Reviving the Euston Arch: A Mixed Reality Approach to Cultural Heritage Tours

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Abstract

Augmented Reality (AR) and Virtual Reality (VR) users have distinct capabilities and experiences during Extended Reality (XR) collaborations: while AR users benefit from real-time contextual information due to physical presence, VR users enjoy the flexibility to transition between locations rapidly, unconstrained by physical space.

Our research aims to utilize these spatial differences to facilitate engaging, shared XR experiences. Using Google Geospatial Creator, we enable large-scale outdoor authoring and precise localization to create a unified environment. We integrated Ubiq to allow simultaneous voice communication, avatar-based interaction and shared object manipulation across platforms.

We apply AR and VR technologies in cultural heritage exploration. We selected the Euston Arch as our case study due to its dramatic architectural transformations over time. We enriched the co-exploration experience by integrating historical photos, a 3D model of the Euston Arch, and immersive audio narratives into the shared AR/VR environment.

Index Terms: Human-centered computing [Human computer interaction (HCI)]: Collaborative and social computing—Collaborative and social computing systems and tools; Human-centered computing [Human computer interaction (HCI)]: Interaction paradigms—Mixed / augmented reality

1 Introduction

In recent years, Augmented Reality (AR) and Virtual Reality (VR) have become influential forces in reshaping our interaction with digital environments. AR systems are matured now and offer robust performance even in outdoor settings. The widespread accessibility of mobile phones has further popularised these platforms as vehicles for AR.

On the other hand, VR technology, which has developed more rapidly than AR, has enabled the creation of expansive virtual worlds. These range from the diverse fictional universes in Massively Multiplayer Online Role-Playing Games (MMORPGs) to metaverse platforms such as Second Life. Moreover, VR has given rise to highly detailed photo-realistic models of real-world environments, with Google Earth VR being a prime example.

Our work bridges the mature foundations of VR technology with the rapidly increasing potential of AR systems. We are particularly focused on integrating photo-realistic world models into AR/VR experiences to foster seamless collaboration between AR and VR users. Building on our previous research in indoor environments [17] and standalone models of outdoor scenes [16], we explore diverse collaboration possibilities between AR and VR users within outdoor settings, using world models and accurate tracking. Moreover, we strive to enhance communication and interaction methods that could facilitate a fluid transition across the reality-virtuality continuum [15]. Through this demonstration, we showcase how these advancements can create a unified and immersive environment, thus enhancing interactions between AR and VR users and blurring the boundaries between the physical and virtual worlds.

1.1 Paper Structure

1. We discuss the concept of the Reality-Virtuality Continuum and the role of AR/VR collaboration. Following that,we provide background for cultural heritage and tour guides, emphasising its importance and relevance to AR and VR.

2. We outline the key components of our system, encompassing both the software and hardware facets.

3. We describe the collaborative environment, detailing the setup process and the unique aspects of individual interaction types.

4. We discuss our demo's strengths and weaknesses, limitations, and potential directions for future development.

2 Related Work

The evolution of outdoor AR can be traced back to Feiner et al. [7], who developed a single-user outdoor AR system. This system, composed of a magnetometer, a two-axis inclinometer for orientation tracking, and differential GPS for position tracking, laid the groundwork for the field of outdoor AR.

Reitmayr and Schmalstieg [20] demonstrated an outdoor AR system for collaborative navigation and location-based information browsing and annotation. Their tracking system was based on differential GPS, inertial measurement units and marker-based visual tracking.

Despite the innovations, these early AR systems suffered from practical limitations. Their elaborate setups involving backpacks, helmets, and differential GPS base stations rendered them impossible to affordably deploy on a large scale.

With the progression of technology, Gauglitz et al. [9] presented an outdoor MR system that enabled a remote user to explore the scene and provide instructions to the local handheld AR user . However, the tracking area was restricted to the vicinity of the workspace.

In 2019, Rompapas et al. [21] presented an outdoor collaborative AR experience called *HoloRoyale* and evaluated it with experiments for users to explore the design space. In the subsequent year, Platinsky et al. demonstrated a city-wide collaborative mobile AR system, offering a detailed recipe for handling large-scale localization and tracking [18].

Despite these notable advancements in AR and VR fields, compelling questions remain, particularly concerning the interaction

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dynamics between local and remote users and the integration of asymmetric interfaces such as AR and VR. This system aims to contribute to this ongoing discussion by exploring the potential pathways for seamless collaboration across AR and VR platforms within a unified, immersive environment spanning both physical and virtual spaces.

3 Reviving Culture Heritage: the Euston Arch

Constructed in 1837 as the original gateway to the Victorian Euston Station, the Euston Arch represented a significant emblem of London's historical architecture. However, in 1962, in the face of widespread public opposition, the Euston Arch was demolished during the station's reconstruction.

Our decision to focus on this heritage site[1] is based on three main considerations. Firstly, Euston Station's proximity to our laboratory and its familiarity to our team members allow for an intimate exploration of local history. Secondly, the unsuccessful efforts to preserve the Euston Arch underscore its value to London's cultural heritage. Prior projects have already acknowledged this significance [23]. Finally, the abundance of archival material related to Euston Station and the Euston Arch facilitates their transformation into assets that can be incorporated in collaborative environments.

(a) The Euston Arch in the 1890s [26] (b) A large (column) stone from the Euston Arch retrieved in the 1990s [3]

Figure 1: Two photos of the Euston Arch. Left: the Euston Arch before it was demolished. Right: a piece of the demolished arch being recovered from a canal from where it had been "safely" stored.

AR offers a unique platform to delve into cultural heritage objects. Contrasting with VR's immersive transport to a different environment, AR overlays virtual entities onto the real world. This seamless blend of past and present empowers users to examine objects up close, promoting rich interaction and exploration [19]. As past studies have shown, such AR experiences can effectively engage users and facilitate collaboration in architectural contexts [22]. Building on the proven potential of MR collaboration [17], our project integrates AR-driven user engagement with collaboration among VR and AR users.

Previous AR cultural heritage applications have revealed users' desire for more contextual information about the objects they're exploring, suggesting audio guide integration [19]. Our project brings this to life, creating an interactive tour experience that blends the different visual perspectives of AR and VR. The AR perspective provides real-time, site-specific information, while the VR perspective allows for swift navigation through virtually replicated real-world locations. This unique approach fosters innovative interactions with cultural heritage objects.

[1]The term 'site' here refers to the entirety of Euston Station. Although in our demonstration the Euston Arch is depicted between the Euston Tap and the Cider Tap, its historical position was closer to the platform. For the purpose of accessibility in our demonstration, we relocated the Euston Arch.

4 Software Framework and Hardware

We utilised the Ubiq software [8] and Unity platform to facilitate synchronised avatar interaction, networked object manipulation, and communication (video and audio). The scene incorporated movable, networked objects via Ubiq, and the bidirectional video-audio stream was handled through Ubiq's WebRTC service.

4.1 Hardware Setup

Our setup consists of a Meta Quest Pro headset and a Google Pixel 6 Android phone, with all rendering performed locally on each device, eliminating the need for desktop rendering/streaming. We also tested compatibility with desktop extensions and Microsoft HoloLens 2, aligning with the approach described in [16]. Internet access was provided to the Android phone using an iPhone as a hotspot.

(a) View of AR user (b) View of VR user

Figure 2: Photos of AR and VR users operating on their devices

4.2 Tracking and Authoring and Alignment

Registration or augmentation of virtual objects into desired physical locations requires both accurate authoring and tracking. Both tracking and authoring requires accurate model of the environment and therefore the size of the model decides the coverage of the tracking and authoring system, essentially the available are of AR system.

4.2.1 Tracking

In our previous work [16], we used the World Locking Toolkit (WLT) [14] to anchor the HoloLens's coordinate system with the target building. Despite being designed for indoor use, the HoloLens showed impressive performance over vast outdoor areas. However, to use the WLT anchors, we had to install QR codes at precise locations in the environment. This proved to be cumbersome and labour intensive.

Therefore, in our demo, we use the Google Spatial Service, which is built upon their Visual Positioning System (VPS). VPS usually rely on a prebuilt world map of visual feature points, and intuitively, Google Earth and Google Street View maybe leveraged for this purpose. Lynen et al. provided a good survey paper in this area [13], and Platinsky et al demonstrated a similar system in [18].

4.2.2 Authoring

The Google Geospatial Creator [10] was used to author location-based AR content. To geospatially register the content properly, the system leverages the Google Earth model hosted by Cesium.

4.2.3 Alignment between AR and VR coordinate system

By default, both the AR and VR systems start at the origin of their own local coordinate system, where the starting points are their own origins. Those coordinate systems are not connected, and divergence in the coordinate system will happen. This divergence arises due to the practical constraint that VR and AR users are unlikely, or often unable, to initiate from precisely the same location. Therefore, alignment between the coordinate system becomes essential for users to collaborate in a shared coordinate frame seamlessly.

Typically, the VR system confines its tracking to a local space, such as a room, which lacks information about its position in the broader world frame. On the other hand, VR and desktop users are likely to start at the same physical location, such as inside a fixed room. Therefore, we could leverage this prior information to register this recurring starting physical position (achieved by placing an anchor) in AR coordinate system to represent the VR users' origin so that it can be dynamically updated in AR users' coordinate system at runtime.

Once AR tracking is initialised, the anchor position stabilises within the AR frame. We then calculate and apply an offset to AR users' coordinate systems. This offset is determined by taking the inverse of the VR anchor pose. Through this, the VR user origin will be effectively at the origin of the AR user, and hence two coordinate systems are aligned.

5 Demo Setup

5.1 Unity Scene Setup

Both the AR and VR scenes contain `Cesium3DTileset` objects that render the world mesh. The origin of both tilesets are synced at the front of our office (`Latitude:51.5269, Longitude: -0.1318 and Height 69m`). The world mesh in the AR scene is used for authoring in conjunction with an `AR Geospatial Creator Anchor` to provide scenes around the anchor. It is geometrically correct globally but of low fidelity. VR user could obtain a sense of actual scale of the real-world which contributes to immersiveness and blurry the boundary between VR and AR.

We created a mock 3D model [1] of the Euston Arch for illustration purposes.

(a) Unity Scene overview

(b) Close up view of the virtual Euston Arch model and other assets

Figure 3: A overview and close up of the scene setup. Note the virtual Euston Arch with the Orange columns.

5.2 Interaction

5.2.1 Quest Controller Setup

- Button A: Teleport to the point of the ray intersection. Green ray indicates teleport-able and red ray indicates un-teleport-able.
- Button B: Switch between bird-eye view and ground view with smooth position transition. AR user location will be highlighted while VR user on the sky.
- Button X: Toggle menu for asset selection for 3D pen, Video and image which is attached on the left wrist.
- Button Y: Press for ray pointer indicating point of interest.
- Grip: Grab objects for manipulation.
- Trigger: Toggle 3D pen stroke.
- Joystick: Left for view change and Right for horizontal movement.

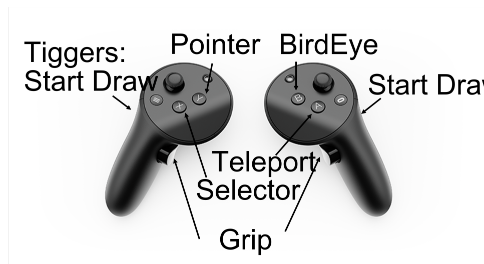
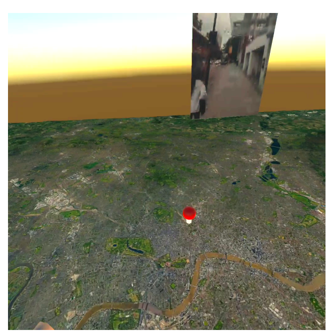


Figure 4: Button layout of the Meta Quest Pro controller for different functionalities in our demo

5.2.2 Bird's-eye View of the VR world

Cesium provides the flexibility of dynamically loading large-scale mesh models, potentially forming a photo-realistic environment for VR users. To demonstrate this, the VR user starts off from a large altitude above the ground to obtain an overview of the available point-of-interests. This highlights the degree of freedom for VR user positioning and the scale of the available digital earth model.



(a) View from above at 10km

(b) Approaching ground entering point of interest

Figure 5: View change for VR user landing into point of interest and meet the AR user

Once the VR user selects a point of interest, they could join the local AR user for a collaborative experience. In our demo, we chose a tour experience. Our AR/VR framework allows users to communicate both ways, blurring the boundary between the virtual and physical worlds.

AR user was able to stream video to the VR user to show what's going on at the site and provide a close-up view that isn't available in the mesh model. VR user, especially desktop user have higher accessibility to other information sources to accompany the tour experiences.

(a) AR View (b) VR View (c) AR User Perspective

Figure 6: AR user and VR user greeting each other after landing.

5.2.3 Pointer

A pointer is provided for the VR user to pass a ray in AR user's view indicating VR user's point of interest to facilitate the tour guide.

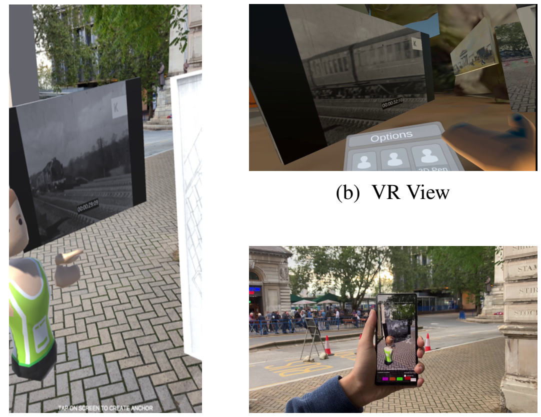
Figure 7: VR user using pointer explaining image assets to AR user

5.2.4 Video and Image Sharing

Aside from static images and meshes placed through anchor in the AR scene syncing with the VR environment, the VR user is able to place additional assets at run time and manipulate them as the context changes. Figure 8 shows the scene of video asset being pulled out by the VR user from different perspectives.

5.2.5 Annotation

In our demo setup, we provided a pen for 3D annotation [25] in the common environment. Such annotation can either be used for highlighting particular areas or for sketching to express ideas.

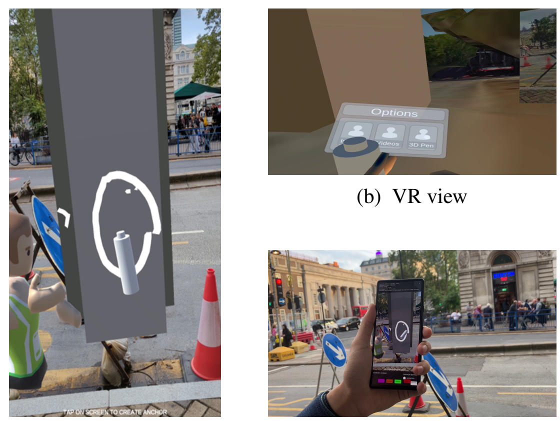


(a) AR View (b) VR View (c) AR User Perspective

Figure 8: Scene of Video asset spawning and explanation

5.2.6 Video Streaming from AR view

As shown in fig. 5, we streamed the live view of the AR user to the VR user and the screen is tagged along with the VR users. We wish this could allow AR user to stream high-fidelity video of the real scene to improve VR user's immersion of the physical world.



(a) AR view (b) VR view (c) AR user perspective

Figure 9: Scene of using the pen for 3D annotation

6 Demo Experience

We prepared two stories in the demo video:

- *Tour guide of the Euston Arch*. AR users stream the actual world through a camera and VR users can drop a few videos/images into the world to explain relevant information about the Euston Arch to the AR users, as well annotation and highlight with 3D pen.
- *Architectural design:* AR users annotate in 3D their sketch and VR users put up pieces of the virtual Euston Arch in the specified positions.

7 Discussion and Future Work

Our two scenarios showcased the potential of seamless collaboration between AR and VR users, providing an exciting glimpse into the future of mixed reality interactions.

Reflecting on our findings, we identified valuable lessons for improving future iterations of the Ubiq framework. The limited field of view on mobile AR devices can hinder users' situation awareness in the virtual world. Furthermore, the teleportation of VR users posed challenges in tracking their locations accurately, affecting their collaborative interactions with other users.

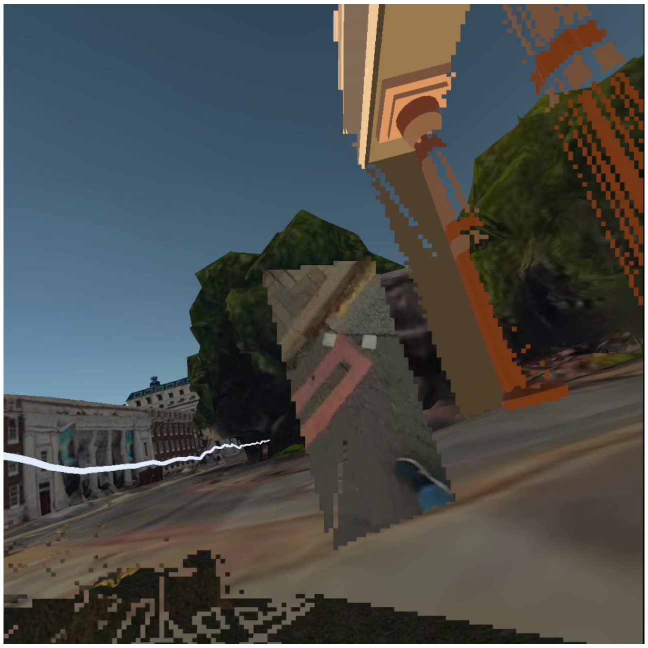


Figure 10: VR scene vertices down-sampled after 3D annotation

An additional issue arose during the demo, where the VR scene exhibited pixelation when initiating the 3D pen. This behavior was likely a consequence of an excess number of vertices, overwhelming the headset's processing capacity. Importantly, this behavior was not observed when streaming from a desktop, indicating future optimization.

7.1 Potential Scalability

7.1.1 Infrastructure

To expand the applicability of our framework, we considered factors that influence its scalability. A key aspect is infrastructure, with the necessity for a central server to facilitate one-to-all broadcasting of the AR live view. Ensuring a robust and low-latency connection to this central server is crucial to enable seamless interaction and perception, especially when users moving rapidly in both VR and AR environments.

7.1.2 Flexibility

Furthermore, Ubiq's flexibility plays a crucial role in determining its scalability. By offering the option for local hosting, the framework can support peer-to-peer communication or scale up to facilitate entire virtual classrooms. Moreover, the seamless integration of various hardware and sensory inputs enhances its adaptability for diverse applications and user scenarios.

7.2 Future Applications

With the potential scalability and flexibility, Ubiq can be easily extended to other fields and other applications.

7.2.1 Robot teleoperation

For instance, controller movements and video streaming pipeline can be easily extended to robot teleoperation application. Robot teleoperation share some of the key requirement with AR and VR collaboration such as low-latency and high degree-of-freedom of interaction. AR devices similar levels of hardware constraint with agile robot platforms such as drones.

7.2.2 Design and construction

Drawing inspiration from previous research by Carozza et al. [6] and Hansen et al. [11], Ubiq can be extended in the area of design and construction projects. Leveraging dense models and high-accuracy tracking systems, outdoor AR solutions can significantly improve visualization and interaction in real-world contexts, aiding urban designer and construction professionals.

7.2.3 Urban Planning

Saßmannshausen et al. [22] developed an AR system that would allow users to actively participate in the design process for local civic buildings and other architectural public work projects.

7.2.4 Volumetric video streaming

Moving beyond our current static mesh model approach, future work can explore the use of volumetric video or depth streams [24]. By enabling dynamic real-world environment streaming to VR users, this advancement would elevate immersion and realism, opening up new possibilities for interactive and engaging experiences.

7.3 Conclusion

In conclusion, our demo system represents a promising step towards bridging the virtual and physical realms, fostering collaboration between AR and VR users. By addressing scalability considerations and exploring diverse future applications, we anticipate that our system will continue to push the boundaries of mixed reality interactions, ushering in a new era of collaborative and immersive experiences.

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Appendix

List of assets used and their sources

1. Train Video from [12]
2. 3 Euston Arch Images from [3]
3. Low-poly greek style 3D model from [1]
4. Euston station layout from [2]
5. Euston Arch image from [26]
6. Euston Arch stone model from [4]
7. Euston Arch stone image from [5]

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