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UKRI Arts and Humanities Research Council

UNPATH'D WATERS: UNPATH Navigator: Technical Development

Supporting Technical Report: Work Package 4

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1. List of Acronyms

ADP – Aggregated Data Point (the UNPATH dataset derived from the UNPATH Portal RDF data)
ADS – Archaeological Data Service
APK – Android Package Kit (delivery versions of the Navigator)
CV - Curated Voyage (tailored route through manually curated content)
DOI – Digital Object Identifier
HER – Historic Environment Record
HMD - Head Mounted Display
ME - Marine Environment – in this context, mapping inc. hydrographic/seabed as well as coastal region in the area around the UK and the Isle of Man
RDF – Resource Description Framework
SDK - Software Development Kit
SFR - Shipping Forecast Region
VR - Virtual Reality

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4. The Unpath'd Navigator: Development and Overview

The codebase for the Unpath Navigator which is described below is available for examination and downloading/installation at:
UNPATH Navigator GitHub – code base - https://github.com/JFlint-Unpathd/Unpathd-URP-Explore

4.1 Overview

This additional technical report is to be read in conjunction with the main Unpath'd Waters project report, specifically the sections relating to Work Package 4 on the development of the Unpath'd Waters Navigator VR system (hereafter referred to as the Navigator). This report gives further detail on the technical specifications for the development of the Unpath'd Waters Navigator and the development process itself arising from the co-design process discussed in detail in the Work Package 4 sections of the main report.

The designed immersive Navigator application was developed in Unity and optimised for Oculus Quest 2. The development team at the School of Innovation and Technology at the Glasgow School of Art developed the application using Unity version 2020.3.12f1. The Oculus Quest 2 was chosen for its widespread use, excellent cost-to-performance ratio, and the appeal of a standalone device. Newer models, like the Oculus Quest 3, were not yet available at the start of development.

The Navigator uses data multiple maritime datasets enhanced and aggregated through other Unpath'd Waters work packages, notably WP1 and WP2. The data was collated in an SQLite database (derived from the aggregated data RDF hosted in ARIADNE and queryable via the Unpath'd Waters Portal) and further refined by adding custom fields that allow for tagging by theme, gross subject and location (Land/Sea). These classifications were identified as areas of interest during co-design and were populated by the project team via machine learning. These themes include: People, Migration, Slavery, Crew, Cargo, Material, Technology, Warfare, and Destinations. The gross subject columns are: Plane, Submarine, Cargo Ship, Passenger Ship, War Ship, and Artefact. For location, the defining categories are Land/Sea and the Shipping Forecast areas: Fair Isle, Hebrides, Malin, Rockall, Shannon, Fastnet, Lundy, Plymouth, Portland, Irish Sea, Wight, Dover, Thames, Humber, Tyne, Forth, and Cromarty.

The organisation of the data significantly influenced the design of the application. Top-level categories break down into more detailed subcategories, allowing users to search the database by theme, gross subject, location, or a combination of these criteria, accommodating searches with up to three terms. The application employs an 'INNER JOIN' query, displaying results only when they meet all specified search criteria.

Visually, this core concept is a virtual search room where users are surrounded by 3D icon-like models corresponding to each potential search term. Users can select and place these 3D models onto a virtual platform in front of them, effectively adding each term to their search query. Once the query is defined, the results are displayed on a 3D map of the UK and surrounding seabed as Aggregated Data Points (ADPs). Users can navigate between ADPs using in-app locomotion. Selecting an ADP provides additional information based on the maritime datasets available.

The Oculus Quest 2 was used as the initial design platform because it is currently the most widely supported and amenable headset for development in VR and is readily available commercially. Due to the volume of processed data from the integrated datasets exceeding the capabilities of the Quest 2, with query results being capped at c1000 results (very broad queries could return tens of thousands of results, which would in any event be unusable for the user), other HMDs should be considered as alternatives for a possible second iteration of the project.

Additional routes to base data other than free exploration, searching and selection are proposed. For example, Curated Pathways – providing co-designed user routes through the integrated dataset. The current curated voyages, designed in collaboration with research participants from each research group, focus on the following themes: "Women and Shipping in the 20th Century," "Submerged Landscapes of the Mesolithic," and "Dumfries and Galloway in the Napoleonic Wars".

Based on co-design sessions, free input for searching and in-VR keyboard input were found to be awkward, unintuitive, and unsuitable for VIPs and lacking fluidity for most users. Additionally, displaying external links via web windows were excluded as they required pre-loaded URLs with no further navigation, limiting flexibility. Accessing information via URLs requires Wi-Fi and relies on an unsatisfactory third-party browser. Future implementations would require a more efficient solution.

4.2 Use Model

This section contains information on the Navigator's functionality. Although the core elements remained consistent throughout the project the UI elements and/or other functionality changed in response to the evaluation phase of the co-design process.

ID	Use Model Description
001	The application starts with a welcome voice-over that provides a brief description. The Navigator provides voice descriptions of the surrounding environment and guidance on its available functionality. The Navigator allows the user to set their preferred audio settings, increased readability settings and image adjustment settings.
002	Users can explore the surrounding environment using in-app locomotion features, such as teleportation, and interact with objects by selecting them to access detailed information through descriptive labels or associated voice-overs. The Navigator enables users to query the database through an engaging "select and snap'' mechanism. Users can choose a 3D model representing refining themes, gross subjects, or locations, and then initiate a search.
003	The Navigator allows users to explore all displayed ADPs on a suitably scaled 3D map of the UK and surrounding seabed using in-app locomotion. Users can select individual results to expand a detailed information panel. Additionally, by selecting the bird icon, users can switch to a bird's-eye view, providing a high vantage point to see the results from above.
004	The Navigator provides Curated Pathways, which are co-designed user routes through the integrated dataset. These pathways offer guided tours through

	subsets of maritime data, each telling a unique story—such as "Women and Shipping in the 20th Century," "Submerged Landscapes of the Mesolithic," and "Dumfries and Galloway in the Napoleonic Wars." Additionally, there is a co-design pathway that highlights the co-design process of the project, featuring footage from co-design sessions. Another pathway, created in collaboration with students from the GSA MDes program, offers an audio-only creative soundscape experience.
005	The Navigator features a demo scene where the user can learn/experiment with actions such as teleporting, selecting, grabbing, and toggling the In-Game menu panel, all accompanied by voice-overs that guide the user through each demonstration.
006	The Navigator features a credits scene with a rolling video that lists all the project contributors, including co-design partners and participating institutions.

Table 1: Use Model Elements

4.3 Technical Elements

This section describes the Navigator's functionality.
All images are screen grabs from a video walk through of the navigator available here:
UNPATH Navigator Prototype Video Walkthrough - https://vimeo.com/1054159800?share=copy#t=0

Element Description	Dependencies
Introductory Environment - Intro Scene This environment serves as an introductory setting designed to help users acclimatize to wearing the headset before the main audio begins. It features a gently swaying sea, drifting clouds, distant islands, and a lighthouse. At the centre of the scene is the Unpath logo. This serene visual scene not only introduces the theme of the application but also complements the introductory voice-over, setting the stage for what is to come. See Figure 1below.	The basic elements of the Introductory Environment have developed, contingent on time allowance; this scene could easily be expanded to include more dynamic features – but should not run counter to VIP accessibility requirements.

Figure 1: Intro Screen, screen grab from video walk

Settings These include; brightness, contrast, vignette, hue and text size. NB User specified visual settings are not a native functionality in the UNITY interface and these required coding directly, in response to VIP co-design input.	
RefineOrVoyage This scene offers users multiple pathways to begin exploring the application, functioning similarly to a menu but within a 3D environment. Users can choose from various objects to start their journey: selecting a pair of binoculars will transport them to a search room where they can explore themes and subjects and interact with the Aggregated Data Points (ADPs) that result from their search. Alternatively, they can opt for one of the curated voyages, represented by ticket stubs that split into individual stubs for each journey. If users wish to refresh their understanding of the application's controls, they can click on an information sign icon to start a demo. Additionally, selecting a ship wheel will take them to the credits scene. All options are displayed in a line, with labels and voice-over descriptions that activate upon hovering. RefineOrVoyage Scene takes place in a circular room with a parallax effect, featuring layered elements like clouds, mountains, and sea. This stylized environment was chosen based on co-design principles, providing a visually distinctive and contrast-	This scene can be further expanded and may need changes in terms of layout based on the number of available user journey paths.

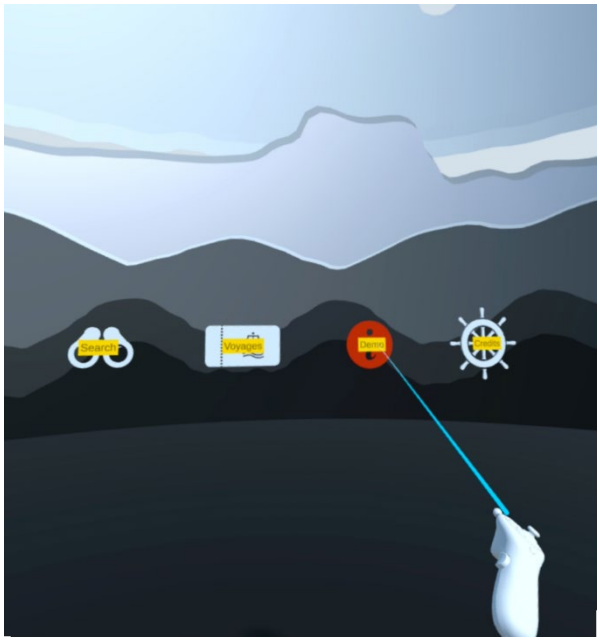
rich setting that enhances visual clarity, particularly for users with visual impairments. *Image below: RefineOrVoyage - screen grab from video walk.*	
 *Figure 2: RefineOrVoyage*	
Tutorial Pathway The tutorial is designed as a guided tour to introduce inexperienced users to the Navigator's functionality. It covers key actions such as teleporting, selecting, grabbing, and toggling the menu panel. Each action is explained through both audio instructions and on-screen prompt panels. The tutorial follows a chronological sequence, ensuring users learn all the main controls of the application. The demo takes place in a circular room with a parallax effect, featuring layered elements like clouds, mountains, and sea. This stylized environment was chosen based on co-design principles, providing a visually distinctive and contrast-rich setting that enhances visual clarity, particularly for users with visual impairments.	Input from the co-design process. NB This scene has not been tested since it was itself developed in response to feedback from beta stage testing.

Image below: Tutorial Scene - screen grab from video walk-through 'Casting_Video_Long_Edited.mp4'. Labels on controls, teleport, select and grab.	

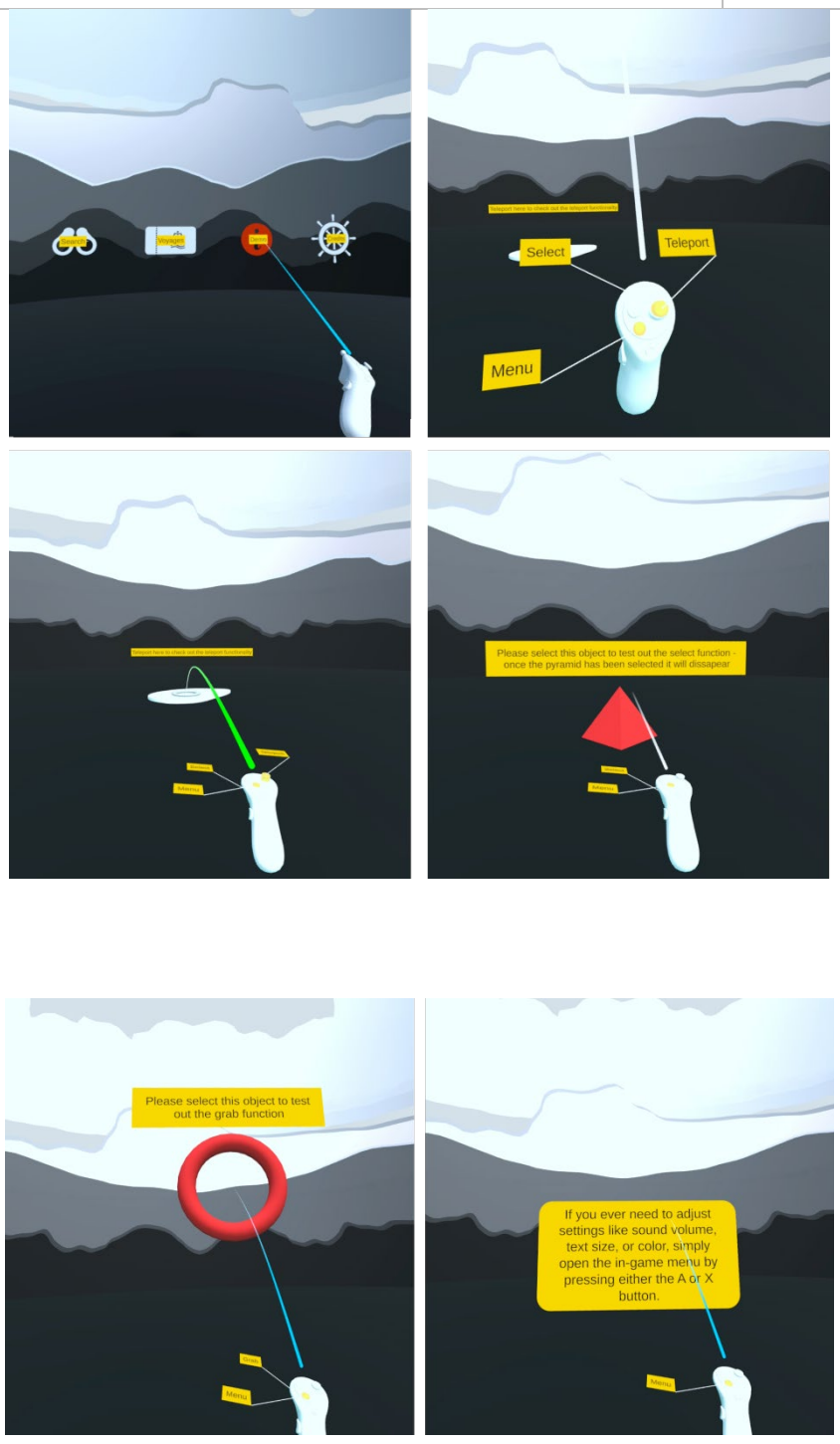


Figure 3 Tutorial Scene.

User Environment	Well-formed ADP data

Database Search Scene

This is the primary user environment of the Navigator.

It positions the user at the centre of a circular arrangement of 3D models, each an expanded vector icon that represents the various themes, gross subjects, and location-defining categories outlined in the 'Use Model' section.

Theme icons are:

- People - person outline
- Migration - luggage icon
- Slavery - fist with broken chains icon
- Crew - person outline wearing sailor outfit
- Material - material icon
- Cargo - shipping container icon
- Technology - Cog icon
- Warfare - Crossed scimitar icon
- All Warfare - Crossed scimitar Swords
- WWI - Zeppelin icon
- WWII - war ensign icon
- Destinations - Map pin icon

Gross subject icons are:

- Plane - plane icon
- Submarine - submarine icon
- Cargo Ship - cargo ship icon
- Passenger Ship - passenger ship icon
- War Ship - war ship icon
- Artefact - coin with human profile

Land/Sea icons are:

- Sea - anchor icon
- Shore - seafort icon

Shipping Forecast Region icons are depicted as a map, each region, extruded and shaped as defined on an official SFR map.

When icons are selected, a voice-over announces their label, accompanied by a descriptive panel. I chose to trigger the voice-over on selection rather than on hover due to the high volume of items and the user's tendency to rapidly toggle between them, which could easily lead to confusion about which item was just read. To enhance clarity during navigation, a click

sound, haptic feedback, and a model colour change are triggered when an object is hovered over, signaling interaction. The voice-over, however, plays only upon selection. Once the object is snapped to the selection pods in front of the user the models change colour again, signaling this change of status. The snapping action is the interaction modality through which the user formats the query search being able to pick one to 3 items by which to refine the search.

The Database search takes place in a circular room with a parallax effect, featuring layered elements like clouds, mountains, and sea. This stylized environment was chosen based on co-design principles, providing a visually distinctive and contrast-rich setting that enhances visual clarity, particularly for users with visual impairments.

This scene incorporates a 3D schematic “bathymetric” map of the surrounding UK seas.

Image below: Database Search Scene. Selecting multiple items, placing them on the selection zones.

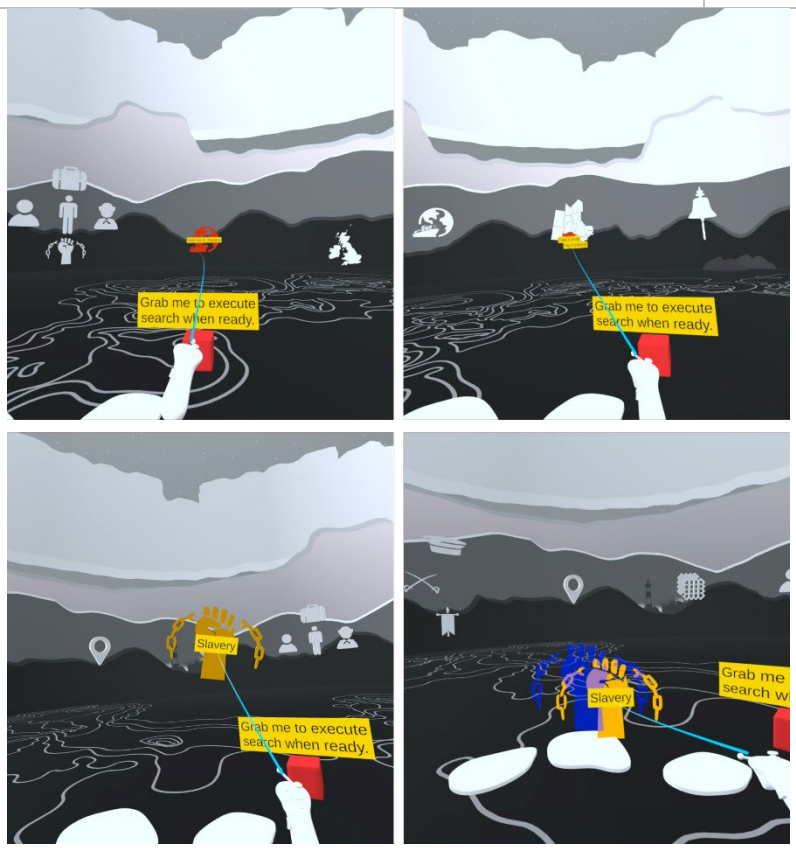


Figure 4: Database Search. Selecting multiple items, placing them on the selection zones.

Results Scene

After a search is defined and executed, the environment transforms to display a visual representation of the results that match the query. Each ADP is represented by a cube. An attempt was made to display these as more contextually appropriate 3D assets, such as a ship, boat, or shipwreck. However, since the SQLite query operates as an AND query, items of multiple types are never simultaneously displayed. A solution has not yet been found to represent results as either an artefact or a ship when the result could be classified as both, based on contextual hierarchical information. This feature is currently under development.

At present, the results are displayed as cubes with labels. When hovered over, both the label and the item change colour and increase in size. Upon selection, the result is isolated, and an info panel with extended information, including the title, location, and description, is displayed. All results are placed on a scaled map of the UK, where land is textured green and the shipping forecast regions are depicted in a whitish colour.

Image below: Database Search Scen. Selecting multiple items, placing them on the selection zones.

Note – The appearance and use of these assets was substantially adjusted during development.

The latest version of the Navigator now uses icons representing 'Gross Subject' rather than cubes as a significant visual enhancement.

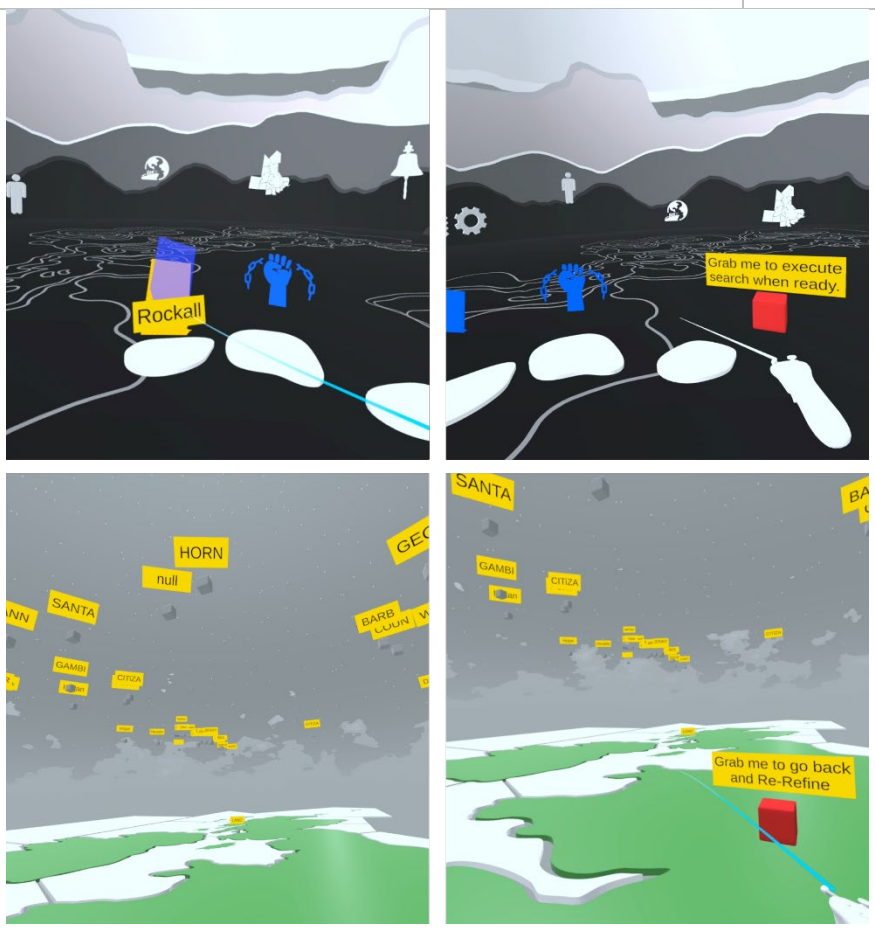


Figure 5: Database Search Scene. Selecting multiple items, placing them on the selection zones.

3D Results Map The environment is based on a scaled 3D map of the UK, which includes the Shipping Forecast regions. This map serves as a positional reference for ADPs, with the items geolocated in relation to the mapping data, while accounting for varying degrees of positional accuracy in the base data. Additionally, the results are organised along a vertical axis to reflect their chronological position: more recent results are positioned higher, while older results, such as those from the early Mesolithic period, are placed closer to the bottom. Finding a suitable map resource compatible with a Unity environment proved challenging, so the map was hand-traced from an SFR Map. The units of the original map were then converted to match those used in Unity. To ensure proper geolocation, all regions were adjusted in relation to 'Plymouth SFR.' This reference point was positioned based on a calculation of its area relative to Unity units and its centre was determined accordingly. The location was then verified against the result coordinates for best accuracy.	None

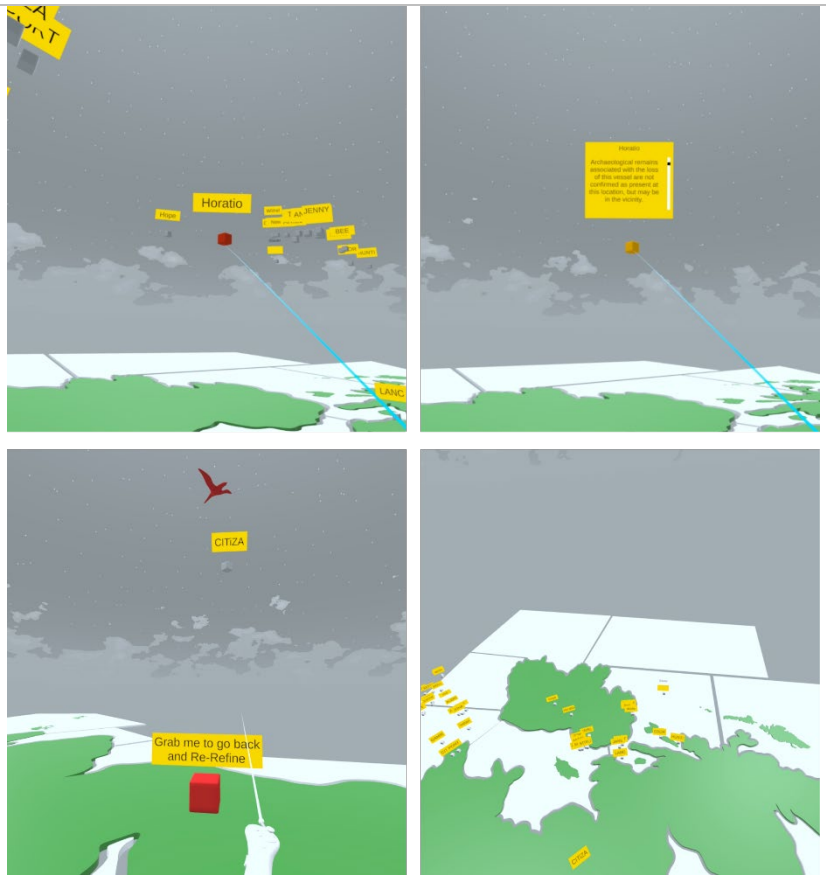


Figure 6: screen grab from video walk-through.

Video Display The initial prototype for displaying external video data in the results scene was developed but ultimately discarded due to its cumbersome nature and high computational demands. This prototype involved accessing videos via URLs linked to specific ADPs and required a Wi-Fi connection to load content. The in-app web browser used for this purpose was a third-party asset, which performed unsatisfactorily. Should this feature be reconsidered in the future, a more efficient solution would need to be identified.	Appropriate resolvable links and streaming service.
Curated Pathways Based on the results from the co-design process, user routes through the integrated dataset were prepared by Scott Carballo in collaboration with Vicky Blencowe and McNabb Laurie. Additionally, the creative soundscapes were made by David Dore, Dennie Landsman, Ellie Ford, Samuel Alexander, Marie Wahrn, Jamie Graham.	Any number of voyages may be added – see the main report and the section on Curated Pathways below on why specific choices were made for this iteration as well as useful feedback from the

The curated pathways are set in a consistent environment featuring dark, calm water, a light sky, and a bright moon with stars overhead. The journey is represented by a series of islands, each representing a point in the journey. Each island includes forward and backward navigation buttons, except for the first and last islands, which have only a "next" and "back" arrow, respectively. Users can move between pods either by using these arrows or by teleporting. Each pod contains diverse types of content, such as images, text, videos, voice-overs, or 3D models. To enhance readability, a curved UI system was chosen for its clarity and visual appeal. A feature introduced later in development is responsive voice-over and audio. Each pod includes text content that is read aloud. As users move from one island to another, the voice-over corresponding to the new pod plays automatically. If users return to a previous pod, the voice-over resumes from where it left off, ensuring they pick up the story seamlessly. If they revisit a pod after the voice-over has already completed, it will restart from the beginning. This setup provides a smooth and coherent storytelling experience. Some pods feature 3D models that, when hovered over, display a "Grab Me" ticket. Grabbing the object brings it closer, allowing users to rotate and explore it up close.	CDMR group on potential major enhancements – outwith the scope of this project.
Positional Audio Positional audio (binaural sound) was investigated as an element of the primary User Environment. The incorporation of positional audio was discarded as a request of the visually impaired community, with a concern that it would be too confusing as the hardware does not isolate from environmental sound.	None
Query Scripts: Reset Refine Query scripts allow the user to interrogate the integrated maritime datasets and return a subset for display according to predefined criteria. Written in C# and integrated as part of the Unity project. The scripts involved in providing this functionality is the ResetRefine script. The ResetRefine script is designed to manage the setup, reset, and destruction of different scenes and objects in the environment. It handles the instantiation and arrangement of scene objects, including maps and prefabs, and provides methods to create and destroy scenes based on user interactions or system events. The script also manages object positioning, including arranging items in a circular layout, and toggles the visibility and intractability of various UI elements and game objects. It interacts with the	None

SqliteController to manage data and state transitions between refining and results scenes.	
Query Scripts: SqliteController Manages SQLite database interactions and resource handling. It initialises and maintains a connection to the database, ensuring it is copied to the persistent data path if needed. The script executes SQL commands, including basic SELECT queries and complex JOIN operations, while managing query terms with logical operators like AND and OR. For resource management, it creates and positions GameObjects based on query results, using prefabs for different types of resources and mapping temporal tags to specific Y-coordinates for accurate placement. It also handles large datasets efficiently by processing results incrementally through coroutines and manages resource cleanup and query stopping to avoid performance issues. Additionally, the script integrates with the MapProjection controller for visual updates and communicates with ResetRefine to signal when processing is complete. Overall, SqliteController combines database access, dynamic resource creation, and smooth performance management.	Access to the SPARQL endpoint provided by ADS. Confirmation of the format of the SPARQL endpoint. For further detail, look at script architecture section below.

Table 2: Technical Elements

4.4 Delivery Schedule

This section outlines the timetable for the completion of the Navigator based on the functionality and the technical elements of the design described above. This timetable is split up into three phases:

- Phase 1 – Basic layout and functionality. Basic prototyping of all the technical elements of the functionality along with scripting the SPARQL query and formatting the local data (Navigator Actual 1.0).
- Phase 2 – As initial dependencies are fulfilled and the first feedback from the co-design process became available elements of the Navigator were developed along with integrating the functionality of displaying, accessing and querying data. This process was highly iterative, feeding back into the co-design (and evaluation) process.
- Phase 3 – As the co-design process neared completion Technical and functional elements of the Navigator were finalised. This phase focussed on the functionality of the user interface and included elements like the Curated Voyages and Creative Soundscapes.

Elements	Completion Date
Phase 1	
User Environment (Navigator Actual 1.0): Basic scene setup	9/11/2023
Image Settings Functionality 1st iteration	17/11/2023
UI Settings Menu	20/11/2023
Changeable Text Size using slider 1st Iteration	22/11/2023
Zoom on results functionality (later removed)	24/11/2023
SFR Map implementation	29/11/2023
Chronological Y-Axis Data Point Implementation	4/12/2023
Spawn Object Script	8/12/2023
Refining Objects 3d Models	9/12/2023
Spawn and Toggle	12/12/2023
Socket Interaction Manager	12/12/2023
Implementing Database with synthetic data	20/12/2023
Map Spawn functionality	0/09/2024
Birds Eye View	11/01/2024
Bathymetric Map	16/01/2024
VO Implementation 1st iteration	22/01/2024
Phase 2	
Reset Refine Script	23/01/2024
Beta APK Build	01/02/2024
Animated Bathymetric Map	14/02/2024
Iterations for Final Look and Feel	23/02/2024
Final Scene Environment	14/03/2024
Final UI Setup	22/03/2024
Hover Float Script	25/03/2024
Interactable Voice-over Scripts	30/03/2024
Item Selection Controller	30/03/2024
Voyage Scene setup	02/04/2024
Lighting Setup	03/04/2024
Final Search Scene	09/04/2024
Object Snap and Scale	15/04/2024
Empty Execute Warning	24/04/2024
Global Sound Volume Settings	25/04/2024
Scene Change Handling	10/05/2024
Final VOs recorded by Ellie Ford & Scott Carballo	20/05/2024
Phase 3	
Demo Scene	23/05/2024
New Oculus SDK	02/06/2024
Slideshow Function Voyages	24/06/2024

VO Playback for Voyages	11/07/2024
Initial Exhibition APK	05/07/2024
MDES Soundscapes	8/07/2024
APK Update 1 - The APK updates include the addition of a co-designed voyage, enhancements to some 3D models, and the implementation of results model differentiation based on query type, a script section was updated in the SQLite controller to support these changes.	18/07/2024
APK Update 2 – The latest APK update includes several improvements: a new bird model with flapping wings, enhanced maps with solid, color-differentiated land masses replacing previous cutouts, and a slideshow pause feature for co-design voyages that pauses when hovering over an image.	26/07/2024
APK Update 3 - The latest APK update features several enhancements: the entire co-design voyage has been reorganized into sections based on themes, collider sizes for the image slideshow pause function have been adjusted for smoother performance, and issues with intro voiceovers have been fixed alongside improvements to the voiceover management system. Additionally, voyages now support free teleportation between pods, which required updates to the teleportation system to ensure the active pod is properly recognized.	9/08/2024
Final codebase enhancements (after evaluation/exhibition): Replacing search result icons with 3D icons representing 'Gross Type', enhancement of the query to sample results set geographically across all returned results giving a better/more meaningful distribution of results. This avoids the issue of capping large results sets (0<>1000) returning sequential results by area, i.e. large results sets initially showed those results from a specific geographical dataset rather than being distributed across all geographical datasets. This was the final significant enhancement.	**November 2024**

Table 3: Delivery Schedule

5. The Curated Voyages

5.1 Introduction to Curated Voyages

As discussed above, VR can integrate multiple data types, including video, 3D audio, 3D objects, in addition to text and 2D images. Indeed, failure to integrate these data types would limit any proposed VR system, as the full potential of an immersive space would not be realised. As mentioned above, these data types are not available or accessiblein virtual reality at this time. They are yet to be linked to aggregated data points or addressed as DOIs. Due to problems associating rich data and multimedia content with individual records, WP4 have sought to overcome these limitations by curating multimedia content on certain maritime themes to highlight specific routes through the Unpath datasets while also realising the full potential of immersive systems.

To fully realise this potential, we curated multimedia content offered by several Unpath Partners (and some outside sources). Partners were able to offer rich and varied resources from their institutions' digital libraries. They also offered many research themes which aligned with our research themes. However, we were keen to further adhere to a 'user-generated' design ethos and return to our co-design partners. we were also conscious of complying with the Unpath'd Waters Living Values Framework. Especially:

- Empowering through collaboration: We aspire to empower through collaboration – actively enabling individuals to link to wider communities and global narratives and vice versa.

- Adventurous: We embrace adventure – we are driven by curiosity, optimism and challenging the status quo with open minds and a concern for creativity. We value failure as much as success. (Unpath'd Waters, 2024)

Therefore, in the first instance we were very keen to go back to our co-design partners and work in collaboration with them to build voyages that reflected their interests, rather than the professional and academic priorities represented by partner suggestions (or WP4's own aspirations). With that said, WP4 are also keen to highlight the work of Unpath partners, incorporating narratives and content derived from Unpath'd Waters work.

5.2 Enriching the Immersive with Curated Voyages

The following Curated Voyages are included in the Navigator at the close of the project.

- **Dumfries and Galloway in Napoleonic Wars**, designed by McNabb Laurie (NCC), Scott Carballo and Maria Cotuna. Content provided by Historic Environment Scotland/SCRAN, Dumfries and Galloway Museums, National Maritime Museum (Andrew Choong). Voiceover by Ellie Ford (GSA).

- **Women and Shipping in the 20th Century**, designed by Vicky Blencowe (VIP), Scott Carballo and Maria Cotuna. This is an audio-centred voyage, but also contains a side voyage with 'Women and Shipbuilding' exhibition images, provided by Historic England and Lloyd's Register Foundation. Voiceover by Ellie Ford.

- **Submerged Landscapes of the Mesolithic**. This was drawn from Unpath'd waters Work Package 3.3. This voyage was also enhanced by 3d/image/video content provided by Maritime Archaeology Trust. Script written by Phil Murgatroyd. Voiceover by Ellie Ford (GSA).

- **The Co-Design of the UNPATH Navigator**. This voyage includes selected snippets of our audio-visual record of our co-design workshops with each group. It highlights some of the most important and interesting discussions in each case, and outlines the reasoning behind decisions on heritage themes, design cues, and VIP accessibility.

- **Creative Soundscapes** – These are creative soundscapes included for our VIP cohort. Feedback in co-design workshops showed how high-quality binaural audio could help VI users feel 'transported' and aid immersion. WP4 engaged our MDes Sound for the Moving Image students at GSA to create six maritime themed soundscapes for our VIP audience.

Multimedia content was required from outside sources in order to demonstrate the full potential of a maritime immersive system. This was one of the more challenging aspects of implementing the Curated Voyages. Copyright issues, particularly with video content, prohibited inclusion of large amounts of rich content initially thought to be available. Approaches to large archive holders (for example the BBC and the Scottish National Moving Image Archive, held by the National Library of Scotland) revealed insurmountable copyright or charging constraints. Ultimately, the rich content which could be incorporated was that provided by Unpath'd Waters partner institutions.

6. WP2 Data Enhancement Request Table

The initial dataset supplied ex-ARIADNE was converted into a 'flat file' format for SAPRQL querying in the navigator. Record details that would allow us to parse the records thematically were distributed across both record TITLE and DESCRIPTION and WP2 (Jack Pink, who provided the technical details used here) was able to run word matching queries across these field against controlled word lists to allow themes to be populated. In addition, a spatial query against record Lat/Long was used to assign records to SFA. WP2 used geopandas and Shapely to process the spatial data for this task – runtime of the model was about 10 hours. Note: estimated runtime for these queries using tqdm it was 65 hours on a standard university desktop (it was run on a higher spec. Personal computer and took c. 8 hrs. For future iterations of work and follow-on projects we should be ensuring these processes run as a multiprocess script across the full CPU chip, requiring access to multi-core hardware.

For the land/sea theme everything was initially in a 'sea' area which is due to the shapefile from ONS/Open Government Data. This is clipped to the UK mean high water boundary (probably aligning with how the NMRs/HERs have divided their sites/records with everything ingested for Unpath'd being from the 'Marine').

Where Shipping Forecast areas (labelled as Unknown Water Area) fall between the clip boundaries of the two datasets, these were generally ports, harbours, and other coastal structures and ultimately assigned to land features.

Table of queries and controlled lists:

Field Name	Source/Data Enhancement
PK	Ex - Ariadne RDF
label	Ex - Ariadne RDF
title	Ex - Ariadne RDF
description	Ex - Ariadne RDF
placename	Ex - Ariadne RDF
lat	Ex - Ariadne RDF
lng	Ex - Ariadne RDF
ids	Ex - Ariadne RDF
uri	Ex - Ariadne RDF
temporal1	Ex - Ariadne RDF
temporal2	Ex - Ariadne RDF
subject	Ex - Ariadne RDF
GSA_SFA	To be assigned a shipping forecast area through a GIS query on lat/long
GSA_Themes_People	Set to Y is any personal name occurs in title/description (this will aslo give us ships with personal names, which I think is okay)
GSA_Themes_Migration	Perhaps 'migration/ed' or 'immigration/ed' would work.
GSA_Themes_Crew	Set to Y if any naval/marine role title occurs in title/description - file of role titles sent separately
GSA_Themes_Slavery	Set to Y if 'slave', slavery' etc. occurs in title/description
GSA_Themes_Material_Cargo	Set to Y if any word occurs in title/description that also occurs in: Cargo Thesaurus, https://www.heritage-standards.org.uk/fish-vocabularies/
GSA_Themes_Material_Technology	Set to Y if any word occurs in title/description that also occurs in: Object Materials Thesaurus or Maritime Fixtures and Fittings Thesaurus https://www.heritage-standards.org.uk/fish-vocabularies/

GSA_Themes_Destination	Set to Y if any word occurs in title/description that also occurs in: Maritime Place Names Thesaurus, https://www.heritage-standards.org.uk/fish-vocabularies/ or Getty Thesaurus of Geographic Names (Getty TNG, https://www.getty.edu/research/tools/vocabularies/tgn/index.html)
GSA_Themes_Warfare_WW1	Set to Y if 'World War One', 'WW1', 'WW'I etc. occur in title/description.
GSA_Themes_Warfare_WW2	Set to Y if 'World War Two', 'WW2', 'WWII' etc. occur in title/description.
GSA_Themes_Warfare_All	Set to Y if the word 'War', 'Warfare' or 'WW' occurs in title/description.
GSA_GrossSubject_Plane	We have harvested bottom level terms from the RDF but need the top-level terms to do this.
GSA_GrossSubject_Submarine	We have harvested bottom level terms from the RDF but need the top-level terms to do this.
GSA_GrossSubject_CargoShip	We have harvested bottom level terms from the RDF but need the top-level terms to do this.
GSA_GrossSubject_WarShip	We have harvested bottom level terms from the RDF but need the top-level terms to do this.
GSA_GrossSubject_PassengerShip	We have harvested bottom level terms from the RDF but need the top-level terms to do this.
GSA_GrossSubject_Artefact	Set to Y if any word occurs in title/description that also occurs in: Archaeological Objects Thesaurus, https://www.heritage-standards.org.uk/fish-vocabularies/
GSA_Land/Sea	WP4 to Set Manually
GSA_RichData	WP4 to Set Manually – if there is associated addressable data (ie a resolvable DOI)
GSA_Voyage	WP4 to Set Manually

Table 4: queries and controlled lists

7. Script Architecture

A design a functionality Miro board visually representing the link/depeencies below is available here:

UNPATH Navigator Design MIRO Board (Maria Cotuna) - https://miro.com/app/board/uXjVKT74s1k=/

7.1 Data Query Structure

The system's functionality is organized through the interaction of several key scripts, each playing a distinct role in managing and displaying resource data within Unity. **SqliteController** is the primary script responsible for connecting to the SQLite database, executing queries, and handling the creation and management of resource GameObjects based on database results. It interfaces with **ResetRefine** to signal when data processing is complete, enabling the scene to be refreshed or reset as needed. **InputUpdate** handles user input, capturing and processing interactions that involve querying or manipulating the displayed resources. **ItemSelectionController** manages user selection of resources, allowing users to interact with specific items, often integrating with the UI to reflect selected items. **UnpathResource** represents individual resources in the scene, storing relevant data and attributes for each GameObject instantiated by the **SqliteController**. Finally, **UnpathSelector** provides additional functionality for selecting and filtering resources based on user input or queries. Together, these scripts create a cohesive system that allows dynamic querying of the SQLite database, interactive user engagement with resources, and visual representation of data in Unity, ensuring a responsive and integrated experience.

7.2 UnpathResource

This script, UnpathResource, defines a data structure for storing information about a resource in a Unity project. It includes fields for various attributes such as a label, title, description, place name, and geographical coordinates (LatLng). Additionally, it maintains a list of IDs associated with the resource. Two Boolean properties, isSelected and isHovered, are used to track the state of the resource, indicating whether it is currently selected or hovered over. This script is used to manage and interact with resource objects within a Unity environment.

7.3 UnpathSelector

The **UnpathSelector** script is responsible for managing user interactions with selectable objects. It handles select click, where it communicates with a **SqliteController** to update or run queries based on user input. It manages UI elements such as a TextMeshProUGUI label and an Image component, which are shown or hidden based on the object's hover state using XR interaction toolkit events. This script also contains methods for updating label text and handling hover events, providing visual feedback and interaction functionality within the Unity environment.

7.4 InputUpdate

The InputUpdate script handles user input and interaction with the database in a Unity project. It listens for specific input actions, to update queries in a SqliteController instance. When the user points the controller, it

performs a raycast to detect if an UnpathSelector object was hit, then updates the query based on that object's data. The script also provides methods for executing queries, resetting them, and handling specific input events, ensuring that the user interactions are correctly processed and reflected in the database operations.

5. ItemSelectionController

The ItemSelectionController script manages the visual and interactive behavior of items in the scene, focusing on user interactions with XR elements. It handles layout adjustments when items are hovered over or selected, including resizing and scaling UI elements to provide visual feedback. When an item is selected, it displays detailed information about that item by interacting with a SqliteController and toggling visibility of UI panels. The script also manages the state of a title panel and an information panel, ensuring that the correct panels are shown or hidden based on user interactions and selection status.

7.5 ResetRefine

The ResetRefine script is designed to manage the setup, reset, and destruction of different scenes and objects in the environment. It handles the instantiation and arrangement of scene objects, including maps and prefabs, and provides methods to create and destroy scenes based on user interactions or system events. The script also manages object positioning, including arranging items in a circular layout, and toggles the visibility and intractability of various UI elements and game objects. It interacts with the SqliteController to manage data and state transitions between refining and results scenes.

Description:
The ResetRefine script manages the creation and destruction of two primary scenes within a Unity application: the refining scene and the results scene. It handles the following:

Refining Scene:

1. **Creation**: Instantiates and positions key objects such as the starting environment, refining objects, and interactive components like socketInteractor. It arranges these objects in a circular pattern and sets up the initial scene state.
2. **Destruction**: Clears all instantiated objects related to the refining process, including interactive components and visual elements.

Results Scene:

3. **Creation**: Activates and positions elements such as the SFRMap and a results-specific reference object (reRef). It ensures the correct setup of the results scene by activating relevant objects and handling audio playback.
4. **Destruction**: Deactivates or destroys all objects associated with the results scene, including the map and any additional visual elements like birdsEye. It also resets the database and clears the query results.

   The script ensures that the transitions between these scenes are smooth and manages the lifecycle

of interactive and visual components effectively.

7.6 SqliteController

The SqliteController script manages interactions with an SQLite database, handles query execution, and manages resources within a Unity application.

It initializes and maintains a connection to the database, ensuring it's copied to the persistent data path if needed. The script executes SQL commands, including basic SELECT queries and complex JOIN operations, while managing query terms with logical operators like AND and OR.

For resource management, it creates and positions GameObjects based on query results, using prefabs for different types of resources and mapping temporal tags to specific Y-coordinates for accurate placement. It also handles large datasets efficiently by processing results incrementally through coroutines and manages resource cleanup and query stopping to avoid performance issues.

Additionally, the script integrates with the MapProjection controller for visual updates and communicates with ResetRefine to signal when processing is complete. Overall, SqliteController combines database access, dynamic resource creation, and smooth performance management to support complex data-driven interactions.

Key Components and Functionality:

Database Interaction:

1. Database Path and Initialization:

1. The script sets up the path to the SQLite database, ensuring it is copied to the persistent data path if necessary.
2. Initializes the SQLite connection and command objects.

2. Database Commands:

1. ExecuteCommand: Executes a command to query the database with a SELECT statement, applying a limit to the number of results.
2. ExecuteCommandWithJoin: Executes a JOIN query to combine tables based on specific conditions.

Query Management:

3. Adding and Removing Query Terms:

1. AddToQuery: Adds terms to the current query, managing logical operators (AND, OR) and resetting the query list if necessary.
2. RemoveFromQuery: Removes a specific term from the current query list.
3. ResetQuery: Clears the current query list.
4. Running Queries:

1. RunQuery: Constructs and executes a query based on the current query list, handling results in a coroutine for efficient processing.

Resource Management:

5. Creating and Destroying Resources:

1. CreateAll: Instantiates GameObjects based on query results, positions them, and stores them in dictionaries. It handles large result sets by loading them incrementally.
2. StopQuery: Stops ongoing queries and cleans up resources.
3. ClearResourceDictandLists: Clears the resource dictionary and results lists, also destroys existing GameObjects.

6. Resource Prefabs:

1. Prefabs for resources (m_ResourcePrefab, m_SubmarineMarker, m_ArtefactMarker) are used to instantiate objects based on query results.

Positioning and Tag Handling:

7. Temporal Tags:

1. temporalTagToCoordinateMap maps temporal tags to specific Y-coordinates for object placement.
2. GetYCoordinateFromTemporalTag retrieves the Y-coordinate based on a temporal tag.

8. Original Positions:

1. originalPositions stores the original positions of resources for potential future use.

Integration and Utility:

9. Map Projection:

1. mapProjectionController is used to manage map projections and update visuals.

10. Query Coroutine:

1. queryCoroutine handles the asynchronous processing of query results to ensure smooth performance.

11. ResetRefine Integration:

1. The script interacts with ResetRefine to notify when processing is complete and manage scene transitions or resets.

Additional Points:

1. Error Handling and Logging:

1. Debug logging is used extensively to track database paths, commands, and errors.

2. Performance Considerations:

1. The use of co-routines helps manage performance by loading data incrementally.
2. The script includes checks to prevent multiple queries from running simultaneously and manages resource cleanup effectively.

Overall, this script is designed to handle database interactions, resource instantiation, and querying efficiently, with a focus on performance and integration with other Unity components.

7.7 Other Script Structure

The application features an extensive array of scripts that facilitate various functions integral to its functioning. These include:

CurvedUIRaycaster, UpdateTextBoxStyle, ArrowTeleport, CustomTeleportationAnchor, PostProcessing, InputUpdate, CurvedUITMP, ChildObjectController, TeleportationManager, TextMeshProUI, CircleObjectPlacer, MapProjection, CurvedUISettings, VignetteManURP, TeleportationAnchor, XRGrabInteractor, XRSocketInteractor, CurvedUIVertexEffect, MapSpawnAndToggle, XRUIInputModule, BloomManagerURP, TeleportationProvider, ReRefine, ColorAdjustmentManagerURP, IsOnPod, UIColorSetter, ZoomController, SocketInteractor, XRCanvasSwitcher, CurvedUIInput, ControllerButtonGlow, LatLng, SqliteController, ResetRefine, SpawnAndToggle, BirdsEyeView, XRRayInteractor, VoiceOverManager, AudioManager, SoundVolume, TransformKeeper, ParentObjectController, UnpathSelector, ActionBasedControllerManager, ActionBasedController, Marker, XRDirectInteractor, InteractableVoiceover, ButtonClickAudio, ColorProperties, ItemSelectionController, HoverFloat, XRInteractorLineVisual, InteractableVoiceoverHover, ButtonHoverAudio, XRInteractionGroup, UnpathResource, XRInteractionManager, XRInteractableSnapVolume, ExecuteQuery, XROrigin, InfoPanel, CharacterController, LocomotionSystem, Demo Scripts, Voyage Scripts, Sound Scape Scene Scripts, UI Scripts, Moving between Scenes Scripts, SoundScapePlay, TransformKeeper, VolumeHandleColorChange, VoyageOrRefine, LinearArrangement, ControllerButtonGlow, ImageCycler, MenuPopup, ImageSlideshow, ColorInteractionChange, HoverFloat, CircularArrangement, ManagePanels, EnlargeImage, SceneChangeOnGrab, ParentObjectController, PersistenceManager, ColorInteractionChange, VoyageShowcaseRotation, RestartApp, NextScene.

These scripts are responsible for managing data queries, object handling, and UI functionality, sound functionality, post-processing, scene management, and general application operations. This includes features like application resetting, maintaining persistent data, and facilitating seamless transitions across different scenes within the application.

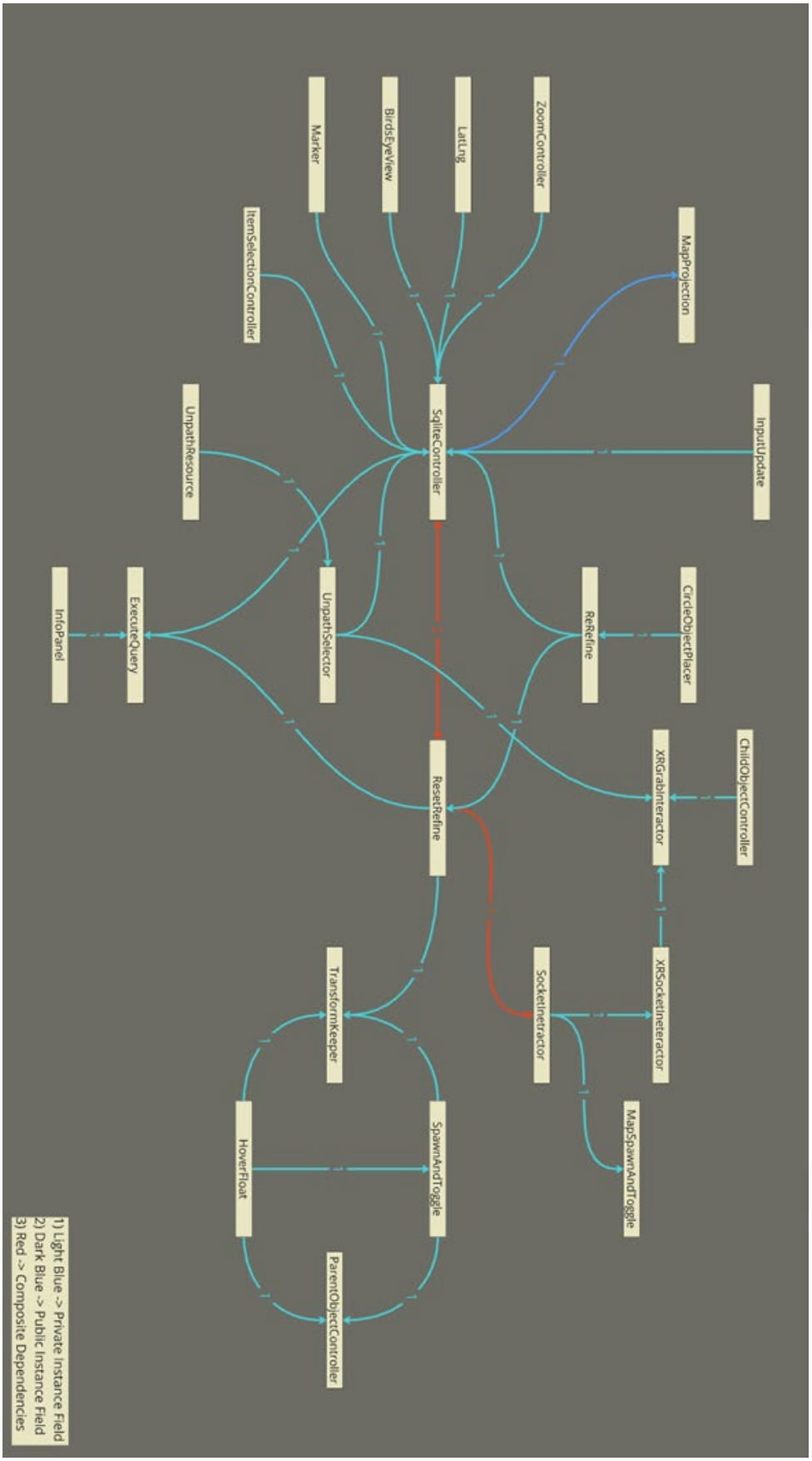


Figure 7 Script Dependency Map

8. Recommendations

8.1 Data Formatting

Through the Unpath'd Waters Navigator, we achieved our aim of co-designing an immersive system to display aggrecated multimodal heritage datasets. This has been accomplished due to the work of Unpath'd Waters partners in curating and enhancing existing datasets. However, there are some functionalities which were desired at the outset of the project which could not be incorporated. Some rich content associated with individual records cannot be displayed in the application. This is due to the absence of workable web viewers in Unity, and the disconnect between Unpath'd Waters metadata and records archived in national repositories. Links between Unpath'd Waters metadata and individual records are not present within the proposed national collection dataset beyond basic record information held on the Unpath'd Waters Portal. All associated content, such as pictures, videos and additional curatorial information, is still held in digital infrastructures curated by other organisations. We offer some important recommendations in approaching the development of a National Collection.

- Rich content than can be meaningfully associated with an aggregated data point should be referenceable via DOI and linked via RDF in the datapoint – e.g. image data, 3D data, video/audio, text data, which represent the actual research resources, could be linked directly with the ADP metadata. This could include data held outside of the institution curating the core record, linking to data in other memory institutions, museums, galleries, and archives.
- It is not clear if the CIDOC CRM or any RDF predicate set has the richness to capture these relationships – or if they can be generated automatically (i.e. using ML or similar)
- Although this iteration of the immersive was developed to be explicitly 'stand-alone' due to issues of latency and concerns over internet access at exhibition venues, in future it should still be possible to query the ADPs live (e.g. via the UNPATH portal), although this would require a mechanism whereby record enhancements such as those carried out by WP2 are integrated (or better, linked) to the aggregated maritime dataset.
- The UNPATH Navigator also does not include functionality to share, create user generated pathways or follow-up on research outside of VR. This was flagged as highly desirable functionality (CDMRs and NCCs), but would require substantial server-side infrastructure (including moderation) to implement. However, it would also transform the dataset into a working research and/or personalised work space. It would only make sense to create this functionality if the above point on addressable rich data was also addressed.
- A very interesting suggestion to arise from the CDMR group was the potential for generating search themes on the fly, i.e. the immersive space not only allows exploration of the aggregated datasets, but allows the specification of a new 'theme' - this would require much more, and quite complex integration of the immersive querying system and the enhancement work undertaken in WP2 – However, as an approach this could have enormous potential in further transforming the immersive from a passive to an active research environment, especially if it encompassed the rich datasets as

discussed above. *This is an exciting new technical research avenue that has arisen directly and unexpectedly from the wishes of co-design partners.*

8.2 Navigator Design and Enhancements

With data limitations in mind, investigations into the affordability of virtual reality as a heritage tool have yielded encouraging results. The burgeoning market for VR and increased capabilities of headsets since the Unpath'd Waters project began means that future projects will be able to build on this work to produce further achievements. For example, native text-to-speech readers have now been incorporated into the Meta software since the release of the Quest 3 headsets, a feature that was unavailable during the co-design of the Navigator and is useful for VI use.

Having additional time and resources to build on successes of WP4 would also mean that sharing research, saving research for future use, and collaborating with colleagues are features that could be incorporated into a virtual reality application. These functions were requested by both CDMR and NCC test groups on multiple occasions. However, they require a much larger back-end infrastructure in technical development and could not be achieved in this phase.

Meta XR SDK should be considered in future iterations due to its new features, including voice assistive technology. This advancement could significantly streamline the development process by enabling text-to-speech (TTS) capabilities, eliminating the need for (much) traditional voice recording, however VIP feedback on automated voice technology, was not all positive, they found automated voices distancing and preferred fully human voices/inflection (this is in addition to the point in section 3 about the nature and tone of voice over content).

8.3 Co-Design Process

Although the CD process for UNPATH was highly successful, resulting in very valuable insights for further immersive developments, for future co-design activities, we would recommend adding additional time for workshops when using VR, particularly with the VI community – this reflects the learning process in navigating and manipulating objects in an immersive environment which is not a process that can be easily short cut.

An additional time constraint was the simultaneous evaluation of the CD methodology and audit of values alignment with the actual CD process. This is obviously valuable work, but future CD exercises should perhaps deal with this in a separate phase. A caveat to this recommendation is that there is no sense that all lessons from the CD methodology development/process have been fully analysed, nor are they likely to be entirely universal and each group of co-designers needs to be responded to individually by the co-design team. Different audiences may require different approaches (as per our project values).

Appropriate software to allow for VR streaming is also essential (Oculus developer accounts are required for streaming via link cable). Wi-Fi access is essential for workshop activities and researcher demonstrations.

9. Resources

UNPATH Navigator Design MIRO Board (Maria Cotuna) - https://miro.com/app/board/uXjVKT74s1k=/

UNPATH Navigator GitHub – code base - https://github.com/JFlint-Unpathd/Unpathd-URP-Explore

UNPATH Navigator Prototype Video Walkthrough - https://vimeo.com/1054159800?share=copy#t=0