# AR-Driven Exhibit Interaction: A Prototype for Enriched Display

## Final Report

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# Abstract

In recent years, the the introduction of new augmented reality (AR) capable headsets has expanded the potential and application domain of AR interactive experiences. In contrast, physical exhibits in galleries, libraries, archives, and museums (GLAM) have often lack interactivity, resulting in disengagement and limited learning experience for visitors. Introducing "AR-Driven Exhibit Interaction: A Prototype for Enriched Display", a project that leverages AR technology in head-mounted display (HMD) to enhance visitor engagement and improve outcomes in GLAM exhibit. The project includes the development of an interactive AR interface prototype for an exhibit and the evaluation of this prototype by conducting an user study. This report first presents the background of this project, relevant studies on interactive exhibits and AR technologies used in GLAMs, and the methodologies use for the prototype and user study. Then it discusses the result of the prototype development and the user study. Finally, the report will conclude with the challanges, limitations, and future plans of this project.

## Acknowledgement

- To Dr. Choi, Yi King, my supervisor, I want to express my gratitude for serving as my project supervisor. The meeting I had with you have greatly help me in shaping my project idea and providing me valuable suggestion on for resolving the issues I encountered. I also appreciate your support as my unofficial academic advisor in the previous year and your willingness to write a letter of recommendation for my master's applications.

- To Dr. Wu Chuan, I extend my heartfelt thanks for your valuable feedback and suggestions, which have greatly contributed to the improvement of this project. Your insights have been helpful in refining the work, and I truly appreciate your time and expertise

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- To my friends and parents, who have patiently listened to my complaints about the stress brought on by this project, I am deeply thankful. These past few months have been particularly challenging, and I can't imagine how I would have coped with the mental strain without your support.

# Contents

## Glossary

**augmented reality** The technology that creates an environment where users are able to see the real world overlaid or combined with virtual object with information related to the real world context and allow real-time interaction[1, 2].

**field of view** The angular extent of the observable area covered by the AR image the user can see through the device.

**galleries, libraries, archives, and museums** Refer to cultural institutions, mainly galleries, libraries, archives, museums, that provide public access to knowledge and maintain cultural heritage.

**head-mounted display** Any display which is mounted or placed on the user's head with information displayed within the normal viewing range of the user [3].

**Human-Computer Interaction** An interdisciplinary research about the relationship of humans and computers and how can they work together to solve a problem in a particular scope. The report will only be focusing on the computer science, interaction design, and information science aspects of HCI..

**optical see-through** A type of AR enabled head-mounted device that has cameras facing outside the device and a normal display, where live feed of the real world environment captured by the cameras will be played on the display with virtual objects rendered [4, 5].

**video pass-through** A type of AR enabled head-mounted device with a see-through display made by transparent mirrors and lens where the overlaid virtual object can be displayed while the real world environment can be see through the display [6, 5].

**virtual reality** The technology that allows the users to be immersed in a completely virtual environment [6].

## Abbreviations & Acronyms

**AR** augmented reality. i, 1–9, 12, 17–26

**FoV** field of view. 6, 10

**GLAM** galleries, libraries, archives, and museums. i, vi, 1–5, 8, 25, 26

**HCI** Human-Computer Interaction. 8

**HMD** head-mounted display. i, 1, 2, 5–7, 9, 20, 24, 26

**OPT** optical see-through. 6, 25

**VPT** video pass-through. 6, 24, 25

**VR** virtual reality. 4, 7, 26

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# 1 Introduction

The technology that combines the real and virtual worlds is referred to as augmented reality (AR). AR has been rapidly evolving, especially with the introduction of new AR-capable headsets like Meta Quest Pro and Microsoft HoloLens. This technological leap has improved the landscape of interactive experiences, expanding the horizons of AR applications beyond entertainment and business.

In parallel, exhibits in galleries, libraries, archives, and museums (GLAM) have always played a crucial role in providing learning opportunities outside our formal education system [19]. However, conventional physical exhibits (as seen in Figure 1) often lack visitor engagement, leaving visitors with a passive and single-dimensional visiting experience, which may diminish the overall learning experience.

One solution is interactive exhibit, which are exhibits with interactive elements, as research shows that they can increase visitors' engagement level [20, 21, 22]. Although, since the 2000s, GLAMs have been using various technologies to incorporate interactive elements to exhibits. Existing technologies have their imitations, as they tend to divert visitors' attention away from the exhibited object or are primarily used to summarize the entire exhibition rather than enhance individual exhibits [23, 9].


***Figure 1:*** *An example of a traditional physical exhibit is the National Museum of American History, where the exhibit's information is text placed next to the exhibited items.*
*Image Source: [7]*

## 1.1 Motivation

Since AR is a technology that can facilitate interactive exhibits as it allows the display of differnt multimedia content while the overlaying nature of AR might be able to address the issues previous interactive technologies face, and the recent development of AR-enabled head-mounted displays (HMD) have become more usable and accessible with advantages over AR used on handheld device. This project proposes an AR prototype that enables interactive information display for GLAM exhibits through an AR-enabled HMD.

### 1.2 Objective and Deliverable

This project seeks to deliver two key deliverables. First is an AR prototype with an interactive interface for displaying exhibit information. In this prototype, information will be presented as interactive virtual elements in different multimedia formats, including audio, text, and images. Through this interactive AR interface, the project seeks to elevate visitor engagement level and educational result of GLAMs' exhibit while maintain most of their focus on the exhibited piece. The second deliverable is a user study which will be conducted to evaluate thffeteness of the interactive AR interface on improving visitors' experience and ensure the application provides an user-centered experience. For the evaluation, it will focus on the differences in visitor engagement and learning outcome between using and not using the AR interface, and how well the interface can improve interactiveness while reducing the distraction for viewer's attention on the exhibited item.

### 1.3 Report Outline

In the remaining of this report, a literature review of relevant studies and existing applications in GLAM exhibits will be provided in Section 2. Then, Section 3 will present the AR HMD used, the technology stack, and user study methodologies. In Section 4 and 5, the report will delve into the result of the two deliverables, the AR interface prototype and user study, respectively. Finally, challenges faced, limitations, future works, a conclusion of the reported will be include in Section 6.

## 2 Related Studies and Existing Technology

This section provides an overview of the relevant studies about GLAM exhibits, interactivity, and AR. Existing interactive technologies used in GLAM, both AR and non-AR, will also be shown in the followings.

### 2.1 Interactivity, Engagement, and GLAM Exhibits

GLAMs, especially museums, have always played a significant role in providing learning opportunities outside our formal schooling system [19]. Therefore, it is crucial for exhibits in these institutions to be engaging to attract visitors to visit and have to an effective learning experience.

Witcomb [20] suggested that interactive exhibits are considered more entertaining than traditional exhibits and thus can increase engagement and visitor interest. Another study also support Witcomb's idea by showing the more interactive element an exhibit has, the longer the time visitors will spend on it [21]. This is shown in the result of the average staying time of visitors increase from 13.8 to 23.8 seconds when they can manually manipulate exhibit component from the study conducted by [22].

Other than making GLAMs more captivated to visitors, increasing the level of interactivity in exhibited can also provides an environment for active learning [24]. According to [19], interactive exhibits allow visitors to actively participate, determine what content is presented, and narrate their own experiences, such as letting visitors decide the order and detail level of the exhibit's information they consume. In which these active interaction that are controlled by the visitors overlap with features of an active learning experience [19].

## 2.2 Existing Interactive Technologies in GLAMs Other than AR

Before and even after AR technology has matured to the today's level, other interactive technologies, including information kiosks, tabletop displays, and video game stations, are widely used in interactive GLAM exhibits.

During the 2000s, information kiosks (see Figure 2a) were one of the primary digital devices used to improved an exhibit's interactivity. They are screens with either a touch display or buttons and are placed alongside exhibits to provide different information in an interactive way, such as paying a videos about the exhibited object's production, operation, and texture after pressing some buttons [25]. However, an issue with information kiosks is that visitors may spend most of their time fidgeting the kiosk than actually viewing the exhibited object [23], which may cause it to contradict the purpose of interactive exhibits.

On the other hand, tabletop displays (see Figure 2b) and gaming stations (see Figure 2c) are two other commonly used interactive technologies for GLAM exhibits. Tabletop displays are horizontal workspace surfaces where hand gestures or everyday objects, such as mouse or mouse-like objects and RFID-tagged paper, are used as controls to mimic how people interact with their surroundings in daily life [9]. Meanwhile, gaming stations in GLAMs are equipped with serious games which are educational games related to the exhibit's information. Serious games is well research and have been proven to provide great level education and entertainment values [26]. Although both technologies provide great interactivity and is proved to have good result in increasing visitors, they are usually not related to one specific exhibit but instead to summarize the entire exhibition [9].

***(a)** Information kiosk.*

***(b)** Tabletop display.*

***(c)** Gaming stations.*

***Figure 2:** Examples of existing interactive technologies use in GLAMs.*
*Image Source: [8, 9, 10]*

## 2.3 AR and GLAM Exhibits

The nature of AR, fulfills the requirement of interactivity and can lead to the increase in the engagement and learning outcome of GLAM exhibits mentioned in Session 2.1. One of the properties of AR is the embodyment of an audio-visual display and graphical interface [27, 28]. According to [29], the graphics presented in the AR environment are suitable for learning abstract, dynamic, and non-intuitive concepts, which are the nature of the information that GLAM exhibits have. Besides, AR technologies' audio-visual display nature with interactive elements implements as triggers can allows it to substitute the role of an information kiosk.

Additionally, overlaying content is another feature of AR. As AR can achieve the overlay of virtual information on real world environment, allowing the user to view the physical exhibits object and the exhibition spacial layout while using application . This provides a bidirectional communication of the content in both the AR interface and the real world and thus preserves the traditional relationships between the space, object, information, and the visitor [29, 30]. These traditional relationships may allow visitors to move in the exhibition space while concentrate on both the information and the exhibited object, which are major factors need for learning according to museum studies' theory [31, 29].

## 2.4 Existing AR Application in GLAMs

Many GLAMs, mainly museums and galleries, have already start adopting AR mobile application to improve visitor experience. For example, the "Skin and Bones" app by the Smithsonian National Museum of Natural History is for its "Bone Hall" exhibition with the skeletons of every major group of vertebrate animal [11]. This AR app uses image tracking located and overlay images and animations of how the animals of each skeletons sample move and look when alive (see Figure 3). The visitors' responses were very positive, and the time they stayed in the "Bone Hall" exhibition increased from 1 minutes and 34 seconds to 14 minutes after the app was launched [32].


***Figure 3:*** *A scene of how the "Skin and Bones" app work.*
*Image Source: [11]*

Another example is the "Chicago00 Eastland Disaster" app from "The Chicago 00 Project" launched by the Chicago History Museum [12]. This project used both AR and virtual reality (VR) technology o showcase the museum's film, photo, and sound archive about Chicago stories. Figure 4 show one of the app's feature of reassembling the disaster in Chicago with the single most significant number of death. this feature uses AR to overlay historical photographs and newsreel films to the real-world location where the disaster happened.

The final example is used in the "ArtLens Gallery" in The Cleveland Museum of Art, which is an interactive exhibition hall filled with interactive exhibits and installation. The app named "ArtLens App"

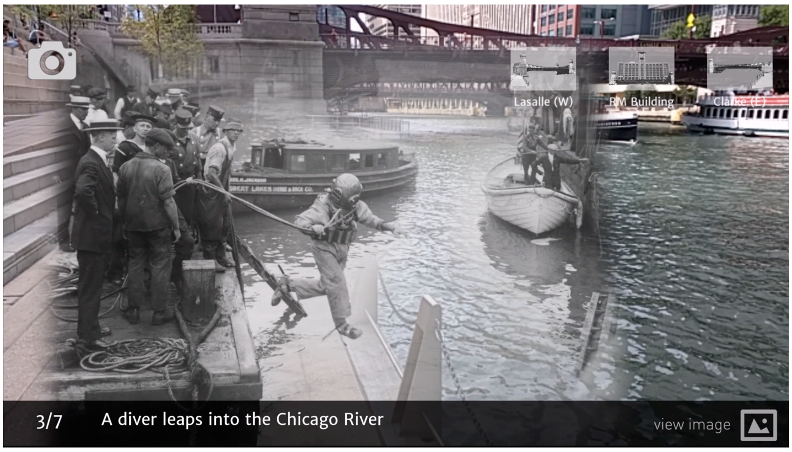



***Figure 4:*** *Screenshot of the "Chicago00 Eastland Disaster" app's AR feature.*
*Image Source: [12]*

is an overall guiding app for the exhibition, and one of the major features is using image recognition to recognize a selection of 2D and 3D artwork and provide curatorial and interpretive information [33]. For 2D artwork, the additional content is located according to the artwork using image tracking (see Figure 5).

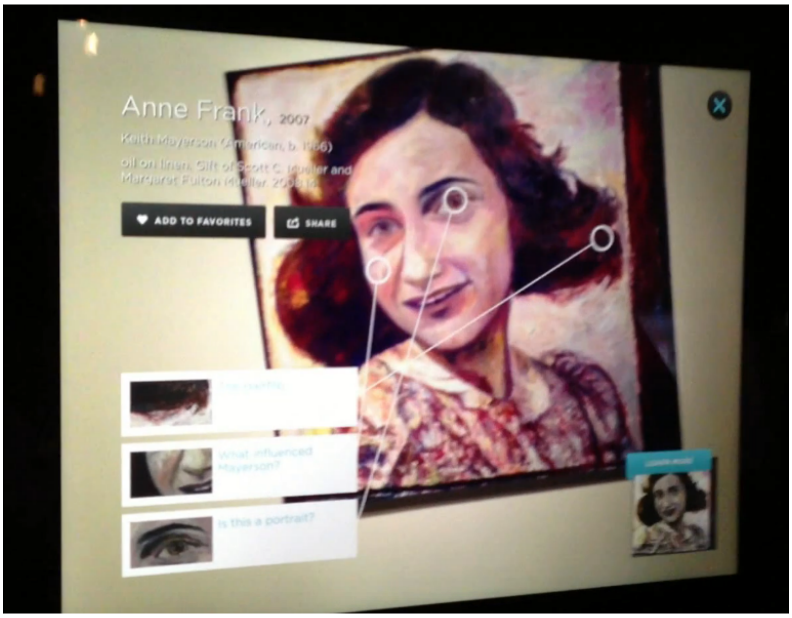



***Figure 5:*** *The AR feature of The Cleveland Museum of Art's "Artlens" app.*
*Image Source: [13]*

Although there are a number of AR applications in the market for GLAMs, most of them are developed for handheld mobile devices and there is lack of these kinds of AR application use on AR-enabled HMD. Moreover, because of recent advancement AR-enabled HMD allow it to be more ergonomic and accessiable, this project hopes to develop an application for AR-enabled HMD to understand and utilize the advantages headsets have over mobile devices improving exhibit's interactiveness. Additionally, this project may reference some of the features of the existing AR application mentioned, especially the pinpoint information feature in the "ArtLens App" from The Cleveland Museum of Art.

# 3 Methodology

This section delves into the methodology employed for both the AR interface prototype (Section 3.1) and the user study (Section 3.2).

## 3.1 Methodologies for AR Interface Prototype

This followings will list out the methodologies for developing the AR interface prototype, focusing on the choice of AR-enabled HMD (Section 3.1.1), development platform and technology stack (Section 3.1.2), and tracking method for locating the exhibited piece (Section 3.1.3).

### 3.1.1 AR Enabled Head-Mounted Device

Currently, there are two major types of AR enabled HMDs available in the market: video pass-through (VPT) and optical see-through (OPT) devices .

OPT devices feature a transparent display that overlays virtual objects on the display while users can see the surroundings due to the transparency [6, 5]. The transparent display provides a clear view of the user's physical environment [34]. However, OPT devices usually have a relatively more narrower FoV and low brightness, making them less suitable for outdoor usage and have lower immersiveness [5, 6, 35].

On the other hand, VPT devices use standard monitor (LED or OLED) that present live video feeds of the real-world surroundings captured by cameras on the device and acn achieve AR by displaying virtual elements on the monitor that is playing streaming the live view [5, 4]. While VPT devices do not share the limitations of OPT devices, they provide a relatively lower clarity of the real world due to the constraints in display resolution and camera capture quality [6]. Additionally, the latency of the video feed may result in eye strain, fatigue, and motion sickness after a long period of usage[5, 4].

Given that this AR prototype requires users to examine the details of the physical exhibited object closely, the clear real-world view offered by the transparent display of OPT devices is more suitable than the VPT devices with limited video quality. Furthermore, since the prototype is intended for indoor exhibit usage, where users' eyesight should be focused on the exhibited item, the issues of a smaller FoV and lower contrast brightness are unlikely to impact the viewing experience significantly.

Among the available OPT devices, Microsoft HoloLens 2 stands out as one of the better options. Compared to its predecessor (Microsoft HoloLens 1) and other OPT devices from startup companies, it provides a broader range of features, such as QR code detection, and better support with MRTK (details in Section 3.1.2). Therefore, the prototype of the AR interface application will be developed on the Microsoft HoloLens 2.

### 3.1.2 Development Platform and Tech Stack

For the development of the prototype, one of the major game engines, Unity, will be the development platform. Unity is a suitable choice as it supports the development and deployment of lightweight AR applications to different AR-capable HMD, including Microsoft HoloLens 2. Additionally, compared to Unreal, another major game engine commonly used for AR and VR application of HMD, Unity is a more appropriate option for development. This is because Unity is the more dominant platform for AR and VR development, shown by its 70% share of AR and VR applications on the market and 59% of all AR and VR developers prefer Unity [36], which result in better support on tools to facilitate AR and VR development. The primary programming language will be C#, which aligns with the development language used by the Unity engine.

In addition to Unity and C#, we will be utilizing relevant assets and toolkits for AR development. Two notable ones are the Mixed Reality Toolkit (MRTK) and the QR code NuGet package. MRTK will play a pivotal role in the prototype development, offering a well-polished and comprehensive toolkit that includes input methods, spatial interactions, and AR user interface components. It also supports simulation within the Unity editor, facilitating rapid prototyping. The use of MRTK is expected to significantly reduce development time and enhance the overall reliability of the final product. Similarly, the QR code NuGet package is essential for implementing the QR code tracking feature, providing the QR code SDK required for the control and data retrieval of the QR code detection function in Microsoft HoloLens 2.

### 3.1.3 Exhibited Piece Tracking

Two tracking methods, QR code tracking, and image/object recognition, can be implemented on Microsoft HoloLens 2 to locate the exhibited piece.

As mentioned in Section 3.1.1 and 3.1.2, Microsoft HoloLens 2 can detect QR codes out of the box, and Microsoft provides a QR Code SDK for developing QR code detection in Unity. By leveraging these capabilities and tools, Microsoft HoloLens 2 can use a QR code as an anchor to record the coordinate exhibited piece in real-world space. QR code tracking is a ”lightweight” and accurate method as it requires relatively less computing power and can identify the exhibited item as each is anchored with a unique QR code. However, using a 2D QR code might make it too hard to develop the virtual elements for 3D exhibited items, such as potteries and installation art, and having a QR code right next to the piece might look odd.

Meanwhile, as Microsoft HoloLens 2 allows developers to retrieve the video feed captured by the webcam, image/object recognition with computer vision is another way to implement exhibit object tracking. The image/object recognition can be developed by pre-trained computer vision models, such as Azure AI Custom Vision or You Only Look Once (YOLO) [37, 38]. Although this method can be used on all kinds of exhibited pieces, it might not be suitable for this project due to the high demand for computing power and the limited development of painting and art piece detection technology. According to [39], most existing computer vision models and research for painting recognition focus on classifying painting genres rather than recognizing individual paintings and depend on analyzing high-resolution images, which demand high computing power and storage.

Since Microsoft HoloLens 2 is a relatively compact device with limited computer capacity and this project requires the prototype to identify individual exhibited pieces, the QR code tracking method will be a better choice. Besides, part of the future plan for this project is to develop an authoring tool for GLAM experts to make an AR interface for different pieces (details in Section 6.3), the QR code tracking method might be more straightforward for GLAM experts who might have less technical knowledge to understand and use compare to image/object tracking with computer vision. As for the oddness of having a QR code next to the exhibited item, please refer to Section 5.5 for the evaluation.

For the more details of the QR code tracking's implementation, please refer to Section 4.2.

## 3.2 User Study Research Methods

User study, also called user testing and user research, are crucial to software engineering, Human-Computer Interaction (HCI) research, and user experience design, as it allows early user involvement in an application's development to evaluate the application's usability and effectiveness better.

The user study in this project is primarily focused on the concept of user study in HCI. The following sections will present the various research methods used, including usability tests and other quantitative and qualitative research methods.

### 3.2.1 Usability Test

*Usability* is defined as "the extent to which specified users can use a system, product or service to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use" [40]. Thus, usability testing evaluates how effective and satisfied users are for a product for a particular usage. In this project, the product is the AR interface prototype, and the effectiveness and satisfaction are about the user's engagement level, learning outcome, and attention span of the exhibited piece and its information.

Usability test can be illustrated as "one or more observers watch one or more participants perform specified tasks with the product in a specified test environment differs from usability test", which differs from other research methods with the existence of tasks, product, and a test environment [41]. The task in this project's context is to view the exhibited object and absorb the information provided about the object. The product can be a complete product, a product under development, or a prototype of any level of fidelity [41]. The AR interface prototype developed for this project has the completeness between a high-fidelity prototype and a complete product because the process of QR code tracking is not yet completely automated and requires the observer to control it manually. Finally, we set up mock painting exhibits as the testing environment; please refer to Section 5.2.2 for more details.

Since for this user study, we would like to compare how different exhibit viewing experience is between exhibits using the AR interface prototype (i.e., AR exhibit) and ones that do not use the prototype and display information in the conventional way (i.e., traditional exhibit) to evaluate the effectiveness of the prototype, measurement-focus test will be used. Measurement-focus test focuses on comparing quantitative factors of different products or scenarios to determine how well the product has met its goals [41]. As the objectives for the AR interface prototype are to improve engagement level and learning result and shift user's attention to the exhibited item, they can be measured by difference quantifiable observation, such as exhibit viewing duration, scores of quizzes about the exhibit's information, and duration of user not looking at the AR element.

### 3.2.2 Quantitative and Qualitative Research Methods

Other quantitative and qualitative research methods will be used along with usability testing to better analyze the prototype's effectiveness. A combination of quantitative and qualitative research methods is necessary to form a conclusion with a high degree of comprehensiveness [42]. Quantitative research generates measurable and objective data that works well in testing hypotheses developed based on the product's objectives. Meanwhile, qualitative research is usually narrative, allowing it to summarize nonnumerical observations and clarify the result of quantitative research.

Surveys and interviews are two of the most common quantitative and qualitative research methods. The survey approach in this project will consist of numerical and open-ended questions to collect quantitative and qualitative data for evaluating the objective hypothesis and understanding the user's reasoning for such a decision. The interview will be about the user's overall experience, including likes and dislikes, and suggestions for improvement of the AR interface prototype.

# 4 AR Interface Application Prototype

One of the deliverables of this project is the AR interface prototype, which will also be used for user study with more details in Section 5. Due to the time constraint, interfaces for only one exhibited item will be developed. The exhibited piece is a Chinese painting, "The Cassia Grove Studio," by Wen Zhengming in the Ming Dynasty (see Figure ). Meanwhile, a printout of this painting will be utilized because of limited resources. In the printout, a QR code will be placed at the right-hand corner of the painting (as depicted in Figure 29). The image of the painting is in the public domain (CC0 1.0 Deed), which allows the copying and distribution of the image work without permission from the owner [43].

This section delve into the four significant aspect of the AR interface prototype: interface design (Section 5.2), QR code tracking (Section 4.2), AR interactive components (Section 4.3), and hand gesture control (Section 4.4).

## 4.1 Interface Design

An interface design is made before developing the AR interface prototype on Unity. The original design was done by sketching the wireframes (Section 4.1.1), while the final interface developed on Unity (Section 4.1.2) is slightly different from it.

### 4.1.1 Wireframe of Initial Design

Figure 29 shows the wireframe of the initial layout of the prototype. Components in blue are the virtual components displayed on the AR HMD, while the painting and QR code are part of the real-world

***Figure 6:*** *"The Cassia Grove Studio" by Wen Zhengming.*
*Image Source: [14]*

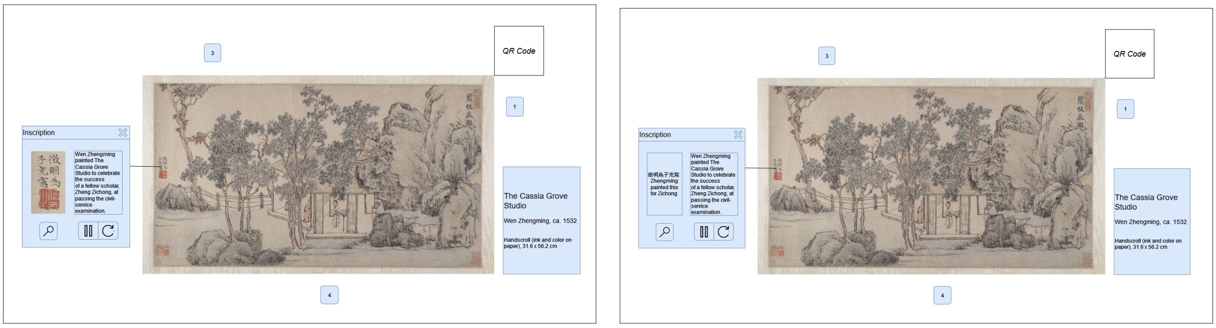
***Figure 7:*** *The printout of the painting for the AR exhibit with the QR code.*
*Image Source: Adapted from [14]*

environment. There are, in total, five virtual components: a museum label placed next to the painting with basic information about the painting and four interactive components around the painting.

Initially, the interactive components are buttons (i.e., rounded corner squares) that users can use to display information about a specific painting part. This information will be displayed in an information panel as different forms of multimedia, including images, text, and audio, with an edge pointing to the relevant part of the painting. As shown in Figure 31, some of the multimedia information is interactive, such as the button (shown with a magnifying glass) under the inscription images will display the text, PingYing, and English translation of the inscription and the pause and restart button for the audio description. For information panels that have more lengthy text, instead of showing all text on the panel, the text will be scrollable to avoid having the information panel being too big that it gets out of the FoV or cramming all text, causing it to be hard to read.

More details of the interactive components will be included in Section 4.3, and please refer to Appendix A for the complete wireframe.


***Figure 8:*** *Wireframe of the initial interface of the AR prototype.*




***(a)*** *Initial layout*

***(b)*** *Inscription Text after interacting with the magnifying glass button*

***Figure 9:*** *Wireframe of information panel with text, audio player, inscription image.*

### 4.1.2 Final Interface

Figure 11 shows the initial interface developed prototype. There are a few changes to the final design of the interface parts. First, a magnifying glass icon on the button for getting the inscription text had switched to the text of ”To Text” and ”To Image” to let the user better understand what the button is for (see Figure12). The Second change is on the location of the audio control buttons; they moved from under the text to on the title bar, which groups them with the close button (see Figure 13). The last change is also shown in Figure 13, where instead of only the text part, the whole content area is scrollable for longer text to provide a larger area for more straightforward scrolling action.


***Figure 10:*** *wireframe of information panel with scrollable text.*


***Figure 11:*** *Initial Interface of the developed AR interface prototype.*

## 4.2 QR Code Tracking and Object Placement

The QR code tracking is a significant part of the AR interface prototype, which locates the exhibited object and places the virtual component on the real-world coordinate accordingly. The QR code tracking is controlled by the QR code SDK (Section 4.2.1) and is composed of 3 game objects: QR code manager (Section 4.2.2), QR code panel (Section 4.2.3), and QR code visualizer (Section 4.2.4).

### 4.2.1 QR Code SDK

Although Microsoft HoloLens 2's QR code tracking is automatically turned on, the QR code SDK is needed to allow developers to develop applications on Unity with QR code tracking. The required SDK named ”Microsoft.MixedReality.QR” is installed from NugetForUnity, a package management system client that runs in Unity.


***(a)** When inscription image is shown*


***(b)** When inscription text is shown*

***Figure 12:** Information panel with new button form inscription image.*

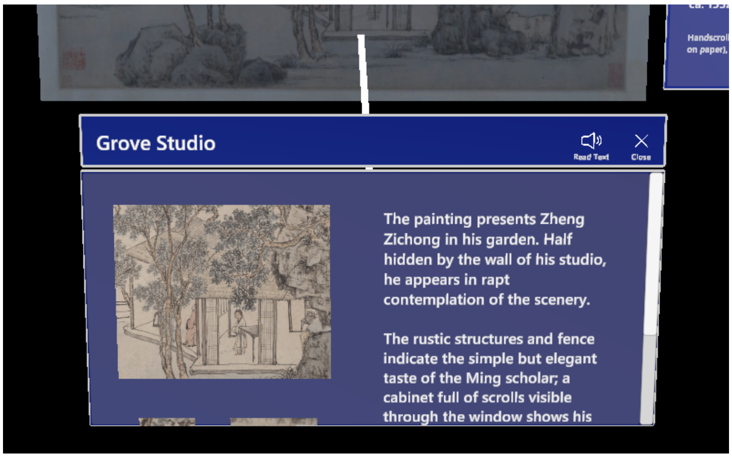



***Figure 13:** Information panel with a new button from audio control located on the title bar and scrollable panel.*

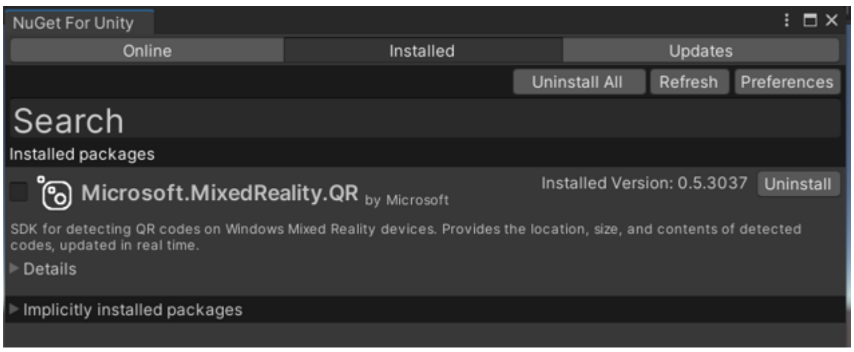



***Figure 14:** The visual editor window of NugetForUnity for installing the QR code SDK.*

### 4.2.2 QR Code Manager

A manager must also control the SDK and allow it to work with other game objects in the prototype. The QR code manager is composed of 2 scripts: the ”QRCodeManager” script for accessing and controlling the QR code SDK and the ”QRCodeVisualizer” script for placing the game objects, including the QR Code Visualizer and the interactive components, based on QR code’s coordinate (see Figure 15).

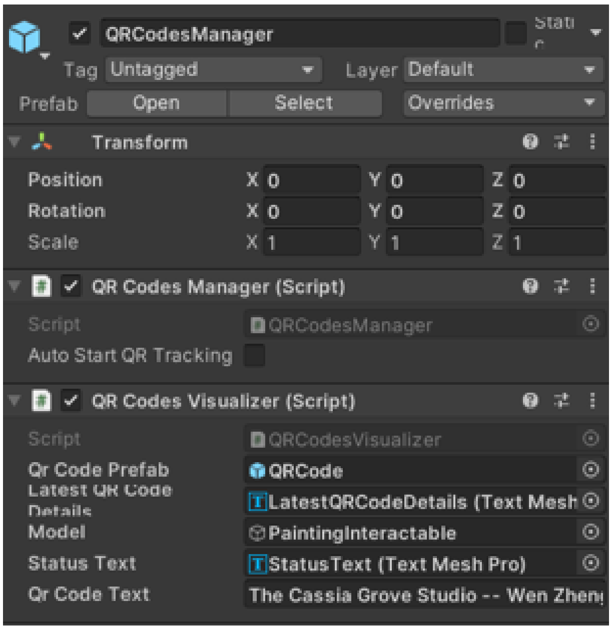



***Figure 15:*** *The inspector window of the QR code manager game object.*

### 4.2.3 QR Code Panel

The user will see the QR code panel when the application is first opened. This panel has a user interface (UI) to control the QR code tracking and know its status. As seen in Figure **??**, there is a text field in the middle of the panel for showing the text embedded in and the coordinate of the detected QR code 3 button for control (see Figure 16).

### 4.2.4 QR Code Visualizer

After the start QR code detection button is ”clicked”, the QR code SDK will let the Microsoft HoloLens 2 know and start to track the QR code. When the QR code is tracked, a QR code visualizer prefab (see Figure 17a) will be placed where the QR code is located with the coordinate of the upper left corner recorded by the application and relevant information of the QR code shown (see Figure 17b).

## 4.3 AR Interactive Components

As mentioned in Section 4.1.1, this prototype has four interactive components. Each interactive component is made up of two types of UI elements provided by MRTK: buttons (Section 4.3.1) and slate

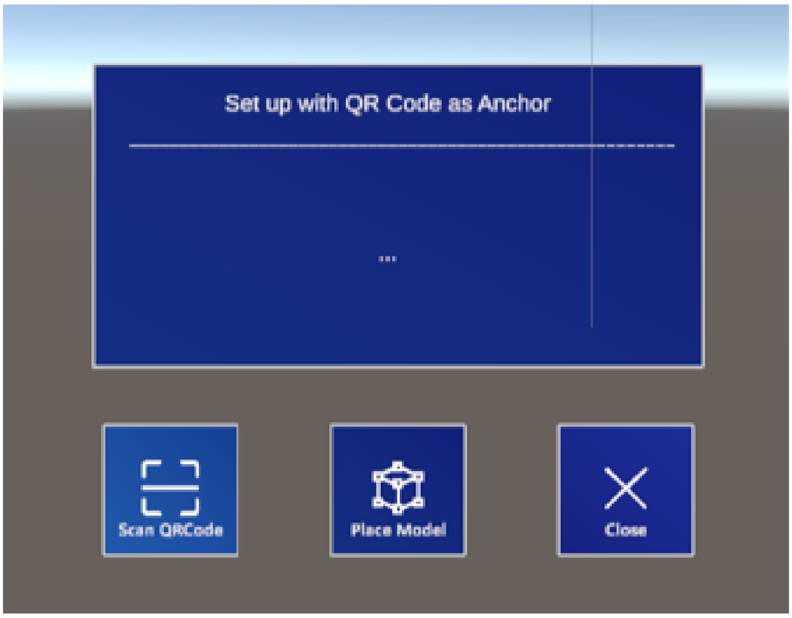
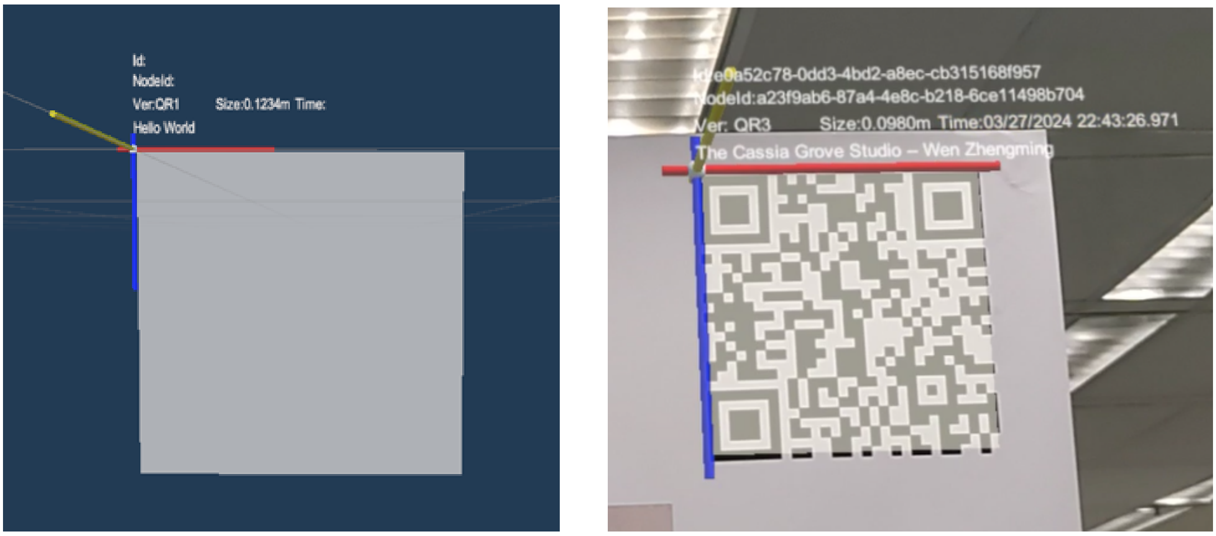



***Figure 16:*** *The QR code panel with a text field and three buttons for starting the QR code detection, placing the virtual element based on the QR code's location, and closing the panel (left to right).*




***(a)*** *When inscription image is shown*

***(b)*** *When inscription text is shown*

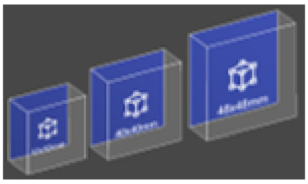
***Figure 17:*** *Information panel with new button form inscription image.*

4.3.2.

### 4.3.1 Buttons

Two kinds of buttons are used for each interactive component. The first kind is a round button for opening the informational panel, with the numbering and title text placed next to it (see Figure 21a). This button will disappear when the information panel is opened and reappear after it is closed. The second kind of button is a square shape for audio control and closing the panel (see Figure 21b). This kind of button with a border will be shown when the user hovers over or interacts with it (see Figure 21c).


*(a) Round button*



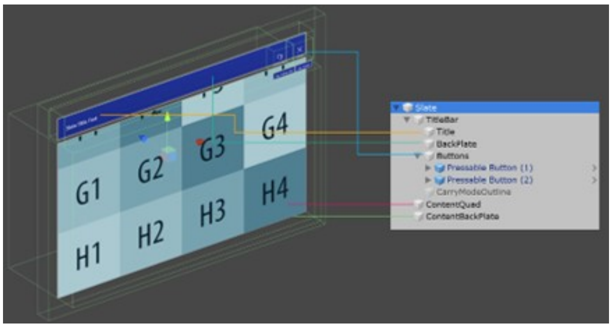
*(b) Square button*

*(c) Square button when hovered over*

***Figure 18:*** *Buttons used for each interactive component.*

### 4.3.2 Slate

Slate is a prefab offered by MRTK, which is used for the information panel in this prototype (see Figure 19a). It has different elements, including the "ContentQuad", where the information is placed. To increase interactiveness and allow users to have more control, a bound control is added to the slate of the information panel for users to relocate, resize, and rotate it (see Figure 19b).




*(a) Composition of slate prefab*


*(b) Bound control*

***Figure 19:*** *Slate prefab used as an information panel.*
*Image Source: [15]*

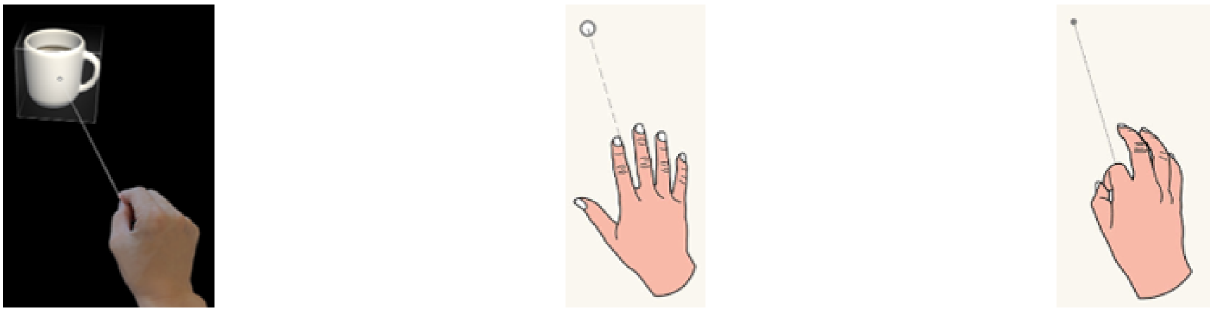
## 4.4 Hand Gesture Control

This prototype used hand gestures for the control, which relies on the built-in hand tracking feature in Microsoft HoloLens 2 that is compatible with MRTK by configuring it with the "Default-HoloLens2HandTrackingProfile" in MRTK's input setting.

In this prototype, two types of gesture input models, point and commit 4.4.1 and direct manipulation 4.4.2, can be used by users to interact with the virtual elements.

### 4.4.1 Point and Commit

For the point and commit input model, a ray that functions as a hand extension emerges from the user's palm. The ray's end has a cursor attached to it to show where it is when the ray collides with an object [16]. The thumb and index finger can interact with the object the cursor lands on by making an air-tap gesture.

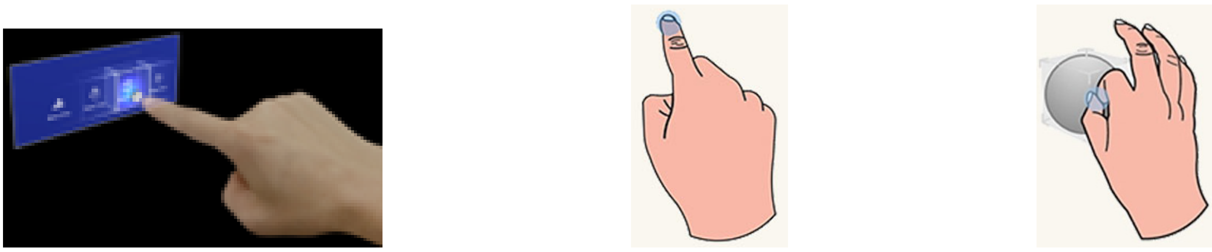


*(a) Interacting with object* *(b) Ray from palm* *(c) Air tap*

***Figure 20:*** *Point and commit input model.*
*Image Source: [16]*

### 4.4.2 Direct Manipulation

The direct manipulation input model allows the user to touch the objects's holograms directly with their hands. A collider is placed on the index finger where it will be the active touch point, allowing hand gestures that involve itself and other fingers, such as one-finger press and two-finger pinch [17].



*(a) Interacting with object* *(b) Press* *(c) Pinch*

***Figure 21:*** *Direct manipulation input model.*
*Image Source: [17]*

# 5 User Study

A user study involving the AR interface prototype discussed in Section 4 is conducted to gain insight into how effective the AR interactive interface is in improving visitors' visiting experience.

In this section, we will first present this user study's hypothesis (Section 5.2), the design and setup (Section 5.1), and the participant (Section 5.3. Then, we will discuss the data collected and its analysis (Section 5.5).

## 5.1 Hypothesis

Since the purpose of the user study is to evaluate the effectiveness of the AR interface prototype discussed, three hypotheses based on the AR interface prototype's objectives (refer to Section 1.2) will form as the bases of this study. The hypotheses focus on the visitor's engagement level, learning result, and attention to the exhibited object, which are as follows:

**H1** : Engagement levels of visitors using the interactive AR interface will be higher then those no using the interactive AR interface.

**H2** : Visitors viewing exhibits with the interactive AR interface will result in a better learning experience.

**H3** : Visitors' attention on the interactive AR elements will not overshadow their attention on the exhibited object.

## 5.2 User Study Design and Setup

In the following, the design of the user study based on the three hypotheses (Section 5.2.1) and the setup of the mock exhibit environment (Section 5.2.2) will be presented.

### 5.2.1 Parts and Procedures

The user study will be divided into pre-study, exhibit experience, and post-study.

First, in the pre-study, an introduction to this user study will be given to the participants, asking them to sign a consent form to ask for their consent to recording (Appendix B.1). Then, the participant is asked to fill in a pre-survey with questions regarding their demographic, experiences with AR technology, and background in Chinese painting or art exhibits (Appendix B.2). Finally, a tutorial on how to use the Microsoft HoloLens 2 will be given, which consists of a tutorial program with a button, a slate (i.e., information panel), and hand gesture controls, same as the AR interface prototype (see Figure 22) and a tutorial video demonstrating how to use the different hand gesture controls to interact with the button and slate in this program.


***Figure 22:*** *Tutorial program for participants to get familiar with the UI and controls.*

The second part is the exhibit experience, where participants will experience two exhibits, one employing the AR interface (i.e., AR exhibit) and the other follows a traditional exhibit format (i.e., traditional exhibit) with the museum label and text description placed next to the painting (see Figure 23). The pieces in both exhibits are Chinese ink and color paintings on paper done during the Ming dynasty to reduce the interference of the different paintings on the study result. A video user's perspective of viewing the AR exhibit is recorded on the Microsoft HoloLens 2. After viewing each exhibit, the participants will be asked to finish a quiz with four multiple-choice questions (2 questions with single answers and 2 questions with multiple answers) related to the exhibit's information.

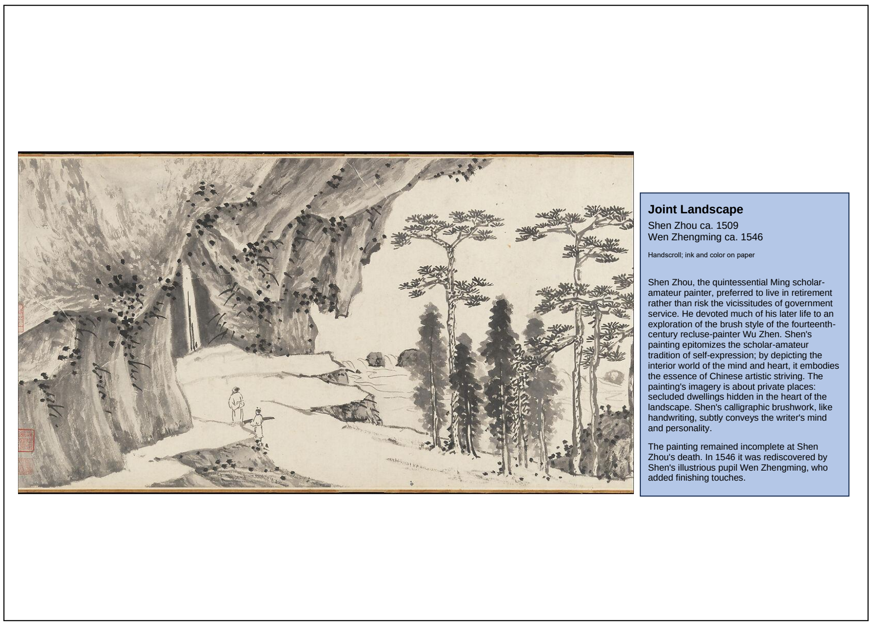



***Figure 23:*** *The printout of the painting for the Traditional Exhibit.*
*Image Source: Adapted from [18]*

The post-study is the last part of the user study, where the participants will first be requested to complete the post-survey (Appendix B.3). This survey includes quantitative and open-ended questions to ask them about their overall experience of the two exhibits, focusing on their engagement levels, satisfaction, and learning experience. Then, an interview regarding their thoughts, feedback, and suggestions on the AR interface prototype and the user study.

### 5.2.2 Mock Exhibit

As mentioned in Section 3.2.1, a mock exhibit will be used for the user study. The mock exhibit for the study is set in a study room of the university library, where the printout of the paints is taped on one side of the room, and the participants can walk freely in the study room space to view the paintings (see Figure 24).

Other than the room setting of the mock exhibit, as the AR interface prototype has audio for the text information, we need to include audio of the description for the mock traditional exhibit to avoid the lack of audio being the cause of the different result. To mimic how real museums work, a smartphone connected to a wired headphone with the description audio played on it is provided to the participants during the traditional exhibit round.

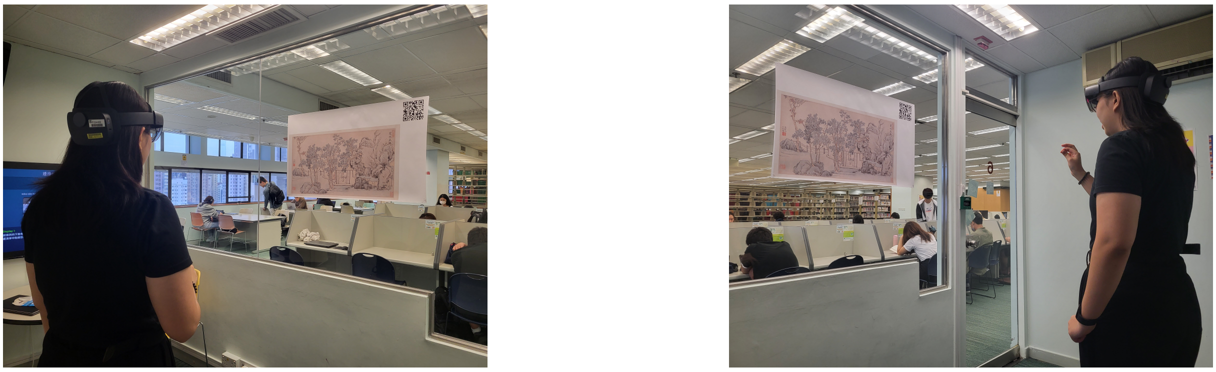


***Figure 24:*** *Mock exhibit environment for the AR exhibit*

### 5.3 Pilot Study and Participants

In the main study, 5 participants have joined, as studies 4 to 5 participants are enough to detect 80% of the usability problems [44]. Among the 5 participants, 3 identify as female and 2 as male. 4 of the participants are in the age range of 21 to 25 and 1 participant in the age range of 31 to 35. As for the highest education level (including ongoing studies), 1 participant has/will have a PhD, and 4 participants have/will have a Bachelor's degree. 2 of the 5 participants are from a Computer Science background, while the other 3 are all from different backgrounds, including Economics and Finance, Social Science, and Education.

To better understand potential bias, the participants were asked about their experience with AR technology and background in Chinese painting and exhibits in the pre-survey. All 5 participants have experience using AR with handheld devices, while 1 participant has experience using AR on HMD. However, all of them rarely use AR technology and rate themselves a low level of experience.

| | P1 | P2 | P3 | P4 | P5 |
|---|---|---|---|---|---|
| Use AR with handheld devices | Yes | Yes | Yes | Yes | Yes |
| Use AR with headset | No | No | No | No | Yes |
| AR usage frequency | Rarely | Rarely | Rarely | Rarely | Rarely |
| Self-rate level of experience with AR (1-5) | 2 | 2 | 1 | 1 | 2 |

***Table 1:*** *Participant's AR experience.*

The participants' responses regarding knowledge and interest in Chinese painting and art exhibits are less unified. The participants have various levels of interest in Chinese painting. Meanwhile, most of them believe they have relatively low knowledge in this area. However, all participants have visited Chinese painting exhibits before, but the number of visits varies.

### 5.4 Data Collection

During the user study, different types of data were collected during each part of the user study, which can be categorized into 6 categories: Duration, Demographic, Experience and Background Knowledge, understanding of Exhibit Information, Engagement, and Other (Appendix D). The Demographic and

| | P1 | P2 | P3 | P4 | P5 |
|---|---|---|---|---|---|
| Interest level in Chinese painting (1-5) | 1 | 3 | 3 | 1 | 4 |
| Knowledge level in Chinese painting | 1 | 1 | 1 | 3 | 2 |
| Number of Chinese painting exhibits' visits | 1 | 1 | > 5 | 3 | > 5 |

***Table 2:*** *Participant's knowledge and interest in Chinese painting.*

Experience and Background Knowledge data have been presented in Section 5.3. The remaining data will mainly used for analyzing the 3 hypotheses mentioned in Section 5.1.

## 5.5 Data Analysis

The Duration and Engagement data can be used to analyze H1, the hypothesis regarding engagement level. The viewing duration (in seconds) of the AR exhibit and the traditional exhibit of each participant is shown in Figure 25, where all participants viewed the AR exhibit for a longer time. The staying length at a museum has often been used as an indicator of engagement for museum studies research since time is a necessary requirement for visitors to be engaged [45]. Moreover, the participants are asked to rate their engagement level of the two exhibits on a scale of 1 to 5 (1 as lowest and 5 as highest). 4 out of 5 of the participants have rated the AR exhibit with a higher engagement score (see Table 3). Therefore, this hypothesis of the exhibit using the AR interface prototype has a higher engagement level and is valid.

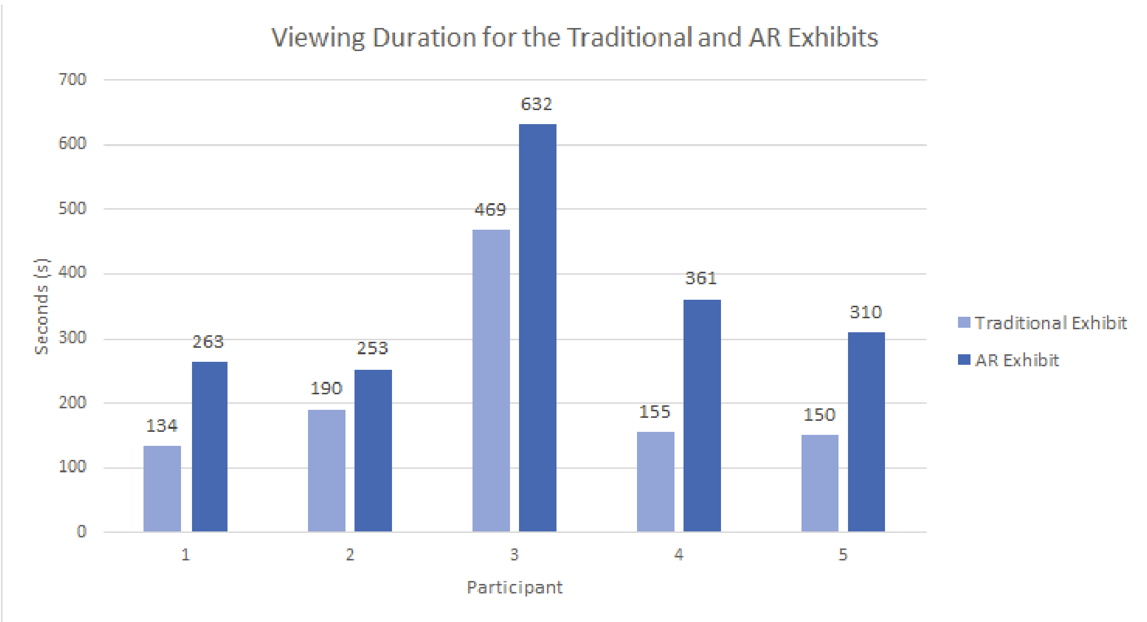



***Figure 25:*** *Bar chart of exhibit viewing duration for AR and traditional exhibit for each participant.*

| | P1 | P2 | P3 | P4 | P5 |
|---|---|---|---|---|---|
| Engagement level for AR exhibit (1-5) | 3 | **4** | **5** | **3** | **4** |
| Engagement level for AR exhibit (1-5) | **4** | 2 | 3 | 2 | 2 |

***Table 3:*** *Participant's self-rated engagement level for each exhibit.*

H2 is about the visitor's learning outcome, which the Duration and Understanding of Exhibit Information data can be used to analyze. Other than engagement, the length of stay in an exhibit is essential for learning at the museum [45], which the overall higher viewing time for the AR exhibit has already been stated in H1's proof and in the bar chart of Figure 25. As for data categorized under Understanding of Exhibit Information, quiz scores after viewing the exhibit directly assess the learning result of a museum visit [45]. As seen in Table 4, almost all participants did better on the quiz for the AR exhibit while 1 scored the same for both quizzes. We also asked participants to self-evaluate the enhancement level in their understanding of the exhibit's information using the AR interface. All participants agree that the AR interface has enhanced their understanding of the exhibit content to some degree (see Figure 26). The analysis of these data proves that the use of the AR interface prototype results in a better learning outcome.

| | P1 | P2 | P3 | P4 | P5 |
|---|---|---|---|---|---|
| AR Exhibit Quiz Score | 3.5 | **4** | **3.5** | **3** | **3.5** |
| Traditional Exhibit Quiz Score | 3.5 | 2.5 | 2 | 2.5 | 3 |

***Table 4:*** *Score of the quizzes taken after viewing each exhibit.*

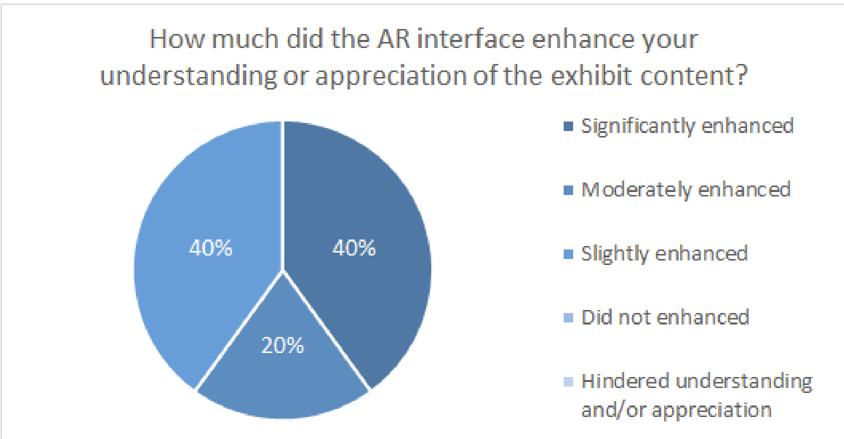



***Figure 26:*** *Pie chart of the distribution of participant's self-evaluation on the level of enhancement in their understanding of the exhibit's information by the AR interface.*
*2 participants stated it significantly enhanced, 1 participant stated it moderately enhanced, and 2 participants stated it slightly enhanced.*

The last hypothesis, H3, is about visitors maintaining focus on the exhibited piece. From the Duration data, precisely the duration of how long the participants look at each AR interactive components, the different viewing time of the participants on and not on the AR components is summarized in Figure 27. As seen in this figure, most participants (4 out of 5) spend most of their time viewing focusing on the AR components while only at maximum 1/3 of the total viewing time is on another aspect of the exhibit, including actually looking at the exhibited piece. This being the result, the AR interface cannot help maintain viewers' attention on the exhibited piece.

Other than the 3 hypotheses, other data relevant to the overall satisfaction can also reflect how well this AR interface functions. When the participants were asked which exhibit would they more likely to revisit, the participant would either choose the AR exhibit or both exhibits (see Figure 28). Participants

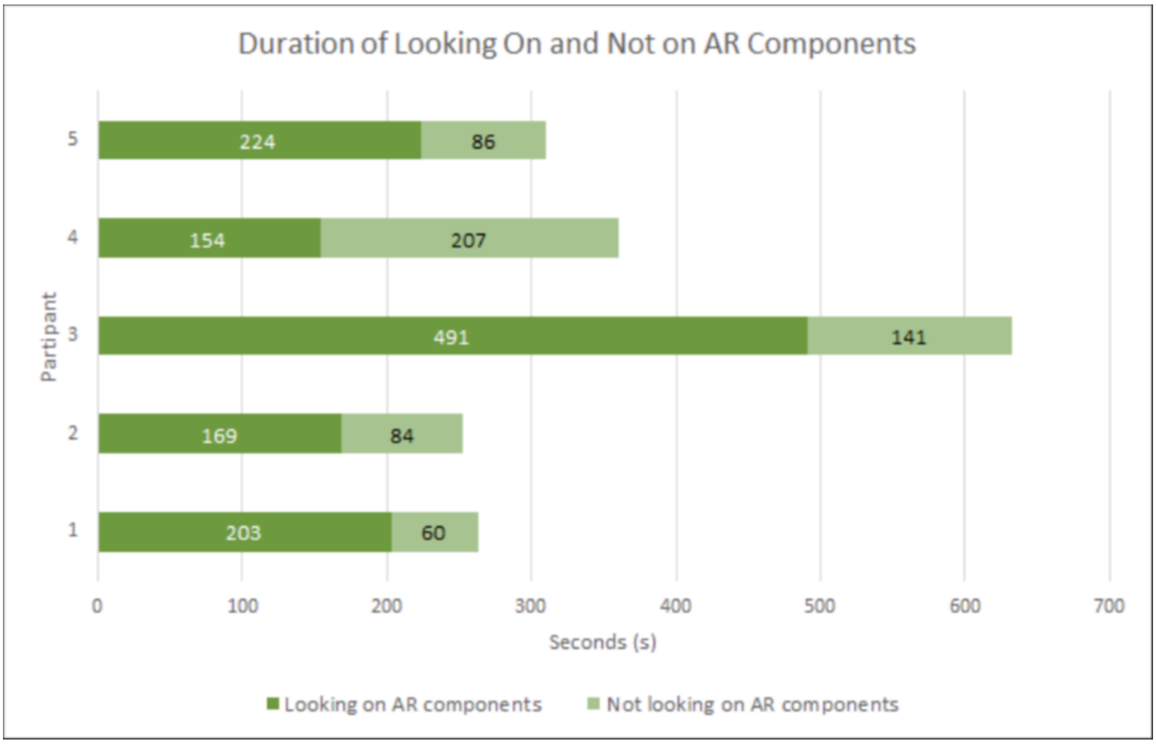



***Figure 27:*** *Categorization of all types of data collected.*

are also asked which exhibit they enjoy the most, and all agree the AR exhibit is more enjoyable.

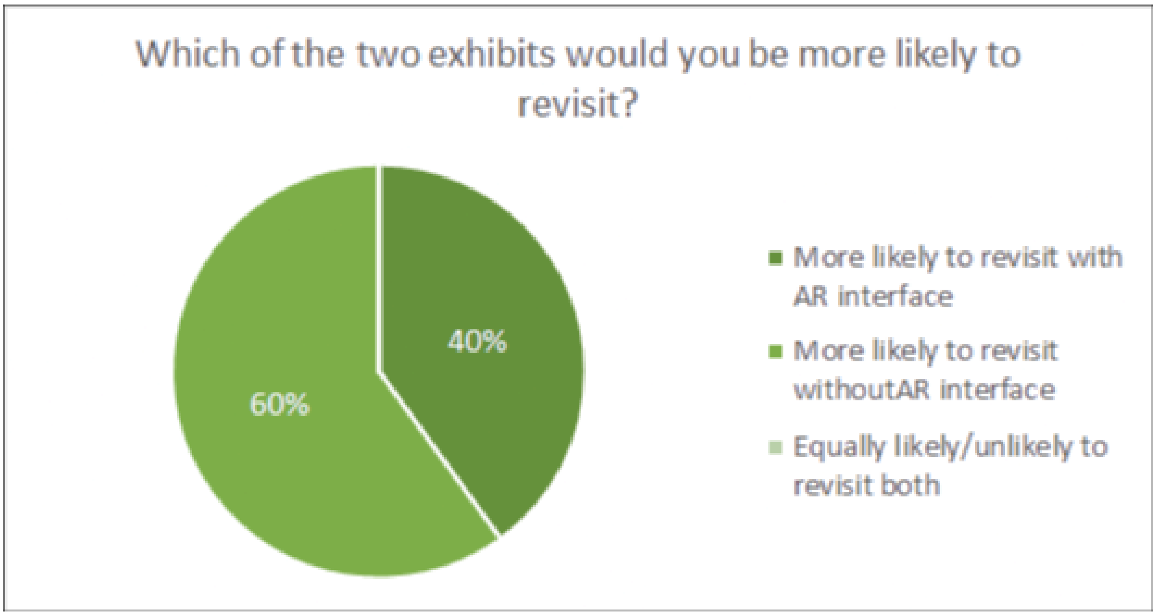



***Figure 28:*** *Pie chart of the distribution of which exhibit the participants are more likely to revisit. 2 participants stated they were more likely to revisit the AR exhibit, and 3 participants stated they were equally likely to revisit both exhibits.*

### 5.6 Discussion

In Section 5.5, the AR interface prototype effectively improves visitor's engagement and learning experience. According to the participants, a few critical factors of the AR interface contribute to this improvement. According to participants who scored the AR exhibit with a higher engagement score, they stated that the interactivity and the freedom to control and explore different interactive components offered by the AR interface are the primary reasons that make them feel more engaged. For a few of the participants who have not experienced AR through AR-enabled HMD before, this new experience makes the exhibit viewing more interesting and thus adds to the engagement. In addition, participants also expressed how the information (in both text and audio form) is divided into smaller chunks, and pinpointing the relevant parts of the painting helped them better understand the information than the large paragraph of description in the traditional exhibit.

Participants also commented on their user experience of the AR interface prototype, focusing on the controls, input methods, and the usage of Microsoft HoloLens 2. One of the participants stated that the audio control for the AR interface is more intuitive than controlling the audio through a recorder or mobile phone app that is commonly used for traditional exhibits as the audio control buttons are on the same device, and right next to the relevant text. However, some participants have feedback on some negative issues with the hand gesture control and Microsoft HoloLens 2. For the participants who have not used AR-enabled HMD before, they took quite a long time to get used to the hand gestures control even after having the tutorial, and a few might even get annoyed when some hand gestures are not tracked properly. They also mentioned that the lack of physical and tactile response when interacting with the interactive components causes the interactions to be less intuitive. Additionally, a participant stated that the Microsoft HoloLens 2's transparent display results in a dimmer view and dulls down the exhibit painting, which hinders their appreciation of the piece.

## 6 Challenge, Limitation, Future Work, and Conclusion

This section will first present some of the challenges (Section 6.1) and limitations (Section 6.2) that we have faced during this project. Then, it will talk about the plan after the current progress (Section 6.3). Furthermore, finally, a conclusion to conclude this report (Section 6).

### 6.1 Challenge

During this project, both the development of AR interface prototype and the execution of the user study faced different challenges that, in the end, have found ways to solve them.

In the initial stage of proposing the project idea, we intended to use a VPT device, specifically the Meta Quest Pro, for this prototype. However, after researching the tracking methods for locating the exhibited object, it is found that all of the VPT headsets from larger tech companies, such as Meta, Apple, and HTC, do not allow developers to access the video feed captured by the exterior cameras due to privacy policies. This causes all the mainstream VPT devices, including the Meta Quest Pro we intended to use, to be unable to do image/object tracking. Although some start-up companies' VPT headsets do allow access to the video feed, it is also possible to use trackers and sensors, such as the HTC's Vive tracker with Steam's Valve Index Base Station, to allow the tracking, both of these methods are too expensive and over the allowed budget. Therefore, we decided to opt for an OPT device, the Microsoft HoloLens 2. With more research, it is clear that OPT headset and the QR code tracking feature offered by Microsoft HoloLens 2 are more suitable for this project's usage.

As for the user study, there were some challenges in recruiting participants and creating an exhibit environment. Since the user study needs to be done in a relatively short time frame and this project does not have the ethical approval to recruit participants from the university communication channels, having a decent number of participants is hard. However, we found out, according to studies about usability evaluation, 80% of usability issues are found by evaluation on 4 or 5 subjects, which new subjects are less likely to provide additional information, and most serious usability issues are found in the first few subjects [44]. This justifies the effectiveness of user studies with fewer participants, allowing. Defend this user study has only 5 participants in the main study.

### 6.2 Limitation

Other than the challenges that have been resolved, this project also has limitations that have not been solved as of the date of writing this report.

3D models relevant to the exhibited piece were intended to be added to the AR interface prototype to increase interactivity and better utilize the capability of the Microsoft HoloLens 2. Despite this thought, this solo team for this project lacks 3D modeling skills, and the time allowed for this project is too short for someone to gain enough advanced level of 3D modeling skills to make complex models. Although there are many online 3D model resources, those models are either irrelevant to the specific Chinese painting the prototype is developed for or are in a file format incompatible with Unity3D.

Besides being unable to include 3D models, the mock exhibit environment is not ideal. The original plan is to work with a museum or a small-scale exhibition in GLAMs, but it is not feasible for such a small-scale project in a less-than-a-year time frame to be accepted for collaboration. The solution is to create a mock exhibit environment by printing out the exhibit piece and conducting the study in a study room. Although the mock exhibit mimics most of the critical aspects of an exhibit, there are still many differences from an actual exhibit.

### 6.3 Future Work

The project's future plan will focus on solving the limitation mentioned, adopting the application to OpenXR and image/object recognition, and creating an authoring tool.

Since the limitations of including 3D models can be resolved with more time provided, the first thing for the continuation of this project is to make relevant 3D models. Blender will be used to make 3D models, as it is one of the major 3D modeling software, and it exports 3D models in FBX format comparable with Unity. As for the exhibit environment, one of the future goals is to collaborate with a small-scale exhibition, such as a limited-time exhibition in a school library, to test the usability in a more realistic environment.

Besides resolving the limitations, adopting OpenXR is another plan for the AR interface's future. The current prototype uses the Windows Mixed Reality platform, which has the best compatibility with Microsoft HoloLens 2 as it is its default platform. However, Microsoft devices can only use Windows Mixed Reality, limiting future development and usage on other AR-enabled HMD. Thus, an adaptation of the AR interface to OpenXR, an open source platform for VR and VR that is used by most available devices, will be part of the plan. Other than OpenXR, since QR tracking is not available for other AR-enabled HMD, switching the tracking method to image/object recognition will be needed. While the high computing power requirement and most current image/object recognition algorithms do not identify individual paintings, researchers at North China Electric Power University are researching a painting recognition algorithm that detects individual paintings with low enough computing capacity requirement to allow them to be used on mobile phones [39], which can be used by the AR interface in the future.

After all the previously mentioned plans have been done and tested on usability, the project can move on to create an authoring tool. The authoring tool will have an easy-to-use UI (e.g., drag and drop) to allow museum and art history experts with a non-technical background to create individual AR interfaces for different exhibited pieces. This will be the first step for the AR interface to be used by GLAM.

## 6.4 Conclusion

This project explores the intersection of AR technology and GLAM exhibits to enhance visitor interactivity and engagement. By examining related research and existing technologies, the gap of lacking AR application used on AR-enabled HMD for GLAM exhibits is identified. Thus, this project aims to develop an AR interface prototype for GLAM exhibits information display and conduct user studies to evaluate its efficacy.

The AR interface prototype comprises various interactive components, QR code tracking of the exhibited piece for components placement, and hand gesture control to navigate components. The user study validated the AR interface to enhance educational outcomes while providing insights into its usability and effectiveness.

Challenges were faced during both the development of the prototype and conducting the user study, in which solutions were found. Despite encountering unresolved limitations, our project sets the stage for future development of the AR interface for GLAM exhibit. Addressing these limitations will be a primary focus, along with transitions of the AR interface for broader compatibility. Looking ahead, collaborating with small-scale exhibitions and developing an authoring tool will allow us to get closer to the aim of enhancing visitor experiences through the use of technology.

## References


[1] E. Klopfer and K. Squire, "Environmental detectives-the development of an augmented reality platform for environmental simulations," *Educational Technology, Research and Development*, vol. 56, pp. 203–228, 04 2008. Copyright - Copyright Association for Educational Communications Technology Apr 2008; Last updated - 2023-07-31.

[2] R. T. Azuma, "A Survey of Augmented Reality," *Presence: Teleoperators and Virtual Environments*, vol. 6, pp. 355–385, 08 1997.

[3] P. Milgram and J. Herman W. Colquhoun, "A framework for relating head-mounted displays to mixed reality displays," *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, vol. 43, no. 22, pp. 1177–1181, 1999.

[4] J. Kawai, H. Mitsuhara, and M. Shishibori, "Tsunami evacuation drill system using motion hazard map and smart devices," in *2016 3rd International Conference on Information and Communication Technologies for Disaster Management (ICT-DM)*, pp. 1–7, 2016.

[5] R. Van Krevelen and R. Poelman, "A survey of augmented reality technologies, applications and limitations," *International Journal of Virtual Reality (ISSN 1081-1451)*, vol. 9, p. 1, 06 2010.

[6] P. Milgram, H. Takemura, A. Utsumi, and F. Kishino, "Augmented reality: A class of displays on the reality-virtuality continuum," *Telemanipulator and Telepresence Technologies*, vol. 2351, 01 1994.

[7] National Museum of American History Smithsonian Institution, "American television exhibit installation 1989." `https://www.flickr.com/photos/nationalmuseumofamericanhistory/4408830200`. (Accessed: 2023-10-23).

[8] National Library of New Zealand, "Campaigns Latest News." `https://www.tepunafoundation.org.nz/campaigns-news`. (Accessed: 2023-10-23).

[9] T. Geller, "Interactive tabletop exhibits in museums and galleries," *IEEE Computer Graphics and Applications*, vol. 26, no. 5, pp. 6–11, 2006.

[10] Wikimedia Commons, "File:Video games - Tekniska museet - Stockholm, Sweden - DSC01675.JPG — Wikimedia Commons, the free media repository." `https://commons.wikimedia.org/w/index.php?title=File:Video_games_-_Tekniska_museet_-_Stockholm,_Sweden_-_DSC01675.JPG&oldid=456036121`. (Accessed: 2023-10-23).

[11] Smithsonian National Museum of Natural History, "Bone Hall." `https://naturalhistory.si.edu/exhibits/bone-hall`. (Accessed: 2023-10-23).

[12] "The Chicago 00 Project." `https://chicago00.org/`. (Accessed: 2023-10-23).

[13] YouTube, *Navizon Indoor Triangulation System - ArtLens @Cleveland Museum of Art*. (Accessed: 2023-10-23).

[14] The Metropolitan Museum of Art, "Wen zhengming — the cassia grove studio — china — ming dynasty (1368–1644)." https://www.metmuseum.org/art/collection/search/44601. (Accesed 25-04-2024).

[15] Microsoft, "Slate – MRTK2." https://learn.microsoft.com/en-us/windows/mixed-reality/mrtk-unity/mrtk2/features/ux-building-blocks/slate?view=mrtkunity-2022-05. (Accessed: 2024-04-25).

[16] Microsoft, "Point and commit with hands." https://learn.microsoft.com/en-us/windows/mixed-reality/design/point-and-commit. (Accessed: 2024-04-25).

[17] Microsoft, "Direct manipulation with hands." https://learn.microsoft.com/en-us/windows/mixed-reality/design/direct-manipulation. (Accessed: 2024-04-25).

[18] The Metropolitan Museum of Art, "Shen zhou — joint landscape — china — ming dynasty (1368–1644)." https://www.metmuseum.org/art/collection/search/39556. (Accesed 25-04-2024).

[19] N. Haywood and P. Cairns, "Engagement with an interactive museum exhibit," in *People and Computers XIX — The Bigger Picture* (T. McEwan, J. Gulliksen, and D. Benyon, eds.), (London), pp. 113–129, Springer London, 2006.

[20] A. Witcomb, *Interactivity*, ch. 21, pp. 353–361. John Wiley  Sons, Ltd, 2006.

[21] J. Stevenson, "Getting to grips," *Museums Journal*, vol. 94, no. 5, pp. 30–31, 1994.

[22] G. Hein, *Learning in the Museum*. Museum meanings, Routledge, 1998.

[23] D. vom Lehn and C. Heath, "Accounting for new technology in museum exhibitions," *International Journal of Arts Management*, vol. 7, no. 3, pp. 11–21, 2005.

[24] J. Falk and L. Dierking, *Learning from Museums: Visitor Experiences and the Making of Meaning*. American Association for State and Local History book series, AltaMira Press, 2000.

[25] D. Vom, L. Christian, and J. Hindmarsh, "Rethinking interactivity: design for participation in museums and galleries," 06 2005.

[26] M. Konstantakis and G. Caridakis, "Adding culture to ux: Ux research methodologies and applications in cultural heritage," *J. Comput. Cult. Herit.*, vol. 13, feb 2020.

[27] M. Billinghurst, A. Clark, and G. Lee, "A survey of augmented reality," *Found. Trends Hum.-Comput. Interact.*, vol. 8, p. 73–272, mar 2015.

[28] K. Kim, M. Billinghurst, G. Bruder, H. B.-L. Duh, and G. F. Welch, "Revisiting trends in augmented reality research: A review of the 2nd decade of ismar (2008–2017)," *IEEE Transactions on Visualization and Computer Graphics*, vol. 24, no. 11, pp. 2947–2962, 2018.

[29] L. Pujol and M. Economou, "Exploring the suitability of virtual reality interactivity for exhibitions through an integrated evaluation: the case of the ename museum," 09 2023.

[30] S. Münster, F. I. Apollonio, P. Bell, P. Kuroczynski, I. Di Lenardo, F. Rinaudo, and R. Tamborrino, "Digital cultural heritage meets digital humanities," *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. XLII-2/W15, pp. 813–820, 2019.

[31] J. Falk and L. Dierking, *The Museum Experience*. Whalesback Books, 1992.

[32] M. Ding, "Augmented reality in museums," tech. rep., Arts Management & Technology Laboratory, Carnegie Mellon University, May 2017.

[33] The Cleveland Museum of Art, "ArtLens App." `https://www.clevelandart.org/artlens-gallery/artlens-app`. (Accessed: 2023-10-23).

[34] R. Lovreglio and M. Kinateder, "Augmented reality for pedestrian evacuation research: Promises and limitations," *Safety Science*, vol. 128, p. 104750, 2020.

[35] Y.-H. LEE, T. ZHAN, and S.-T. WU, "Prospects and challenges in augmented reality displays," *Virtual Reality Intelligent Hardware*, vol. 1, no. 1, pp. 10–20, 2019.

[36] VentureBeat, "How Unity convinced investors it's worth $2.6 billion." `https://venturebeat.com/games/why-unity-was-able-to-raise-400-million-at-a-2-6-billion-valuation/`. (Accesed 25-04-2024).

[37] Microsoft Azure, "Azure AI Custom Vision." `https://azure.microsoft.com/en-us/products/ai-services/ai-custom-vision`. (Accessed: 2024-04-24).

[38] J. Redmon, S. K. Divvala, R. B. Girshick, and A. Farhadi, "You only look once: Unified, real-time object detection," *CoRR*, vol. abs/1506.02640, 2015.

[39] Z. Wang, J. Lian, C. Song, Z. Zhang, W. Zheng, S. Yue, and S. Ji, "Sas: Painting detection and recognition via smart art system with mobile devices," *IEEE Access*, vol. 7, pp. 135563–135572, 2019.

[40] "Ergonomics of human-system interaction – Part 11: Usability: Definitions and concepts," standard, International Organization for Standardization, Geneva, CH, Mar. 2000.

[41] G. Salvendy, *Chapter 46: Usability Testing*, p. 1267–1312. Wiley, 4 ed., 2012.

[42] M. J. Verhoef and A. L. Casebeer, "Broadening horizons: Integrating quantitative and qualitative research," *Canadian Journal of Infectious Diseases*, vol. 8, no. 2, p. 65–66, 1997.

[43] Creative Commons, "CC0 1.0 Deed — CC0 1.0 Universal — Creative Commons ." `https://creativecommons.org/publicdomain/zero/1.0/`. (Accessed: 2024-04-24).

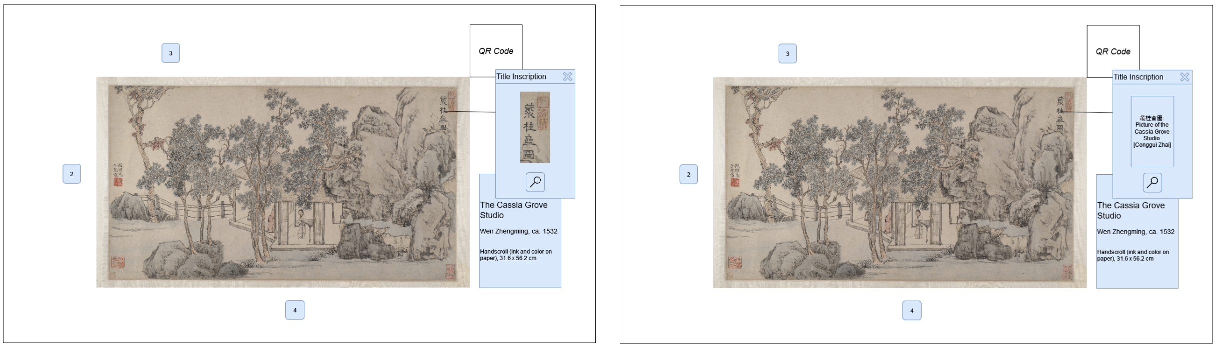
[44] R. A. Virzi, "Refining the test phase of usability evaluation: How many subjects is enough?," *Human Factors*, vol. 34, no. 4, pp. 457–468, 1992.

[45] J. G. Brida, C. D. Nogare, and R. Scuderi, "Learning at the museum: Factors influencing visit length," *Tourism Economics*, vol. 23, no. 2, pp. 281–294, 2017.

# Appendix

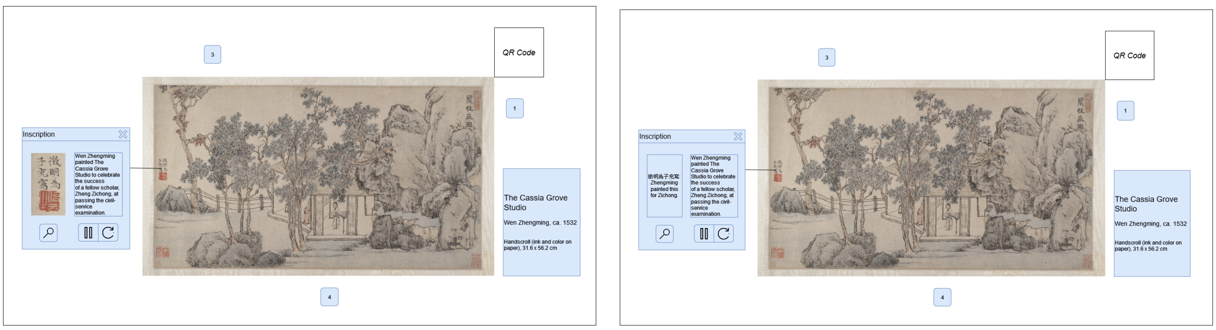
## A Wireframe of AR Interface Prototype


***Figure 29:*** *Initial interface.*




***(a)*** *Information panel with inscription image* ***(b)*** *Inscription Text after interacting the magnifying glass button under the inscription image*

***Figure 30:*** *Interface after interacting with the interactive element labeled "1"*




***(a)*** *Information panel with text, audio player, inscription image* ***(b)*** *Inscription Text after interacting the magnifying glass button under the inscription image*

***Figure 31:*** *Interface after interacting with the interactive element labeled "2"*

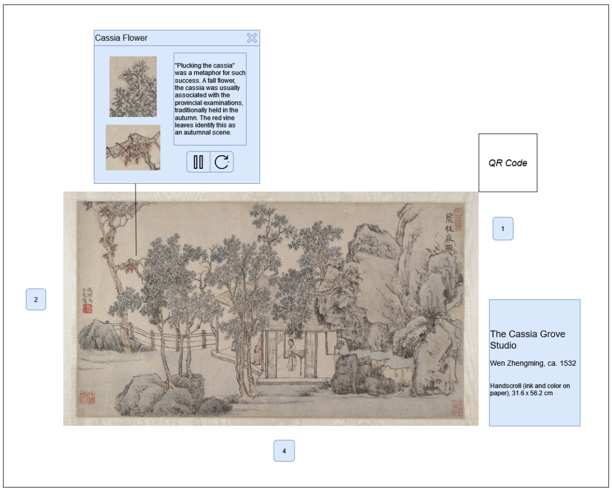



***Figure 32:*** *Interface after interacting with the interactive element labeled "3"*


***(a)*** *Image*


***(b)*** *Image, Description Text and Audio*

***Figure 33:*** *Interface after interacting with the interactive element labeled "4"*

# B Form, Survey, and Quiz

## B.1 Consent Form

### Consent for the User Study

I hereby consent to the recording of my voice and video during the user study regarding the evaluation of an augmented reality (AR) interface for exhibit engagement.

I understand that my participation in this study involves the use of an AR headset and may include interactions with exhibit content, tutorial sessions, and post-survey discussions.

I acknowledge that the purpose of recording my voice and video is to facilitate the analysis of my interactions with the AR interface and to gather insights for research and development purposes. I understand that the recordings will be securely stored and may be used for educational or research-related presentations, publications, or other dissemination activities.

I have been informed that my identity will be kept confidential and that any personal information disclosed during the study will be anonymized. I understand that my participation in this study is voluntary, and I may withdraw my consent at any time without consequence.

By providing my consent, I affirm that I have read and understood the information provided and agree to participate in the study under the terms outlined above.

* Indicates required question

1. Name *

_______________________

2. Agree with Consent *

*Mark only one oval.*

- ( ) Yes
- ( ) No

## B.2 Pre-Survey

# Pre-Survey

Before we begin, we would like to gather some information about you to help us better understand your background and experiences.

This survey consists of a few questions related to your demographics, prior experience with AR technology, and your background in Chinese painting and museum exhibits.

* Indicates required question

1. Participant Number *

2. Age Group *

*Mark only one oval.*

- 18 - 20
- 21 - 25
- 26 - 30
- 31 - 35
- 36 - 40
- 41 - 45

3. Gender

*Mark only one oval.*

- Female
- Male
- Prefer not to say
- Other: __________

4. Highest Education Level (including ongoing education) *

*Mark only one oval.*

- ⬭ Secondary School / High School
- ⬭ Associated Degree / Higher Diploma
- ⬭ Bachelor
- ⬭ Master
- ⬭ PhD
- ⬭ Other: ____________________

5. Field of Study *

____________________

## Prior Experience with AR

6. Have you ever used augmented reality (AR) technology before? *

*Mark only one oval.*

- ⬭ Yes
- ⬭ No (please go to next section)
- ⬭ Maybe

7. Which of the following device have you use AR with?

*Tick all that apply.*

- ☐ Handheld Device (e.g. mobile phone, tablet)
- ☐ Headset
- ☐ Other: ____________________

8. How frequently do you use AR in your daily life?

*Mark only one oval.*

- Rarely
- Sometimes
- Often
- Very often

9. Rate you level of experience with using AR technology

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| Not | | | | | | Extremely experience |

## Background & Interest in Chinese Painting and Museum Exhibits

10. How would you describe your level of interest in Chinese painting? *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| Not | | | | | | Extremely interested |

11. Rate your knowledge level in Chinese painting and art history *

*Mark only one oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| Do r | | | | | | Extremely knowledgeable |

12. Have you visited art museums or exhibits focusing on Chinese art before? *

*Mark only one oval.*

- Yes
- No (please submit survey)
- Maybe

13. How many times have you visited art museums or exhibits focusing on Chinese art

*Mark only one oval.*

- 1
- 2
- 3
- 4
- 5
- >5

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Google Forms

## B.3 Post-Survey

# Post-Survey

In this post-survey, we would like to gather your thoughts and impressions regarding your experience with the exhibits, both with and without the AR interface.

* Indicates required question

1. Participant Number *

2. How would you rate your overall level of engagement with the exhibit that included the AR interface? *

   *Mark only one oval.*

   | | 1 | 2 | 3 | 4 | 5 | |
   |---|---|---|---|---|---|---|
   | Not | ◯ | ◯ | ◯ | ◯ | ◯ | Extremely engaged |

3. How would you rate your overall level of engagement with the exhibit that did NOT include the AR interface? *

   *Mark only one oval.*

   | | 1 | 2 | 3 | 4 | 5 | |
   |---|---|---|---|---|---|---|
   | Not | ◯ | ◯ | ◯ | ◯ | ◯ | Extremely engaged |

4. Did you find the exhibit with the AR interface more immersive compared to the exhibit without the AR interface? *

   *Mark only one oval.*

   ◯ Yes
   ◯ No
   ◯ Neutral

5. Which exhibit did you find more visually stimulating? *

*Mark only one oval.*

- Exhibit with AR interface
- Exhibit without AR interface
- Both equally

6. Can you explain why is there a difference or same engagement level for the 2 exhibits?

_______________________________________________
_______________________________________________
_______________________________________________
_______________________________________________
_______________________________________________

7. How much did the AR interface enhance your understanding or appreciation of the exhibit content? *

*Mark only one oval.*

- Significantly enhanced
- Moderately enhanced
- Slightly enhanced
- Did not enhance
- Hindered understanding and/or appreciation

8. How likely are you to revisit the exhibit with the AR interface compared to the exhibit without the AR interface? *

*Mark only one oval.*

- More likely to revisit with AR interface
- More likely to revisit without AR interface
- Equally likely/unlikely to revisit both

9. Why would you have this preference?

10. Which exhibit experience did you find more enjoyable overall? *

*Mark only one oval.*

- Exhibit with AR interface
- Exhibit without AR interface
- Both equally enjoyable

11. Why is there a difference/equal enjoyment level?

## B.4 Quiz for AR Exhibit

# The Cassia Grove Studio

Here are some question regarding the exhibited piece "The Cassia Grove Studio".
This is not a quiz so please do not feel pressured to answer all correct.

* Indicates required question

1. Participant Number *

______________________________

2. 1. Who does Wen Zhengming painted this painting for? * — 1 point

*Mark only one oval.*

- ⬭ Shen Zhou
- ⬭ Zheng Zichong
- ⬭ Liu Lin
- ⬭ Tang Yin

3. 2. What is the primary reason Wen Zhengming painted this painting? * — 1 point

*Mark only one oval.*

- ⬭ To celebrate the success of a fellow scholar at passing the civil-service examination
- ⬭ To commemorate the completion of a prestigious academic degree
- ⬭ To depict the changing seasons in a garden setting
- ⬭ To portray the daily activities of a Ming scholar in his studio

4. 3. Which of the followings related to cassia (the flower)? * (can choose more than 1 answer) — 2 points

*Tick all that apply.*

- ☐ The Season of Autum
- ☐ Provincial Exam
- ☐ Taste of a Ming scholar
- ☐ Ability to serve the court

5. 4. Which of the following aspect(s) are used to depict the devotion to scholarly pursuits and the arts mentioned in Question 1?
(can choose more than 1 answer)

* 2 points

*Tick all that apply.*

- [ ] Rustic structures of the studio
- [ ] Cabinet full of scrolls
- [ ] Iregular shaped rocks and mountains
- [ ] A servant approaching with tea

## B.5 Quiz for Traditional Exhibit

# Joint Landscape

Here are some question regarding the exhibited piece "Joint Landscape".
This is not a quiz so please do not feel pressured to answer all correct.

* Indicates required question

1. Participant Number *

______________________

2. 1. Who is the first and main painter(s) for this painting? * 2 points

*Tick all that apply.*

- [ ] Wen Zhengming
- [ ] Shen Zhou
- [ ] Wu Zhen
- [ ] Liu Lin

3. 2. What does the imagery of painting primarily focus on? * 1 point

*Mark only one oval.*

- ( ) Private places, such as secluded dwellings hidden in the landscape
- ( ) A bustling marketplace
- ( ) The joys of family life in a rural setting
- ( ) The empbodment of being a Ming Scholar

4. 3. Who's brush style did the main painter focus on exploring in his later life? * 1 point

*Mark only one oval.*

- ( ) Wu Zhen
- ( ) Wen Zhengming
- ( ) Tang Yi
- ( ) Qiu Ying

5. 4. What was Shen Zhou's preference regarding government service? * (can choose more than 1 answer)

2 points

*Tick all that apply.*

- [ ] He preferred to live in retirement
- [ ] He avoided government service altogether
- [ ] He actively pursued government positions
- [ ] He aspired to hold high-ranking government positions

---

# C Raw Data

| Participant Number | | | P1 | P2 | P3 | P4 | P5 |
|---|---|---|---|---|---|---|---|
| Pre-Survey | Demographic | Age Group | 21 - 25 | 21 - 25 | 21 - 25 | 21 - 25 | 31 - 35 |
| | | Gender | Female | Female | Male | Female | Male |
| | | Highest Education Level | Bachelor | Bachelor | Bachelor | Bachelor | PhD |
| | | Field of Study / Occupation | Economics and Finance | Design and Computer Science | Computer Science | Social Science | Education |
| | AR Experience | Have you ever used augmented reality (AR) technology before? | Yes | Yes | Yes | Yes | Yes |
| | | Which of the following device have you use AR with? | Handheld Device | Handheld Device | Handheld Device | Handheld Device | Handheld Device; Headset |
| | | How frequently do you use AR in your daily life? | Rarely | Rarely | Rarely | Rarely | Rarely |
| | | Rate you level of experience with using AR technology | 2 | 2 | 1 | 1 | 2 |
| | Knowledge and Intrest in Chinese Paintings and Art Exhibts | How would you describe your level of interest in Chinese painting? | 1 | 3 | 3 | 1 | 4 |
| | | Rate your knowledge level in Chinese painting and art history | 1 | 1 | 1 | 3 | 2 |
| | | Have you visited art museums or exhibits focusing on Chinese art before? | Yes | Maybe | Yes | Yes | Yes |
| | | How many times have you visited art museums or exhibits focusing on Chinese art | 1 | 1 | >5 | 3 | >5 |
| Viewing Duration | Exhibit Viewing Duration | Traditional Exhibit | 134 | 190 | 469 | 155 | 150 |
| | | AR Exhibit | 263 | 253 | 632 | 361 | 310 |
| | AR Interactive Component Viewing Duration | Component 1 | 0 | 47.87 | 175.5 | 16.07 | 49.46 |
| | | Component 2 | 55.66 | 35.38 | 120.44 | 21.85 | 62.08 |
| | | Component 3 | 69.45 | 44.23 | 56.28 | 53.16 | 52.21 |
| | | Component 4 | 78.11 | 41.96 | 138.61 | 63.38 | 60.03 |
| Quiz Score per Question (each question worth 1 mark) | AR Exhibit Quiz | Q1 (1 ans) | 1 | 1 | 1 | 1 | 1 |
| | | Q2 (1 ans) | 1 | 1 | 1 | 1 | 1 |
| | | Q3 (2 ans) | 1 | 1 | 1 | 0.5 | 1 |
| | | Q4 (2 ans) | 0.5 | 1 | 0.5 | 0.5 | 0.5 |
| | Traditional Exhibit Quiz | Q1 (2 ans) | 0.5 | 0.5 | 0.5 | 0.5 | 1 |
| | | Q2 (1 ans) | 1 | 1 | 1 | 1 | 1 |
| | | Q3 (1 ans) | 1 | 0 | 0 | 0 | 0 |
| | | Q4 (2 ans) | 1 | 1 | 0.5 | 1 | 1 |
| Post-Survey | Engagement | How would you rate your overall level of engagement with the exhibit that included the AR interface? (1-5) | 3 | 4 | 5 | 3 | 4 |
| | | How would you rate your overall level of engagement with the exhibit that did NOT include the AR interface? (1-5) | 4 | 2 | 3 | 2 | 2 |
| | | Exhibit with higher engagement level | Traditional Exhibit | AR Exhibit | AR Exhibit | AR Exhibit | AR Exhibit |
| | | Did you find the exhibit with the AR interface more immersive compared to the exhibit without the AR interface? | Neutral | Neutral | Yes | Yes | Yes |
| | | Which exhibit did you find more visually stimulating? | Exhibit with AR interface | Exhibit with AR interface | Exhibit with AR interface | Exhibit with AR interface | Exhibit with AR interface |
| | Learning & Understanding | How much did the AR interface enhance your understanding or appreciation of the exhibit content? | Slightly enhanced | Slightly enhanced | Significantly enhanced | Significantly enhanced | Moderately enhanced |
| | Satisfaction | How likely are you to revisit the exhibit with the AR interface compared to the exhibit without the AR interface? | Equally likely/unlikely to revisit both | Equally likely/unlikely to revisit both | Equally likely/unlikely to revisit both | More likely to revisit with AR interface | More likely to revisit with AR interface |
| | | Which exhibit experience did you find more enjoyable overall? | Exhibit with AR interface | Exhibit with AR interface | Exhibit with AR interface | Exhibit with AR interface | Exhibit with AR interface |

# D Data Categorization

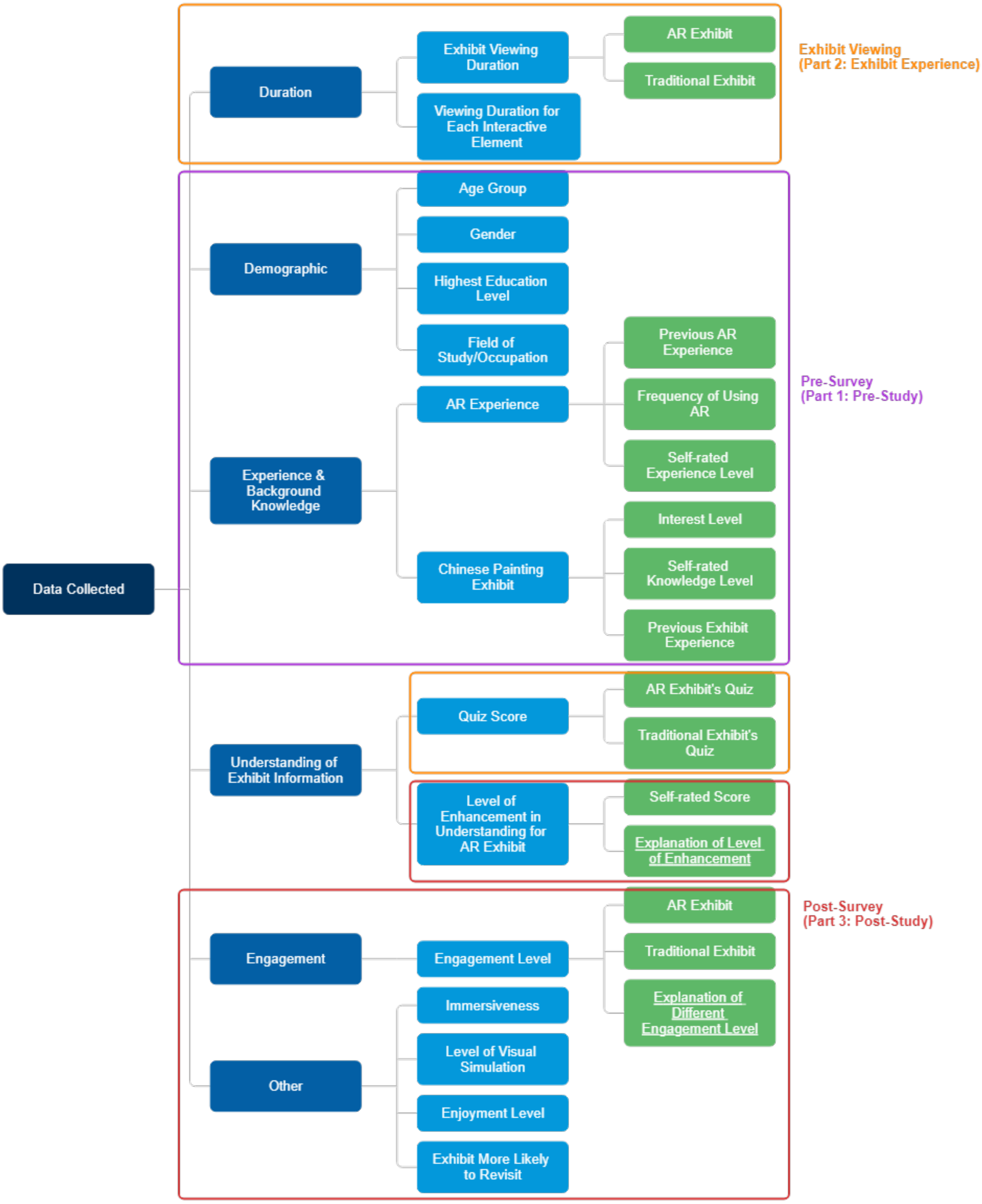


*Figure 34: Categorization of all types of data collected from the user study.*