Augmenting Local and Remote Cultural Visits with Mixed Reality

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Abstract

With the rapid evolution of technology in the last decades came the possibility of executing certain activities remotely. Museum and gallery visits can greatly benefit from remote interaction and can be enhanced by visitor participation and collaboration. The pandemic setting contributed to the active search for its implementation in several areas of society. The framework presented in this paper aims to tackle both of the aforementioned opportunities instantiated by companion and collaborative virtual and augmented reality applications. The first application was built for Oculus Quest devices and serves as a means to immerse the user and provide a sense of presence in remote visits. The second is a smartphone application meant to augment the onsite visitor experience with digital information and the possibility for commenting and annotating the visit. The latter application can also stream a camera perspective to the virtual environment accessible in the first application, enabling a sense of participation and presence in the physical exhibit, to the to the virtual visitor . The system's usability and presence were evaluated in a series of questionnaires performed by a variety of participants.

CCS Concepts

•Human-centered computing → Mixed / augmented reality; Virtual reality; Collaborative interaction;

1. Introduction

The work presented here is designed to promote new engaging and immersive ways to visit cultural institutions by breaking through their physical boundaries. Physical Cultural exhibitions are constrained by the limited interaction and available information support of relevant artefacts. Digitally augmenting the physical visit can increase its interest and potential, by enabling interaction with digital versions of artefacts. The availability of these components also provides content support for enabling systematically generated virtual reality exhibits, based on a set of enhanced virtual components. Finally, visits can greatly benefit from remote interaction and can be enhanced by visitors participation and collaboration in both these environments, in real time.

As a result of a national governmental digitisation effort of historically and culturally relevant artefacts, AR and VR tools are being developed to support, on one hand, augmentation of physical visits and, on the other hand, systematic generation of virtual visits of these relevant cultural institutions. Such is achieved in a system framework composed of several key components. The first of these components is an application for smartphone devices meant to be used while visiting the premises of the cultural site. It uses AR (Augmented Reality) to superimpose digital textual and graphical information on top of cultural artefacts, concerning the artefact itself (additional relevant information) or user input regarding the artefact (visitor's comments or annotations). The second is an application for Oculus Quest VR (Virtual Reality) devices in which

a virtual version of the cultural exhibit can be navigated by users, enabling artefact inspection and access to additional information, as shared with the previously described AR application. The third component is a broadcasting server setup, which enables audio and visual transmission from smartphones' cameras, carried by visitors currently at the exhibit, to the virtual environment featured in the VR application. The fourth and final component of the project is a file management server responsible for collecting and serving data about the virtual exhibit.

The work described here constitutes a collaboration and presence framework for accessing museums and other cultural institutions. Its main objective is to augment the local visit with additional interaction possibilities and to give a sense of presence and collaboration to remote visitors.

2. Related Work

Museums and art institutions have started to realise how crucial technological approaches are for the involvement and immersion of the public, namely using virtual and augmented reality. In fact, museums and art galleries all around the world are already considering and putting into practise digitisation of artefacts or digitally assisted tours. Concrete implementations range from mobile applications that allow visitors to collect animals and plants by photographing their virtual representations (at The National Museum of Singapore), or watch paintings come alive (at Ontario's Art Gallery), or even discover how prehistoric animals looked and behaved (in The

Smithsonian Institution in Washington) [Coa21]. Additionally, examples of Museum virtual tours available online include the Louvre Museum in Paris ([Lou]), the British Museum in London ([Bri]) or the Teatro-Museo Dalí in Figueres ([Fun]). Examples of digital experiments and tools developed and made available by diverse cultural institutions, aiming at visitor motivation and satisfaction, include:

- An experiment performed at Universidad Carlos III in Madrid, involving a transparent interactive display located in front of a cultural artefact, allowing gesture-based interactions [BDA15]. These interactions gave support to textual and video input of experiences with the artefact, which provided knowledge sharing between guests. An alternative way to upload content is through the mobile interface on the visitor's personal device and by scanning the QR codes corresponding to each artefact.
- The "Neanderthal" app [Alv16], ideally used by visitors before, during and after their tours of the Neanderthal Museum, keeps them updated about current and future exhibitions and other relevant museum details. Active QR code scanning is also available, to allow for content accessing on each location. However, the most prominent feature in this project is the ability to passively access content, by connecting to Bluetooth beacons that send signals to nearby devices.
- The design of a virtual representation of The Phillips Collection (Washington, USA), engaging visitors by capturing a series of omnidirectional images and videos with interesting interaction features [HY18]. Users had three different forms of interaction: gaze-based interactions; hotspot interactions; and zooming and moving in a 360º environment.
- A collaboration between different departments of the University of Konstanz and HTWG Konstanz (Germany) with the goal of educating about the cultural impact of the existence and destruction of the city of Palmyra, in Syria, and discussing if it should be rebuilt [SWB*18]. This was accomplished by using technologies like an interactive tabletop, interactive projection, tablets, 3D printing, AR and VR in the three initial rooms of the exhibition, each with a different purpose. In the final room, the visitors make their decision about reconstructing Palmyra.

Virtual reality interaction can liberate the user from physical limitations, enabling telepresence and even transforming the space with asymmetric distortions [CNSR16]. Augmented reality can be used to transmit ideas, in-context, for example by a remote user to guide a local user in maintenance and assembly tasks [ZBW*14] or to enable detailed exploration of artefacts [RRL*14]. Collaborative AR interfaces are used for both co-located and remote AR collaboration [GNTH14]. In remote collaboration, they can enhance the communication with gaze and non-verbal cues, and for manipulating virtual objects. Asymmetric collaborative interaction, which enables two or more humans, from a combination of the real world, using AR, and a virtual world, using VR, to share a workspace, is a typical example that can be made more efficient by using a uniform representation of XR contents, regardless of the user's context [HMKY19]. XR technologies allow both local or remote users to be immersed in collaborative virtual environments (CVEs) [OERF*16, PLH*18]. In this context, Dataspace is a collaborative virtual room [COP*19] where a hybrid of high-resolution screens, AR headsets and projection tables creates an integrated data ex-

ploration center. Rizvic et al [RYC*22] propose a multiplayer VR game to introduce teenagers to the works of Leonardo da Vinci and his role in history.

Interaction methods and interfaces are the forms of communication between humans, resources and AR systems.

Some of these interfaces have been experimented in limited collaborative settings [ZHH*18,TLL*19,BNJ*19,CMN*10]. The current challenge is to go beyond the state of the art by addressing collaboration in evolving physical and virtual representations, addressing presence and collaboration in complex activities [PCAR19].

The evolving nature of the structures and the possibility of telepresence (e.g., by remote access in a virtual world to a live video stream or other media from a local user) pose complex system and interaction level challenges, which are addressed in this project.

Brockmann et al. [BKSB13] list the collaborative dimensions in the collaborative AR taxonomy:

(1) space (co-located, dislocated, variable); (2) time (synchronous, asynchronous, variable); (3) mobility (stationary, mobile, mixed); (4) virtual content (user visualization, object visualization, combined visualization); (5) role concept (one-role-concept, multi-role-concept); and (6) visualization hardware (HMD, handheld display, spatial display, individual spatial display, mixed).

The collaborative aspect of the work presented in here is aligned with these dimensions.

3. Framework Design and Overview

Cultural exhibitions are grounded by the inherent value of the presented artefacts and expert information viewed in association. However, the handling of these items is often dangerous for their status and viewing and interaction must thus be limited. Additionally, associated information may also be constrained by the physical conditions of the exhibit. Augmenting the visit with digital components can increase the visit's interest and potential, and augmented reality features can contribute to this potential, by enabling interaction with digital versions of artefacts and by facilitating digital linking with similar or related artefacts.

The availability of digital versions of the physical exhibited items also provides new opportunities for enriching virtual visits. In this context, the possibility of providing state of the art infrastructure for systematically and rapidly creating virtual exhibits from the set of already generated virtual representations of the artefacts is relevant and may constitute an initial step for creating and enhancing digital exhibits. Finally, visits can greatly benefit from remote interaction and can be enhanced by visitor participation and collaboration in both these environments, in real time. In this context, interaction with the artefacts is valued by enabling several types of comments and annotations, in line with what is currently popular in social networks but also following grafitter's traditions. Drawing and enhancing over well-known artefacts, without the danger of damage, can motivate engagement, while, at the same enabling collaboration and broadcasting of these ideas.

As a result of a national governmental digitisation effort of historically and culturally relevant artefacts, AR and VR tools, contemplated in a complete framework,are being developed to support,

on one hand, augmentation of physical visits and on the other, systematic generation of virtual visits of these relevant cultural institutions. Real-time communication between both visits is also one of the requirements.

As described, the objectives set for the framework engineered in the scope of this project can be divided into three pivotal parts: (1) a mobile phone AR application that grants the visitors the ability to offer, obtain and visualise knowledge about artefacts beyond an exhibit's physical boundaries; (2) a VR application for Head Mounted Displays (HMDs), set up with the intention of performing remote visits to an art exhibit and, consequently, create a sense of presence in it, with additional user collaboration features; and (3) the establishment of data transmission between both above-mentioned applications.

In both applications, either installed on their mobile device, or on an HMD remotely located, visitors may perform several different tasks, which include:

- View relevant details about the artefact, such as its title and description, by pointing their mobile device's camera at it.
- Interact with artefacts by choosing, out of a selection of *emojis*, one which best represents the visitor's emotional outlook on those artefacts.
- Interact with artefacts by providing personal insights on them, in the form of comments, composed of a title and optional content.
- Interact with artefacts by painting over them and appending the result to a comment.
- Register and verify their credentials, such as full name, e-mail and password.

In regards to how both these applications share information, two different *pipelines* were built, the first being the deposit of data onto a web server in the form of a collection of simple files that detail the exhibit's artefacts, its users and their contributions. The second is the audiovisual live streaming of camera footage captured by the visitors' smartphone applications (with the addition of some digital overlays) to the three-dimensional virtual space, accessible through the VR app.

In terms of how data linked to the system is structured, the main concepts and the relationships between them are illustrated in Figure 1.

The most central concept is the User, which includes descriptive attributes and which can be associated with User Input objects. The User Input data type may thus be extended by Reaction and Comment objects. Reaction items include an *emoji* attribute, that specifies the represented reaction. Conversely, Comment items contain the uploading date, title, content of the comment and a list of paths to attached files. Comments may also be attached to a Drawing, which is composed of a list of one or more Strokes. Stroke objects include properties like colour, width and a list of positions of each of the stroke vertices. Artefacts are another vital concept of the data schema and their attributes include their unique identifier, title, description, and positional and rotational coordinates in the gallery. Comments and Reactions are also aggregated to the artefact on which they were posted.

Figure 2 illustrates the framework system architecture. Essentially, it is composed of three clients that indirectly interact with
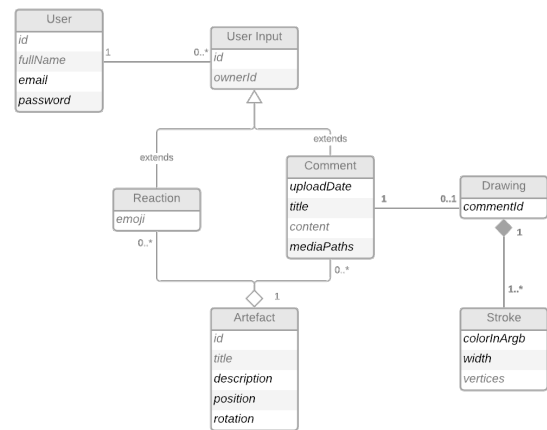

Figure 1: *Object diagram representing how data is structured.*

each other by communicating with a broadly defined server. These three clients (all based on Unity) are the mobile AR and VR client applications along with an administration tool, a desktop app, added for data editing purposes, that inspects the current state of the three-dimensional virtual setting. The abstract concept of server, present in the figure, encompasses a LAMPP web server connected to a Linux file system database, in addition to an Ant Media Server instance that serves as a proxy for broadcasting.
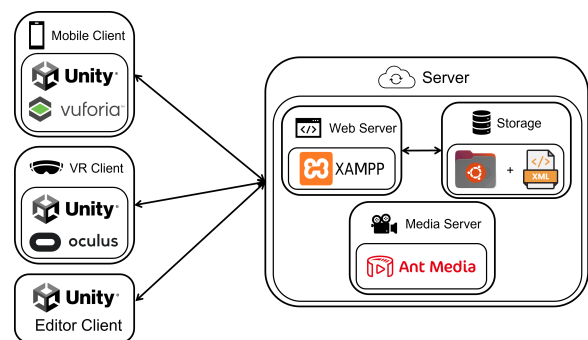

Figure 2: *Framework architecture and technology*

3.1. Mobile Augmented Reality Application

When logged into the main Gallery scene, the user will access a view of their smartphone's camera, enabling a look-through window, accompanied by a couple of Heads-up Display (HUD) constituent elements. This view provides access to a video stream being captured by Vuforia's *ARCamera* GameObject, which, along with an Image Target child GameObject, is responsible for detecting and tracking real-life targets at the exhibit and for overlaying them with other GameObjects. Those Objects are organised within a Prefab named *ArtPieceCanvas*, which is a World Space Canvas attached to the target in the three-dimensional world and which contains information about the art piece such as its title, description and comments. Figure 3 shows the augmented view of an artefact, depicting

the HUD elements together with the details revealed when the Image Target is detected by the camera.

Figure 3: *Informative details overlaid next to the artefact upon target detection. The target detected is the atual painting.*

While on the augmented view, the user may **React** to an artefact by tapping the *emoji* buttons on the side of it, resulting in an increment or decrement of the counter attached to each button, depending on whether the user has previously registered this reaction. Additionally, in order to enhance user feedback, the colour of the *emojis* changes once their reaction button is pressed.

To view comments submitted on an art piece, the user should tap the bottom right button represented by a comment icon. As a consequence, the button becomes highlighted, indicating that comments are being displayed and the description text element is replaced by a comment panel, displaying the oldest comment posted on the art piece, if one exists. Otherwise, instead of activating the comment panel, textual elements become visible, informing the user that no comments are available and suggesting that they should post one themselves. Replacing the artefact's description with the comment panel (when comments are available) as opposed to attaching it to the artefact's overall User Interface (UI), was decided for user convenience, ensuring the fitting of the content to the phone's screen in sufficient visible detail.

The **comment panel** incorporates: a small avatar to be replaced by the profile picture of the comment's author; a message that reads "[Author's first name] says:"; the comment's title; the comment's description; and an additional annex button, enabling access to an user contribution, if one has been associated to the comment. If several comments have been added to the artefact, the panel also features two vertical buttons on its side for navigating between them. Navigation is ordered by the comments registration time.

Tapping the "New Comment" button, which is located on the right of the "Show Comments" button, causes a new comment editing Canvas (shown in Figure 5) to appear. This Canvas is rendered in screen space, and is attached to the scene's camera or, in this case, the *ARCamera*. This is also the case when the menu button or the annex button of a comment is pressed. The reasoning behind this design choice is that these three interfaces benefit from having a static positioning (in relation to the user's point of view), facilitating viewing and interaction. Moreover, interfaces that do not require physically pointing the smartphone's camera at a real object allow visitors to, more frequently, rest their arms, or even their legs by sitting down, and carrying out the task at hand.
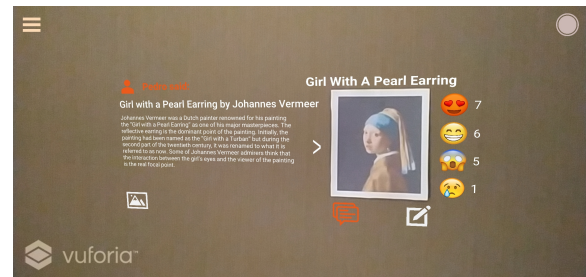
Figure 4: *The comment panel displaying comments pertaining to the currently detected painting.*
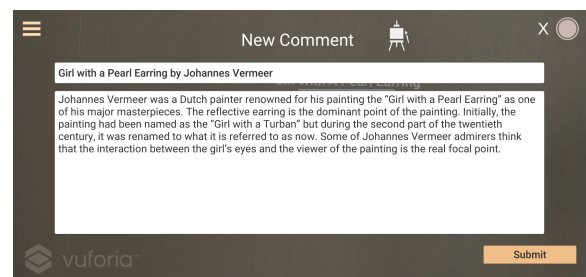
Figure 5: *The comment composition module (canvas) of the comment creation screen.*

The **comment creation screen** is divided into two separate modules that are interchangeably accessible: The first module, illustrated in Figure 5, intrinsically corresponds to the core endpoint for **comment composition** since it includes its title and content text input fields, as well as its submission button. Once again, for feedback presentation purposes, the title input field changes colour, from white to red, if the "Submit" button is pressed when this field is empty and returns to its original colour if selected. A return button is available at the top right corner of the screen, which restores the camera view of the exhibit by disabling the comment creation screen.

The second module, which can be seen in Figure 6, is accessible by tapping the button to the right of the "New Comment" screen title, disabling the previous module and enabling this new one. Here, users can contribute with their own creations in the form of **drawings** overlaid on the **original painting**. Such is achieved either by tapping or swiping on the painting, thereby sending touch input signals to the Event System, which effectively enables the user to draw on the painting while activating a drawing trail.

Surrounding the drawable artefact, this module contains three different but equally valuable tools that allow users to better express themselves by further customising their drawings. One of those is the colour palette, which is located on the right of the artefact and is implemented by an array of ten buttons that alter the colour of the strokes drawn, until another button on the palette is pressed. Another available tool is a slider, positioned on the left side of the art work, which affects the width of any future strokes drawn until the value of the slider is changed again. The last tool is the "Undo" button, represented by a backwards arrow and placed below the

**Figure 6:** *The drawing module of the comment creation screen.*

previously mentioned slider, which is used to erase the last painted stroke (or spot). A submit button is available to finalise the drawing.

As mentioned before, the **comment annex screen** in Figure 7 can be viewed by tapping the annex button on the comment panel, assuming the currently displayed comment has an annex, and is similar but less elaborate than the drawing screen described earlier. This is evident in the figure where a return button, the original painting and the lines and shapes created by another visitor are superimposed. The purpose of this screen is to render a comment's annexed drawing.

Figure 7: *The comment annex screen displaying a comment's annexed drawing.*

The last interface to be explored is the **Main Menu**, which can exist in two different states – open or closed – but is always visible in either form. This object is an Overlay Canvas that includes two buttons, one on each top corner of the screen, which are *interactable* when (but not exclusively) the Menu is minimised. The left button opens the Menu and the right one starts broadcasting what is being captured by an auxiliary camera parented to the *ARCamera*. The latter communicates to the user that their phone's camera footage is being streamed by changing its sprite's colour. Opening the Main Menu results in what can be seen in Figure 8 and in enabling several other GameObjects: the familiar transparent background panel; the return button on the top left corner, which minimises the menu; the "Logout" button, which logs the user out and loads the Login scene; and the "Broadcast View", on the top right corner, which is visible only if the user has pressed the "Start Casting" button. This GameObject contains a *Raw Image* component that serves as a render target for the auxiliary camera's captured footage, displaying a preview of the content being sent to the server and offering another form of feedback to the user.
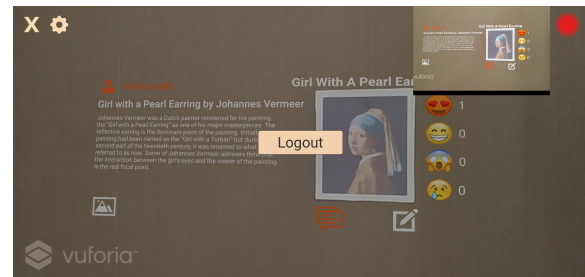
Figure 8: *The main menu of the mobile application's gallery scene accompanied by the "Broadcast View" seen on the top right corner when the user is currently streaming their perspective.*

### 3.2. Remote Virtual Reality Application

The remote VR application was developed on Unity, with support for Oculus Quest and Oculus Quest 2 virtual reality headsets (by importing Oculus Integration package into the Unity project) [Met] . This granted access to various core VR functionalities, scripts and components. The XR Plugin Management package and Oculus XR Plugin were also included to enable VR support in Unity and adjust rendering and quality preferences, like the Pixel Light Count, Texture Quality, Anti Aliasing and Realtime Reflection Probes. Despite their different strategies, the mobile client and the virtual reality application share multiple parallels which will be focused on in this section.

The manner in which the Menu screen functions and reacts to user inputs is equivalent in both apps. Additionally, the Menu Canvas is now in a fixed position in World Space, delivering an improved User Experience (UX), adjusted to the new viewing and interacting conditions, and what can be seen around it is an Environment Skybox [Unia]. Interaction of the user with the scene's UI, is supported by the use of two Prefabs of the Oculus Integration Package ("OVRCameraRig" and "UIHelpers").

"OVRCameraRig" plays a fundamental part in linking the user to the system, transmitting head and positional tracking data to Unity and enabling scene capture, presentation and navigation to the user. Its tracking space child object contains anchor GameObjects for both eyes and hands, a custom VR camera and the "LocalAvatar" Prefab (from the same package). The latter allows for limited but useful default hand models.

"UIHelpers" enables UI interaction and input management on the application, through a Laser Pointer coupled with a Sphere on its tip, representing a cursor that assists in element selection and contextualisation.

This app's Loading Screen is rendered in screen space and is fixed to the scene's main Camera, as opposed to being an Overlay Canvas like in the AR app, favouring VR compatibility. This screen is thus displayed on top of any other object in the scene, regardless of where the user is looking. The smooth transitions achieved by fading in and out this Canvas by the Scene Manager (identical to the one in the mobile app) are all the more indispensable as they prevent sudden visual changes or flashes that could negatively impact the user.
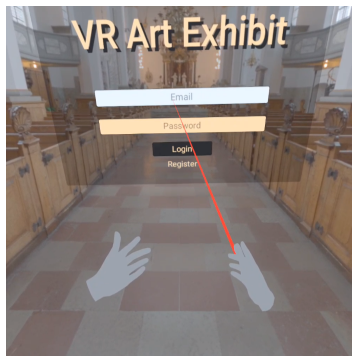
Figure 9: *The hand models included in the "LocalAvatar" Prefab together with the UI cursor.*


[a]   [b]
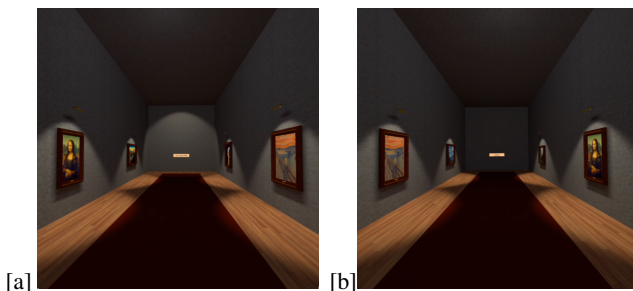
Figure 10: *(a) The front of the gallery scene environment. (b) The back of the gallery scene environment.*

The main Gallery scene assembled for this application is slightly more elaborate than the one available on the mobile AR application, as it is composed of several models, components, lights and settings that had to be designed, placed and adjusted to fit a three-dimensional and VR space. Nevertheless, some elements of both scenes have compatible implementations.

When the visitor successfully signs in, the loading panel is once again "dismissed" revealing a hallway that accommodates six different art pieces – three on each side –, a broadcast and a settings menu. This is a default scene which should, in the future, become a basic template for the virtual visit. This environment can be viewed in Figure 10.

Placing the user inside the Gallery scene is achieved, in practice, by instantiating one more Prefab from the Oculus Integration Package called "OVRPlayerController". Its role is to enable the user's movement around the digital gallery, as well as to handle physics-related interactions, collisions and controls with components like Unity's *Character Controller* [Unib]. The "UIHelpers" Prefab was once again used for handling engagement with the scene's UI, by providing a footstep system where the distance travelled is calculated based on the user's time and velocity of movement. Two Audio Sources are then positioned on each of the user's feet for added realism. Moreover, two arrays of Audio Clips are played, according to the surface which the user is stepping on (carpet or wood flooring).

[a]   [b]
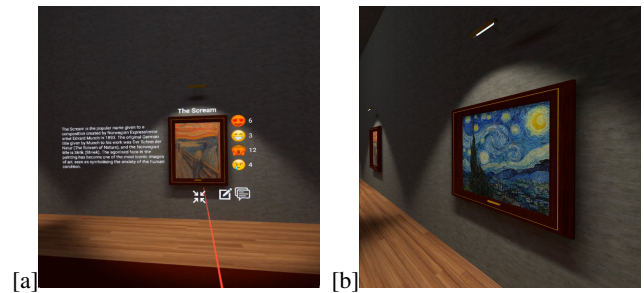
Figure 11: *(a) One of the painting's UI canvas. (b) One of the painting models placed in the virtual exhibit.*

[a]   [b]   [c]
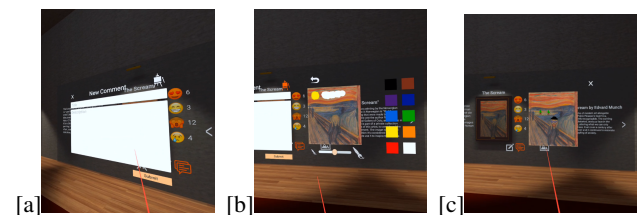
Figure 12: *(a) The comment composition module of the comment screen on the VR application. (b) The drawing module of the comment screen on the VR application. (c) The comment annex screen on the VR application.*

The art pieces themselves, contrasting with the AR application's single art piece approach, are composed of a 3D model that includes the painting's frame, a lamp (a denominated "Focus Detection" plane) and a UI Canvas. For this implementation, the **model**, represented in Figure 3.2, was imported from *TurboSquid* [Tur]. The **"Focus Detection" plane** is a canvas that, upon receiving input, enables one of two mutually exclusive buttons, responsible for expanding or minimising the UI canvas of each art piece. The design decision of not having all UI canvases constantly active stems from the fact that, by doing so, the user can experience the exhibit "absent" of digital visual interference, enhancing presence as if observing the exhibit through a naked eye.

As noted, several GameObjects in both applications described originate from the same Prefabs, which generate similar workflows. However, some interactions had to be adjusted to this particular environment, as listed below.

Firstly, in a VR context, long and precise interactions are not dependent on a smaller "window" to the digital world (represented by a mobile phone) held by the user's hands. Hence, screens like the comment creation screen and the comment annex screen are now static panels rendered in front of their respective art piece, as shown in Figure 12.

Secondly, the positioning of some interface elements differs in the canvases in both apps, as a result of having more available space in a completely three-dimensional environment. One instance of this disparity lies in the placement of the comment panel, which is now located to the right of the reaction buttons and whose accessibility can be toggled on and off by pressing the "Show Com-

ments" button. Moreover, the drawing panel in the comment creation screen can be seen to the right of the comment's input form, as opposed to being interchanged with the same form on the mobile app. This panel can also be enabled or disabled by clicking the "Draw On Painting" button.
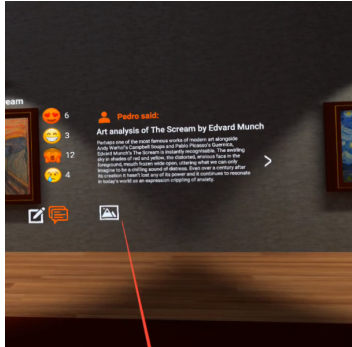
Figure 13: *The comment panel is positioned differently in the VR application.*

The two final interfaces to cover are the Broadcast and Settings menus located at each end of the hallway where the user is placed. Upon entering the scene, the visitor can see, from the first menu, one button that reads "Join Live Feed" (Figure 3.2) and, once clicked, this button is disabled, making a new panel appear in its place. This panel holds a "Leave Live Feed" button on the top left corner and a mute/unmute button to its right, whose visibility and *interactability* are mutually exclusive, acting as a toggle for disabling or enabling the "Feed's" overall audio. Just below these buttons is a Scroll View object, where Raw Image objects are instantiated and updated on every frame, representing live video feeds of all the different perspectives being streamed simultaneously by visitors roaming the physical exhibit. The settings menu allows logging out of the scene with a click of a button.

Figure 14: *The "Live Feed" screen with three concurrent live streams.*

Correctly setting up the Lighting settings of the last scene was of the utmost importance for three primary reasons: the need for a pleasant viewing experience of the scene, performance optimisation and visual defect avoidance. Achieving such results mainly

involved switching the scene's Realtime Lighting to Lightmap Baking. Baked Lightmaps are the result of calculations performed within the Unity Editor, involving the scene's Baked Lights and lighting data collected and stored to disk, to be later loaded at runtime. This logically reduces the performance costs of rendering both the scene's lights and shadows [Unic].

3.3. Administration Tool

An additional administration tool was also built with the purpose of updating and supervising the current state of the system, ranging from user contributions, to live broadcasts, to the virtual environment itself. The development process for this tool was split into two connected phases: reusing the Oculus Unity project and adapting it to a new target platform and input method – mouse and keyboard. The first can be summed up as cloning the VR application and removing non-essential Oculus plugins, prefabs and components from it, among other conflicts. Following this, the second step was to adjust the user's movement, viewing and interactive experience to the new medium. For instance, in this application, movement is achieved by pressing 'WASD' keyboard keys, looking around the exhibit is done via mouse movement and interacting with the UI is possible using mouse clicks, aided by an overlaid small circular *crosshair*. This graphical aid serves as a reference point for the centre of the screen and, most importantly, as a point that defines the direction in which interactions will be triggered (e.g. button clicks) and *Raycasts* will be instantiated.

3.4. Streaming

Broadcasting video and audio from mobile phones to the Oculus VR environment was one of the most demanding aspects of the project's scope, thus, also being a focal point in this work. The streaming server should be available to the outside world, in particular to users receiving all the different streams on their Oculus headset at home or to visitors streaming their perspectives at an art gallery. For this purpose, Ant Media Server (AMS) [Anta] was the tool of choice for developing the streaming element, enabling ultra-low latency one-to-many live streaming and data channel support by using WebRTC [Web]. AMS also provides an SDK for the Unity platform, which supports live stream publishing and receiving for Unity based applications. Because AMS is a commercially available video streaming server, its performance can be monitored (it includes specific tools for managing service) and adapted according to the framework's requirements.

Establishing a connection between each Unity application and the broadcast server is supported by components from the Sora Unity SDK Samples Project [Antb]. This project, provided by the Ant Media Server support team, includes: a Plugins folder, which gives access to WebRTC utilities; three sample scenes that present different use-cases for sending and/or receiving one or multiple streams; and sample scripts used on the sample scenes that make use of the WebRTC utilities.

Based upon this framework, a script holds a plethora of variables that define the broadcast's characteristics, like the type of stream (send or receive and amount of participants), the server

URL, through which a WebSocket Secure (WSS) WebRTC connection is established and a stream identifier. The script is also responsible for controlling the live stream by instantiating, initialising, disposing and calling methods from the provided `Sora` class, which, in turn, can establish or revoke a connection by invoking lower-level operations and protocols from the WebRTC plugin.

3.5. File Management and Sharing

Storing, organizing and accessing data was a notable part of the project. However, since the protection and efficiency of querying data was not its main focus, an XML file format approach was taken to simplify data representation This was possible with the aid of the `C# System namespace`, which contains XML serialization tools able to convert XML files into data objects and vice versa. All aforementioned applications use these tools to better operate and manage data objects such as users, reactions, comments, drawings and artefacts.

In order for the distribution of data to be feasible, a file server was set up beforehand on the same Virtual Machine (VM) as the broadcast server, with an accurately pre-established internet configuration. Such was achieved with the Linux distribution of XAMPP [IBM]. In doing so, a web server became available to HTTP requests, which enabled fetching of information on the database, to be provided remotely to the developed applications.

4. User Evaluation

A perk of designing a system meant to be used virtually or in person by visitors interested in artistic and cultural exhibits and institutions is that the target user base is very broad and diverse. As such, efforts were made so that the testing user pool accurately represented a realistic diverse user base. The study included 17 participants (7 female, 10 male, ages 17-53) with different levels of education and occupation or field of study. Most participants were not very experienced with AR and VR systems, having used VR systems slightly more than AR ones.

The aims of the evaluation were to assess presence in both applications and user experience for the whole interconnected system, as described below. The test was composed of five primary modules. The **first module** presented the study and collected background information about each participant. The **second and third modules** pertained to a hands-on experiment with the implemented smartphone and Oculus Quest applications, in a first section, and a feature-oriented user evaluation about each experiment in the next, respectively. The succeeding module participants encountered an adapted version of the **Presence Questionnaire** (PQ), to assess the degree to which participants experienced presence on a virtual setting in four scales: Involvement, Sensory Fidelity, Adaptation/Immersion and Interface Quality in a list of nineteen items to be answered in a five-point Likert scale. The final questionnaire participants were presented with was the **User Experience Questionnaire** (UEQ), with the objective of evaluating the users' overall experience with the developed interconnected system, from a series of different factors. These vary from Attractiveness to Perspicuity, Efficiency, Dependability, Stimulation, and Novelty and are evident

in a list of twenty-six items with fifty-two opposing terms answered in a seven-point Likert scale [VRMB*20].

Overall, the results of the testing phase were significantly positive, demonstrating that the system could be tried in a realistic scenario. Most participants found the system easy to use, even those less familiar with technology. There were some differences regarding the time to complete the tasks, most likely due to some participants' unfamiliarity with digital concepts, like the creation of application accounts or live streaming and what those terms entail, as well as a necessary adjustment to the equipment and controls. During each usability test, the participants' performance was monitored by counting the time that each person took to complete their test and by writing down relevant observations about it. Below is a compilation of these observations:

- As expected, AR target detection under-performed to some degree in darker lighting conditions but the same cannot be said about target tracking, which held up in any lighting condition.
- Six different users experienced some degree of *cybersickness*, for three of which it was common, and it was felt especially when the left joystick was used to move around the VR exhibit, sometimes due to the inexperience with the technology. That being said, a teleportation-based movement method could be adopted or made available to substantially mitigate this symptom. Nonetheless, because of the novelty factor, many participants found the VR experience to be all the more immersive and realistic as well as, in general, being the most captivating and impressive.
- It is important to note that many users had an easier time understanding the UI layout of the Oculus application since it followed the same patterns and standards as the smartphone application.
- It was not clear at first, for some participants, that their accounts were shared between both applications used when logging in to the VR app.
- The visibility of system status standard was noted by some participants. This happened, For instance, when the colour of the button on the comment creation screen that opens the drawing module changes, meaning that a drawing is currently attached to their comment. One participant enjoyed the use of the aesthetic and minimalist design while another would have preferred to be provided with more information.

Throughout the testing stage, some difficulties experienced by participants and improvement opportunities were noted as well:

- The precision of the Oculus controllers proved to be slightly excessive and unforgiving to some participants, seen as though it was somewhat difficult for them to raise their arms in close to stationary positions for button clicking or waving them to produce precise brush strokes. The drawing aspect could potentially be resolved by increasing the minimum vertex distance, thereby, adding some forgiveness to brush strokes.
- The "Register" button in both applications went unnoticed at first glance by one participant, likely due to its lack of outline that would represent its *interactability*.
- The transition between both modules in the comment creation screen of the AR application presented some obstacles to a number of users. One of those obstacles was the positioning of the button that opens the drawing module, which one user suggested

should be relocated so as to stand out as an *interactable* element. The other obstacle was the fact that both the button for re-enabling the comment editing module and the "Undo" button were thought by some to return to the main view of other visitors' comments. The former also resembled and was situated near the main menu button, which faintly confused one user. The latter could perhaps be fixed by being repositioned or at least by having its icon changed. A third small hindrance for one user was the concern that, if they were to switch to the comment composition module from the drawing one to submit their comment, the drawing would consequently be lost, as it had not been saved.

- Sometimes, both identifying how to start live streaming and how to join the Live Feed took slightly more time than expected. When using the mobile application, the main menu and the "Start Streaming" buttons were even assumed by some to be part of the smartphone's operating system, which might be due to the handling of someone else's phone and would not happen in a realistic scenario. Others did not notice that the "Start Streaming" button was, in fact, interactable and, at times, tried to access the streaming functionalities by opening the main menu before noticing the correct button. One participant, in particular, associated that same button with some photography related feature before even using it.
- During their VR experience, a couple of users attempted to interact with elements covered by interfaces, like the comment creation screen or the comment annex screen, which could be prevented from happening in the future, by further obscuring those screen's backgrounds.

Analysing the answers provided by participants in each section of their tests allows for a few findings to be inferred:

- Regarding the responses from the AR feature specific questionnaire, the most poorly evaluated features were switching between the comment content and drawing screens and the AR artefact detection. On the other hand, the feature least criticised was selecting the brush size.
- In the same vein, the most poorly evaluated feature in the VR application was interacting and viewing other comments while the best rated was, once again, selecting the brush size.
- In the PQ questionnaire, participants seem to have completely agreed with most questions presented to them. The best results concerned examining objects, touching the virtual environment and identifying sounds with 82, 65 and 65% of testers giving these activities the maximum value. Nevertheless, the answers for two questions were not as unanimous. This means that clearly not all users thought that their experiences in the virtual environment seemed consistent with their real-world experiences (94% of testers selected value 4 and value 5) and not all users were involved to the extent that they lost track of time (76,5% of testers selected 4 and 5). Perhaps this could be owed to the fact that some users could discern the virtual and real world more easily than others.
- Interpreting the answers of the UEQ as the participants' descriptive opinions of the system, the most divisive characteristics were the creativity (76% on creative), speed (53% on fast), inventiveness (76,5% on inventive), predictability (53% on predictable), supportiveness (58,8% on supportive) and vanguardism (76,5% on innovative) of the system. In fact, results generally present a

tendency towards the positive term out of the pair in each questionnaire item.

5. Conclusions and Future Work

The project described in this paper is geared towards cultural institutions by technologically enhancing presence for their visitors and providing more involvement and immersion. In order for that goal to be reached, the developed framework system encompasses local and remote collaborative components: (1) an AR smartphone application with an on-site usage in mind; (2) a VR application for Oculus Quest devices, meant to be used outside of the cultural institution; (3) an administration application, for data supervising purposes; (4) a live streaming server responsible for establishing WebRTC conferences that enable the video and audio transmissions between all applications; and (5) a file management web server storing and distributing database files including data about users, reactions, comments, drawings and artefacts. The design and implementation of all three applications conformed to the same standards, patterns and guidelines.

Looking at the results obtained on the testing stage, it can be safely concluded that user response to the system's usability and presence was overall positive as the participants found the interfaces to be natural and captivating. That feedback meant that the combination of techniques and tools adopted throughout the project yielded a successful product. Part of these successful techniques and features target collaboration between remote and local users. This stage was also useful to determine small design imperfections to be rectified and to observe the participants' perception and behaviour, *cybersickness*, for example, towards the relatively leading-edge unconventional technologies involved.

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