40–45%) for additional controls such as duration, sublicensing, derivative rights, and exclusivity, reflecting a desire for more nuanced contractual options. This highlights that while most users are comfortable with open access for non-commercial uses, they want stronger protections against emerging risks such as AI training, along with the option to tailor licensing terms more precisely in a commercial licensing context. In parallel, attribution (30%) and territorial limits (25%) were less emphasized. This can be explained by the extraterritorial nature of digital uses and a rather pragmatic approach with regards the crediting of the author in such uses, which further indicates that attribution is less important than economic exploitation in a context of possibly massive uses of massively offered assets.

Licensing Framework Question: *“If you are not sure about specific licensing conditions, what other concerns would you prefer to see addressed in the XReco licensing and rights management framework?”*

Finally, in response to the open question, participants shared additional feedback. Their responses provide insight into both functional improvements and broader rights management issues. The main points are summarised below:

- **Feature Request:** Enable multi-license selection when searching for assets in the marketplace.
- **Pricing Suggestion:** Adjust asset pricing based on different types of commercial use.
- **Educational Resources:** Create a resource area with guidance on:
 - Copyright basics and open licenses
 - Metadata usage
 - License enforcement and detection of violations
 - Steps to take if a license is violated (including links to helpdesks and tools)



- **AI Training Concern:** Address the issue of creators' content being used to train AI models without consent or compensation; this is a growing concern that needs careful consideration in the project.

General Remarks

In response to the open question *“Would you like to provide any other remarks that we haven't asked you about?”*, participants shared feedback that went beyond the structured questions. Their comments are summarised below:

General / Orchestrator Feedback

- The add-to-basket button should be placed on each item, not as a separate list.
- The video player currently does not allow seeking or jumping to a specific point.
- The marketplace section should include user earnings, transactions, purchases, and published assets, and should not be tied to the user profile.

Search Feedback

- Searches should return results even without keywords, particularly in "My Repository".
- In external repositories, it is unclear that a search term must be entered before applying filters. Users should be able to browse without specifying a keyword.
- The marketplace search bar should trigger a search and show default assets even when left empty.
- Advanced search features would be helpful, such as filtering by publication date, using exact phrases, and applying Boolean operators.
- Filtering by tags or similarity sometimes causes images not to display.
- Image previews respect rotation metadata, but search results do not.
- It is possible to trigger an upload without selecting an asset, as long as the rights box is checked — this should not be allowed.
- Filters should apply immediately when selected.

Marketplace Feedback

- Object previews are occasionally missing.
- Asset publishing sometimes fails without clear explanation.
- Assets marked as successfully purchased do not always appear in the "My Purchases" section.
- The "Add" button above the basket list is unclear in function. A label like "Add to Basket" would improve usability.
- Downloading a purchased asset sometimes results in an error.

Upload Feedback

- Once an asset is selected for upload, it cannot be deleted — only replaced.
- Uploads marked as successful do not always appear in "My Repository".



Tags Feedback

- It is not clear that tags are automatically generated. Users may expect to add them manually.
- Tags can be inconsistent or irrelevant. Clicking on them sometimes returns an error ("Something went wrong").

Repository Feedback

- "My Repository" does not show all uploaded items immediately after upload.
- The distinction between "External Repository" and "Marketplace" is unclear and should be better explained.
- Users must remember the exact title of an uploaded item to search for it, which is impractical.
- There should be filtering options by asset type in "My Repository".
- The search result order appears random, making it difficult to find one's own uploads.
- Users should be able to browse all files in "My Repository" without needing to search by keyword.

Annex II: Reconstruction Services

B2 – 3D reconstruction

Dear tester,

Thank you for filling in this form by following the instructions below or watching [this video tutorial](#). If you are unable to finish the test or have any general questions, contact your XReco tester lead. If you have any questions about the XReco R&D project co-financed by the EC under grant agreement ID 101070250, follow this link: <https://xreco.eu/>.

General instructions for all four 3D reconstruction services

First step: Log in

Go to <https://xreco.az.mog-technologies.com/login> and enter the username (email) and password you were given.

Bear in mind that the XReco platform is still evolving so, when you'll use it, it might not look exactly as shown here.

Second step: Choose a basket

Select the basket whose name begins with the name of the 3D reconstruction service you want to try (step 1 in the figure below).

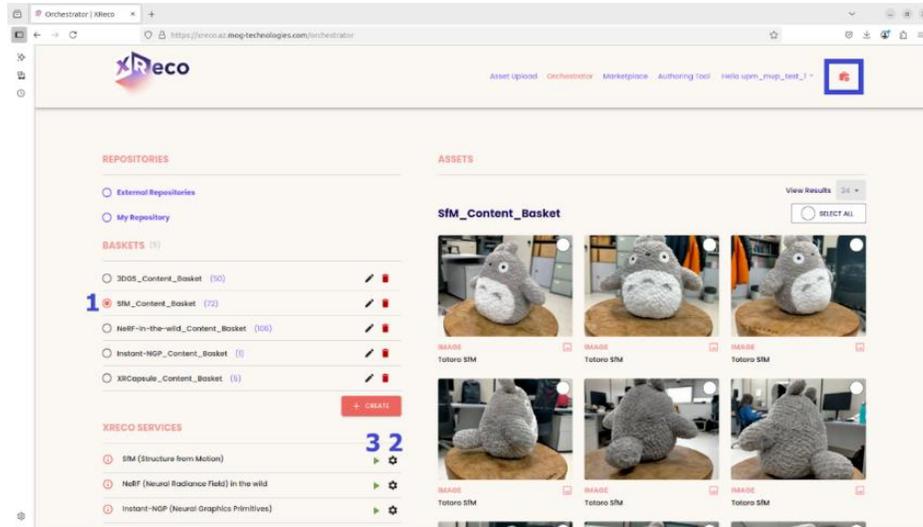
Please note that the content used for the reconstruction includes all materials contained in the selected basket. The selection of individual items (videos or photos) is solely intended to add content to the basket.

Third step: Run the 3D reconstruction

If the 3D reconstruction service of your choice has a gear button "⚙️" (step 2), click it to configure the reconstruction parameters, or to just check and leave their default values. Next, click the play button "▶️" (step 3).

If you want to monitor the process status, click the icon at the top-right corner of the dashboard to open the "Service Jobs" window (highlighted with a square), but be warned that the progress percentage shown might be misleading for some services.



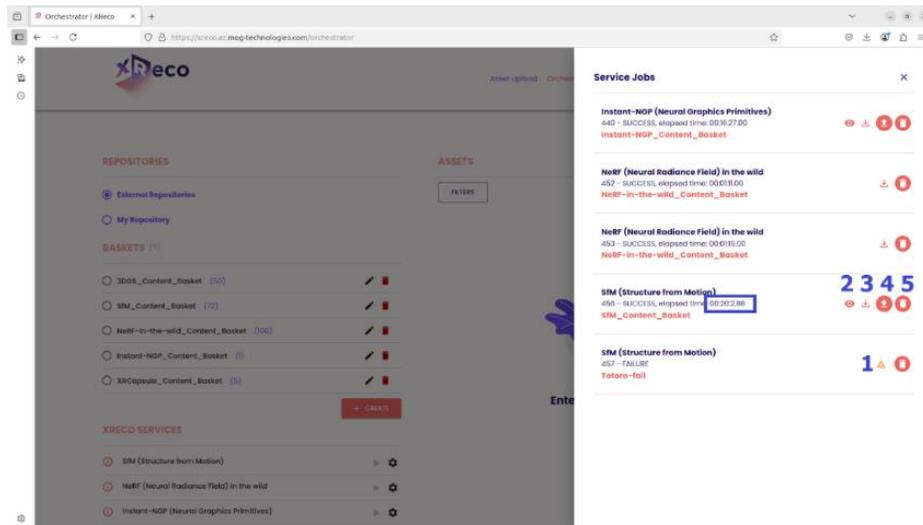


If the warning icon "⚠" appears in the "Service Jobs" window (number 1 in the figure below), it means that an error has occurred and the 3D model could not be generated. In this case, please attempt to reconstruct the model again.

Upon successful reconstruction, the "Service Jobs" window will display the duration of the reconstruction process (excluding any time spent in the queue).

To preview your 3D model, click the eye button "👁" (number 2) located within the same window. If you'd like to save your model, click the download button "📄" (3) to keep a local copy, or choose the upload button "📤" (4) to store it in your XReco repository.

If you aren't happy with the outcome, you may delete the model by clicking the trash bin button "🗑" (5). Please note: if the model has not been viewed or saved, it will be permanently lost. To access it again, the process must be reinitiated.



Fourth (optional) step: Create your own basket

Once you are done with the steps above, you can try to create your own basket and reconstruct other objects.

First, click the "+ CREATE" button below the "BASKETS" window, assign a name to your new basket, and add it to the list by clicking the "ADD" button. You will get a success message once your new basket has been created.

Now you will add a set of images or a video to your new basket. Follow the numbers in the image below.

1) Click on "My Repository."

2) Find an available dataset in your profile.

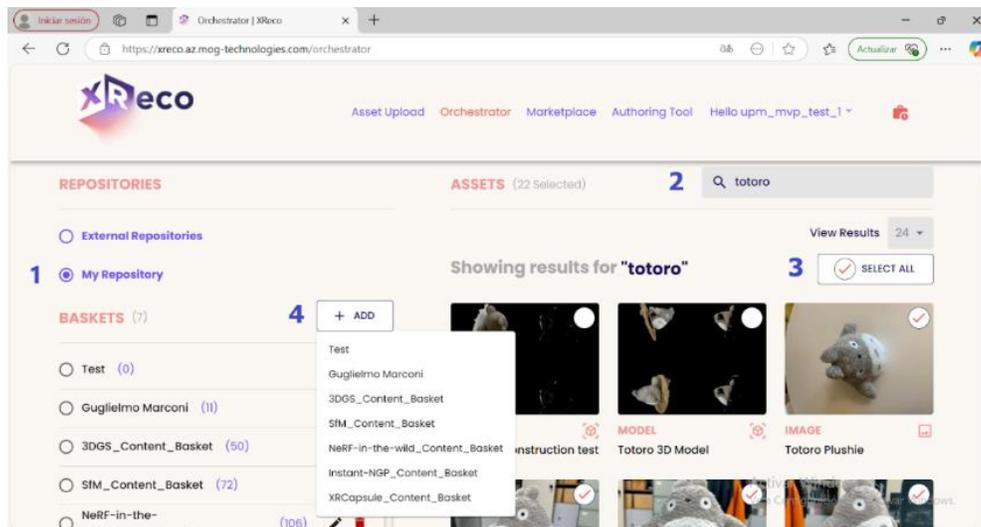
Tip: You can search for "Totoro", "RAI radio", "Lego", "Einstein Tower", etc. to quickly locate media files.

3) Select the data you want to use.

Important: Don't mix different media types. If you want to use a video, select only the video. If you're using images, try to select a single, complete and consistent set. Using just a few images may result in a lower-quality model or even cause the service to fail. Also, if you start by adding only a few images from a dataset and later try to add the rest, you may receive an error saying that some images are already in the basket.

4) Once you've selected your images, click the "+ ADD" button and choose your dataset. You'll see a confirmation message once all assets have been successfully added.

Tip: You can also reuse content from other baskets. Just select the basket you want, then pick the items you'd like to include in your new one.



3D reconstruction service 1: SfM (Structure from Motion)

The configuration parameters for this service are:

- **Texturization:** It allows you to choose between (TRUE) performing the final texturization step or (FALSE) simply producing a naked mesh for quicker geometry check.
- **Number of triangles:** Specify the approximate target number of triangles for the output mesh. More triangles result in smoother, more accurate geometry; fewer triangles simplify the model but reduce detail.



- **Texture size:** Target size of the texture atlas in megapixels. Higher values produce sharper, more detailed surface appearances.
- **Minimum number of images recommended:** At least 50 images from different viewpoints are suggested to ensure accurate reconstruction of geometry and textures.

The expected output from the service includes:

- A naked mesh in .obj format (**scene_dense_mesh.obj**).
- If texturization was TRUE, a textured mesh in .obj format (**textured_mesh.obj**) with its respective material file (**textured_mesh.obj.mtl**) and its texture atlas as a JPEG image (**texture.png**).

To test this service, we recommend to select the "**SfM_Content_Basket**" with the default reconstruction parameters.

3D reconstruction service 2: NeRF (Neural Radiance Field) in the wild

The configuration parameters for this service are:

- **Epochs:** It allows you to choose for how many epochs the training will last (more epochs yield better quality results).
- **Downscale:** It allows you to choose the downscale factor for the images in the content basket (lower downscale factors yield better quality results).

The expected output from the service includes:

- A video to preview the quality of the reconstruction.
- A folder with the checkpoint that the user can download.

To test this service, we recommend to select the "**NeRF-in-the-wild_Content_Basket**" with the default reconstruction parameters to experience usability within the XReco platform (Orchestrator). **Because the service takes a long time to produce results, we have already pre-trained results for your convenience. These results can be viewed [here](#) for occlusion handling, and [here](#) for appearance interpolation. Please consider these results for answering the questions below.** We used the "NeRF-in-the-wild_Content_Basket" dataset with a downscale factor of 2 and 30 epochs of training, that lasts approximately 8 hours. Based on these outputs, the following questions regarding quality can be answered.

3D reconstruction service 3: Instant-NGP (Neural Graphics Primitives)

The configuration parameters for this service are:

- **Epochs:** It allows you to choose for how many epochs the training will last (more epochs yield better quality results).
- **Downscale:** It allows you to choose the downscale factor for the images in the content basket (lower downscale factors yield better quality results).

The expected output from the service includes:

- A point cloud to preview the quality of the reconstruction.
- A folder with the mesh and the results of the reconstruction.

To test this service, we recommend to select the "**Instant-NGP_Content_Basket**" with the default reconstruction parameters.



3D reconstruction service 4: 3DGS (Gaussian Splatting)

There are no configuration parameters for this service.

The expected output from the service includes:

- A .ply file representing a point cloud composed of Gaussian splats.
- A sample frame used in the 3D reconstruction.

To test this service, we recommend to select the "3DGS_Content_Basket".

Results:

The total number of participants was 19 (n=19), considering both gender and expertise level. Most participants were males and had not previous experience with 3D Reconstruction.

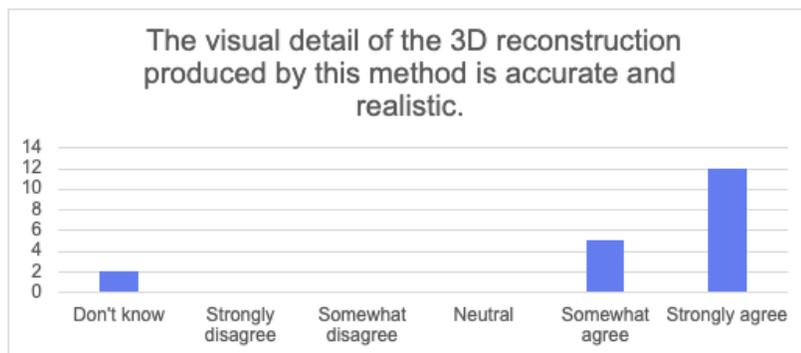
| Experience | Count |
|-------------------|-------|
| 3D reconstruction | 7 |
| 3D modeling | 1 |
| No experience | 11 |

| Gender | Count |
|--------|-------|
| Male | 15 |
| Female | 4 |
| Other | 0 |

SfM

Quality questions

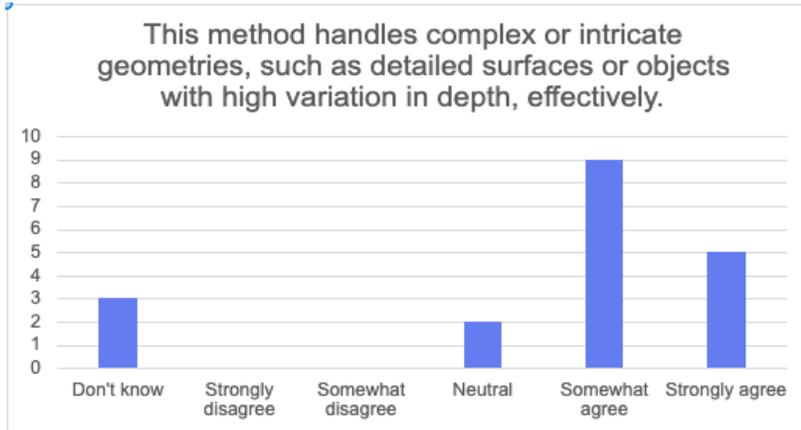
The visual detail of the 3D reconstruction produced by this method is accurate and realistic.



| Opinion | Count |
|-------------------|-------|
| Strongly agree | 12 |
| Somewhat agree | 5 |
| Neutral | 0 |
| Somewhat disagree | 0 |
| Strongly disagree | 0 |
| Don't know | 2 |

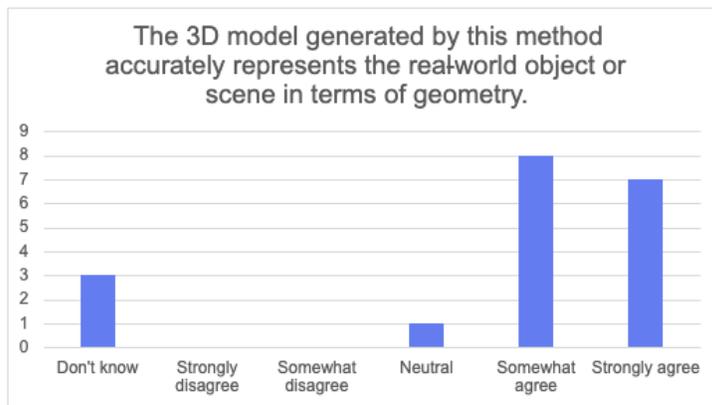


This method handles complex or intricate geometries, such as detailed surfaces or objects with high variation in depth, effectively.



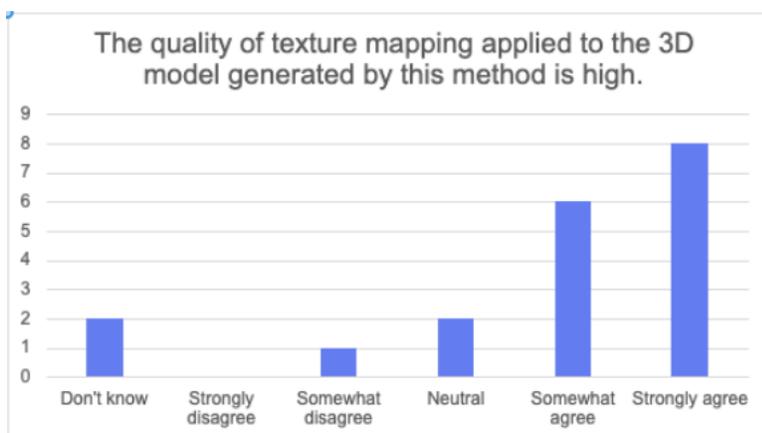
| Opinion | Count |
|-------------------|-------|
| Don't know | 3 |
| Strongly disagree | 0 |
| Somewhat disagree | 0 |
| Neutral | 2 |
| Somewhat agree | 9 |
| Strongly agree | 5 |

The 3D model generated by this method accurately represents the real-world object or scene in terms of geometry.



| Opinion | Count |
|-------------------|-------|
| Don't know | 3 |
| Strongly disagree | 0 |
| Somewhat disagree | 0 |
| Neutral | 1 |
| Somewhat agree | 8 |
| Strongly agree | 7 |

The quality of texture mapping applied to the 3D model generated by this method is high.



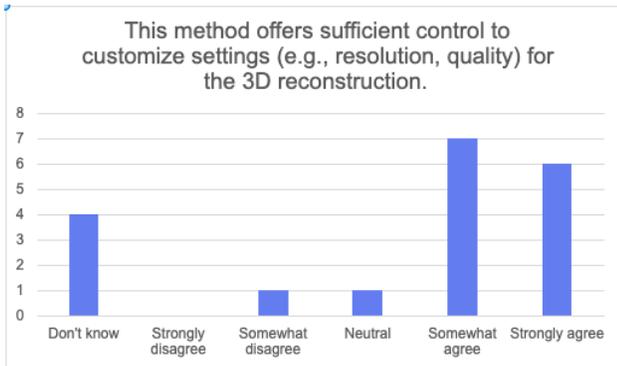
| Opinion | Count |
|-------------------|-------|
| Don't know | 2 |
| Strongly disagree | 0 |
| Somewhat disagree | 1 |
| Neutral | 2 |
| Somewhat agree | 6 |
| Strongly agree | 8 |



The quality-related questions indicate that the majority of respondents view the 3D reconstruction results positively, with most selecting ‘Strongly agree’ or ‘Somewhat agree’ across the different questions.

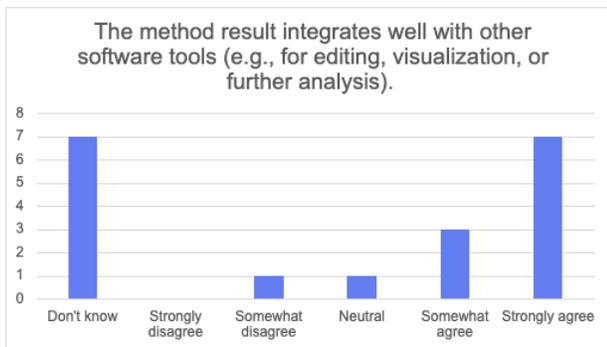
Usability questions

This method offers sufficient control to customize settings (e.g., resolution, quality) for the 3D reconstruction.



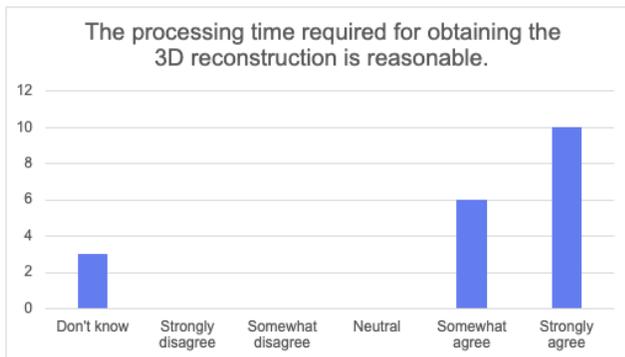
| Opinion | Count |
|-------------------|-------|
| Don't know | 4 |
| Strongly disagree | 0 |
| Somewhat disagree | 1 |
| Neutral | 1 |
| Somewhat agree | 7 |
| Strongly agree | 6 |

The method result integrates well with other software tools (e.g., for editing, visualization, or further analysis).



| Opinion | Count |
|-------------------|-------|
| Don't know | 7 |
| Strongly disagree | 0 |
| Somewhat disagree | 1 |
| Neutral | 1 |
| Somewhat agree | 3 |
| Strongly agree | 7 |

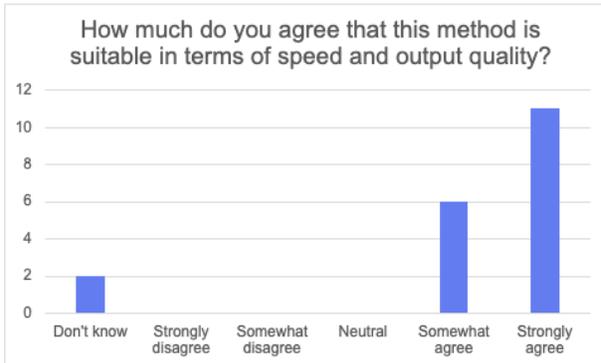
The processing time required for obtaining the 3D reconstruction is reasonable.



| Opinion | Count |
|-------------------|-------|
| Don't know | 3 |
| Strongly disagree | 0 |
| Somewhat disagree | 0 |
| Neutral | 0 |
| Somewhat agree | 6 |
| Strongly agree | 10 |

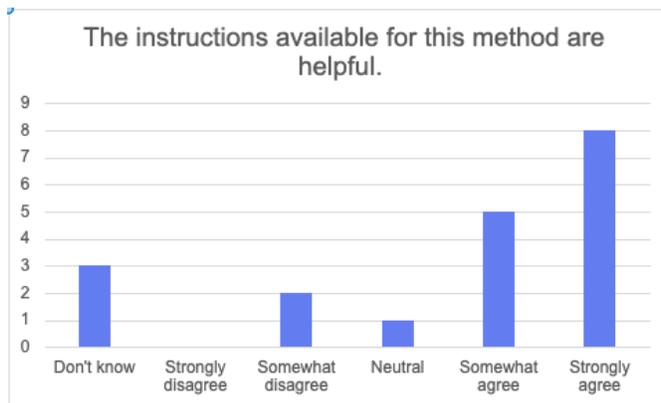


How much do you agree that this method is suitable in terms of speed and output quality?



| Opinion | Count |
|-------------------|-------|
| Don't know | 2 |
| Strongly disagree | 0 |
| Somewhat disagree | 0 |
| Neutral | 0 |
| Somewhat agree | 6 |
| Strongly agree | 11 |

The instructions available for this method are helpful.



| Opinion | Count |
|-------------------|-------|
| Don't know | 3 |
| Strongly disagree | 0 |
| Somewhat disagree | 2 |
| Neutral | 1 |
| Somewhat agree | 5 |
| Strongly agree | 8 |

Overall, the results highlight that the method is perceived very positively in terms of processing speed and output quality, which were consistently rated as strengths. Most participants also agreed that the method offers sufficient customization and integrates well with other software, although a notable share of respondents selected 'Don't know,' suggesting that these features may not have been fully explored or understood by all users (likely reflecting participants with limited prior experience in 3D). Finally, while the instructions provided were generally considered helpful, feedback indicates some room for improvement to ensure clarity and usability for all participants.



Think of a practical real-world application where you would like to use this 3D model. Please describe the use case.

- Entertainment & Media:
 - Creating high-quality 3D reconstructions of landmarks for video games, animation, and AR/VR/XR experiences
 - Building virtual sets for television programs or docu-fiction
- E-commerce & Retail:
 - Allowing customers to visualize products in 3D (shape and texture) for online shopping
- Architecture & Real-world Mapping:
 - Using photogrammetry with drones for architectural or territorial mapping

From these answers we can see that people consider this method useful for different applications.

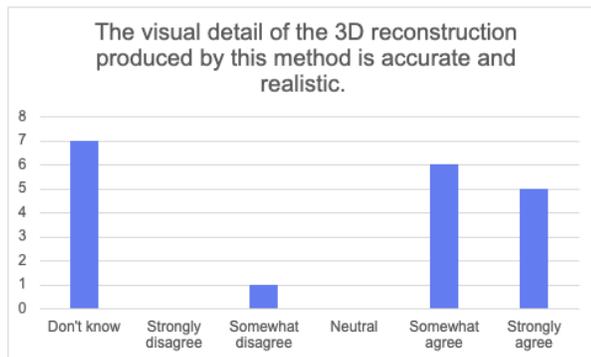
Did you encounter any errors?

| Errors | Count |
|--------|-------|
| No | 12 |
| Yes | 7 |

NeRF in the Wild

Quality questions

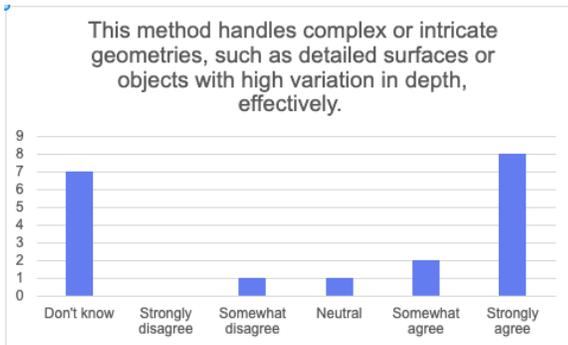
The visual detail of the 3D reconstruction produced by this method is accurate and realistic.



| Opinion | Count |
|-------------------|-------|
| Don't know | 7 |
| Strongly disagree | 0 |
| Somewhat disagree | 1 |
| Neutral | 0 |
| Somewhat agree | 6 |
| Strongly agree | 5 |

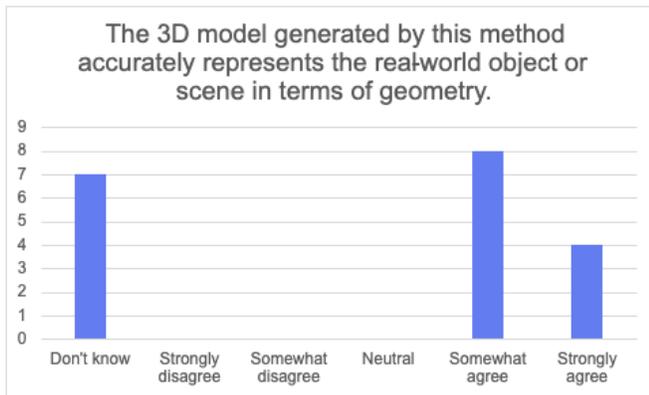
This method handles complex or intricate geometries, such as detailed surfaces or objects with high variation in depth, effectively.





| Opinion | Count |
|-------------------|-------|
| Don't know | 7 |
| Strongly disagree | 0 |
| Somewhat disagree | 1 |
| Neutral | 1 |
| Somewhat agree | 2 |
| Strongly agree | 8 |

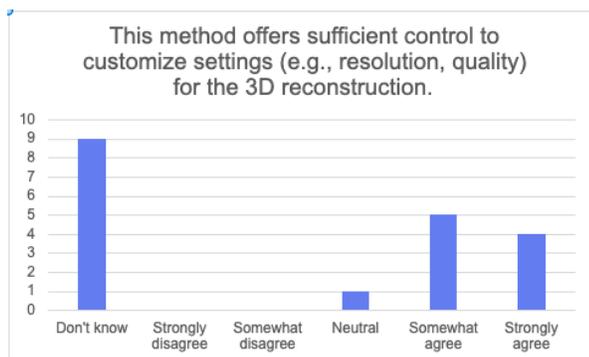
The 3D model generated by this method accurately represents the real-world object or scene in terms of geometry.



| Opinion | Count |
|-------------------|-------|
| Don't know | 7 |
| Strongly disagree | 0 |
| Somewhat disagree | 0 |
| Neutral | 0 |
| Somewhat agree | 8 |
| Strongly agree | 4 |

Usability questions

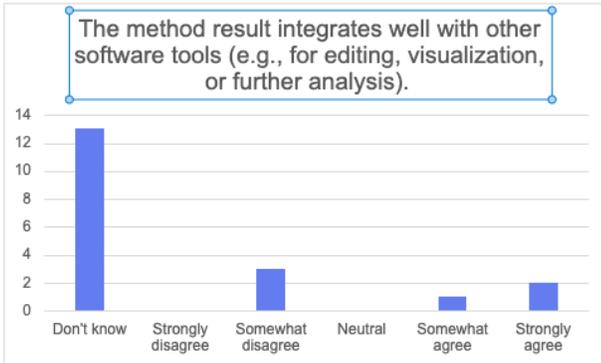
This method offers sufficient control to customize settings (e.g., resolution, quality) for the 3D reconstruction.



| Opinion | Count |
|-------------------|-------|
| Don't know | 9 |
| Strongly disagree | 0 |
| Somewhat disagree | 0 |
| Neutral | 1 |
| Somewhat agree | 5 |
| Strongly agree | 4 |

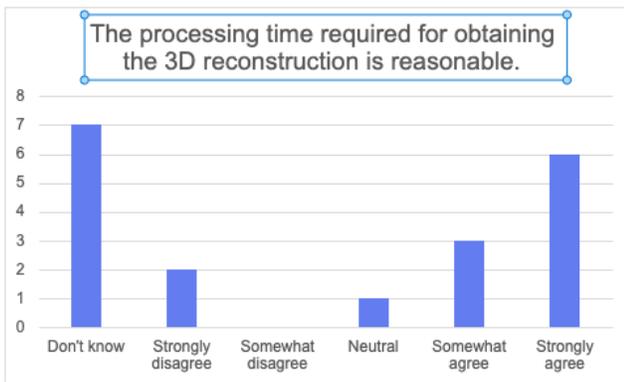


The method result integrates well with other software tools (e.g., for editing, visualization, or further analysis).



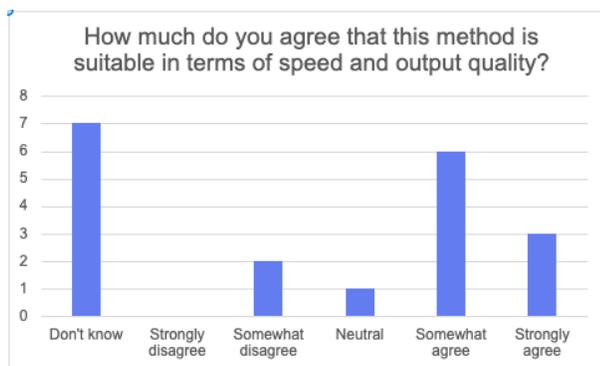
| Opinion | Count |
|-------------------|-------|
| Don't know | 13 |
| Strongly disagree | 0 |
| Somewhat disagree | 3 |
| Neutral | 0 |
| Somewhat agree | 1 |
| Strongly agree | 2 |

The processing time required for obtaining the 3D reconstruction is reasonable.



| Opinion | Count |
|-------------------|-------|
| Don't know | 7 |
| Strongly disagree | 2 |
| Somewhat disagree | 0 |
| Neutral | 1 |
| Somewhat agree | 3 |
| Strongly agree | 6 |

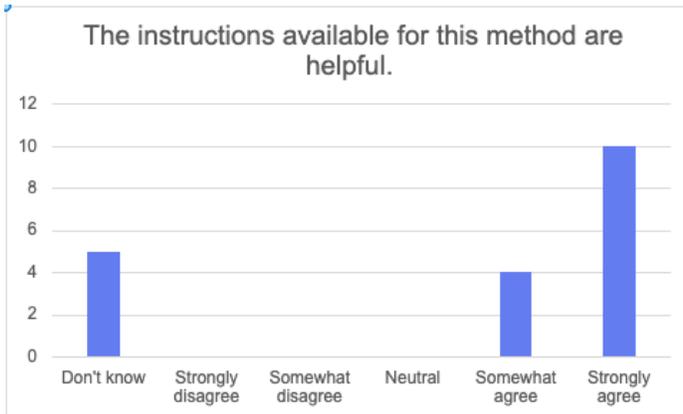
How much do you agree that this method is suitable in terms of speed and output quality?



| Opinion | Count |
|-------------------|-------|
| Don't know | 7 |
| Strongly disagree | 0 |
| Somewhat disagree | 2 |
| Neutral | 1 |
| Somewhat agree | 6 |
| Strongly agree | 3 |



The instructions available for this method are helpful.



| Opinion | Count |
|-------------------|-------|
| Don't know | 5 |
| Strongly disagree | 0 |
| Somewhat disagree | 0 |
| Neutral | 0 |
| Somewhat agree | 4 |
| Strongly agree | 10 |

Did you encounter any errors?

| Errors | Count |
|--------|-------|
| No | 11 |
| Yes | 8 |

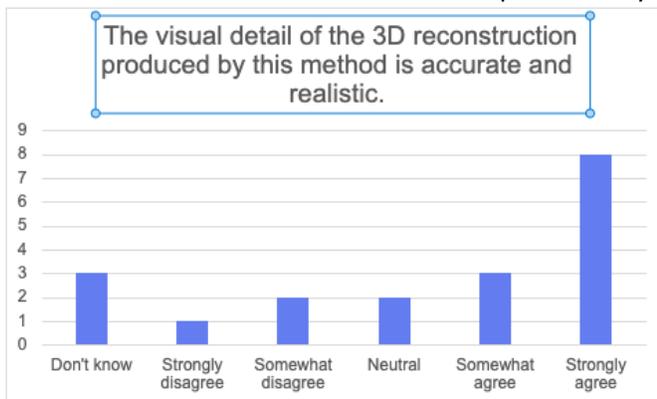
If you did have any problem, please elaborate.

[Free text]

Instant NGP

Quality questions

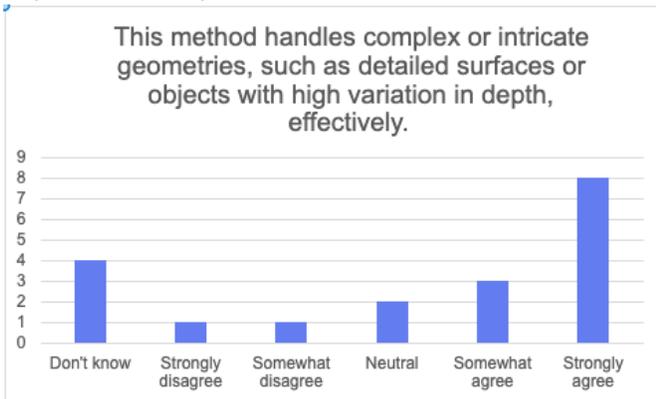
The visual detail of the 3D reconstruction produced by this method is accurate and realistic.



| Opinion | Count |
|-------------------|-------|
| Don't know | 3 |
| Strongly disagree | 1 |
| Somewhat disagree | 2 |
| Neutral | 2 |
| Somewhat agree | 3 |
| Strongly agree | 8 |

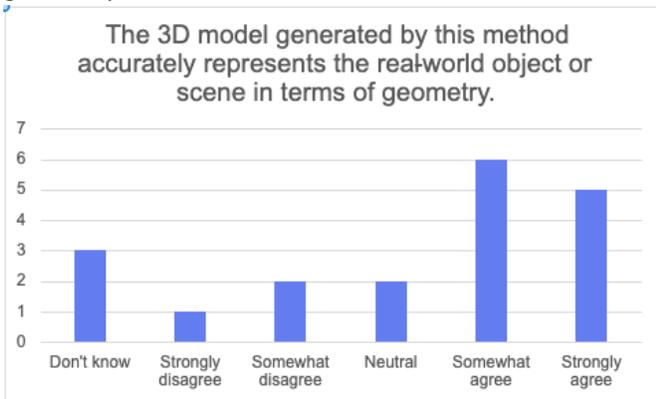


This method handles complex or intricate geometries, such as detailed surfaces or objects with high variation in depth, effectively.



| Opinion | Count |
|-------------------|-------|
| Don't know | 4 |
| Strongly disagree | 1 |
| Somewhat disagree | 1 |
| Neutral | 2 |
| Somewhat agree | 3 |
| Strongly agree | 8 |

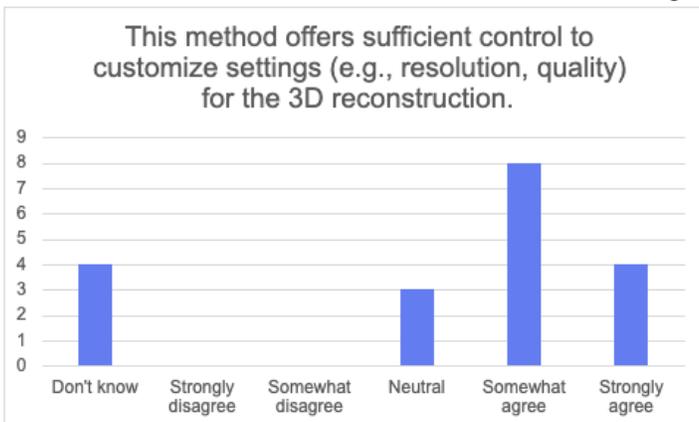
The 3D model generated by this method accurately represents the real-world object or scene in terms of geometry.



| Opinion | Count |
|-------------------|-------|
| Don't know | 3 |
| Strongly disagree | 1 |
| Somewhat disagree | 2 |
| Neutral | 2 |
| Somewhat agree | 6 |
| Strongly agree | 5 |

Usability questions

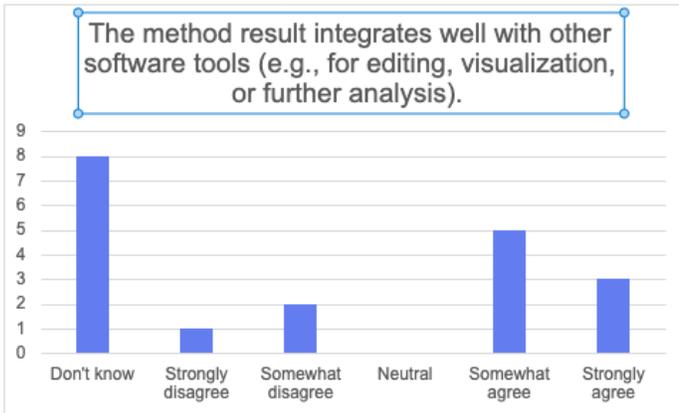
This method offers sufficient control to customize settings (e.g., resolution, quality) for the 3D reconstruction.



| Opinion | Count |
|-------------------|-------|
| Don't know | 4 |
| Strongly disagree | 0 |
| Somewhat disagree | 0 |
| Neutral | 3 |
| Somewhat agree | 8 |
| Strongly agree | 4 |

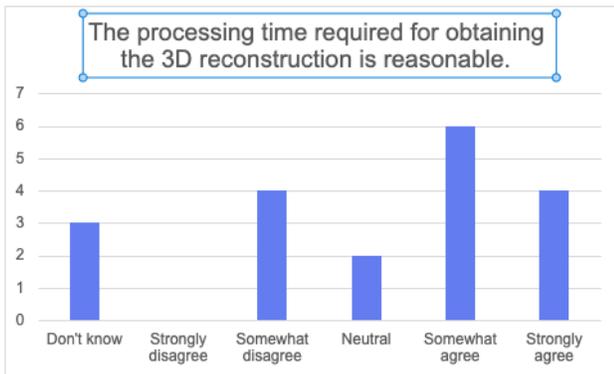


The method result integrates well with other software tools (e.g., for editing, visualization, or further analysis).



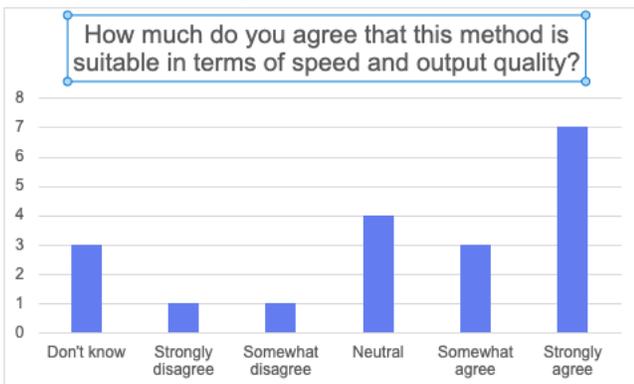
| Opinion | Count |
|-------------------|-------|
| Don't know | 8 |
| Strongly disagree | 1 |
| Somewhat disagree | 2 |
| Neutral | 0 |
| Somewhat agree | 5 |
| Strongly agree | 3 |

The processing time required for obtaining the 3D reconstruction is reasonable.



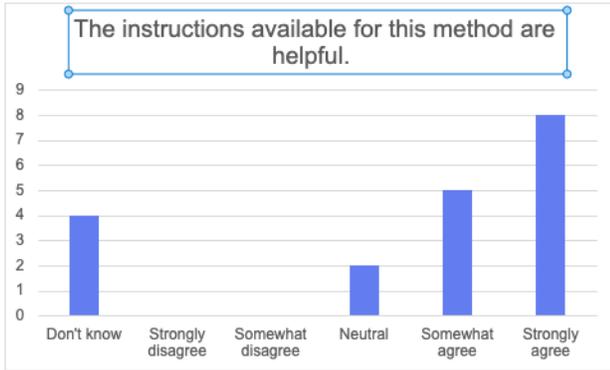
| Opinion | Count |
|-------------------|-------|
| Don't know | 3 |
| Strongly disagree | 0 |
| Somewhat disagree | 4 |
| Neutral | 2 |
| Somewhat agree | 6 |
| Strongly agree | 4 |

How much do you agree that this method is suitable in terms of speed and output quality?



| Opinion | Count |
|-------------------|-------|
| Don't know | 3 |
| Strongly disagree | 1 |
| Somewhat disagree | 1 |
| Neutral | 4 |
| Somewhat agree | 3 |
| Strongly agree | 7 |

The instructions available for this method are helpful.



| Opinion | Count |
|-------------------|-------|
| Don't know | 4 |
| Strongly disagree | 0 |
| Somewhat disagree | 0 |
| Neutral | 2 |
| Somewhat agree | 5 |
| Strongly agree | 8 |

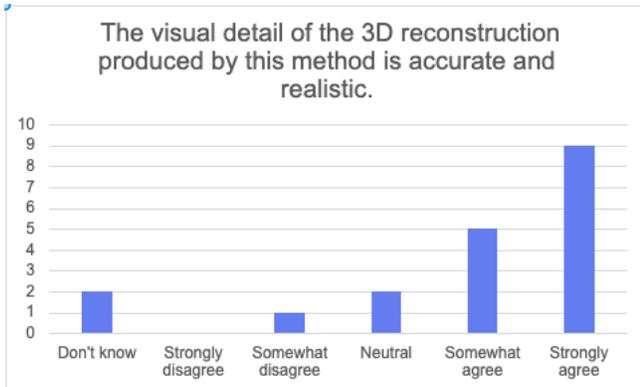
Did you encounter any errors?

| Errors | Count |
|--------|-------|
| No | 13 |
| Yes | 6 |

3DGS

Quality questions

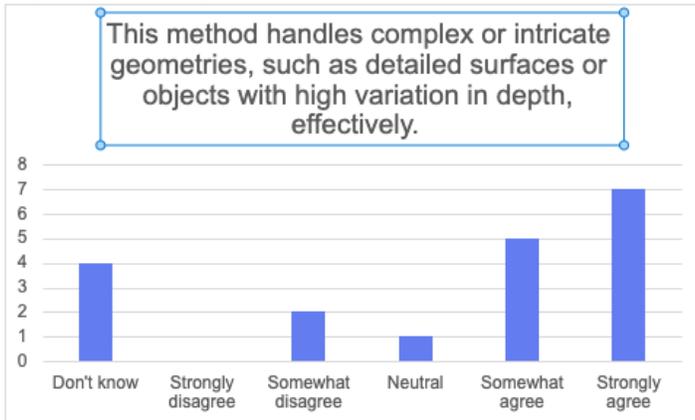
The visual detail of the 3D reconstruction produced by this method is accurate and realistic.



| Opinion | Count |
|-------------------|-------|
| Don't know | 2 |
| Strongly disagree | 0 |
| Somewhat disagree | 1 |
| Neutral | 2 |
| Somewhat agree | 5 |
| Strongly agree | 9 |

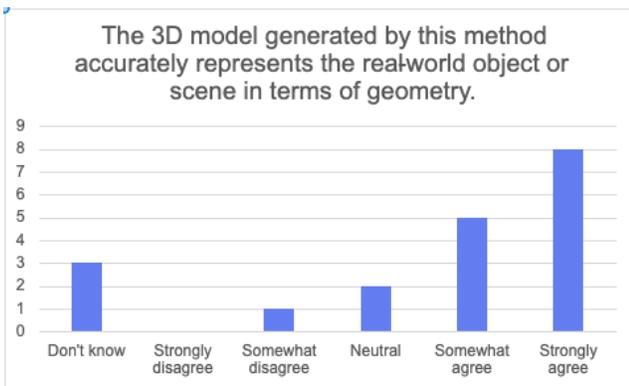


This method handles complex or intricate geometries, such as detailed surfaces or objects with high variation in depth, effectively.



| Opinion | Count |
|-------------------|-------|
| Don't know | 4 |
| Strongly disagree | 0 |
| Somewhat disagree | 2 |
| Neutral | 1 |
| Somewhat agree | 5 |
| Strongly agree | 7 |

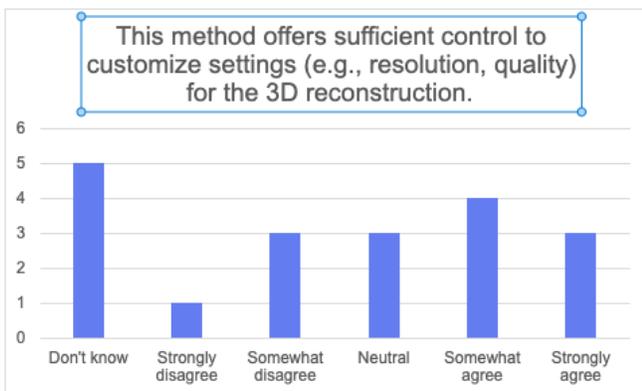
The 3D model generated by this method accurately represents the real-world object or scene in terms of geometry.



| Opinion | Count |
|-------------------|-------|
| Don't know | 3 |
| Strongly disagree | 0 |
| Somewhat disagree | 1 |
| Neutral | 2 |
| Somewhat agree | 5 |
| Strongly agree | 8 |

Usability questions

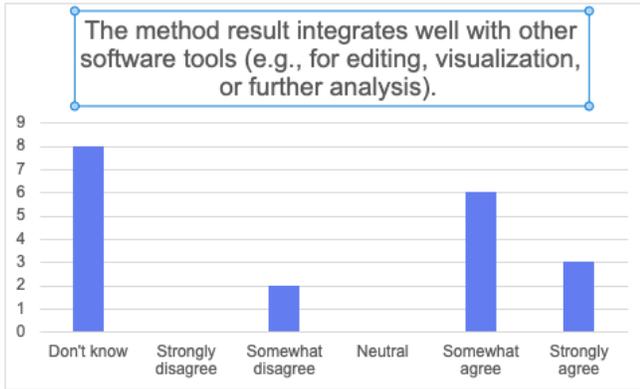
This method offers sufficient control to customize settings (e.g., resolution, quality) for the 3D reconstruction.



| Opinion | Count |
|-------------------|-------|
| Don't know | 5 |
| Strongly disagree | 1 |
| Somewhat disagree | 3 |
| Neutral | 3 |
| Somewhat agree | 4 |
| Strongly agree | 3 |

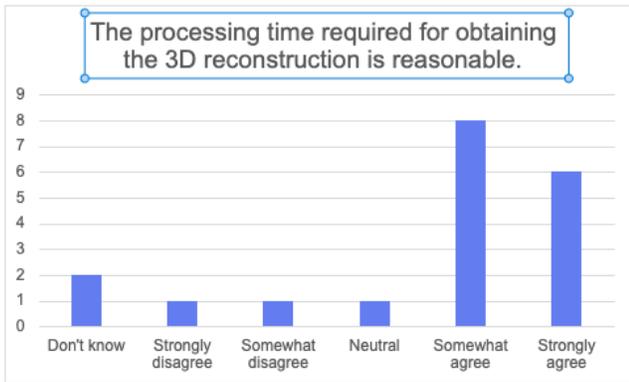


The method result integrates well with other software tools (e.g., for editing, visualization, or further analysis).



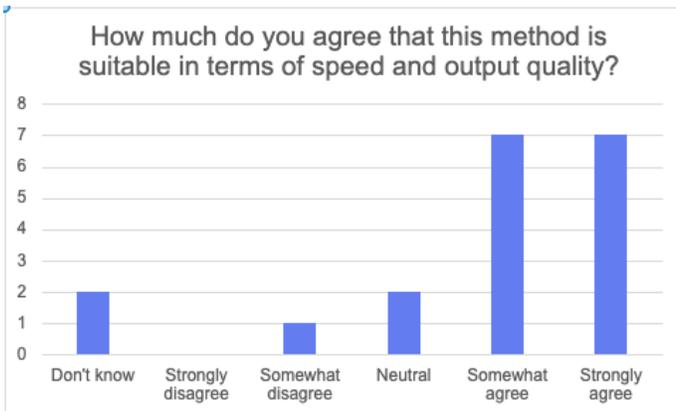
| Opinion | Count |
|-------------------|-------|
| Don't know | 8 |
| Strongly disagree | 0 |
| Somewhat disagree | 2 |
| Neutral | 0 |
| Somewhat agree | 6 |
| Strongly agree | 3 |

The processing time required for obtaining the 3D reconstruction is reasonable.



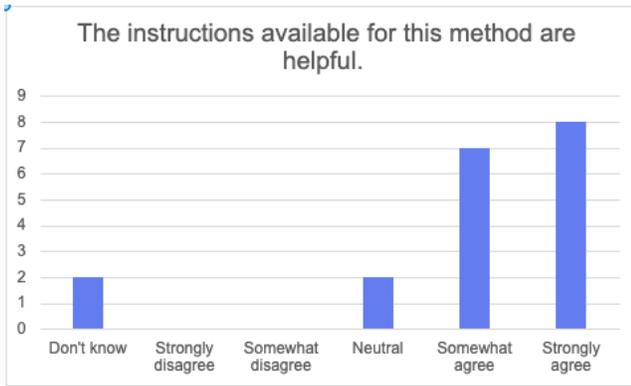
| Opinion | Count |
|-------------------|-------|
| Don't know | 2 |
| Strongly disagree | 1 |
| Somewhat disagree | 1 |
| Neutral | 1 |
| Somewhat agree | 8 |
| Strongly agree | 6 |

How much do you agree that this method is suitable in terms of speed and output quality?



| Opinion | Count |
|-------------------|-------|
| Don't know | 2 |
| Strongly disagree | 0 |
| Somewhat disagree | 1 |
| Neutral | 2 |
| Somewhat agree | 7 |
| Strongly agree | 7 |

The instructions available for this method are helpful.



| Opinion | Count |
|-------------------|-------|
| Don't know | 2 |
| Strongly disagree | 0 |
| Somewhat disagree | 0 |
| Neutral | 2 |
| Somewhat agree | 7 |
| Strongly agree | 8 |

Did you encounter any errors?

| Errors | Count |
|--------|-------|
| No | 16 |
| Yes | 3 |

If you did have any problem, please elaborate.

[Free text]

The service experienced multiple generation failures due to platform issues. In some cases, it remained stuck at the "Initializing" stage. Additionally, the handling of the object in the preview window could be improved.

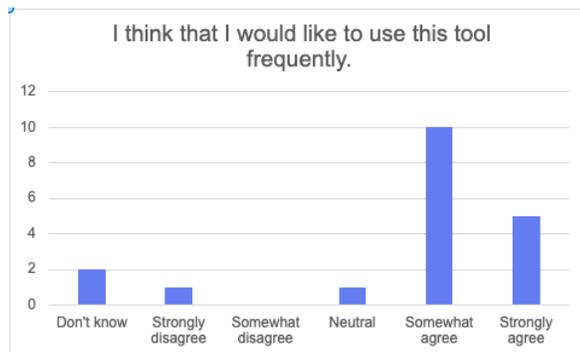


Evaluation of all services

Did you succeed in getting to the end of the test?

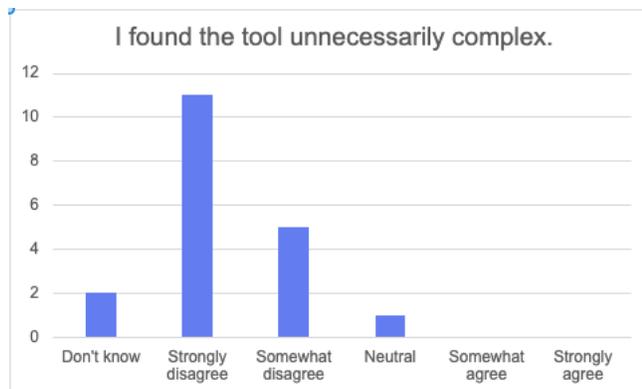
| Response | Count |
|--|-------|
| No, I got stuck, but I can still provide an assessment of the parts I completed. | 1 |
| No, I got stuck early in the process. | 2 |
| Yes | 16 |

I think that I would like to use this tool frequently.



| Opinion | Count |
|-------------------|-------|
| Don't know | 2 |
| Strongly disagree | 1 |
| Somewhat disagree | 0 |
| Neutral | 1 |
| Somewhat agree | 10 |
| Strongly agree | 5 |

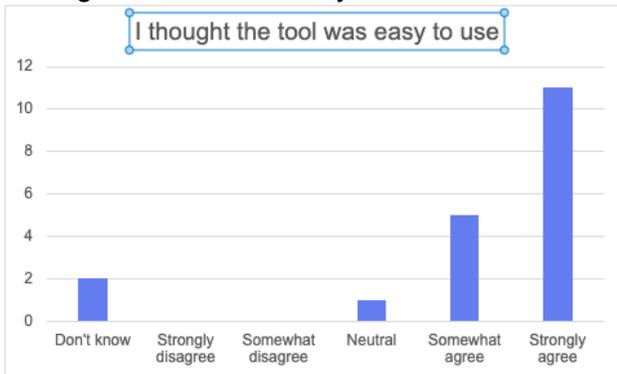
I found the tool unnecessarily complex.



| Opinion | Count |
|-------------------|-------|
| Don't know | 2 |
| Strongly disagree | 11 |
| Somewhat disagree | 5 |
| Neutral | 1 |
| Somewhat agree | 0 |
| Strongly agree | 0 |

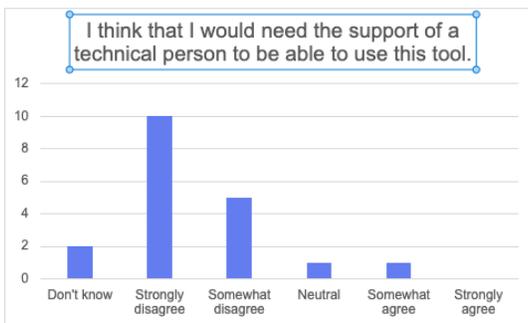


I thought the tool was easy to use.



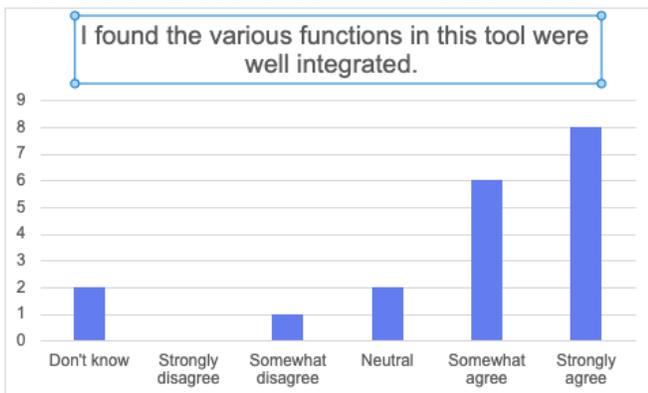
| Opinion | Count |
|-------------------|-------|
| Don't know | 2 |
| Strongly disagree | 0 |
| Somewhat disagree | 0 |
| Neutral | 1 |
| Somewhat agree | 5 |
| Strongly agree | 11 |

I think that I would need the support of a technical person to be able to use this tool.



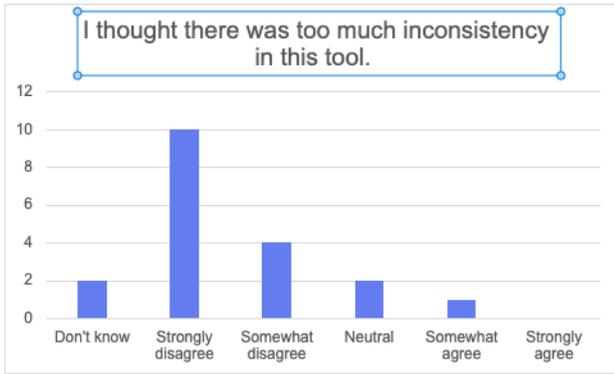
| Opinion | Count |
|-------------------|-------|
| Don't know | 2 |
| Strongly disagree | 10 |
| Somewhat disagree | 5 |
| Neutral | 1 |
| Somewhat agree | 1 |
| Strongly agree | 0 |

I found the various functions in this tool were well integrated.



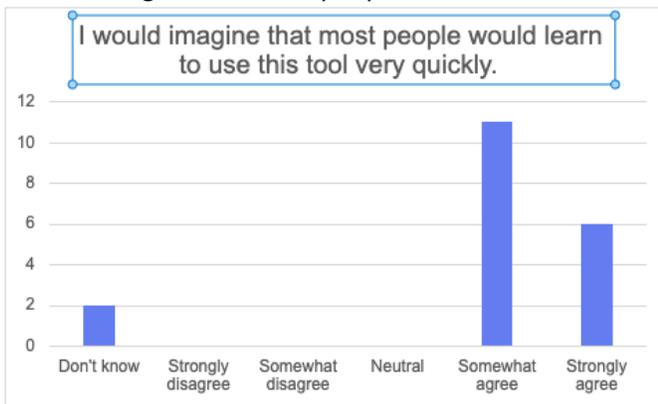
| Opinion | Count |
|-------------------|-------|
| Don't know | 2 |
| Strongly disagree | 0 |
| Somewhat disagree | 1 |
| Neutral | 2 |
| Somewhat agree | 6 |
| Strongly agree | 8 |

I thought there was too much inconsistency in this tool.



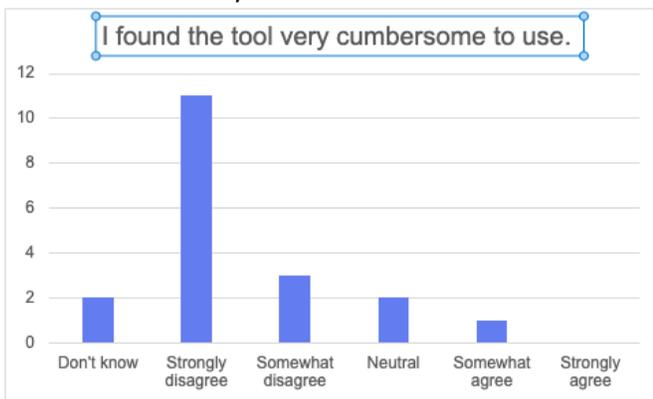
| Opinion | Count |
|-------------------|-------|
| Don't know | 2 |
| Strongly disagree | 10 |
| Somewhat disagree | 4 |
| Neutral | 2 |
| Somewhat agree | 1 |
| Strongly agree | 0 |

I would imagine that most people would learn to use this tool very quickly.



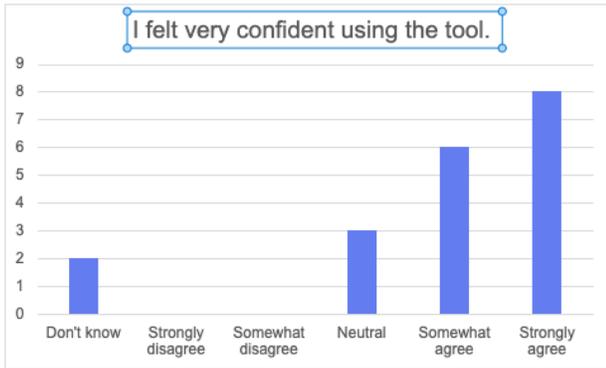
| Opinion | Count |
|-------------------|-------|
| Don't know | 2 |
| Strongly disagree | 0 |
| Somewhat disagree | 0 |
| Neutral | 0 |
| Somewhat agree | 11 |
| Strongly agree | 6 |

I found the tool very cumbersome to use.



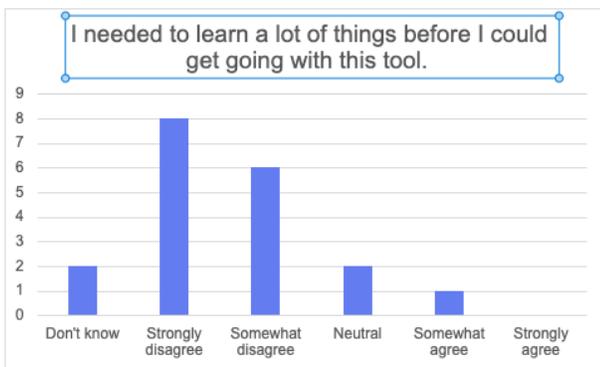
| Opinion | Count |
|-------------------|-------|
| Don't know | 2 |
| Strongly disagree | 11 |
| Somewhat disagree | 3 |
| Neutral | 2 |
| Somewhat agree | 1 |
| Strongly agree | 0 |

I felt very confident using the tool.



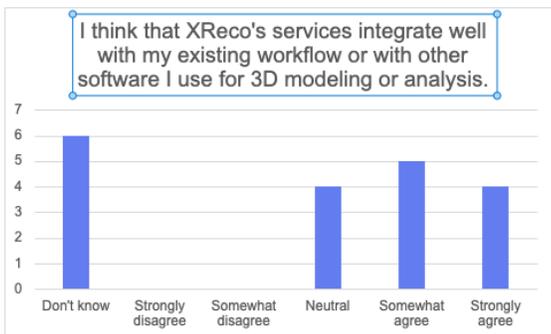
| Opinion | Count |
|-------------------|-------|
| Don't know | 2 |
| Strongly disagree | 0 |
| Somewhat disagree | 0 |
| Neutral | 3 |
| Somewhat agree | 6 |
| Strongly agree | 8 |

I needed to learn a lot of things before I could get going with this tool.



| Opinion | Count |
|-------------------|-------|
| Don't know | 2 |
| Strongly disagree | 8 |
| Somewhat disagree | 6 |
| Neutral | 2 |
| Somewhat agree | 1 |
| Strongly agree | 0 |

I think that XReco's services integrate well with my existing workflow or with other software I use for 3D modelling or analysis.



| Opinion | Count |
|-------------------|-------|
| Don't know | 6 |
| Strongly disagree | 0 |
| Somewhat disagree | 0 |
| Neutral | 4 |
| Somewhat agree | 5 |
| Strongly agree | 4 |

If you would like to provide any other remarks, please do so.

- It's a nice prototype, but the UX/UI is still a little flawed.
- Failed due to technical issues. No service ever succeeded, always error.
- The documentation about the different parameters and how their choice affects quality and execution time should be improved



- the UI feels a bit clunky. It is not clear when selecting a basket what pictures are actually selected from the asset preview, because there is a button to "select all" which is not needed, and when I used it to actually add pictures in my custom basket (I tried the lego set) I had to do select all > add multiple times because it would only add the ones from the current page, and I had to go up and down to change the page and select and add again.
- no content basket for GDNERf. It says it needs a zip as input but it is not clear what the contents of this zip file should be. I tried building my own content basket with the zip files taken from the search (ZAUBAR zip and Rai zip) but it didn't work.
- It would have been nice, at least for the testers, to have a short explanation of how the different kind of engines work.
- I think the preview part of the results obtained could be improved.
- I know that was not the purpose of the test, but I tried to upload a zip file and succeeded. When I tried to upload an image I got : ## Application error: a client-side exception has occurred (see the browser console for more information).

Annex III: XRCapsules

The XR Capsules test starts in the orchestrator with a preconfigured content basket. From there, the user triggers the authoring tool, taking them to the login window of the application. With the step-by-step instructions, the user is expected to be able to navigate the app in the building of their extended reality application.

The practical part of the test concluded in the player, where the tester was able to visualize their augmented reality application just as they had designed it. Afterwards, came an evaluation of the 10 SUS questionnaire Likert scale as well as multiple choice questions and open-ended questions.

The test - B2 – XRCapsules

Dear tester,

Thank you for your participating in this XRCapsules test, a versatile and easy to use authoring tool. For this test, you will be creating a personalized Smartphone AR experience. Following these instructions, in the end you will be able to walk around an Augmented Reality Scene with your Android Phone.

If you have any questions about the XRReco project, follow this link.

To begin, please fill in the following form. Make sure you have enough time, that your computer and your Android phone have enough battery. This test works best in the "Chrome" browser.

Pre-requisites:

- Computer with internet connection with Windows, Mac or Linux
- Android phone (not compatible with iOS)
- Chrome browser

This test has 3 parts: the setup, in which you install the Android application, and the test itself and the evaluation.



To participate, you must have received your user credentials. If you have not, please email your XReco contact. If you are unable to finish the test or have any general questions, contact your XReco tester lead or mcaballero@mediapro.tv

XReco is a Horizon Europe Innovation Project co-financed by the EC under Grant Agreement ID: 101070250.

SECTION 1

- I am over 18 years old and consent to the use of this data.
- I am:
- Male
- Female
- Other
- What's your background? Please select the one you identify most with.
- I am a general user or non-technical expert, with knowledge in office and e-mail applications, web browsers, etc.
- I have some knowledge in 3D modelling/design software: AutoCAD, Blender, etc.
- Other

SECTION 2

XRCapsules Player Setup Instructions.

Android Setup

- Check Android Version:
- Ensure your Android device is running Android 7.0 (Nougat) or higher.
- To check: Go to Settings > About phone > Android version
- AR Requirements:
- XRCapsules Player uses Augmented Reality technology and requires Google AR Services.
- Most modern Android phones come with Google AR Services pre-installed.
- If you encounter AR-related issues later, you may need to install or update Google Play Services for AR from the Google Play Store.

Installing XRCapsules Player

- Download the App:
- On your Android device, visit: [XRCapsules APK]
- Tap on the download button to start downloading the APK file.
- Enable Installation from Unknown Sources (if needed):
- If this is your first time installing an app outside of the Google Play Store, you'll need to enable installation from unknown sources.
- Go to Settings > Security (or Privacy)
- Enable Install from Unknown Sources or Install Unknown Apps



- Select the browser you used to download the APK and toggle the permission on.
- Install the App:
- Open your Downloads folder or notification panel
- Tap on the downloaded XRCapsules Player APK file
- Tap Install when prompted
- Wait for the installation to complete

Initial Launch & Permission Setup

- Open XRCapsules Player:
- Locate the XRCapsules Player icon on your home screen or app drawer
- Tap to launch the application
- Grant Permissions:
- When prompted, allow the app to access:
- Camera (Required for AR functionality)
- Storage (For saving and loading scenes)
- Location (If applicable)
- Verify AR Functionality:
- The app should open its AR view, showing your real environment through the camera
- If everything loads correctly, AR is working properly
- Close the App:
- Press the home button or use the back gesture to exit
- The setup is now complete

You are now ready to proceed with the XRCapsules testing process.

SECTION 3 TUTORIAL

Here starts de PC experience. Make sure your explorer is open in full screen view. Otherwise, you may see overlapping information.

Here you can watch a XRCapsules Video Tutorial video

Step 1: Select your files - Log into Orchestrator

The first thing to do when creating an experience is to select the assets that we are going to work with. We do this not in XRCapsules directly, but in the XReco platform. Let's go ahead and log in.

Open the Orchestrator website: <https://xreco.az.mog-technologies.com/login>

Log into the orchestrator with your credentials, available in your invitation email.

Confirm that the login process is smooth and secure.



Step 2: Select the XRCapsules Basket

If you were to log into the orchestrator as a new user, you would have to create a new "basket" to add your content to be used in XRCapsules. For the ease of this test, the basket has already been created for you with specific assets to be used in next steps.

To the left, you will see a list of "Baskets". Click on the basket "XRCapsules Content Basket" to select it.

Confirm that there are assets that appears in the basket. The following picture is an example; you are not expected to see the same assets.

Step 3: Send the files to XRCapsules

Now we know which files we want to send to the XRCapsules, which will help us build our experience. To send them:

With the XRCapsules basket selected, click the "Play" button corresponding to the XRCapsules' XReco Services to invoke it. This will send the basket to XRCapsules application, opening a new tab. Please, confirm that the application loads without errors. If you get an error, it's probably because you have not selected a basket.

Step 4: Create a New Project and Navigate the Scene

Now, it's time to get creative. We have our XRCapsules tool menu open.

To start, we will create a new project in the XRCapsules web editor.

- The New Project tab will be automatically selected, but if it is not, click on it.
- Choose a name for your project: for this test, it should be your name and last name initials + your favourite number. For instance, MCB11, AFM16, ICP8. Please remember your project name for future steps.
- Choose the template "Smartphone AR", which we will be using for this test.
- Then, choose an "Environment" by clicking the check box. Then, choose one of the 4 environments that you desire. It's up to you.
- Lastly, click "Create" to customize your experience.

By clicking create, this is what it should load: a scene like it shows in the picture. The background is just for reference.

Warning: Do not refresh the page. Whatever progress you make will be lost if you refresh the page.

Play around with the controls

To toggle between default view and Front view, press the F1 key on your keyboard.

To toggle between default view and Side view, press the F2 key on your keyboard.

To toggle between default view and Top view, press the F3 key on your keyboard.



If you don't have the function keys row (F1-F12) on your keyboard, you may use the controls on the bottom right corner and the toggle button on bottom centre.

To zoom in and out, use the mouse scroll wheel

To navigate the scene, hold the Control key on your keyboard while dragging (left mouse button pressed)

To orbit around the scene, hold the Alt key on your keyboard while dragging (left mouse button pressed)

To the left you can see the assets imported from the orchestrator's basket

You can show or hide the selected item by clicking on the "eye" symbol.

To the right, you can use the controls to move items around your screen.

You can delete the selected item.

At the top, there is a menu with options: load files, download files, copy a .json file, configurate the space, and save your project. If you hover with your mouse over a button, you will see a text box which labels each button. For further explanation, you can find:

On the left side:

1. Home to go back to the initial screen to create the project.
2. Upload 3D models from your local folder or Zip file.
3. Upload image from your device or URL.
4. Upload audio from your device or URL.
5. Upload video from your device or URL.
6. Upload JSON from your device or URL with other scenes.

In the middle, the name of the project.

On the right side

7. Create camera view.
8. Manage the space of the working area.
9. Save the project.
10. Open code screen to see the JSON.

Step 5: Modify Asset Properties and Hide/Show Assets

Now it's your turn to configure the scene to your taste. Play with the objects by moving them around with the pivot controls (as seen on screen) or modifying the right menu inspector inputs. In the left-side panel, use the "eye" button to hide and show an asset.

- Select an asset in the 3D workspace.
- Modify its position, rotation, and scale using the right-side panel.
- Confirm that the changes are reflected in the scene.

Remember:



Holding the "Control" button + maintaining the left mouse button: you can navigate the scene in a single axis.

Holding the "Alt" + maintaining the left mouse button: you can navigate the scene in an "orbit" fashion.

Warning: Do not refresh the page. Whatever progress you make will be lost if you refresh the page.

Step 6: Add Triggers to Assets

You can further customize your scene, apart from arranging assets, by animating them with triggers. The triggers can be configured in XRCapsules, but can't be played on this configurator. To see the result, you can view it in the XRCapsules Player once you have saved your experience. Let's go ahead with the triggers:

You can further customize your scene, apart from arranging assets, by animating them with triggers. The triggers can be configured in XRCapsules, but can't be played on this configurator. To see the result, you can view it in the XRCapsules Player once you have saved your experience. Let's go ahead with the triggers:

Step 7: Save Project

Once you are happy with how the assets are placed, save your work by clicking the save button.

XRCapsules Player

Now, you're going to visualize your creation.

On the menu, press the Home button:

Get the project public JSON URL You will see a list of public JSON files. Every JSON file is a project with a scene description as the one you just created and saved.

On the list, look for your recently created project. You can see its name, full URL (deep link / universal link) and a button to launch the project on a device.

You can do either of those options:

A: On an Android XR capable device (tablet or smartphone) with the XRCapsules Player app installed, just press the play button of your saved project. The XRCapsules Player app will launch and automatically load your project.

B: On the device you used to create the project, just right click over the play button and a contextual menu will appear. Press "Copy Link Address". Send it to your Android XR capable device (via mail or a messaging app). On the device, copy the received link and open the XRCapsules Player app. The app will access your clipboard and read the copied link, then automatically load your project.

Scan the QR code



Using the XRCapsules Player

You are now on the XRCapsules Player mobile app and your project is being loaded. At first you will not see any content. You have to slowly move around, focusing on the floor and surroundings with your device's camera. Then, touch on the screen where you want to attach the content.

The project you created on XRCapsules Web editor will be placed on your environment. You can move it to another location just by clicking again on a valid surface (the floor or a table).

Interact with the content: You can watch videos, listen to audios or see different images while you walk around 3D models.

Evaluation

Thank you for trying out the XRCapsules Augmented Reality Smartphone AR experience. Now, provide your honest opinion.

Please mark these statements:

- I think that I would like to use this system frequently.
- I found the system unnecessarily complex.
- I thought the system was easy to use.
- I think that I would need the support of a technical person to be able to use this system.
- I found the various functions in this system were well integrated.
- I thought there was too much inconsistency in this system.
- I would imagine that most people would learn to use this system very quickly.
- I found the system very cumbersome to use.
- I felt very confident using the system.
- I needed to learn a lot of things before I could get going with this system.

Now reply to this questions with the scale: Very easy, Easy, Neutral, Difficult, Very difficult

- How easy was it to create a new project (input project data, select template, environment, etc.)?
- How useful did you find the ability to import 3D models, images, videos, and audio files?
- How clear and accessible were the asset controls in the 3D workspace (position, rotation, scale)?
- How easy was it to add and manage triggers for different assets?
- How satisfied were you with the navigation controls (Control + Mouse, Alt + Mouse)?
- How helpful were the predefined views (F1, F2, F3)?
- How useful did you find the code export feature and JSON download?
- Overall, how satisfied are you with XRCapsules?

And open-ended questions:



- What would you use XRCapsules for?
- What other uses can you imagine for XRCapsules?
- Would you like to provide any other remarks that we haven't asked you about?

Results:

Population

| Gender | Count |
|--------|-------|
| Male | 6 |
| Female | 1 |
| Other | 0 |

| Experience | Count |
|-----------------|-------|
| General user | 3 |
| Some experience | 4 |
| Other | 0 |

SUS Questionnaire

1 Acceptance - I think that I would like to use this system frequently.

| | |
|-------------------|---|
| Strongly disagree | 3 |
| Somewhat disagree | 2 |
| Neutral | 2 |
| Somewhat agree | 0 |
| Strongly agree | 0 |

2 Complexity - I found the system unnecessarily complex.

| | |
|-------------------|---|
| Strongly disagree | 2 |
| Somewhat disagree | 3 |
| Neutral | 0 |
| Somewhat agree | 1 |
| Strongly agree | 1 |

3 Ease of use - I thought the system was easy to use.

| | |
|-------------------|---|
| Strongly disagree | 1 |
| Somewhat disagree | 1 |
| Neutral | 0 |



| | |
|----------------|---|
| Somewhat agree | 3 |
| Strongly agree | 2 |

4 Support needed - I think that I would need the support of a technical person to be able to use this system.

| | |
|-------------------|---|
| Strongly disagree | 3 |
| Somewhat disagree | 2 |
| Neutral | 0 |
| Somewhat agree | 1 |
| Strongly agree | 1 |

5 Integration - I found the various functions in this system were well integrated.

| | |
|-------------------|---|
| Strongly disagree | 1 |
| Somewhat disagree | 1 |
| Neutral | 3 |
| Somewhat agree | 3 |
| Strongly agree | 0 |

6 Inconsistency - I thought there was too much inconsistency in this system.

| | |
|-------------------|---|
| Strongly disagree | 2 |
| Somewhat disagree | 1 |
| Neutral | 1 |
| Somewhat agree | 3 |
| Strongly agree | 0 |

7 Learning Curve - I would imagine that most people would learn to use this system very quickly.

| | |
|-------------------|---|
| Strongly disagree | 1 |
| Somewhat disagree | 2 |
| Neutral | 0 |
| Somewhat agree | 3 |
| Strongly agree | 1 |

8 Cumbersomeness - I found the system very cumbersome to use.

| | |
|-------------------|---|
| Strongly disagree | 1 |
| Somewhat disagree | 0 |
| Neutral | 6 |
| Somewhat agree | 0 |
| Strongly agree | 1 |

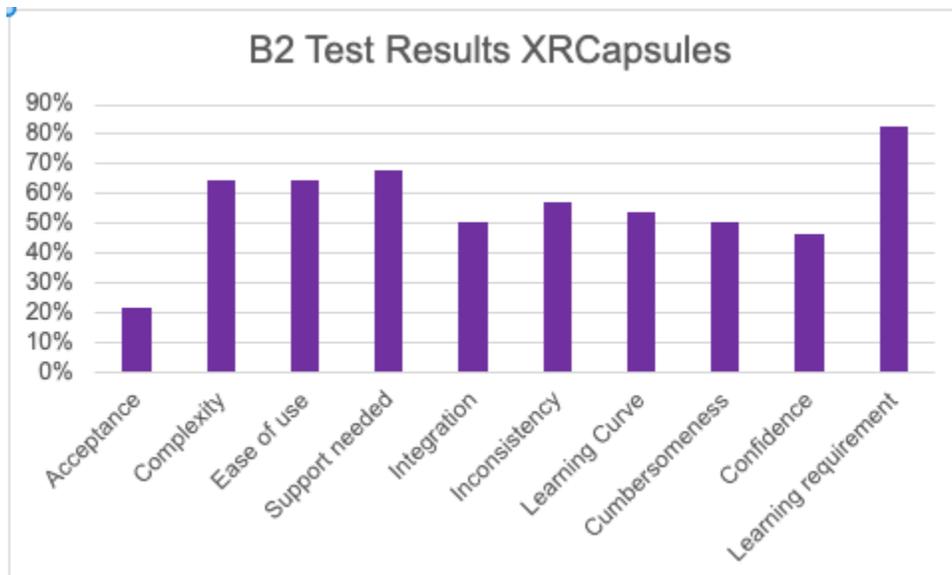
9 Confidence - I felt very confident using the system.

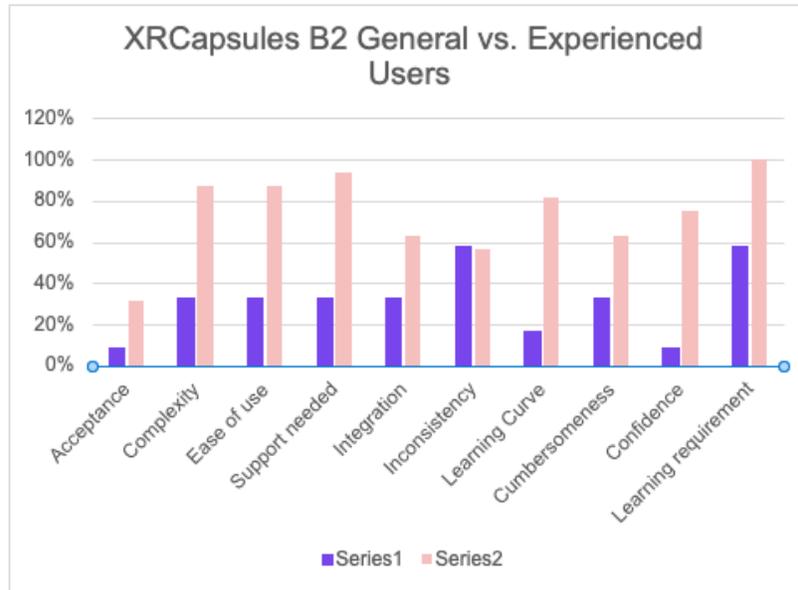
| | |
|-------------------|---|
| Strongly disagree | 2 |
| Somewhat disagree | 1 |
| Neutral | 1 |
| Somewhat agree | 3 |
| Strongly agree | 1 |

10 Learning requirement - I needed to learn a lot of things before I could get going with this system.

| | |
|-------------------|---|
| Strongly disagree | 5 |
| Somewhat disagree | 0 |
| Neutral | 0 |
| Somewhat agree | 2 |
| Strongly agree | 0 |

The results from even numbered questions were inverted for ease of interpretation as described in the methodology section:





What would you use XRCapsules for?

- Maybe for showing scenes from pictures or something in AR, but I can't find any other uses right now
- Scene creation prototyping and setup, as well as playground and sharing of virtual experiences.
- Planning for physical space set up like showroom.

Would you like to provide any other remarks that we haven't asked you about?

GENERAL USER EXPERIENCE

Positive Aspects

- Web application (PC): Well-executed and functional.
- Tools: Found useful overall.
- Editor Functionality Requests:
 - Export whole scene to use in 3D software (suggested USD format).
 - Preview triggers in editor (like Spline.Design).
 - Include virtual 3D scenes, not only 360° backgrounds (like Spatial.io).



NEGATIVE FEEDBACK & ISSUES

Android App (XRCapsules App)

Project Handling:

- Unable to save projects.
- Saved projects not appearing in project list.
- Could not launch existing projects (Play button unresponsive).
- Pasting a project URL not possible (input field unusable).

Clipboard Integration:

- Cumbersome when working across devices.
- Loading from URL doesn't work; clipboard contents unclear; URL format not displayed.

Visual/Rendering Issues:

- Brown polygon artifacts obscure parts of the scene (unknown cause).

Mobile UI/UX:

- Project table formatting broken on smartphone.
- "xrcapsule://loadcapsule" URL association not working.
- Scenes fail to open from mobile browser to app.

Web Application / XRCapsules Editor (PC)

Navigation & Views:

- View switching (Front/Side/Top) is inconsistent:
- Must reset to default view before switching.
- Zoom and navigation reset after changing views.
- Selected object gets deselected when switching browser tabs.
- Thin/flat objects (videos, images) not visible in top/side views.
- Small objects obscured by larger ones (can't select them).

Editor Usability:

- Drag-and-drop in 3D scene doesn't work.
- Transform handles on objects are too small.
- Object selection in Inspector is confusing:
- Pressing ENTER then DELETE deletes object instead of clearing field.
- Resizable JSON panel can exceed container (should be fixed size).
- Cannot close code panel once opened.
- Undo functionality missing.
- Generated filenames are not intuitive (should reflect user-defined name).
- Tooltips missing (would help explain unclear UI elements).
- Meaning of P, R, and S coordinates is unclear.
- "Upload asset" function not clearly labeled (should indicate it's for 3D content).

Project Saving & Stability:

- Project not saved after clicking "Save Project":
- Popup says "JSON file uploaded successfully" (misleading).
- On "Home", popup says unsaved changes exist, despite saving.



- Connection to assets/project lost after page refresh.
- Editor crashes when reopening project with triggers (canvas goes white).
- "Unsaved changes" warning shown even immediately after saving.

Media/Trigger Issues:

- Cannot preview triggers in-editor (feature requested).
- Not clear if transformation must be set before or after adding a trigger.
- Videos autoplay — user prefers on-request playback.
- Camera activation does not render the scene from the camera's view.

Instructions & Onboarding

- Instructions are misleading:
- Unclear when to use PC vs Android device.
- Mobile web app is practically unusable.
- Terminology and UI lack clarity (e.g. upload button, coordinates).
- No guidance on error handling or expected project saving behaviour.

FEATURE REQUESTS & SUGGESTIONS

| Category | Suggestion |
|--------------------|--|
| Export | Use USD format for full scene export to preserve integrity |
| Triggers | Visual preview of triggers in-editor (like Spline.Design) |
| Scene Types | Add support for full virtual scenes (not just 360° backgrounds), similar to Spatial.io |
| UI/UX | Add icons/labels for clarity (e.g. upload asset for 3D content), tooltips, better naming for exports |
| Inspector | Support text field selection, prevent accidental deletion |
| Views | Retain zoom/navigation when switching views |
| Stability | Fix crashes on object selection with triggers |
| Project Management | Improve feedback and accuracy of save/load states |

Annex IV: Unity

Section 1:

Dear tester,

Thank you for your participation.

Please fill in the following form. Make sure you have enough time, that your computer has battery, and that you follow the provided instructions. The test will take about 30-60 minutes (without counting with the setup).

For this test, you will be asked to time yourself after you are done with the setup. The test will tell you when to start your timer.

We assume you already have a recent version of **Unity 6** (we would recommend version 6000.1.4 but a newer version of unity 6.1 will also work just fine) installed on your machine, if not please do so before your test. You will need admin rights to install unity, instructions can be found here: <https://learn.unity.com/tutorial/install-the-unity-hub-and-editor#>

You can download some sample assets (3d, audio, image) from here: <https://drive.google.com/file/d/1hM7YTglz4641XfA9h9xCxtpawbBGx1cf/view?usp=sharing>
But you can also use your own 3d assets.

You can then download and extract the XReco Authoring Tool from here: https://drive.google.com/file/d/1pnRrbXcOBSpyWUwCwaFoJ-OOLbkhZlfi/view?usp=drive_link

Please note that this program is a Minimum Viable Product (MVP) and therefore does not yet include all functionalities. There could be some incompleteness in the documentation and certain functions in the other scene templates. Additionally, further enhancements will be made to improve the understandability of the program. We greatly appreciate any detailed feedback you can provide.

We expect for testers to be autonomous throughout the test. If you can't get to the end or get stuck when following the test, please pull through with what you can do, until you get to the Evaluation section: your insights are still valuable to us. Still, if you get stuck or can't get to the Evaluation part, please contact: holger.durach@capgemini.com

If you have any questions about the XReco project, follow this link: [Home - XReco](#)

If you are unable to finish the test or have any general questions, contact your XReco tester lead.

For more detailed explanation you can also watch our user test videos that are linked in the corresponding steps in this document.

XReco is a Horizon Europe Innovation Project co-financed by the EC under Grant Agreement ID: 101070250.



I am over 18 years old and consent to the use of this data.

I am:

- Male
- Female
- Other

What's your background?

- I'm some kind of technical expert
- My technical skills are "General user" / Non-technical expert
- I'm familiar with 3d Software

Section 2: Setup

Make sure that you have:

- a recent unity version installed (Unity 6.0.36 or newer).
- the sample assets extracted on your disk
- the authoring tool extracted on your disk
- an internet connection, so that you can reach the documentation
- one hour of time

Then you can start the timer and start with the user test.

Section 3: Welcome

We will now explain the basic usage of the Game Engine Unity and show you some of the features that the XReco Authoring Tool provides on top of it. Something, others take a long time to learn - and we will do in less than an hour! At the end, you will even know how to make your own infographic application.

Add the Authoring Tool project

Open the Unity Hub and select "Add" then "Add project from disk" and select the folder with the extracted Authoring Tool that you downloaded during the setup.

Optional Video introduction can be found here: <https://drive.google.com/file/d/1BDvUuuE-jZ1CFu0b2GWtiwYm5zJnfmuO/view?usp=sharing>

Navigate to your extracted Authoring Tool folder and select "Open". Then you will find the project in the Unity Hub, simply open it by clicking on it.

Remark: If you don't have the exactly correct unity version installed (for example: Unity 6.0.44 instead of Unity 6.0.36), you will be asked to download it, but you can also choose to "change version". As long as it's a newer version than Unity 6.0.36 it will work fine.



Remark: You have to confirm twice, that you really want to change the unity version.

Section 4: Tutorial

After a short loading time the Authoring Tool (AT) will greet you with a welcome dialog. We start with an interactive tutorial which explains you the basics of the Unity interface, click on Open Tutorials and select the "Unity Basics" Tutorial.

Optional Video instructions to the next steps (not including the tutorial, which should explain itself) steps:
<https://drive.google.com/file/d/1qh43vL4r10Q6MQdAEaARFHqmmhvBSngl/view?usp=sharing>

We start with one of our interactive tutorials, which explains some of the basics of Unity and the Unity Editor. Select "Open Tutorials" and then select the "Unity Basics" tutorial. Follow the tutorial steps to learn more about the Unity.

When you are done with the tutorial (~5 minutes) continue with the next step in this document.

Step 2 Start working with a new Template Scene

After we have now learned the basics of the Unity Editor Interface we start with one of the provided Templates. We will use the most basic one, the Model Viewer.

Select the Modelviewer Template and click on Create (if unity asks whether you want to save the results of the basics-tutorial, just select "no")

Your project should now look like this.

On the left side you can see all the important objects highlighted in purple. On the right side you can see that currently the TemplateDescription Object is selected. This object holds a short overview of the template. It also holds a reference to the documentation, you can open it by clicking on the "--> Open Documentation" button in the inspector.

Now we want to import our own assets. We start with the 3d model. In the Project View (at the bottom third of the editor) locate the "My Assets" folder, open it, right click inside, and select "Import New Asset".

Now browse to the extracted sample assets and select the "Test_3dModel" file. After a short importing-dialog the 3d model will be available.

(If you want you can also import the Texture, Video and Audio file)

Now we want to display it in the scene. For this we select the "3D Asset PlacementHelper" in the Hierarchy View (on the left side) and we have to change the "Content to Place" Property in the Inspector (right side). Here we select our newly imported "Test_3dModel".

Optional video instructions for the next steps:



<https://drive.google.com/file/d/1nYs5NSB8frp--c0uI0Wfpod26GBVndll/view?usp=sharing>

Nice. Now we want to save our scene. Select File/Save from the TopMenu, or press Ctrl+S. In the popup-dialog you can select a folder (for example the "My Scenes" folder) and specify a good name, for example "myModelViewer".

Now we want to optimize the lighting a bit, play around with the "Light Intensity" and "Light Angle" sliders, until you find nice values.

Now we want to add an annotation to our model. For this we open the "Prefabs Window", which contains a collection of all XReco Prefabs. Prefabs are preconfigured objects that provides a specific functionality.

Optional video instructions for the next steps:
<https://drive.google.com/file/d/1qbd8Tbye9DvODkeKxG7a7Vjdl6DDt-CG/view?usp=sharing>

Create the 3dAnnotation, by clicking on 'Create'. Observe that there is also a preview image and a link to the documentation here

After you created the annotation it will be attached to your Mouse cursor, therefore you can easily position it roughly at the correct location in your model. Once it is close to the position where you need it, simply click once more. Now you can move it to the exact position where you need it, by dragging one of the three coloured arrows of the gizmo. You can at any time reactivate the "attach to cursor" feature, by selecting the object you want to position ("3dAnnotation" for example) and select "Attach To Cursor" from the XReco toolbar in the sceneview (or keyboard-shortcut Ctrl+Shift+X).

You can also rotate the annotation, by selecting the "Rotate Tool" (keyboard shortcut 'E'). To go back to moving the object select the "Move Tool" from the toolbar (or keyboard shortcut "W")

Now we want to setup the content of the annotation. For this we select the "3dAnnotation" object in the SceneHierarchy Window (on the left side of the Editor). Then the properties of the annotation are displayed in the inspector on the right side. Try to change the text, add an image and maybe also add an audio file to the annotation (you can use the files from the test assets pack). Remember that you can also open the documentation by clicking on the "?" icon in the inspector, to get more explanations about each of the properties.

Optional video instructions:
https://drive.google.com/file/d/1GKNvIMpJmSGmgr0h7n8waM8ur8P9eMH_/view?usp=sharing

Now it's time to save the scene again (Ctrl+S) and test it. You can do so by simply pressing the "Play" button in the top Center of the editor.

The App should start running in the editor.

Try to open the annotation by clicking on it.

You can move the camera around when you press the right mouse button and then move the mouse. You can also zoom with the mouse wheel. This functionality comes from the "OrbitCamera", if you want you can also inspect that object in the scene and play around with it's values (start position, movement limits, movement speed...)



Now we want to build a standalone application. For this we simply need to click on the corresponding option in the XReco Menu. "XReco/Build/Build Scene For Desktop" (shown in the image). This process might take some time, if you do it the first time.

Once the building-process is done, you should get a message in the console telling you about the Success and also a File Explorer window containing the build output will be opened. This is your app. You can start it by double clicking the exe file. You can also send this folder to colleagues.

Great, you are done! Stop the timer.

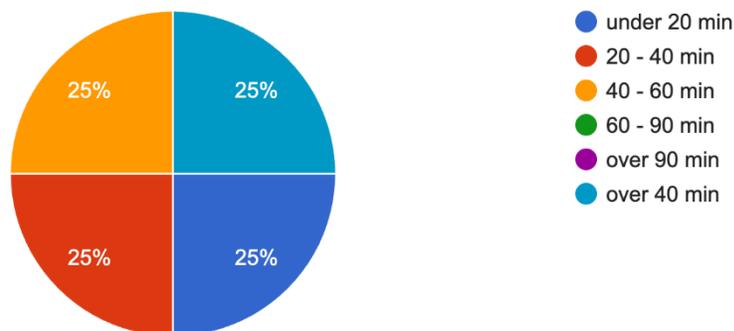
Bonus: If you still have some time available you can play around a bit more with the scene. Maybe try to change the UI text from "XReco Model Viewer" to something more customized. Or try to add more annotations. Or maybe try to add a greenscreen video (this is another prefab you can find in the "Prefabs Window". You can also try to make this greenscreen video to always face the camera (Hint: There might be a script that you can add to the greenscreen video object).

Evaluation

How long did you take to complete the entire user test (in minutes)?

How long did you take to complete the entire user test (in minutes)?

4 responses



SUS questionnaire:

Acceptance - I think that I would like to use this system frequently.

| Opinion | Count |
|-------------------|-------|
| Don't know | 0 |
| Strongly disagree | 0 |
| Somewhat disagree | 1 |
| Neutral | 2 |
| Somewhat agree | 5 |
| Strongly agree | 1 |

Complexity - I found the system unnecessarily complex.

| Opinion | Count |
|-------------------|-------|
| Don't know | 0 |
| Strongly disagree | 2 |
| Somewhat disagree | 4 |
| Neutral | 1 |
| Somewhat agree | 2 |
| Strongly agree | 0 |

Ease of use - I thought the system was easy to use.

| Opinion | Count |
|-------------------|-------|
| Don't know | 0 |
| Strongly disagree | 0 |
| Somewhat disagree | 2 |
| Neutral | 0 |
| Somewhat agree | 4 |
| Strongly agree | 3 |



Support Need - I think that I would need the support of a technical person to be able to use this system.

| Opinion | Count |
|-------------------|-------|
| Don't know | 0 |
| Strongly disagree | 3 |
| Somewhat disagree | 5 |
| Neutral | 0 |
| Somewhat agree | 1 |
| Strongly agree | 0 |

Integration I found the various functions in this system were well integrated.

| Opinion | Count |
|-------------------|-------|
| Don't know | 0 |
| Strongly disagree | 0 |
| Somewhat disagree | 2 |
| Neutral | 0 |
| Somewhat agree | 2 |
| Strongly agree | 5 |

Consistency - I thought there was too much inconsistency in this system.

| Opinion | Count |
|-------------------|-------|
| Don't know | 0 |
| Strongly disagree | 4 |
| Somewhat disagree | 3 |
| Neutral | 2 |
| Somewhat agree | 0 |
| Strongly agree | 0 |



Learning Curve - I would imagine that most people would learn to use this system very quickly.

| Opinion | Count |
|-------------------|-------|
| Don't know | 0 |
| Strongly disagree | 0 |
| Somewhat disagree | 2 |
| Neutral | 0 |
| Somewhat agree | 6 |
| Strongly agree | 1 |

Cumbersomeness - I found the system very cumbersome to use.

| Opinion | Count |
|-------------------|-------|
| Don't know | 0 |
| Strongly disagree | 2 |
| Somewhat disagree | 2 |
| Neutral | 4 |
| Somewhat agree | 1 |
| Strongly agree | 0 |

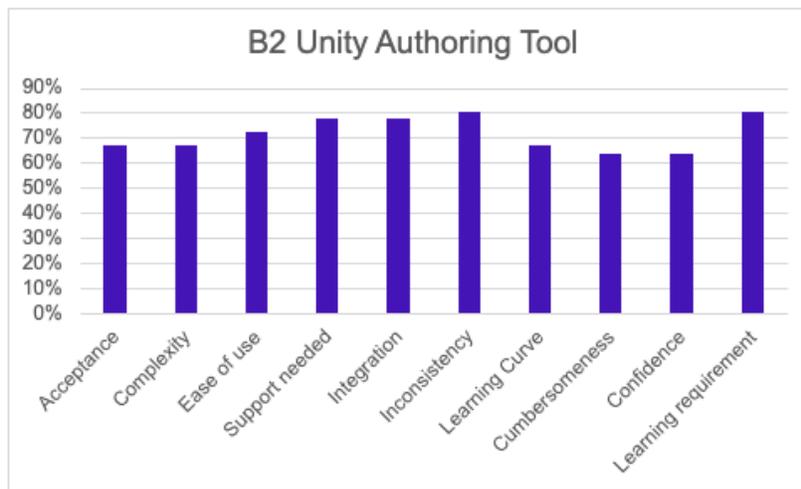
Confidence - I felt very confident using the system.

| Opinion | Count |
|-------------------|-------|
| Don't know | 1 |
| Strongly disagree | 0 |
| Somewhat disagree | 1 |
| Neutral | 3 |
| Somewhat agree | 2 |
| Strongly agree | 2 |



Learning requirement - I needed to learn a lot of things before I could get going with

| Opinion | Count |
|-------------------|-------|
| Don't know | 0 |
| Strongly disagree | 6 |
| Somewhat disagree | 0 |
| Neutral | 2 |
| Somewhat agree | 1 |
| Strongly agree | 0 |



What additional features would you like?

- Maybe the possibility to include more objects in the same view, in order to compare both of them or something like this.
- Simplified visualization of the annotation object. The Anchor would be sufficient.
- On click function that allows me to open the video if I want after placement in the annotation.
- Add video
- It would be good to learn how to switch between the different scenes you created and how to fix the start position of the camera that is seen in the end result.
- I would like the tool helping me placing several 3D models into the scene and not just one
- Improve the guide/this test by getting feedbacks from first time users.
- A tutorial overview which shows what you can achieve by investing how much time.
- remove all panels, only to show minimum information
- For simple/fast workflows these would be all the features I would need.



- i'd like to have a prefab for a live stream video with green screen, that could be from a video camera attached to the pc or from a IP stream

What did you like/dislike in the workflow?

- I liked that everything was very intuitive and easy. I didn't dislike anything.
- The XR Cubes serving an object anchors were very distracting. Also the 3D annotation Object was visually very complex with its Text, Video and Image parts.
- I liked everything as it was very straightforward and I did not have any issues. Everything run smoothly. I am imagine that it could be use as a tool to help users getting familiar with 3D tools in general and easily create a small XR application
- The Unity installation process and attaching the project to a very specific unity version
- The tutorial was very well written and the steps easy to follow. I think it helped that I have tried a similar template before, but I would still consider myself a beginner with Unity. What I dont understand is how to use the WASD keys to move in the scene view, it did not work on my computer (only to rotate game objects). I always use the mouse for navigation. I also think it is confusing for testers that there are annotations floating around the model even before you have even created one yourself. Lastly, the images in the instructions (here, in this form) are not always aligned with what the tester does: When you ask testers to create content for the annotations (e.g., name it number 1 or add an image), the tester-form is already showing the results many steps ago. Perhaps because the pictures were taken in game mode? This is a knit pick though, it is not that big of a deal. Overall, it was a very good test for me.
- I think the Authoring Tool could be a valuable asset for content placement systems, but I don't see the need for it to be linked to Unity. In my opinion, it would be less cumbersome as a standalone build.
- I liked that the annotations are automatically placed close to the model
- Explanations in the test have been very clear, just the 3D navigation was very unfamiliar to me, frustrated a little bit. I could only move once I rotate with the right mouse key.
- I was unsure where I use something which is pure "Unity" and which is "XReco".
- It's unity
- Having used Unity before, I found that the workflow is very easy to follow. The only thing I would maybe change would be the colors in the scene hierarchy (I know! How important can this be? But), I think that they are too bright/saturated and it makes traversal in the hierarchy more difficult. Maybe more subtle colors would do the thing.
- The tutorials were really helpful. The tool requires a bit of a learning curve but that's okay!
- I like the structure of the workflow, it was so clear to me

What additional Scene Templates would you like to see?



- I'm good with the ones there.
- I don't know.
- Virtual Production, AR experience Creation similar to SparkAR, VR templates, MXR templates
- Xreco Virtual production setup
- Perhaps a template to change the background colour?
- A map based placement scene
- No idea yet.
- Did not yet make up my mind. Some generic, usual places publicly known or available like living room, office, school, mechanical working site, fun park.
- none
- Cannot think of a use case needing more templates.
- I liked those that were there
- I'd like to have a templates for a news tv studio with environment, lights etc...

What other features from the XReco ecosystem would you like to see integrated? How would you like to see them integrated?

- I don't know.
- I don't know any other features of the XReco ecosystem.
- Connection to the XReco marketplace to search files and import them directly, similar to the sketchfab plugin or megascan for Unreal
- AI based 3D models generation
- I would like the marketplace to be directly integrated, to directly search, purchase and place assets
- I am not sure if this is already a feature, but it would be great to download assets directly from the XReco platform.
- No idea yet.
- Templates of objects to assemble a scene. E.g. for an office: tables, chairs, flip chart. For a living-room a TV, couch, table, plants. First of all designed in a simple way having in mind to replace them by ones created by the user, maybe with textures taken from originals.
- none
- Maybe searching for assets, and purchasing/downloading assets directly in my project.
- I would love direct access to my XReco baskets. That would enable a team to prepare annotation assets and even 3D models and then load them directly into the scene

Would you like to provide any other remarks that we haven't asked you about?

- I did not understand how to make the green screen video follow the camera movement.



Did you notice any errors during your test? If yes, please provide a brief description

- Yes, opening the Unity project and touching any option I had some troubles, but clicking quickly in the tutorial they ended.
- Missing: click on circle to open dialogue to add asset. Missing: Prefabs window is accessed via XReco menu. The word 'Gizmo' was not explained!. After building, there was not file explorer.
- No errors
- The link for the video instructions did not work (i just tried the last two)
- Only the one with the color chooser and the key "f" did not work in the scene to go back to the start position. At least that was what I expected.
- Despite the one with the colour, no.
- I think you forgot to ask about the time it took me ;-) (I had to take a call during the test and then later substracted a few minutes and added based on gut feeling, but I would say it was) 52 minutes - I'm a slow reader and played around a lot. Not everything was clear at first try, but I got around
- No

Did you manage to complete the whole test?

- Yes – 10 testers marked “Yes”
- No – 0 testers marked “No”

Section 6: Issue Reporting

Please describe your issues during the user test

Annex V: ZAUBAR

Section 1:

Dear tester,

Thank you for your participation.

Personal access is required to use the application. If you do not yet have one, **please contact Sebastian Göttert (Project Manager, ZAUBAR) by email at sebastian@zaubar.com.**

About the test:

The ZAUBAR CMS is a tool that can be used so that tour guides, teachers, media centres and anyone else who is interested can easily create virtual AR tours.

For the test, imagine you are a teacher who wants to create an AR station for your class to make lessons more interactive.



Please fill in the following form. Make sure you are available for 60 minutes, that your computer has battery, that you have a smartphone, and follow the provided instructions.

If you get stuck at any part of the test, please follow the instructions until the end, where you will have the option to let us know that you have not made it until the end successfully.

If you have any questions about the XReco project, follow this link.

If you are unable to finish the test or have any general questions, contact your XReco tester lead.

XReco is a Horizon Europe Innovation Project co-financed by the EC under Grant Agreement ID: 101070250.

I am over 18 years old and consent to the use of this data.

I am:

- Male
- Female
- Other

What's your background?

- I'm some kind of technical expert
- My technical skills are "General user" / Non-technical expert
- Other

Section 2: Tutorial

Please follow the steps described here to perform the test. You will be walked through the application and in the next section, you will be asked some questions regarding your impressions of the experience.

Scenario:

Imagine you are a teacher who wants to tell his students something about the Sanssouci Palace in Potsdam (Germany). So that it is not just a boring lecture, you have decided to create an interactive AR station outside, which can be viewed by the students at any time and provides knowledge about this place.

Create this station in the following test.

Step 1: Preparation

1. Download the ZAUBAR Editor on your phone

The ZAUBAR Editor is as a tool to create the AR stations and place the content. It is available for Android and iOS. Click on the corresponding link and download the app from the App Store (iOS) or Play Store (Android).



iOS: <https://apps.apple.com/app/zaubar-editor/id1536119820>

Android: <https://play.google.com/store/apps/details?id=com.zaubar.zaubartours&hl=gs>

2. Back to your computer - Download the following files Imagine that you have already designed the content of this station and now want to work with your files. To do this, download the files that are available in this folder to your computer.

Content: https://drive.google.com/drive/folders/1DNcD3RH1pXgT9IOEzPvrQvB0t0tuifc1?usp=share_link

Step 2: **Login to Web CMS:**

- Access the ZAUBAR Web CMS using the provided test account credentials. Follow this link <https://h2932910.stratoserver.net/cms/admin/>

| Step | 3: | Upload | AR | Content |
|------|----|--------|----|---------|
|------|----|--------|----|---------|

- Upload the materials downloaded in step 1. Those include: 3D models, audio narration, photos and videos to the subfolders of your account. You can find the folders under “File Library > Tours > [your username / mail]”. To upload the materials, drag and drop from your computer. Each asset type should be allocated in the corresponding folder as specified here:
- 3D models --> _Object Prefabs

Audios --> _Audio

Images --> _Vista Images

Videos --> _Videos

Step 4: **Plan and create tours** You have now loaded your content into the CMS and are ready to create the station for your students.

Note: You can still do the next 2 steps indoors. From step 6 onwards, you must continue the test outside.

- Now we are going to be using your phone:
- Open the ZAUBAR app (ZAUBAR Editor) that you downloaded in "Step 0: Preparation".
- Log in with the same account credentials as for the Web CMS. Now you're logged in.

Step 5: Create the navigation:

1. Tap on the button with the 3 bars at the top right
2. Create stations by pressing the plus button



3. Add all the content information you want, like the station title.
4. Place your station on the map at the location where it should be located by tapping on the distance indicator.
5. Set Calibration Method to “CalibrationMode.Geospatial” to use it on the streets.
6. Create the AR scene. To do this, tap on your scene in the station view.
7. Assign a title to the scene and then add your audio file to the scene.

Step 6:

Content placement:

From this step, you need to go outside and continue the test in a public space. As the ZAUBAR Editor needs to access location data and location references, look for a place that is publicly accessible, such as pavements or public squares. Avoid locations such as courtyards, parks or secluded places that are difficult to access, as sufficient location references cannot be guaranteed for these locations.

Mobile Internet or public hotspots are required from here on.

Place AR Elements

1. Go to the location where the content should be placed.
2. Enter the station by tapping on the station preview.
3. Follow the instructions on the screen and scan the floor first and then your surroundings. You will receive an acoustic signal when the scan is successful and the instructions on the screen disappear.
4. Tap on the pen to enter the Placement Mode and then click on the plus button to select your content in the library.

Use the provided tools to place your content.

- Ensure the elements are accurately placed and aligned with the physical environment. (This of course corresponds to your personal feelings)
- If you want to edit an object, tap on it. You can see which object has been selected by the yellow frame around it.

Die Tools:

- Drop: content selected in the library can be placed in AR.
- Ground: moves the objects in physical space
- Rotate: Objects can be rotated
- Scale: adjust the size of the object

Step 7:

Preview your experience:

1. If you are happy with your placement, tap on "Done" and confirm in the pop-up that your changes have been uploaded. This is the only way to save them in your account.
2. . Tap on the map icon to leave the station again.



3. Tap on your station thumbnail on the map again to re-enter the station and view the placements.

End of practical test:

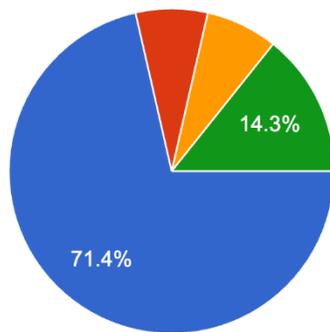
You have reached the end of the practical part of the test and the AR station is ready for your students. Please complete the survey in the following steps and share your experiences with us.

Evaluation

Disclaimer: *you need to have followed the previous steps closely before answering these questions to the best of your ability.

Please mark one box only:

14 responses



- I was able to finish the test and I can now reply to the next questions
- I was not able to finish the test because the technology malfunctioned.
- I was not able to finish the test because I got stuck in the process
- I was not able to finish the test but for other reasons.

SUS Questionnaire:

Acceptance - I think that I would like to use this system frequently.

| Opinion | Count |
|-------------------|-------|
| Don't know | 2 |
| Strongly disagree | 0 |
| Somewhat disagree | 0 |
| Neutral | 6 |
| Somewhat agree | 3 |
| Strongly agree | 0 |



Complexity - I found the system unnecessarily complex.

| Opinion | Count |
|-------------------|-------|
| Don't know | 1 |
| Strongly disagree | 1 |
| Somewhat disagree | 4 |
| Neutral | 1 |
| Somewhat agree | 2 |
| Strongly agree | 1 |

Ease of use - I thought the system was easy to use.

| Opinion | Count |
|-------------------|-------|
| Don't know | 1 |
| Strongly disagree | 0 |
| Somewhat disagree | 3 |
| Neutral | 1 |
| Somewhat agree | 4 |
| Strongly agree | 0 |

Support Need - I think that I would need the support of a technical person to be able to use this system.

| Opinion | Count |
|-------------------|-------|
| Don't know | 1 |
| Strongly disagree | 2 |
| Somewhat disagree | 2 |
| Neutral | 1 |
| Somewhat agree | 3 |
| Strongly agree | 0 |

Integration - I found the various functions in this system were well integrated.

| Opinion | Count |
|-------------------|-------|
| Don't know | 1 |
| Strongly disagree | 0 |
| Somewhat disagree | 0 |
| Neutral | 2 |
| Somewhat agree | 4 |
| Strongly agree | 2 |



Inconsistency - I thought there was too much inconsistency in this system.

| Opinion | Count |
|-------------------|-------|
| Don't know | 1 |
| Strongly disagree | 1 |
| Somewhat disagree | 4 |
| Neutral | 2 |
| Somewhat agree | 1 |
| Strongly agree | 0 |

Learning Curve - I would imagine that most people would learn to use this system very quickly.

| Opinion | Count |
|-------------------|-------|
| Don't know | 1 |
| Strongly disagree | 1 |
| Somewhat disagree | 2 |
| Neutral | 3 |
| Somewhat agree | 2 |
| Strongly agree | 0 |

Cumbersomeness - I found the system very cumbersome to use.

| Opinion | Count |
|-------------------|-------|
| Don't know | 1 |
| Strongly disagree | 1 |
| Somewhat disagree | 2 |
| Neutral | 4 |
| Somewhat agree | 1 |
| Strongly agree | 0 |

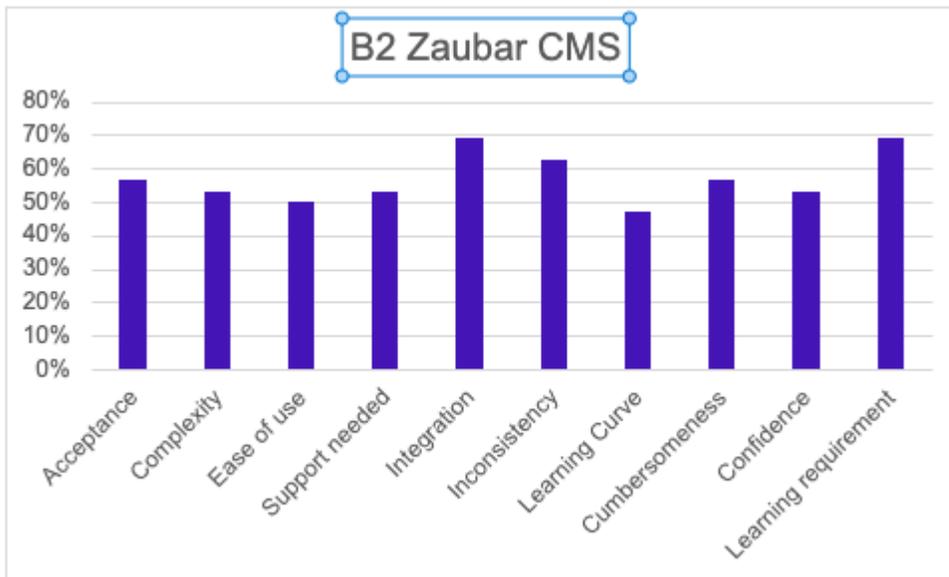
Confidence - I felt very confident using the system.

| Opinion | Count |
|-------------------|-------|
| Don't know | 1 |
| Strongly disagree | 1 |
| Somewhat disagree | 2 |
| Neutral | 0 |
| Somewhat agree | 4 |
| Strongly agree | 1 |



Learning Requirement - I needed to learn a lot of things before I could get going with this system.

| Opinion | Count |
|-------------------|-------|
| Don't know | 1 |
| Strongly disagree | 1 |
| Somewhat disagree | 5 |
| Neutral | 2 |
| Somewhat agree | 0 |
| Strongly agree | 0 |



Overall Experience: Describe your overall experience using the ZAUBAR applications. What did you find most intuitive, and what aspects were challenging?

- The usage was easy, to creat the experience was not posibile and misunderstandable, because of the selectetion on the location.
- Probably I would have needed some info regarding options available in the app: the instructions are ok to perform a quick test but don't really give me a full picture of how the tool is supposed to work
- Login was challenging, worked only after restarting the app The button to access the placing functionality could be labelled with a place marker icon or similar, the edit next to "distance" is not fully intuitive
- it is a good tool



- The overall experience was decent, although some difficulties were encountered when placing the contents, which led to the need to repeat the process. Therefore, the most intuitive parts were uploading the AR contents and the creation of the station (steps 3 and 5), while the most challenging part was the content placement, especially steps 6.3 and 6.4.
- I enjoyed using ZAUBAR's applications, but I found them a bit complex.
- On mobile phone the GPS location was a nightmare as was not detecting properly my position. The UI is not user friendly at all, and in my Android device the menu's button were at the height of my frontal camera making them hard to read sometimes. The AR overlay guidance were flickering constantly till i arrive to the destination point.
- It was intuitive to edit the station and scene as well as uploading media with the tool and it was more challenging to add the media to the station and place it correctly.
- the interface for uploading and placing assets was quite intuitive, with some exceptions (e.g. the selection of the calibration method options). however the login mechanism was not intuitive as it kept giving failing messages although the login was actually successful.
- Placing objects is fantastic. The login screen to the app was unintuitive, and the slow response time of the app made it difficult to understand whether my input was working/accepted or blocked. In the end when I had placed something I could not go back into my scene and view it because of an error, so I was missing only the last step.
- User interfaces are smooth and clean
- The content upload was very easy and fast. The most challenging part for me was modifying the placement of AR elements. I also encountered a problem logging into the editor (mobile app).
- I think is a good application and a lot of people can use in the future. The most intuitive was the use of the material and define the position of the assets. It was a challenge to use the geometrical location.
- Overall it was quick and it was fun. I think the test sheet could be made more helpful for beginners. It would have been good to mention way earlier that you have to go outside using your phone - and that it would be wise to work with this test sheet on the phone as well, not on the computer. You should also let people know that they must enable location-access ("Standortzugriff") when using the app or the test won't work.

Upload and Management: What was your experience like uploading and managing AR content (e.g., 3D models, audio, videos)? Did you encounter any issues or have suggestions for improvement?

- I couldn't upload any content because my iPhone (XR iOS18.4.1) was not connected with the CMS (windows 10).



- Upload was fairly easy to do
- was very easy and straightforward
- no
- Uploading and managing the AR content was perfectly fine, as all worked without a problem at the first try.
- Was good, didn't find any issues
- Pretty straightforward, the drag and drop operation was fairly easy.
- Good experience uploading and managing content, no issues encountered.
- uploading and management of content was done without issues
- Upload from the web: easy.
- Images are duplicated when dragged and dropped inside the web CMS
- The content platform is very user-friendly. I didn't encounter any problems.
- I have a problem with the name of the folders, because in the mobile app it doesn't appear.
- Uploading was no problem.

Content Creation Process: How easy was it to create a new AR experience using the CMS? Were there any steps that you found particularly straightforward or difficult?

- I couldn't create an AR experience because no access to the content
- Using the mobile app to create the experience was harder than I thought: several options are available in the UI, but I don't have a clear picture of many of them
- getting to the editing of content was not easy at the first time
- no
- Creating the station was fine, as the images provided are straightforward and easy to understand.
- Content Placement was a little difficult
- The tool is very cumbersome with too much information / text / buttons, I did not like at all the UI. There is no wizard that can guide you throughout the process and I had to go back and forth (PC - outside space) to see what comes next in the instructions
- Very straightforward and intuitive use of creating the new AR experience.
- creating a new experience was enabled efficiently by the interface
- Upload from the app: difficulty loading what was already stored on the account, long loading time, didn't display the audio file.
- Don't know
- Creating an experience was a bit tricky at times, but overall pretty easy. The main menu (map screen) was a bit hard to get used to. I didn't understand the difference between station, experience and

time travel. I also believe that the direction at which you are facing is not showing up correctly in app. Creating a station and a scene was pretty easy (provided the instructions in this form).

- Very easy.
- Certain terms could be explained better. Someone who does not know anything about AR creation perhaps does not know what "stations" are, how many you can/ are supposed to place etc. You should also explain why the app keeps asking you to "upload your progress". I found it confusing until I realized it was like saving steps in between. I thought I had uploaded my AR creation somewhere to many people even though I was not ready. In the app I did not always see where I was supposed to click as it was light grey on white.

Mapping and Placement: How did you find the process of placing AR elements in the real environment? Were the tools provided sufficient for precise placement?

- I set an location spot but this was changing several times.
- Placement was fairly ok, but I probably neded more background to perform the test in a more meaningful way
- indoors the location drifts
- yes
- Mapping was fine once I was able to enter the experience, although I found the instructions to do so a bit vague. When managing the contents for the placement part, I did encounter some problems. At the beginning, when I tried to place the content, as soon as I clicked on the pen to enter the Placement Mode and then on the plus button to select my content in the library, it decided that the chosen content was the station profile picture, and then it closed the station, not letting me add anything to the scene. I had to give it a couple of tries of repeating the whole process from start to finish without changing any of the steps, but I was eventually able to finish the test. Finally, once I was done with the placement and I uploaded it, I was not able to re-enter the station and view the placements, as it took me back to do the mapping, which showed an empty scene.
- They provided precision.
- That was the easiest part, however button misplacement and bad UI are still an issue
- The most challenging part in my experience, at first difficult to understand how to choose the tool to edit with and later slightly difficult to place and move objects with the AR background.
- mapping and placement in the real environment was not accomplished 100% due to the testing conditions (indoor) that didn't allow precise gps calibration. as a result the asset was placed some meters away from where I initially placed it. for the same reason I wasn't able to find the triangle outside, so I had to use the one that was provided on the laptop. In other matters the process was intuitive and easy.

- Sufficient, easy.
- Don't know
- The process of placing and moving the element was very easy and user-friendly. However, I was not able to rotate or scale the element.
- We use an image to recognize the place, not geometrical location
- I thought the process was overall intuitive and straight-forward. However, I did have difficulties getting to the preview of what I had anchored outside - I don't know what I did wrong. But instead of showing me what I wanted to see, it showed an old progress, not the placement I wanted.

Would you like to provide any other remarks that we haven't asked you about?

- I like the tool and I would suggest some changes in the process.
- having the URL for the app per mail would be useful leftover ASK Sebastian in the questionnaire
- No
- The form and the guide were composed by different separated blocks and were not easy to follow. Moreover some of the description/words were in German and it felt that the test was prepared with less care than the others that I took.
- Login from phone took a few tries, maybe because of my internet connection. Also had difficulties in last part when checking the added media in AR.
- no
- The Login in the editor should show a button to unhide the password
- I encountered a small problem logging into the mobile app. When providing my credentials, I was getting an unidentified error message. I restarted the app and then I was logged in without the app asking for my credentials again.

