

A Collaborative Authoring Tool for Cultural Heritage in eXtended Reality

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Abstract

The prototyping and development of a cultural heritage exhibition or application can be a collaborative process between a cultural heritage institution and a cultural heritage developer. Extended reality (XR) and remote collaboration have the potential to enhance this process. XR can enable a higher level of visualisation of the final product, allowing for faster prototyping and development times, and can allow the exhibition to be built directly within the intended space. Remote collaboration can allow for geographically displaced users to meet together and collaborate using online communication platforms. By combining authoring in XR with remote collaboration, users can meet within a shared virtual recreation of physical space and collaborate together to prototype and develop a cultural heritage exhibition. In this paper, a Collaborative Authoring Tool for Cultural Heritage in eXtended Reality (CATCH-XR) is presented. CATCH-XR allows for two or more users to remotely meet in a recreation of the host's physical space to prototype and develop a cultural heritage exhibition and import assets through a content management system. Alongside CATCH-XR, a worked example of an exhibition showcasing Irish history, created using CATCH-XR, is also presented.

CCS Concepts

• **Human-centered computing** → **Collaborative and social computing systems and tools**; **Mixed / augmented reality**; **Collaborative interaction**; **Visualization toolkits**.

Keywords

Cultural Heritage, Extended Reality, Mixed Reality, Authoring Tools, Creativity Support Tools, Virtual Museums, Cultural Heritage Applications, Remote Collaboration, Hypertext

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1 Introduction

Virtual museums draw upon the character and curation of heritage sites to deliver rich experiences that may be interactive or personalised [28] but brings new challenges in the curation, design, and creation of digital content.

A range of technologies, commonly described as Creativity Support Tools (CSTs) [9] or Authoring Tools [14], have emerged to support the design and creation of interactive digital content, enabling the production of virtual museums as platforms for the representation and preservation of digital cultural heritage [7, 26, 27]. However, as Mixed Reality (MR) becomes an integral component of digital cultural heritage technologies [2] and remote collaboration gains increasing importance, existing CSTs provide limited support for these emerging requirements.

This work exists within the tradition of Hypertext systems papers on CSTs/Authoring Tools that leverage Hypertext as both a technology to support creation and as a lens to understand new mediums as part of interdisciplinary research [4, 6, 11, 17, 25]. Virtual museums as collections of linked content are fundamentally hypertextual both in terms of spatial links in the composition of an exhibition, and more direct links in connecting interactive elements or textual information to visual artefacts. While recent tools have explored the use of Hypertext and CSTs to support MR [6] we seek to explore this further by making the CST itself a MR environment



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leveraging What You See Is What You Get (WYSIWYG) principles that a desktop MR CST cannot.

This paper introduces the **Collaborative Authoring Tool for Cultural Heritage in eXtended Reality (CATCH-XR)** (CATCH-XR), a novel collaborative authoring tool that enables cultural heritage exhibitions to be authored within extended reality itself, rather than merely authored for XR as an output medium. CATCH-XR uniquely combines mixed and virtual reality with synchronous remote collaboration, allowing geographically distributed curators and developers to co-author exhibitions using a WYSIWYG, in-situ approach directly within reconstructions of real-world spaces. The system supports an asymmetric collaboration model in which a host authors in mixed reality within the physical exhibition space, while remote collaborators join in virtual reality, sharing a common spatial context. By reducing abstraction, grounding design decisions in embodied spatial experience, and improving communication across distributed teams, CATCH-XR accelerates iterative exhibition prototyping and visualisation.

2 Related Work

2.1 Extended Reality

The Virtuality Continuum was presented by Miligram and Kishino's "A Taxonomy Of Mixed Reality Visual Displays" [22]. Within their continuum, Real Environment (consisting solely of real objects) and Virtual Environment (consisting solely of virtual objects) sit at opposite of the spectrum, with Augmented Reality and Augmented Virtuality existing between them. They provide a definition of a Mixed Reality environment as one where the real and virtual world are presented within one display [22], such as within an Extended Reality headset. Skarbez et al. has since revised Miligram and Kishino's original continuum, renaming Virtual Environment to External Virtual Environment and adding "Matrix-like" Virtual Environment to the far right. The reasoning for this is due to a virtual environment being unable to be fully immersive [30]. Additionally, Bekele et al. [2] define **Augmented Reality (AR)** as the superimposing of virtual information on the view of the real-world, **Virtual Reality (VR)** as a solely computer generated environment with no means to see or interact with the real-world, and **Mixed Reality (MR)** as a blend of the real and virtual environment.

XR systems have also often been framed as Hypertextual - both in terms of game technologies and understanding play and interactions as links [1, 19, 23], but also in terms of links between space and reality. The composition of items in a virtual environment (such as a virtual museum) form a spatial hypertext of the subject matter of that exhibition using the spatial links of proximity and geometry [3], and MR locative systems similarly link items from one reality to places in another creating links of not only physical traversal but also across reality [16, 17]. Consequently it is important to understand XR experiences as Hypertext with links that are navigational, spatial, and across reality.

2.2 Authoring Tools

Authoring tools can be defined as a tool which allows the author to create a solution within a particular domain [5, 14] without a need for technical skills, such as programming [20], and can provide a WYSIWYG environment, allowing for real-time feedback and

decreasing the number of iterations required for development [10]. Authoring tools are a fundamental part of the Hypertext research landscape [4, 6, 11, 17, 25] in that how we support the creation of Hypertext shapes the Hypertext itself [15].

The use of authoring tools can allow cultural heritage institutions to create innovative and interactive exhibits more efficiently at lower costs, allowing them to attract new visitors and stay relevant [8]. Various cultural heritage authoring tools exist within the literature. One such tool is the CHES system, whose aim is to enrich a museum visit by using personalized interactive storytelling [32]. CHES caters to visitors who consume CHES experiences and provides authors with the CHES Authoring Tool (CAT), where they can design CHES experiences for visitors. Another example which uses virtual reality is the VIRTUE system (VIRTUAl Exhibition hall) [13]. VIRTUE is a customisable, virtual reality system that allows curators to easily create multi-modal, virtual 3D exhibitions for visitors to navigate and enjoy. The authors note that the VIRTUE offers unlimited exhibition space and support for any configuration of exhibition. Furthermore, other tools are often used in a cultural heritage context, such as the explicitly Hypertextual StoryPlaces [17, 24]. While some authoring tools do work with XR [6], this is normally as part of a desktop tool rather than authorship within XR itself.

2.3 Remote Collaboration

The development of a cultural heritage exhibition requires collaboration, either internally within the institution or with elements outsourced to external partners [18, 21, 31]. This collaboration could take place in-person, or remotely over platforms such as Google Meet, Zoom, or Microsoft Teams. Schäfer et al. [29] provide a taxonomy for remote collaboration, consisting of Environment, Avatars, and Interaction. Additionally, they categorise remote collaboration systems uses as Meeting (users share a common workspace), Design (combines systems such as product design or architectural design), and Remote Expert (includes a local and a remote user, with the remote user often being an expert). Furthermore, Druta et al. [12] notes that tasks are accomplished better and faster when a visual workspace is shared between participants, as well as mixed reality showing to be useful for tasks involving complex design instructions, whilst also decreasing time and mental effort.

3 CATCH-XR

3.1 Curate

CATCH-XR is a collaborative mixed and virtual reality authoring tool that enables multiple users to meet remotely in a recreation of the host's real-world space. It can be used to experiment and create visual prototypes for physical exhibitions for a real-world space (e.g. galleries, museums); to create a prototype or a complete virtual exhibition for a real-world or digital space; or to create a prototype or a complete mixed reality exhibition for a real-world space.

Within CATCH-XR, users can:

- **Curate** (see Section 3.1) their exhibition, by placing and editing various Display, Signage, and Artefact objects into their real-world space using mixed reality, or the virtually recreated space.

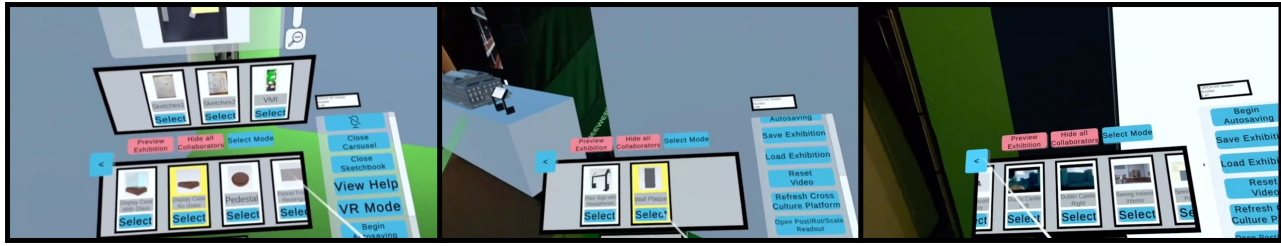


Figure 1: Curate menu for CATCH-XR. Left: Display menu. Middle: Signage menu. Right: Artefact menu

- Create **Custom Walls** (see section 3.2) to introduce virtual walls into existing spaces which can also act as surfaces for Displays or Signages
- Place **Annotations** (see Section 3.3) in the form of digital post-it notes with an attached voice recordings, allowing users add notes, comments or feedback for themselves or others
- Access to a **Sketchbook** (see Section 3.4), which draws from an external image repository, enabling users to reference assets, such as sketches or blueprints without needing to remove the headset
- A variety of other authoring features (see Section 3.4), such as saving and loading, exhibition realignment, lighting editing, and viewing the exhibition without authoring elements or other users present

Using the Meta headsets room scanning functionality, the Cultural Heritage Institution (CHI) can capture their real world exhibition space and share an automatically generated simplified version of this with the Cultural Heritage Developer (CHD). This allows both parties to effectively "meet" and build in the same location remotely. From a networking perspective, the CHI functions as the host, and the CHD functions as the client. Participants will see rudimentary avatars of each other and can use the built in microphone to communicate within CATCH-XR. Once the virtual space is generated, it can be used in situ (at the original world space) as a Mixed Reality experience, or anywhere as a purely Virtual Reality Experience. CATCH-XR was developed using Unity 6000.0.58f2 and Meta Quest 3 and Pro.

Within the **Create** sub-menu, users can select from a variety of Displays, Signage, and their uploaded Artefacts objects to build their exhibition as desired (see Figure 1). Users point to their desired location and see a preview of the desired object in their mixed reality or virtual reality space before placing. The object responds and adjusts according to the scanned surroundings, such as portraits rotating to lie flat against the walls, or not allowing floor displays to be placed on walls. Users can also rotate and scale their chosen object, with the exclusion of 2D Artefacts (images and video). Within the **Edit** sub-menu, users can select an existing object to edit it. The user will see the desired object highlighted orange and, once selected, will be highlighted green for that user and red for others to indicate editing.

3.1.1 Displays. Within CATCH-XR, Displays are used to house Artefacts. Floor based displays, such as display cases and pedestals,

are used to house 3D object Artefacts. Wall based displays can be used to house image or video Artefacts.

3.1.2 Signage. Signages are used as containers of information, and there are versions that can be placed on the floors or on the walls. Signages can link to Displays or Artefacts. For floor-based displays, the text on the Signage will find the description of the Display. For wall-based displays with an Artefact attached or an Artefact object, the Signage will automatically find the information for that Artefact. The information is downloaded from an external repository and is cached within CATCH-XR for quick retrieval (Section 3.1.3 for further details).

3.1.3 Artefacts. To allow assets to be imported into a CATCH-XR exhibition, CATCH-XR connects to an external repository which contains user uploaded content in the form of **text** for descriptions and titles, **links** to a download location, **images** as JPGs, **videos** as Vimeo links, and **3D content** as Unity asset bundles. In this case, CATCH-XR is built to connect with Noho's Cross-Culture Platform¹ to access user uploaded content, as seen in Figure 2. While this work uses the Cross Culture Platform, the integration is not inherently platform-dependent and could be adapted to alternative open platforms. Within the Cross Culture Platform, entries can be further grouped into collections, allowing similar entries to be grouped together for ease of use. By using the Cross Culture Platform, simple content (e.g. images and video) can be easily uploaded by the CHI, while more complex content, (e.g. 3D objects), should be given to the CHD to be processed² and uploaded. Within CATCH-XR, users can view and select collections, see the available entries for these collections, select an entry to add to the exhibition, and see it previewed before placing it.

3.1.4 Editing of Displays, Signage, and Artefacts. Once a Display, Signage or Artefact has been selected for editing (see Figure 3), or a new one placed, the user is presented the following options:

- **Finish, Delete, Cancel Changes** — complete, remove, or revert edits (with local undo available)
- **Move, Scale, Rotate; X/Z Scaling (Displays and Signage only); Match to Another Display/Signage/Artefact** — transformation and scaling operations
- **Font, Colour, Alignment (Signage only); Link Signage (Signage only)** — signage formatting and linking

¹<https://noho.ie/project/?noho=6356f7d023267>

²In this instance, processing refers to activities such as retopology, texture baking, and creating a Unity asset bundle that can be uploaded to the Cross Culture Platform to be downloaded within CATCH-XR

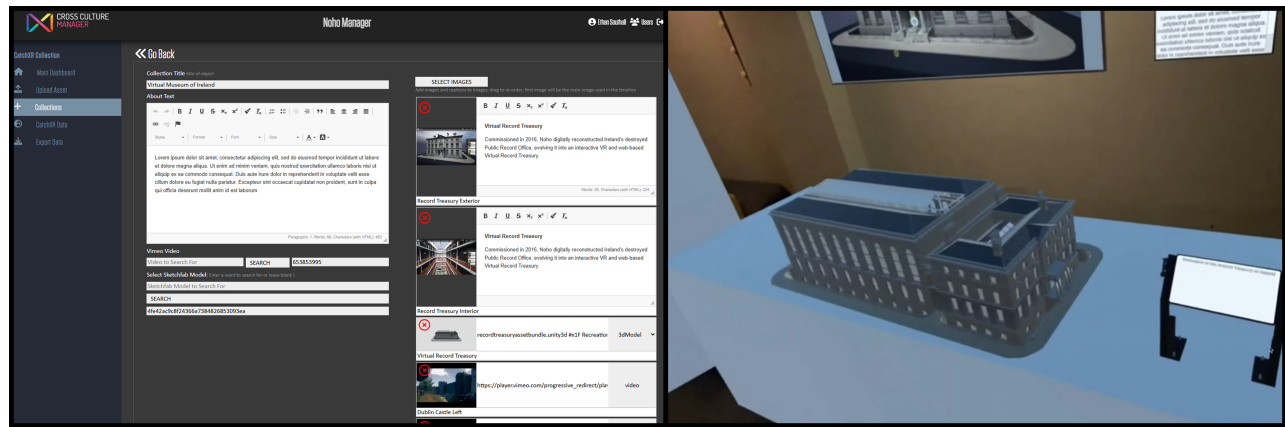


Figure 2: Left: 3D object and images in the Cross Culture Platform. Right: 3D object and images from the Cross Culture within CATCH-XR.



Figure 3: Edit menu for a Signage (highlighted in green)

- **Scale Audio Distance (Displays and Artefacts only)** — adjust audio range
- **Hide Display Method (Displays only); Hide Signage Method (Signage only)** — visibility controls

When editing, the object highlights, and changes are seen in real time by both host and client, consistent with placing a Display, Signage or Artefact object. The object also reacts and adjusts contextually to the scanned environment.

3.2 Custom Walls

To further develop the desired exhibition, users can also create their own virtual walls within their environment. These walls can function as additional display surfaces for wall-based Displays on the vertical faces and floor-based Displays on horizontal faces. They may also be used to create new partitions or obscure architecture within the existing space. This feature is particularly well suited to mixed reality, as it allows for the same physical space to be extensively customised according to the needs of the users.

3.2.1 Custom Wall Creation. Within the **Create** sub-menu, users can create their custom wall by selecting a series of points in the environment (as illustrated in Figure 4), by selecting the initial starting point of the wall by aiming at their real-world or replicated floor, then specifying the width of the wall by aiming at another

point on the floor, then specifying the depth of the wall, by aiming at point at the floor perpendicular to the line created by points one and two, then setting the height of the wall, either by snap to a ceiling socket or rotating the controller. Whilst building the wall, the user will see a preview of the wall.

Within the **Edit** sub-menu, users can edit already existing Custom Walls. When a wall is selected to be edited, the user is presented with the following options (as illustrated in Figure 4):

- **Finish, Delete, Cancel Changes** — complete, remove, or revert edits (with local undo available)
- **Left Side, Right Side, Depth Side** — reposition corresponding points
- **Height** — adjust height via controller rotation or socket snapping

As with editing Display, Signage or Artefact elements (see Section 3.1), changes to walls will be seen in real-time between client and host, and the highlight will change to the appropriate colours.

3.3 Annotations

To assist with the exhibition prototyping process, users can place digital post-it notes with attached audio recordings. These allow users to leave comments such as requests, fixes, and reminders to themselves or others entirely within the application, eliminating the need to remove the headset and record external notes. This positions Annotations as key feature for enabling remote collaboration by allowing both synchronous and asynchronous collaboration in a remote mixed / virtual reality environment.

Within the **Create** sub-menu, users will be given a preview of the annotation (see Figure 5). Users can move their controller to choose a location for the annotation. The annotation can also be rotated and offset from the controller. Upon confirming the annotation, the user will automatically be able to edit the annotation.

Within the **Edit** sub-menu, users can edit existing annotations. When an annotation is selected, the user is presented with the following options (as illustrated in Figure 3.3):

- **Finish, Delete, Cancel Changes** — complete, remove, or revert edits (with local undo available)
- **Move and Rotate** — reposition or rotate the annotation

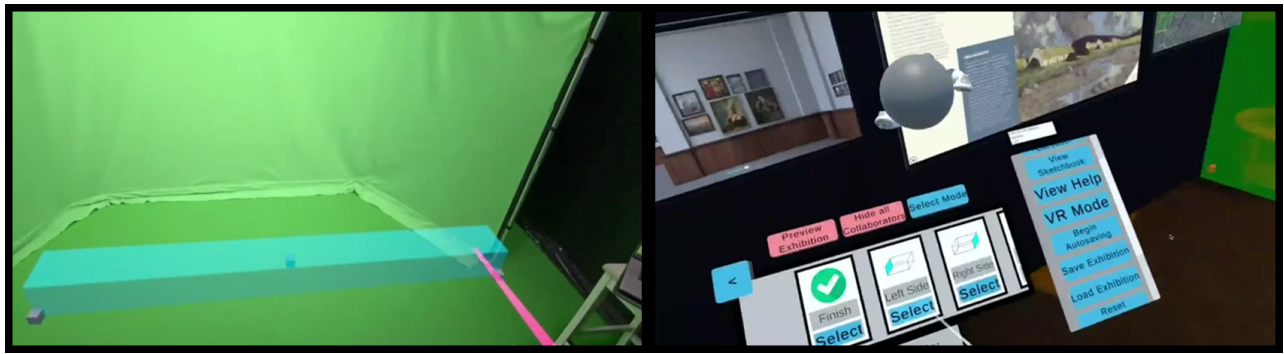


Figure 4: Left: Custom Wall in the process of being created. Right: Edit menu for Custom Walls

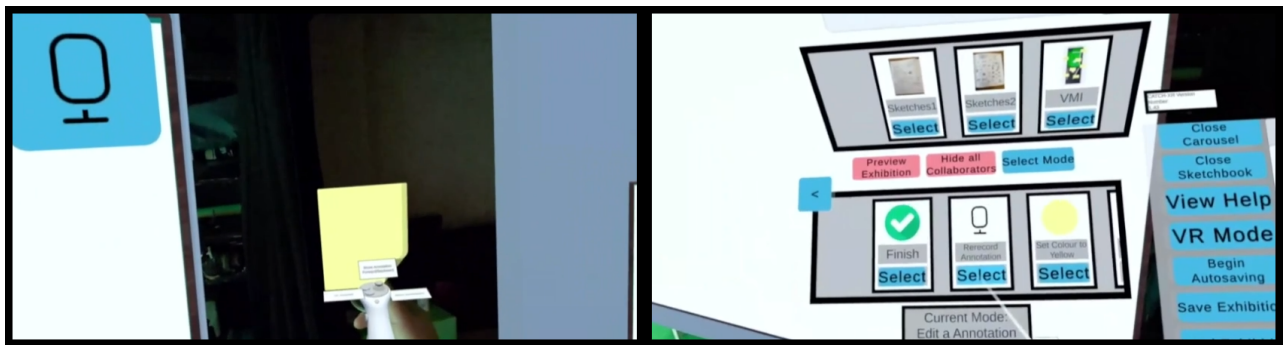


Figure 5: Left: Annotations in the process of being created. Right: Edit menu for Annotations

- **Rerecord** — Rerecord the audio annotation
- **Set Colour to Yellow/Green/Orange/Red/Blue** — assign a predefined colour

As with the previous features, the changes made to the Annotations are reflected across the server in real-time, with the appropriate colour highlighting.

3.4 Other Authoring Features

CATCH-XR also features the following additional authoring features:

- **Sketchbook** - Allows users to view external documents in the forms of images without removing the headset
- **Lighting** - The user can rotate the scene's directional light to allow them to edit the overall lighting of the scene
- **Realign Exhibition** - Due to the use of mixed reality, there is a possibility that the exhibition may be come misaligned from it's intended location. To address this, the entire exhibition can be moved and rotated as a single unit, avoiding the need to manually relocate each object
- **Saving and Loading** - To allow users to work on an exhibition over a long period of time, the exhibition can be saved as a JSON file on an external server, which can be later loaded back in when needed
- **Preview Exhibition** - Hides authoring elements, such as annotations or Signage links, to allow the user to preview the exhibition as if it were complete.

- **Hide All Collaborators** - Allows users to view their exhibition without seeing collaborators

By integrating the features described in this section, CATCH-XR provides a fully immersive WYSIWYG authoring environment in which users author within extended reality itself, rather than through an external or abstracted interface. Users can place and visualise provided or user-generated content directly within a reconstructed real-world space, temporarily modify the spatial environment, and persist their work through saving and loading, all inside the same XR workspace. Crucially, these tools are designed to operate within a shared spatial context, supporting geographically distributed collaborators who co-author in real time while viewing changes as they occur. This XR-native approach to authoring reduces abstraction, grounds design decisions in embodied spatial experience, and positions CATCH-XR as a distinctive collaborative authoring system that leverages the affordances of mixed and virtual reality to enhance remote exhibition design and prototyping.

4 Contributions

CATCH-XR's contributions lie in its ability to enable rapid prototyping and visualisation of a cultural heritage exhibition, through it's use of mixed and virtual reality, combined with remote collaboration. With these technologies existing in a single application, CATCH-XR allows for exhibitions to be developed, tested, and presented within the real-world space, supporting a WYSIWYG approach. Unlike existing cultural heritage authoring tools that operate either on desktop platforms or support XR only as a target

medium, CATCH-XR enables authoring within XR itself, combining in-situ mixed reality authoring with synchronous remote collaboration in a shared spatial replica of a real exhibition space.

MR allows for the host to view their real-world space with their virtual changes, thereby reducing the need to imagine what a space looks like, or use other methods, such as 3D renderings or sketches. By having virtual objects appearing in the real world space, CATCH-XR provides an immediate understanding of scale and space. Combined with the easy to use editing features, it is possible for CATCH-XR to support rapid design iterations and clearer communication of exhibition concepts across all parties. The Custom Walls feature aids this, by allowing authors to prototype not just content, but the architecture itself as a curatorial device, which further supports the environmental storytelling.

This enables several use cases, such as presenting and convincing a CHD's clients on a particular exhibition design, to build an exhibition in an already existing real-world space without reworking said space, or a mixed reality exhibition as a final experience. There is also the potential that the exhibition could be built entirely away from the real-world space, if said space is currently unsuitable for working in.

Combined with remote collaboration, CATCH-XR allows users from several geographically separate locations to design and prototype within the same virtual session, and it also supports both real-time/synchronous communication through audio-video capabilities, as well as offline/asynchronous communication and collaboration being bridged via the Annotation system, which also act as persistent spatial discussion threads. Provided that the host is physically present in the real-world space, collaborators can join them and prototype an exhibition in real-time with each other. Uses for this range from allowing parties who are not located together to join in the same space, to allow for group contribution to the exhibition, or for users to individually work on separate areas of the exhibition. Through CATCH-XR, a hybrid co-presence model where physical and virtual perspectives are unified through shared spatial context is provided. This enhances the curator-developer power dynamics, trust, authorship, and decision-making, and reduces miscommunication about scale and placement.

5 Future Work

Future work will involve detailed analysis of a case study, in which CATCH-XR was used to create two gallery exhibitions, including the VMI. In addition, a study will be conducted at Bournemouth University to assess the usability and user experience of CATCH-XR with regard to collaborative exhibition development.

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