Abstract

In this work, research was undertaken to help to determine what the best practices are for incorporating e-learning material into immersive WebVR applications. The implications for this new, highly scalable and device agnostic method of delivering content were beginning to become evident as this research began.

Part of this investigation involved discovering how educational material is currently being incorporated into established virtual reality technologies and frameworks. It was then necessary to take this knowledge, and to see if, and if so how, it is being applied to current WebVR development, and to determine whether there were any new or improved ways in which it could be utilised during the design and development process.

Informed by the findings of the research, a prototype WebVR application was created. The intention was to experiment with a variety of teaching and learning techniques through the WebVR medium. Data and feedback from these experiments were generated and recorded through usability testing with a group of participants. The results were then analysed and evaluated, in order to try and determine the feasibility of WebVR as a tool for learning.

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1. Introduction

1.1 Background and Motivation

WebVR is a relatively new arrival within web development. With the growing adoption of VR amongst the general public, it has become an ever more exciting and interesting field in which to study. Having a low barrier to entry, both for developers and end-users, WebVR could potentially further democratise Virtual Reality technology and learning.

An important aspect of this project involved determining whether virtual reality for the web is suited to delivering an effective e-learning experience. One of the attractions of WebVR is its inherent accessibility. WebVR content can potentially be accessed through any device with an appropriate web-browser. At the more primitive end of the scale, this could take the form of a smartphone equipped with a relatively cheap cardboard viewing device, or at the other end, a piece of VR hardware such as the Oculus Rift or HTC Vive. It is important therefore to consider the scalability and fidelity of any VR software developed for the web. One of the goals of this project is to determine if an application delivered at the lower end of the scale can provide an immersive and enjoyable experience that produces meaningful outcomes.

The project also has the potential to contribute to the understanding of how the internet and WebVR can be used to lower the barriers of entry to virtual reality experiences and technologies. By providing users with content designed not only for dedicated VR hardware, like the Oculus Rift, but also devices as ubiquitous as smartphones, the initial cost to access an entry-level VR experience is reduced to the price of a simple cardboard holder. Accessing immersive, virtual reality content can be as straightforward as clicking a button on a web page, or receiving a link from a friend or colleague. The device agnostic nature of WebVR and its inherent accessibility; in financial terms and additionally with its delivery through the web, may have implications for pedagogy, both in the classroom and the wider public sphere.

1.2 Scope

The idea behind this project is to create and test a prototype WebVR experience. The goal is not to produce a fully-fledged application that is ready for deployment in the real world, but rather to investigate the possibilities and potential of this new and exciting technology. The project shall therefore focus on the user experience, while making use of entry-level hardware such as desktop PCs and mobile phones working in conjunction with headset devices such as cardboard holders and the Google Daydream headset. I believe that focusing on these entry level devices is in keeping with the notion that this technology has the potential to democratise the Virtual Reality experience. By focusing on the most ubiquitous hardware types I hope to reflect that idea in this project.

1.3 Aims and Objectives

I have developed a set of aims and objectives to help describe what I hope to achieve during this process. The aims I have set out relate to what I wish for the project as a whole, while the objectives are more directly related to what must be achieved within the project itself.

Aims

To meet the requirements of the BSc (Hons) Digital Media: Design, Production and Development degree course.

To further expand my knowledge and competency within the fields of front-end web development, WebVR, User Experience Design and E-Learning.

To better understand the potential for WebVR as a platform and a tool for e-learning.

To demonstrate skill and understanding to potential employers.

Objectives

Research and bring together the key concepts and best practices for presenting e-learning material to end-users through immersive 3D environments.

Research and develop an appropriate and optimised development method for combining web-based, virtual reality experiences, with educational material.

Develop a prototype, WebVR-based, e-learning application that delivers educational material via the internet.

Test and measure the usability and perceived value of a variety of pedagogical techniques applied through WebVR.

2. Research

2.1 Introduction

The research undertaken within this project will inform the development of a design specification for the WebVR application I intend to produce. A large part of the research within this project will take the form of an in-depth literature review. The literature review will seek to establish:

The challenges relating to WebVR as a whole, the optimal development methods and approaches to working within the WebVR medium.

The best practices associated with developing e-learning material for the web, and more specifically, developing e-learning materials for immersive 3D environments.

How these best practices can inform the design process for a WebVR application.

It would also be sensible to examine the current offerings from other developers working with WebVR, to see what can be learned. In addition to the in-depth literature review, I will produce a critical review of existing WebVR applications: what they do well; how they can be improved; and how they may relate to the focus of this project.

2.2 Literature Review

2.2.1 VR and WebVR

To begin, it is useful to describe what exactly is meant when we talk about Virtual Reality(VR). It is also important to define what WebVR is, and how it relates to VR as a whole. Pimentel and Teixeira (1993), defined VR as “an immersive, interactive experience generated by a computer”. Immersive VR, as we know it today, works according to the principles of Stereopsis, which describe the human ability to perceive the world in three dimensions (Howard & Rogers, 1995). The idea of VR sounds very modern, yet since the early days of computing, and with the advent of computer graphics in the 1960s, early pioneers were theorising about stereographic headsets and virtual worlds (Earnshaw, 2014). Today, VR is on its way to becoming well established as a consumer-level digital medium. We have recently seen the first generations of competing VR hardware, enter the market.

The next important question to address is: what separates WebVR from other immersive VR platforms? WebVR is an experimental JavaScript API that allows web-browsers to access VR hardware such as the Oculus Rift, Samsung Galaxy VR or Google Cardboard. Data on positioning and movement from these head-mounted displays can be translated from the device to be reflected in a 3D environment within the web-browser (Mozilla, 2016).

2.2.1 VR - Best Practices

Both hardware manufacturers and software developers provide standards and best practices for using and working within VR (Oculus, 2016 & A-Frame, 2016). Failure to follow these standards is likely to have a negative impact on the user experience, and can potentially lead to users experiencing issues such as motion sickness, nausea or discomfort.

Performance

There are certain thresholds for acceptable performance that need to be met when developing VR applications. Failure to meet these minimum requirements can result in a poor and off-putting experience for end-users.

Achieving a minimum acceptable frame rate is a key benchmark for the performance of any VR application. Currently, the ideal frame rate is measured at around 90 frames per second or above. A frame rate of 60 - 75 frames per second is considered acceptable. VR hardware should therefore ideally utilise displays that have a refresh rate of 75hz or above. Should a VR experience drop below this frame rate, users may start to notice screen flicker or sense motion jitter (Oculus, 2016).

Screen resolution is an important factor in relation to the user experience. When using devices with lower resolutions it is likely that users will experience what is known as the “Screen Door Effect”. This is an effect created by a combination of the low resolution screen, and the close proximity of the device to the user’s eyes. Whereby the gaps between the pixels become visible, making it appear as though the scene is being viewed through a screen door. Because of this it is wise to avoid fine details, such as small fonts or narrow, thin lines when designing for VR.

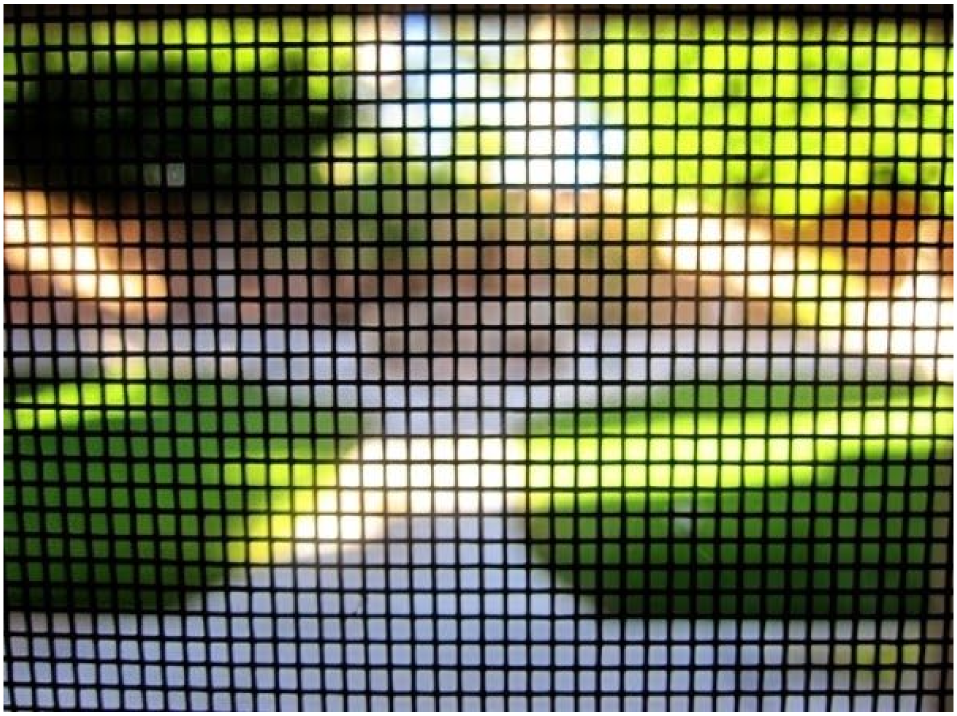


Figure 2.1 - Screen door effect.

During development it is also essential that the application is viewed and experienced through the VR headset it is being developed for. This is because the experience will be different between desktop and VR devices (Oculus 2016).

Interaction

One of the most important rules when designing VR experiences is to avoid taking control of the camera away from the user unexpectedly or without warning (A-Frame, 2016). If a user is required to move their avatar through the scene, the speeds should be kept low, similar to that of a person walking or jogging. Additionally, acceleration should be kept brief and used infrequently (Oculus 2016).

User interfaces should be kept to a minimum and avoided where possible. It is a much more comfortable and immersive experience for the user if information is integrated into the environment, rather than being constantly displayed at the edges of the screen via a heads-up display (HUD). This helps to avoid eye-strain and unnecessary distraction for the user (Oculus, 2016).

The Google developers page (Google, 2016) advises that users should be able to control when the VR experience begins. Once they activate the experience and put on the HMD they should be presented with a button or some form of input that allows them to activate the VR content. This is to avoid making the user feel rushed, and applies especially to mobile VR experiences. Users will likely have to navigate to the content on their mobile phone before placing the device inside a holder, then placing it on their head.

2.2.3 WebVR Technologies

WebVR API

The WebVR API is an experimental programming interface that enables VR devices to be recognised, and VR content to be delivered, through the document-object model (DOM). The API is maintained by the W3C although it is not yet a W3C standard (W3C, 2016).

A-Frame

"A-Frame is an open-source web framework for building virtual reality experiences" (A-Frame, 2016). The A-Frame web framework was created by Mozilla at the end of 2015 with the first stable release occurring in October of 2016. A-Frame is a JavaScript framework, targeted primarily at WebVR developers. Developers can create VR scenes with straightforward HTML and JS markup. The framework makes use of the three.js library and WebGL in conjunction with the WebVR API, and is based on the "entity-component model" - similar to the approach used in game development environments such as Unity. The framework is open-source and developers are encouraged to contribute to the progression of the framework through GitHub. Many features and capabilities of the framework, such as the integration of components to handle Google Daydream and HTC Vive controllers, have been contributed by members and teams within the community, rather than the developers of the framework themselves (A-Frame, 2016).

Vizor

Vizor is an online platform for creating and sharing WebVR content. The platform has an in-built 3D editor with a drag and drop interface. Placing objects in the scene and also implementing behaviours and interactions are all handled through a text and icon-based graphical user interface. This allows for the rapid creation of VR scenes without the need for programming or scripting (Vizor, 2016).

Sketchfab

Sketchfab is an online platform designed for publishing and sharing 3D content. The website has a substantial user-base and hosts over a million 3D assets and scenes. Assets can be shared and viewed through web browsers, with their in-built WebGL viewer, through mobile devices, and can also be easily integrated into 3D or VR applications. The platform supports both free and paid content, and assets are compatible with nearly all file formats associated with VR. (Sketchfab, 2016)

Browser Support

As the WebVR API is still in the experimental stage and is not yet a W3C standard, support for the API is limited to only a few web browsers. As of March 2017 the WebVR API is currently supported by Google Chrome for Android and in the Chromium build for desktop (Google, 2017). The API is also supported in the nightly builds of Firefox (Mozilla, 2016). Microsoft have announced that they are working on support for the API in the next version of the Edge browser (Microsoft, 2016).

WebVR is not supported in Safari, it is also notable that at the time of writing, Apple have yet to announce any plans or state an intention to release any proprietary VR hardware. Developers can, however, make WebVR content available to users with standard stable versions of web browsers, by utilising the WebVR Polyfill in their projects (GoogleVR, 2016).

VR Hardware

There is an ever-increasing number of different VR devices entering the market. Generally, it could be said that they fall into one of three categories: Cardboard devices, more advanced mobile devices with controllers that have three degrees of freedom (3DoF), or higher end devices that utilise controllers with six degrees of freedom(6DoF) and room-scale position tracking. The capabilities of each of the three device types vary greatly and it can be a challenge for developers and consumers alike to determine what will work best on each particular device. Each device type provides different methods for interacting with VR content, and in order to determine what types of experiences will work well with different device types, it is useful to look at their technical capabilities. In keeping with the scope of this project I shall focus on both Cardboard devices and the Google Daydream headset in this section.

Firstly, we can look to the most basic of device types: a mobile phone paired with a cardboard holder.

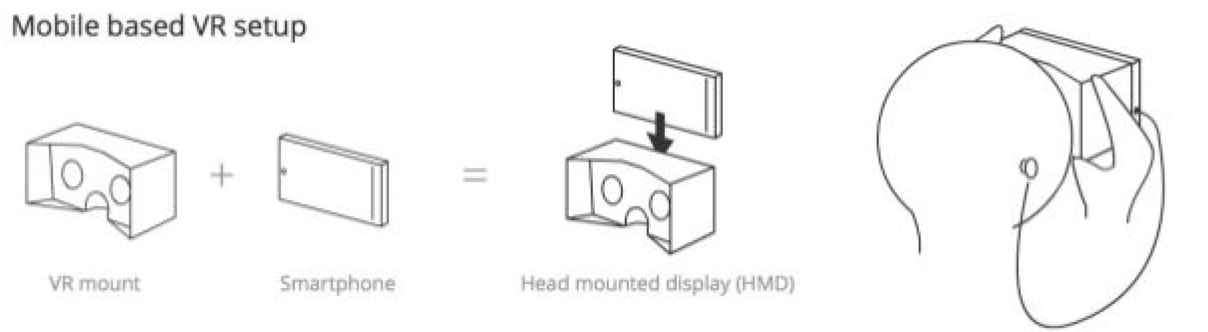


Figure 2.2 - Mobile based VR setup

The gyroscope inside modern mobile phones allows for the implementation of head tracking. Head tracking refers to the ability of objects in virtual space to maintain a fixed position. The screen resolutions and pixel densities of smartphones currently entering the market (such as the Samsung Galaxy S8 or Google Pixel XL) are now extremely high and beginning to reach 4k resolutions, and pixel densities of over 500 pixels per inch (Pixensity, 2017). Developers should consider however, that most users will have slightly older versions of smartphones.

The next step up from cardboard devices are VR headsets such as the Google Daydream and the Samsung GearVR. Each improve upon the cardboard design by adding a further level of interaction capabilities. The Google Daydream headset comes with a small handheld controller which has three degrees of freedom. The controller allows the user to point and click, has a home buttons, and it also has a trackpad feature similar to that of a laptop pc (GoogleVR, 2016).

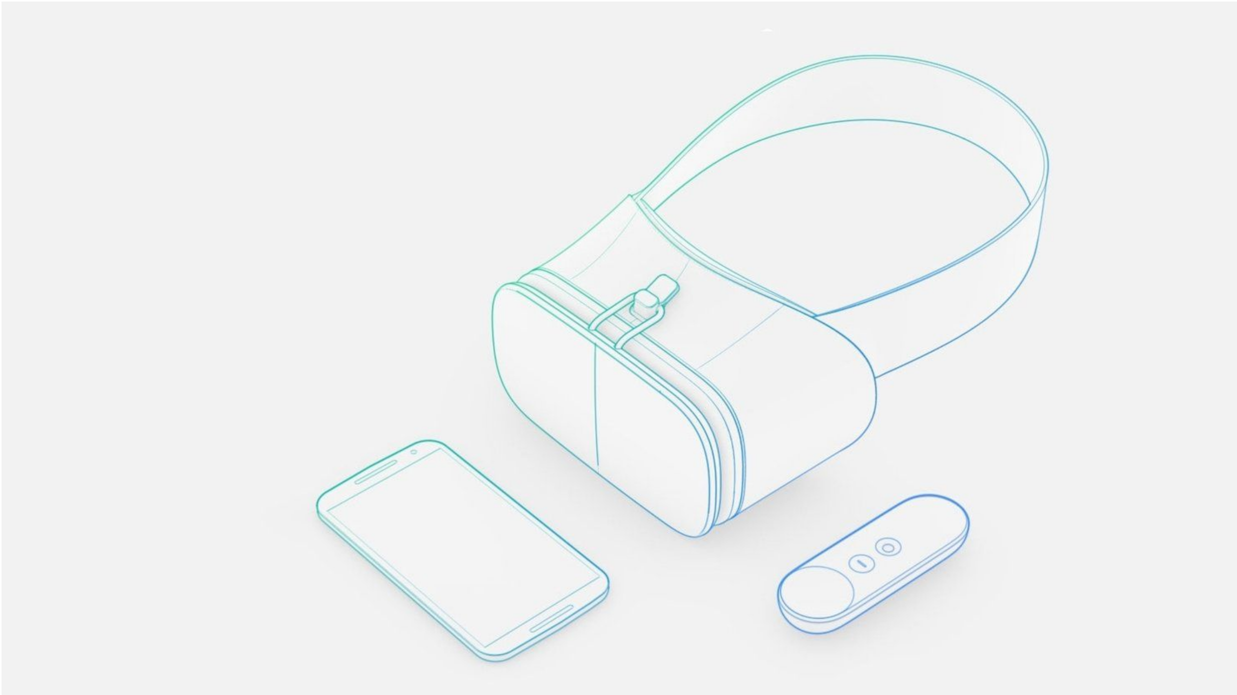


Fig 2.3 - Google Daydream Headset

2.2.4 E-Learning and VR

A succinct definition of e-learning would be "instruction delivered on a digital device that is intended to support learning" (Mayer & Clark, 2016). The field of e-learning is well established, and a large amount of research has taken place on how to incorporate educational material into virtual environments. While undertaking the process of designing course material for e-learning platforms, Mayer & Clark (2016) advise that it is important to keep in mind three considerations: the end goal of the training, the level of knowledge or understanding of your intended audience, and the context (they are referring to platforms/media types in this instance) in which you will present the material.

It is commonly believed that a multimedia approach to learning has significant advantages to traditional text-based delivery methods. Kühl et al. (2010) investigated whether a difference in learning outcomes is observed when dynamic visualisations (videos and animations) are used in preference to static visualisations (diagrams and illustrations) in conjunction with text-based learning material. They found no conclusive evidence that one method was more or less effective than the other. They did, however, find that the "Multimedia Principle"; the assertion that a combination of both text and visual media produces greater learning outcomes than text alone (as coined by Meyer, 2001), still applied. While the "Multimedia Principle" would seem to apply to e-learning material delivered through an immersive VR environment, another important factor to consider is the cognitive capacity of the learner. If we look at the cognitive theory of multimedia learning (depicted in the model below),

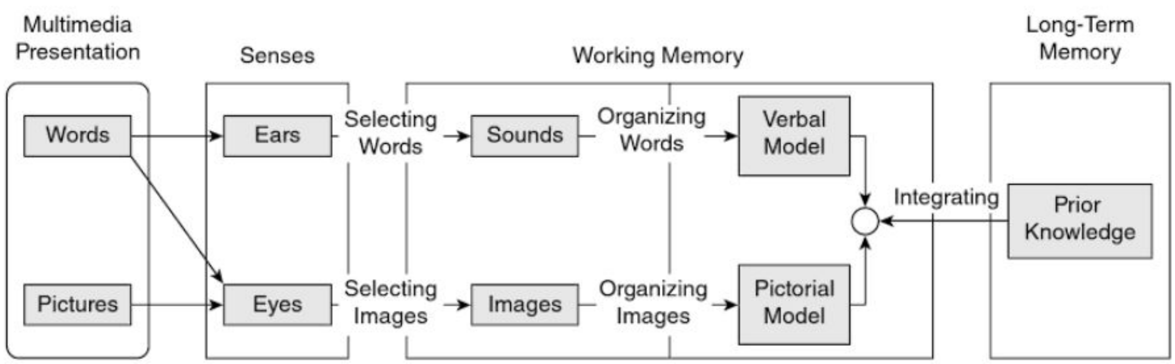


Fig 2.4 - Cognitive Theory of Multimedia Learning

we can see that people receive educational input from both their visual and aural senses, in the form of words and images. It is important to maintain the balance between these input channels as there is only so much information that a learner can process at any given time (Mayer & Clark, 2016). A person's working memory is where they compare the information taken from sensory inputs against the prior knowledge stored in their long-term memory. A person's working memory has a limited capacity, and so they must be selective when it comes to the information they decide to focus upon. This concept is also sometimes referred to as the "Working Memory Bottleneck". If we apply this idea to a VR context, it would imply that any learning material presented should be done so at a pace that is sympathetic to the fact that Immersive VR is already a sensually rich experience for the user.

VR can be used to represent both real and non-real environments. The technology creates a greater sense of immersion for the user through multisensory channels for user interaction and allows users to make more natural manipulations of the environment surrounding them (Mikropoulos & Natsis, 2011). Computer generated 3D objects and visualisations can closely represent their physical counterparts through the use of properties such as ambient lighting and shadows. An added benefit of representing objects and information in 3D is that users have the ability to manipulate properties such as size or scale, as well as being able to instantly filter out certain data or completely replace one object with another. Functions that are much more problematic with real-world equivalents (Butcher, Roberts & Ritsos, 2016).

Weinstein and Meyer (1986), as part of their work, defined two strategies for learning: rehearsal and elaboration. Rehearsal strategies are designed to aid students with recapitulating educational material as effectively as possible. They encourage the memorisation of facts, rather than promoting a deeper understanding of the wider subject and the subject material. Elaboration strategies meanwhile, promote the synthesis of instructional materials and encourage learners to infer meaning and consider the subject in a more in-depth, reflective manner as opposed to simply recalling facts and figures. The ability for VR to present information in a convincing and almost life-like fashion, and the possibility to simulate events and phenomena in relevant settings and contexts, would perhaps steer the focus towards an elaborative strategy when it comes to presenting any educational material.

2.2.5 Educational Context

Mikropoulos & Natsis (2011), conducted a review of 53 peer-reviewed studies that utilised VR learning environments. One of the main focuses of their work was the educational context in which the studies were conducted. They found that 40 of the 53 studies were based on educational contexts referring to science, technology and mathematics. They remarked that this majority was the natural result of a number of characteristics inherent to the nature of the educational material. Firstly, the studies of science and mathematics often involve challenging material, space and time scales that can be far removed from the capabilities of human experience or perception, events and processes which are difficult to observe even in a laboratory setting, and concepts that can be hard to understand or which are abstract and unrelated to real-world phenomena.

2.2.6 Engagement Methodology

Game-based learning is one approach that has proven to be effective (Ke, Xie & Xie 2015). Their study showed that the player's psychological desire for achievement facilitated increased levels of engagement with learning material in order to produce fulfilling outcomes, such as the completion of tasks and the obtainment of rewards, which games often provide in the form of achievements. This could be described as affective engagement. They also observed that there were a number of cognitive processes that occurred during the time that participants spent playing educational games. Players were seen to be engaged in cognitive processes such as rule identification, the planning and execution of strategies and reflection upon the effectiveness of these strategies.

Elements from games can be taken and applied to non-game contexts in a process known as "Gamification". Again, studies have shown that a key factor in the success of learning outcomes here is driven by motivating factors such as the rewards and achievements provided in a game-based context (Domínguez et al, 2012).

Another successful teaching method within VR is the "virtual tour", which gives students the opportunity to visit and experience remote environments and locations (Abdelaziz et al. 2014).

The effectiveness of a variety of different methods suggests that there are a number of ways in which the development of VR e-learning environments can be approached. It would also appear that combining a particular method of engagement with the appropriate subject material is a key factor in determining the teaching efficacy of the learning environment (Mikropoulos & Natsis, 2011). Methodologies that are more passive and require the user to listen and look may be more suited to experiences such as Virtual Tours. More interactive experiences such as games and data visualisations may be more appropriate for material that involves lots of numbers, or recreation of real-world techniques such as simulations of technical procedures in fields like medicine or engineering.

2.2.7 Testing Methodologies

There are a variety of approaches that can be taken to the measurement and evaluation of the efficacy of educational software and environments. In a study by Kühl et al. (2010), verbal protocols, and more specifically, "thinking aloud" were used to measure participant's reactions to, and comprehension of, the learning material presented in a multimedia format. Students participating in the study were encouraged to vocalise their reactions to the material as they experienced it. Care should be taken however not to encourage or prompt participants to react to specific aspects of the content, but rather to allow them to react naturally, as and when they see fit. This is intended to help mitigate any interference this may cause with the recollection and processing of the learning material, and to help ascertain a truer evaluation of the user experience.

The Presence Questionnaire (Witmer & Singer, 1998), is a tool used to evaluate the sense of presence that a user experiences when engaged with a digital 3D environment such as a game or VR experience. Witmer states that in order to achieve presence, a user must be both involved and immersed in the experience. It could be concluded that to achieve a sense of presence in any WebVR experience, it would useful to include an interactive element to the design, rather than simply allowing the user to be a passive observer. The questionnaire they designed to measure the level of presence that a user experiences, presents questions on a seven-point scale and consists of around 32 questions. The questions are generally focused on the user experience and perception of the application they have been using. It helps to generate useful insights on the successfulness of the application's design and implementation, by asking users questions such as "how distracting was the control mechanism?" and "How much did your experiences in the virtual environment seem consistent with your real-world experiences?". Witmer & Singer suggest that an increased level of of presence will also result in enhanced learning outcomes.

2.2.8 Conclusions

Although still in its infancy, WebVR is currently receiving interest from many of the big players in the technological world. Mozilla currently leads the way in terms of support and development for WebVR, and there is also strong support from Google, Microsoft and Samsung (Mozilla 2016, Microsoft 2016). The declaration of interest in WebVR from industry-leaders suggests that there is a future for the technology. As the uptake of WebVR and support for its features becomes more widespread, the potential applications for this technology will become clearer. It appears that there are several advantages that an immersive 3D virtual learning environment (VLE) can have over more traditional e-learning platforms. The idea that an increased sense of presence can enhance learning outcomes is backed up by a number of studies referenced in this literature review. Incorporating game elements aids with motivation and seemingly also contributes to the uptake of educational material. (presence motivation etc.)

2.3 A-Frame

I have decided to use the JavaScript framework A-Frame as the basis for the development of the prototype WebVR experience to be produced within this project. I have chosen A-Frame for a variety of reasons. It seems to be the most complete WebVR framework out there at the moment. The A-Frame website and GitHub pages host a large number of examples and provide thorough and detailed documentation. A major factor in my decision to use A-Frame is its ability to work with other JavaScript APIs, such as d3.js, Angular and jQuery. The most relevant one for this project being d3.js. This library is used to manipulate documents based on data, through the use of HTML, SVGs and CSS (d3.js 2016), and it is generally used to produce detailed visualisations and representations of data sets for the web.

The entity-component model was one I was already familiar based on my experiences with the Unity game engine. Below is a diagram of the entity-component model as it applies to the A-Frame library.

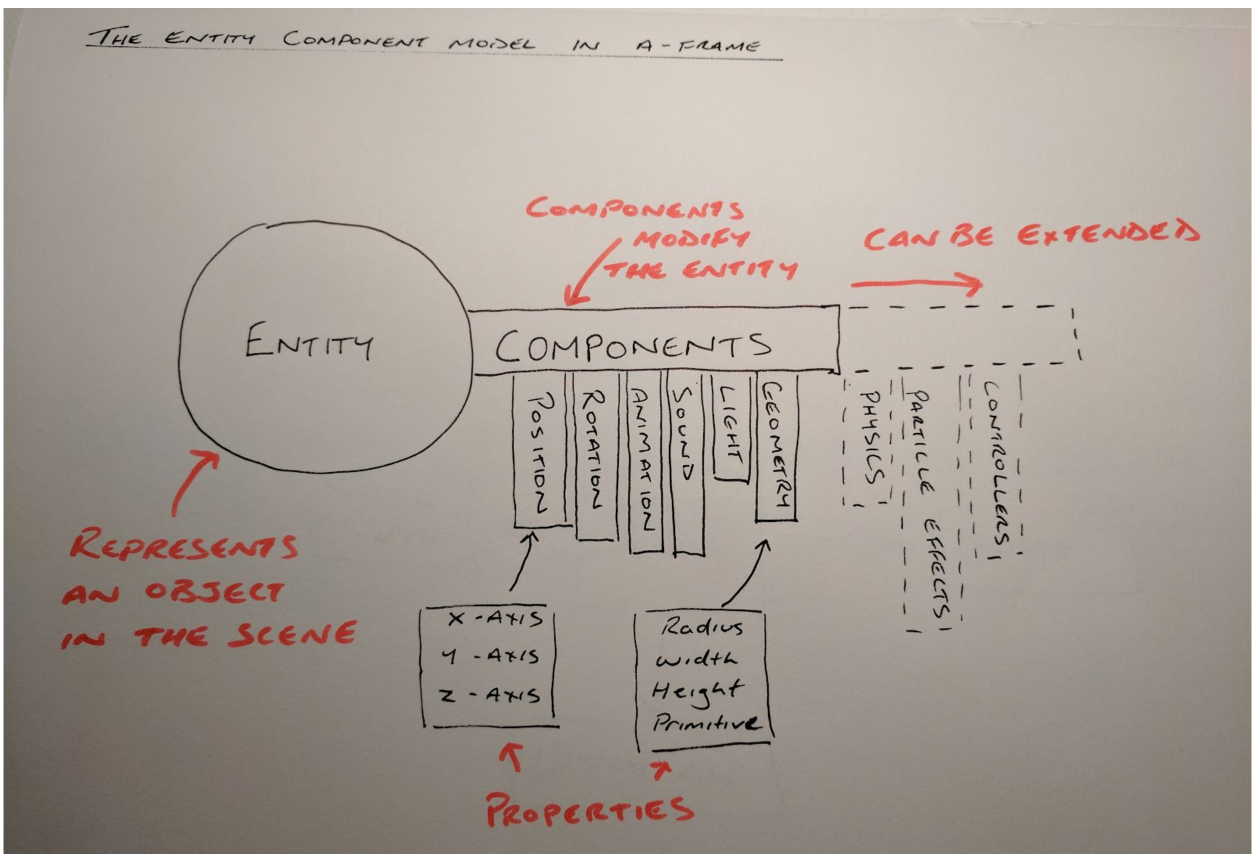


Fig. 2.5 - Entity Component Model

In this case, an entity represents an object in the scene, to provide a more familiar analogy, it could be thought of as an empty <div> tag; alone, the entity has no behaviour or appearance. By adding components to the entity we can define its attributes. The components themselves have properties that relate to their functionality, appearance or position in 3D space, for example. The entity-component system provides a number of benefits - it is an already proven architecture for 3D, game and VR development, components can be extended to provide new behaviours and functionality, components can be reused on multiple entities; once a component is defined it can be added to any number of entities though a CSS-style syntax.

```
<a-entity geometry="primitive: sphere; radius: 1.5"></a-entity>
```

Components are written in JavaScript and must be registered before they can be used in a scene. Everything relating to A-Frame within the HTML document must be contained within the <a-scene> tags. For example the process of creating and implementing a simple “Hello World” component would follow something like:

The component is written in JavaScript, it can be written straight into the HTML document within <script> tags positioned before the <a-scene> tag, or we can write it in a separate document and include it in the HTML document’s <head> section.

```
AFRAME.registerComponent('hello-world', {
  init: function () {
    console.log('Hello, World!');
  }
});
```

To make use of the component we must attach the component to an entity within the scene.

```
<a-scene>
  <a-entity hello-world></a-entity>
</a-scene>
```

A-Frame comes with some pre-defined components that are included with the library. The components become available when the library is included in the <head> tags of the document. In order to implement more advanced or bespoke behaviours and functionality, it is necessary to look to community-created components or to create one’s own components.

2.4 A Critical Analysis of Existing WebVR Applications

To help understand more deeply the capabilities of the WebVR API it was important to look at both the features and components available, and also to investigate what the current WebVR landscape looks like in terms of live experiences and demonstrations. I have selected a variety of different projects to analyse. I have tried to select projects that fall into one of three categories: a virtual tour, game or data visualisation. These three types of engagement methodology were identified during the literature review and will form the basis for the prototype I intend to produce.

2.4.1 StageVR (White, J., 2016)

Fig. 2.6 - StageVR

StageVR is a small WebVR experience that was designed to mimic the experience of giving a presentation from a stage. The application allows users to upload their own slides which appear on both a panel at the front of the stage and on a large screen behind the stage, visible to the “audience”. The panel on the stage also displays a timer which is intended to help the presenter with the delivery of their presentation. Although a relatively simple scene, the concept is useful for learning presentation skills as it provides the user with an experience that is similar to standing on a stage. The application could be improved further with the inclusion of character models to populate the seats in the theater, creating a more accurate representation of a real-world scenario. The panel element is useful, as something similar could be recreated in other VR applications and used as a tool for conveying information to users from within the context of the environment.

2.4.2 Temples of Cambodia (Al Jazeera, 2016)

Fig. 2.7 - Temples of Cambodia: Welcome

Temples of Cambodia is a recent project produced by the Al Jazeera news organisation. The application enables users to experience a virtual tour of the sites and features within the Angkor Wat temple complex in Cambodia. Created using A-Frame, the application consists of around twelve equirectangular images that are used to provide an immersive 360^{o} experience to the user. The experience uses audio narration to guide the user through the tour. Navigation between scenes is handled with a combination of audio and visual cues. Each scene has a unique audio clip associated with it, the audio describes the scene to the user and then asks them to locate an object, such as a statue or doorway, within the scene in order to move onto the next one. A visual cue is also provided to the user in the form of an arrow pointing to the navigation element within the scene.

Fig. 2.8 Temples of Cambodia: Interaction

Users must focus their gaze upon the object within the scene for three seconds in order to activate the navigation. This timed interaction, which requires the user to focus on a particular object, is useful because it prevents the user from triggering the navigation unintentionally as they naturally look around the scene. Technically, the navigation works by overlaying an invisible plane over the object within the scene. The plane acts as a trigger which is activated once the cursor has remained within its boundary for three seconds.

2.4.3 Where is Piers Morgan Disliked the Most? (Mossawi, A., 2017)

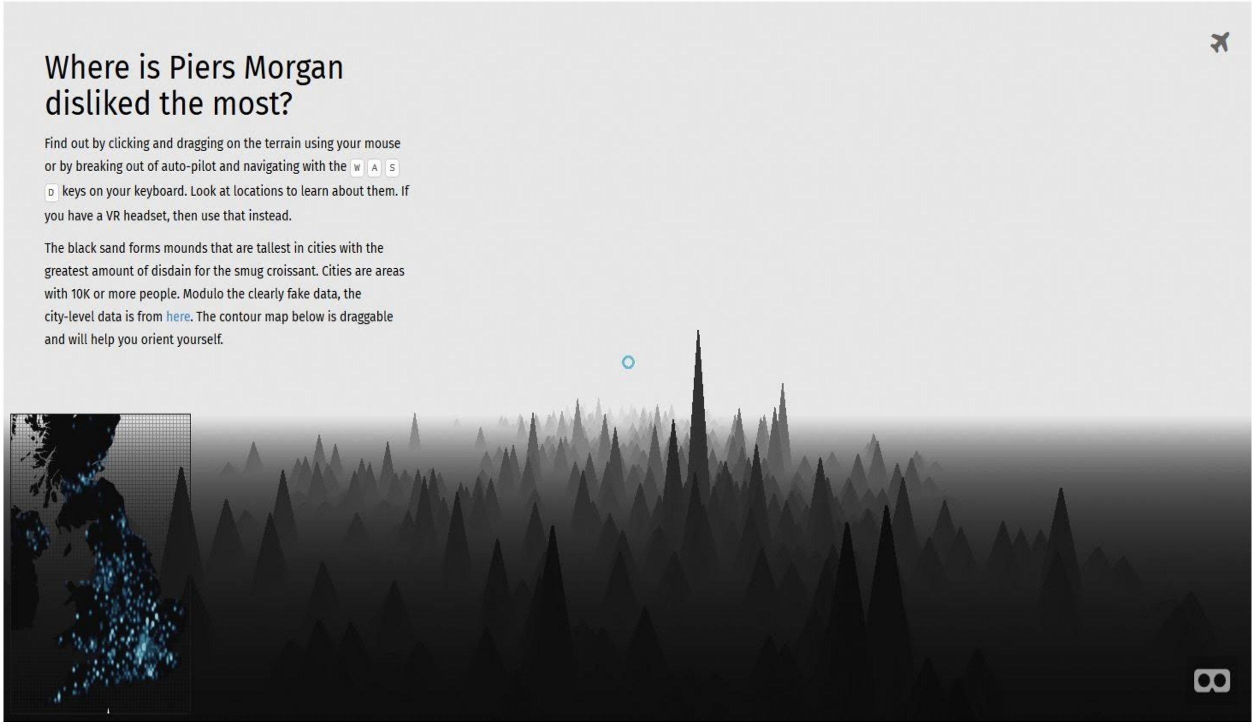


Fig. 2.9 Where is Piers Morgan Disliked the Most?: Home

This humourous WebVR app shows one example of a method of data visualisation in a 3D space. The user is placed in the sky above a map of the United Kingdom. Each data point on the map is intended to represent the disapproval rating of the TV host Piers Morgan, in a particular city. The camera automatically moves across the map, however if viewed on a desktop PC, the user can interrupt the movement and control it themselves using the WASD keys. There is also a minimap in the bottom left of the screen that is intended to help orient users. The application was created with a combination of A-Frame and JavaScript library, D3.js. When the user hovers their cursor over a data point, relevant information is displayed via the user interface in the top left of the screen.

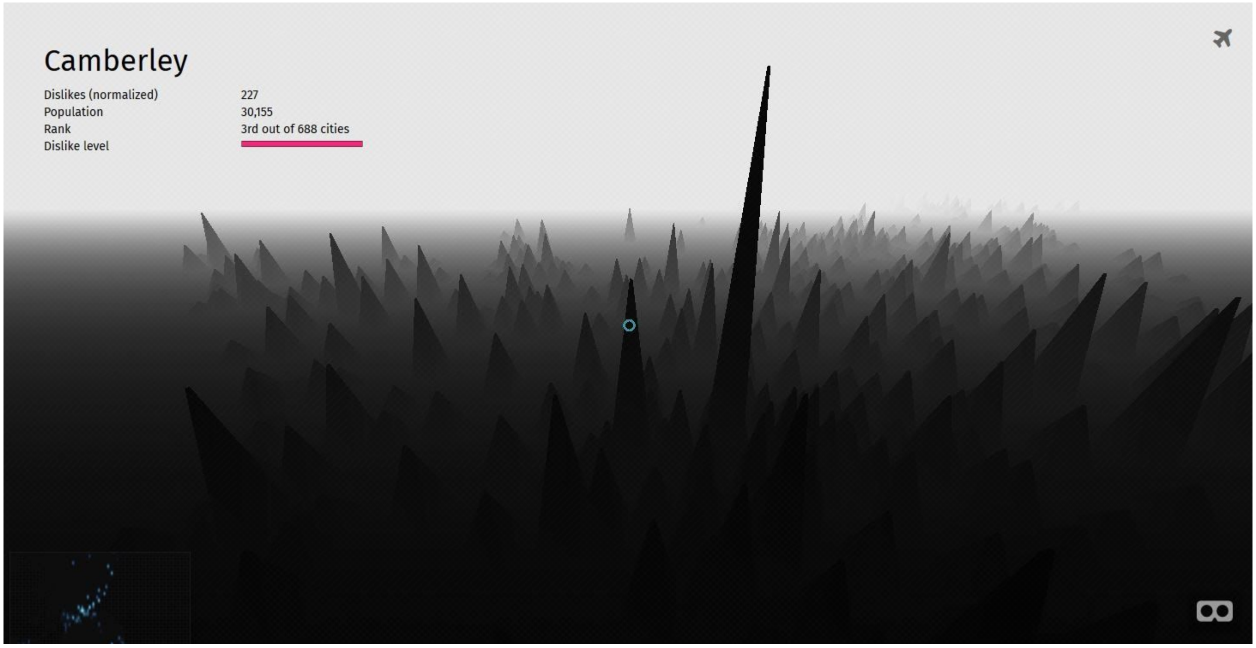


Fig. 2.10 - Where is Piers Morgan Disliked The Most? UI

This application is a good example of how A-Frame can be combined with other JavaScript APIs to create an interesting experience for the user. The context of the information displayed in this case is intended to be lighthearted, it does however serve well as a proof of concept, and within the right context could perhaps be more useful as an educational tool.

2.5 Requirements Specification

The design phase of the project depends on a set of requirements to inform the process. The research I have undertaken shall be used to guide the design process and a set of requirements have been defined for the e-learning application prototype. I have separated the list of requirements into two tables. The first table refers to the requirements of the application itself. The second table refers to the requirements of the educational material contained within the application. Each table will display the name of the requirement, a description of the requirement, whether it is a functional or non-functional requirement and an importance rating for each requirement. The importance of each requirement shall be scored on a scale from 0 (lowest) to 5 (highest) which will give an idea of how necessary it is to the project and the impact that its omission might have. I have also produced a further list of non-functional requirements for the project that detail the software and any materials or hardware that I may require during the course of the project's life cycle.

2.5.1 Software and Hardware Requirements

The software and hardware requirements for this project include:

- Access to the WebVR JavaScript API (A-Frame)
- Text editor/IDE (sublime text)
- XAMPP - Testing on local server
- Magika Voxel - Custom 3D asset creation
- Adobe Photoshop - Textures for custom assets, image formatting, creation of elements used in the design stage.
- Adobe Illustrator - Wireframes, Storyboards and Diagrams
- VR HMDs - Cardboard, Google Daydream, Google Pixel smartphone
- Google Forms - User surveys and Questionnaires
- Audacity - audio recording and editing software

2.5.2 Application Requirements

Table of requirements relating to the VR application:

ID	Requirement Name	Description	Functional/Non-Functional	Importance (0 - 5)
1.0	Experiences	The VR application should contain a minimum of 4 distinct experiences (including the start point)	Functional	4

1.1	Tutorial	The VR application should provide instructions to the user.	Non-functional	4
1.2	FPS	The WebVR experience should ideally run at a constant 90fps, however a rate of 60fps would be acceptable.	Functional	5
1.3	Responsiveness	The application should respond to the user's device type and present the contents accordingly.	Functional	3
1.5	Gaze-based interaction	The user should be able to control and manipulate elements in the scene by looking at them.	Functional	5
1.6	Mouse and Keyboard	The user must be able to control and manipulate elements in the scene by using the mouse and keyboard.	Functional	5
1.7	Navigation	The user must be able to navigate between experiences in the scene.	Functional	5
1.8	Audio Narration	The Virtual tour experience should include user-activated audio narration.	Functional	3
1.9	Aesthetics	The experience should look good and feel authentic.	Non-functional	2
1.10	Data Display	The data displayed in the data visualisation element should be clearly labelled.	Functional	3
1.11	Text	All text elements contained in the scene should be readable and jargon free.	Non-functional	3
1.12	Panels	All panel elements should be positioned so as not to obstruct or interfere with other scene elements.	Non-functional	4

1.13	Smoothness	The application should run smoothly and provide an enjoyable experience for the user	Non-functional	3

2.5.3 Educational Requirements

Table of requirements relating to the educational material:

ID	Requirement Name	Description	Functional/Non-Functional	Importance (0 - 5)
2.0	Educational context	The information and educational material contained within the app should be drawn from a distinct field of study.	Non-functional	4
2.1	Consistency in difficulty	The material used for each experience should be aimed at the same group or level of learners, i.e. university students.	Non-functional	3
2.2	Virtual Tour	The virtual tour element should provide information in the style of a “field-trip” to a location that would be otherwise difficult to reach.	Non-functional	3
2.3	Data visualisation	The information displayed in the data visualisation element should be relevant to the educational context	Non-functional	3
2.4	Game	The subject and learning material included in the game element should be related to the educational context	Non-functional	3

3. Design

The design phase of the project involved a variety of different tasks. It was important to determine exactly what the educational context of the project was going to be - what information did I wish to communicate to users, and what was the best method for doing so? It was also important to design an experience that was visually sympathetic to the subject material. In order to create an immersive experience for the user, the aesthetic choices were important to consider. By incorporating commonly accepted best practices for working with both VR and educational material I hoped to ensure that the experience for users was as positive as it could possibly be. I also considered the user experience by utilising various UX evaluation methodologies during the design process. The usability of the artefact was also evaluated through the application of heuristic principles to elements of the design.

3.1 Initial Ideas and Concepts

The first task in the design process was to get my ideas onto paper and to decide upon an educational context for the project. Based on the findings during the research stage, I had determined that a project focused around subjects such as science and mathematics would be the most likely to produce effective and meaningful learning outcomes. I began by brainstorming a variety of ideas with this in mind and came up with a mind-map to help illustrate some of my thoughts in this regard.

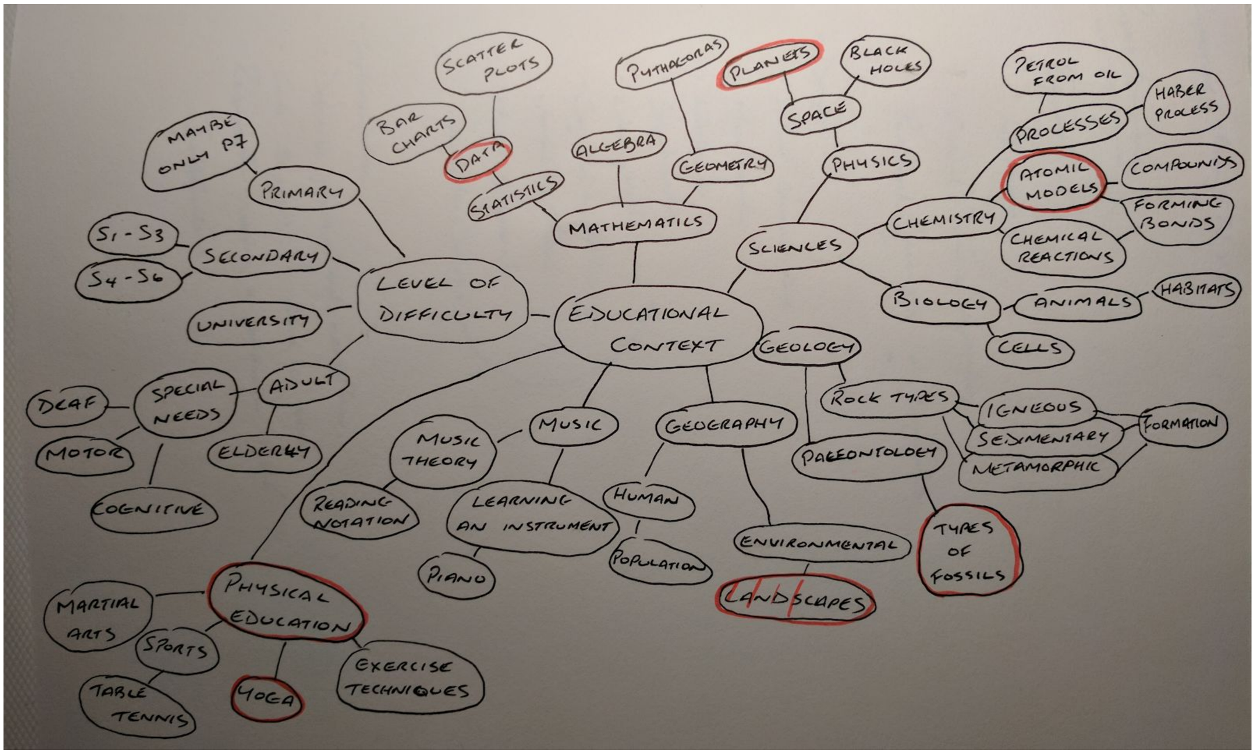


Fig. 3.1 - Initial Ideas Mind Map

I highlighted some subjects that I found interesting and that I also thought would lend themselves well to the VR medium. I came up with a list of potential ideas for applications of VR within an educational context:

- A simulation of the solar system showing the various planets and celestial bodies. Users would be able to navigate around the solar system, while receiving facts and information about the objects within.

- A virtual yoga studio. Users could practice yoga while wearing a virtual reality headset. Immersed in an environment such as a yoga studio or set in a scenic location in nature, users could follow a yoga routine that was demonstrated to them by a virtual yoga instructor.

- A set of atomic models that could be represented in a 3D virtual environment, animations could be used to illustrate processes such as chemical reactions, different forms of chemical bonding or chemical industrial processes.

- An annotated and narrated virtual tour of a remote environment that taught users about a natural process such as erosion, or how a particular landscape was formed.

- A representation of environmental data in a 3D space. An interactible 3D bar chart or scatter plot that could be manipulated and controlled by the user to display different sets of data in different formats.

- A game that required users to find a particular fossil amongst a large variety of fossils embedded into the face of a cliff.

After reviewing the ideas I had produced, I decided upon the three that I liked the most, and that I thought would work well together to produce a coherent experience for the user. I felt that the study of Natural Sciences would work well as a background for the project and so I decided that the three elements of the application would draw material from that particular field of study. Based on this, I chose to include in the application: The fossil finding game, a bar chart that would display data of measurements such as sea level rise over time and average global temperature over a period of time, and also a virtual tour that took users to a location in order to explain a geological process.

3.2 Themes and Setting

Choosing the theme and setting was the next decision I had to make. I knew that the subject material would be related to Natural Sciences, so I would have to base my aesthetic choices and the design of the environment on this theme. It would be necessary to consider the colour choices, models, interactible elements and sounds, and ensure that they were in keeping with the educational context.

Location

I wanted the setting for the experience to reflect the subject material contained within. I came up with the idea of placing the user in the center of a courtyard, from where they could access each unique educational experience. The center of the courtyard would serve as the starting point and tutorial location. I created a wireframe that showed an overview of the application, and how the elements would be positioned in relation to the start point.

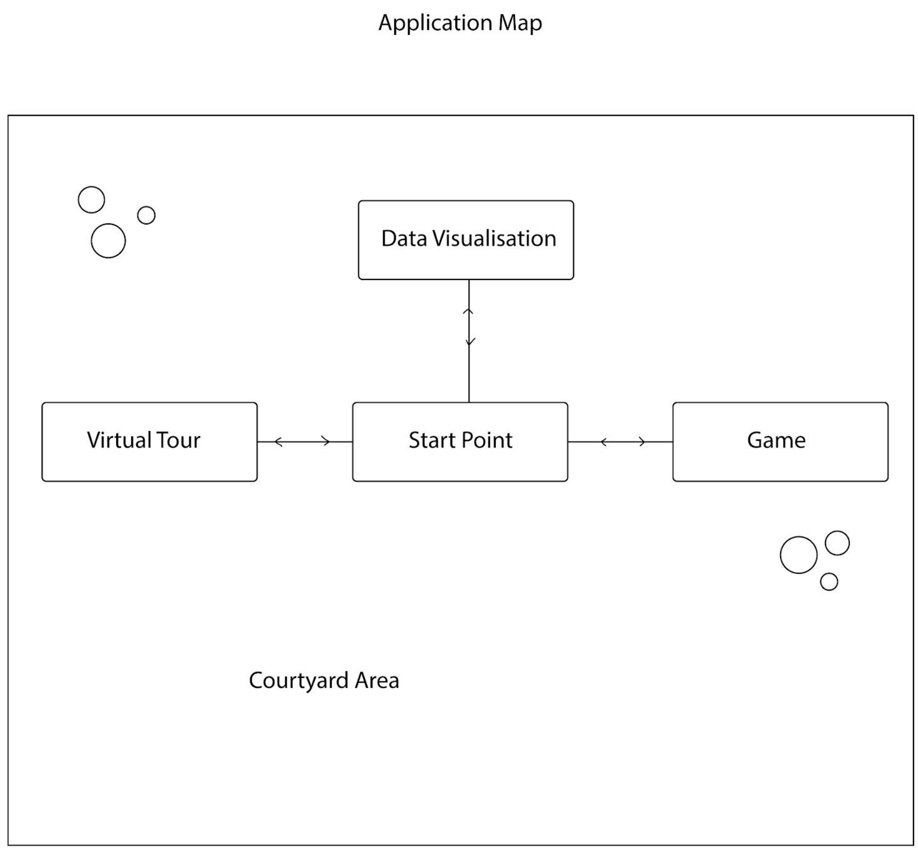


Fig 3.2 - Application Map

Colours

The choice of colours was an important factor in the design process. I wanted the colours to be sympathetic to the educational context and the themes of the design. I created a colour palette based on earthy tones and I would incorporate these into different elements of the application.

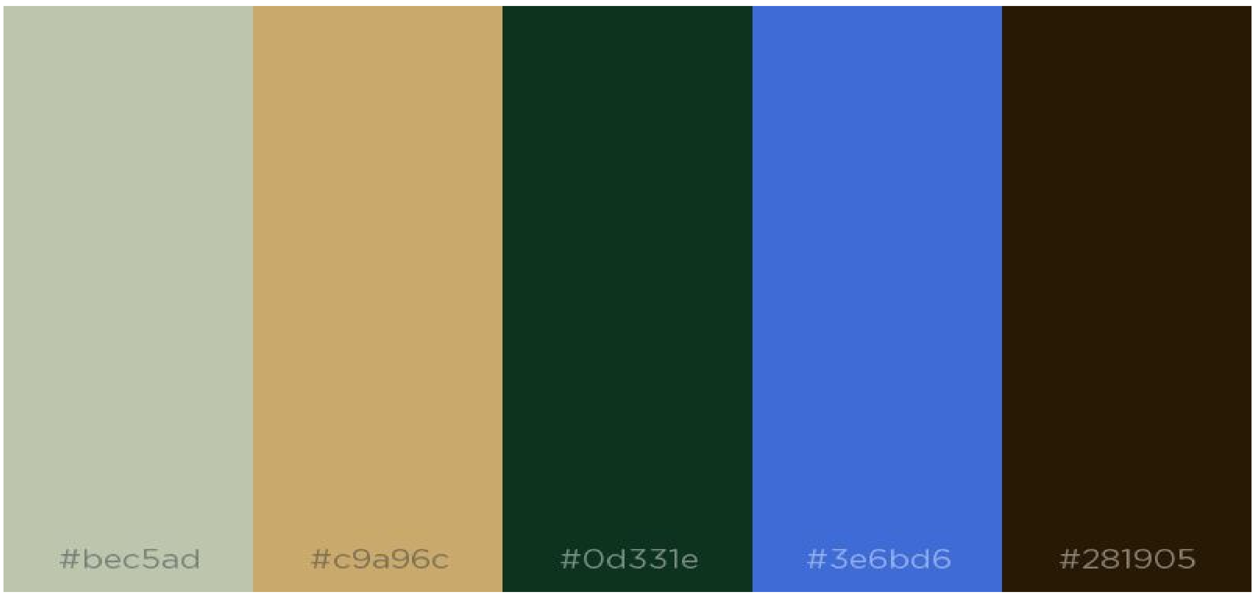


Fig. 3.3 - Colour Palette

3.3 Wireframes

I produced a set of wireframes to help with organising the layout of each element/experience within the application. The wireframes would provide a 2D, top-down view that would allow me to position key elements in the scene relative to one another.

Start Point

I began by creating a wireframe of the start area.

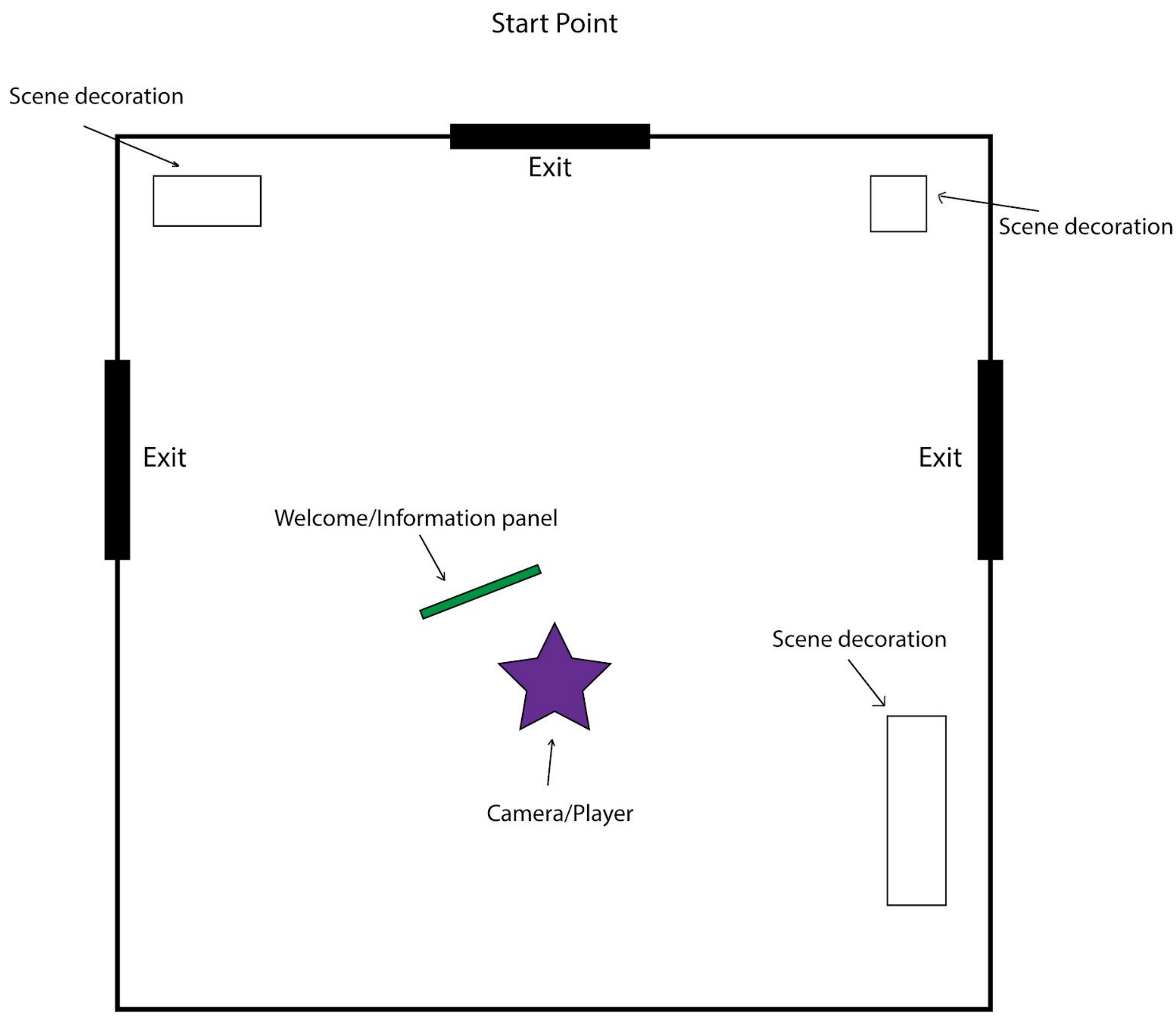


Fig. 3.4 - Start Point Layout

The user is placed in a small building within the center of the courtyard. Before the player is a panel. The purpose of the panel is to welcome the player to the experience and to provide important information on how to interact with the scene. It informs the player on what is contained within the application in terms of educational experiences, and how to interact with elements such as navigation, in the application.

Virtual Tour

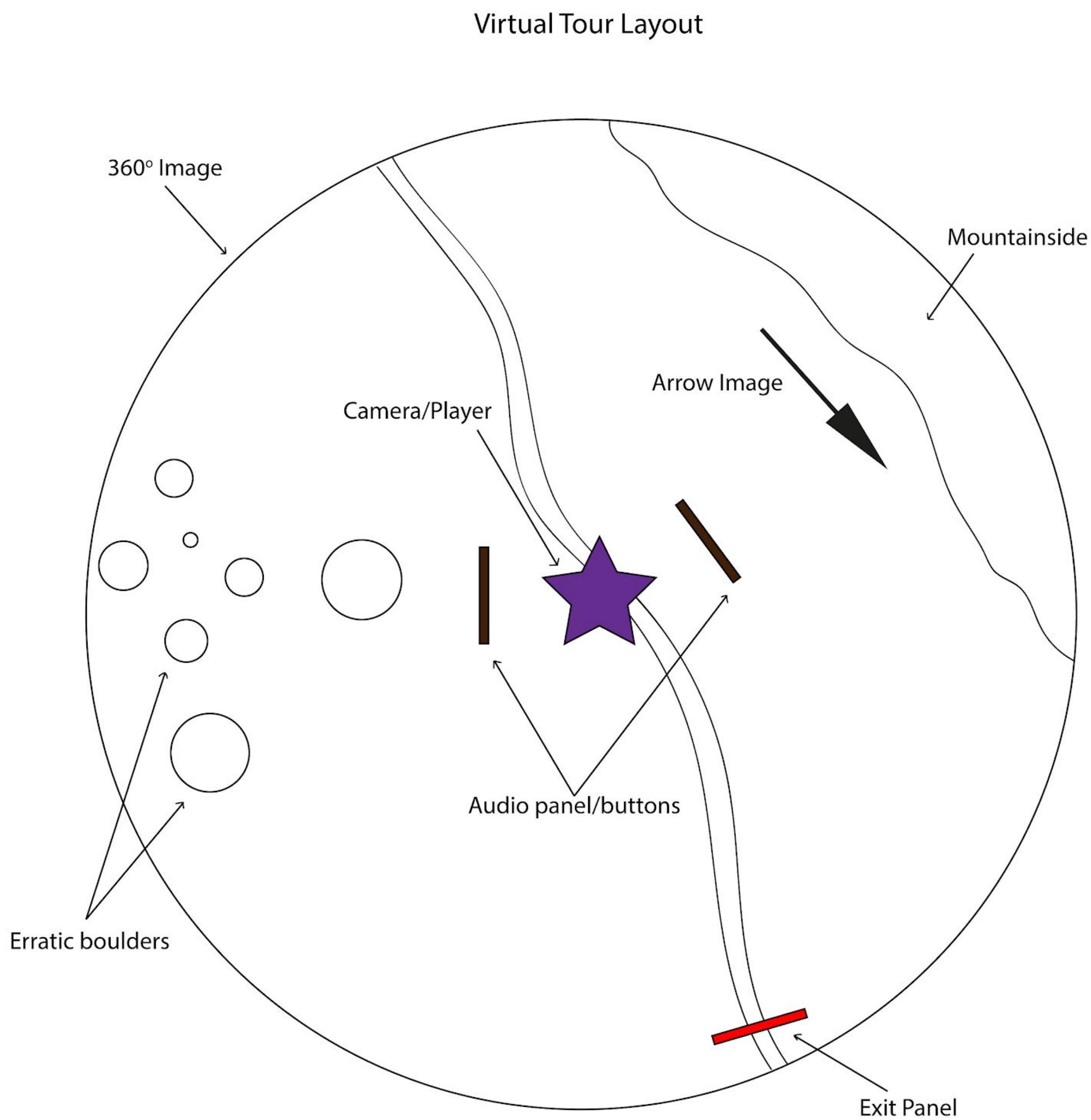


Fig. 3.5 - Virtual Tour Layout

The virtual tour works by surrounding the player with a 360° image. The player is positioned at the center of the image and is flanked by two panels. These panels act as buttons which activate the audio narration when clicked. The experience is annotated with the image of an arrow to help provide context to the audio narration (the direction of glacial movement - how the landscape was formed).

Data Visualisation Layout

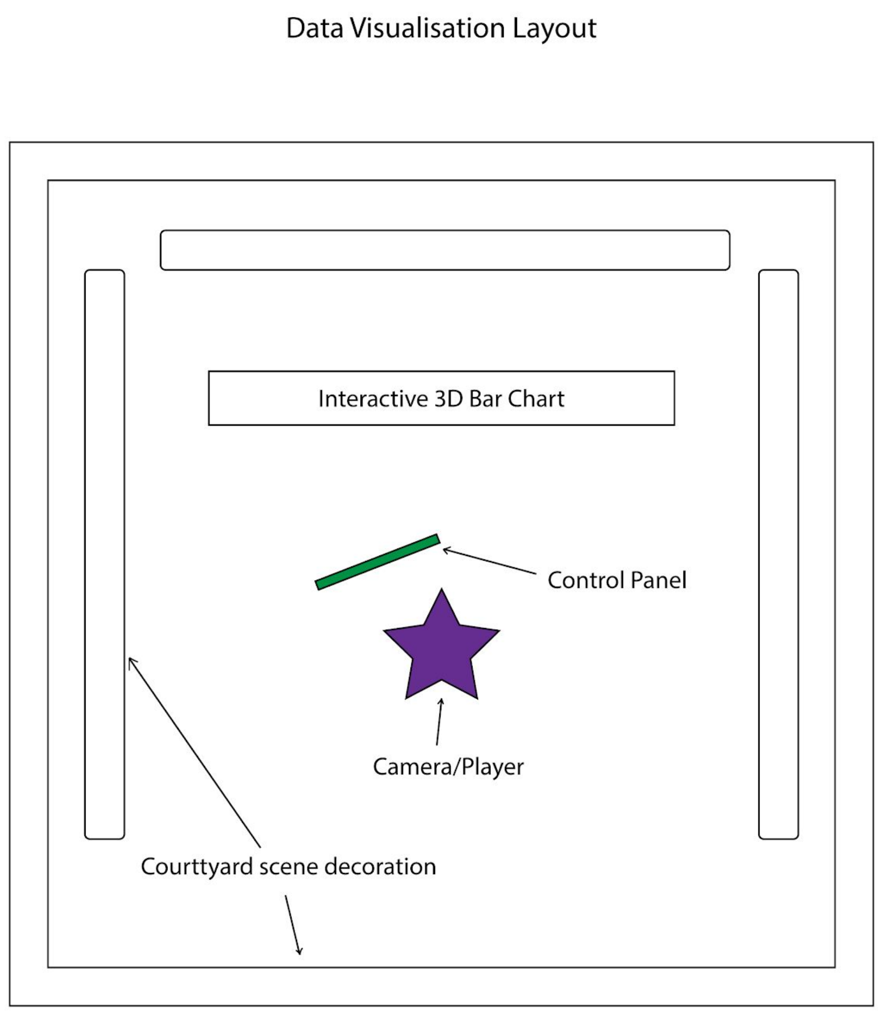


Fig 3.6 - Data Visualisation Layout

The data visualisation section places the user in front of an interactive 3D bar chart. There is a control panel element that allows the user to control and manipulate the data displayed by the chart.

Game Layout

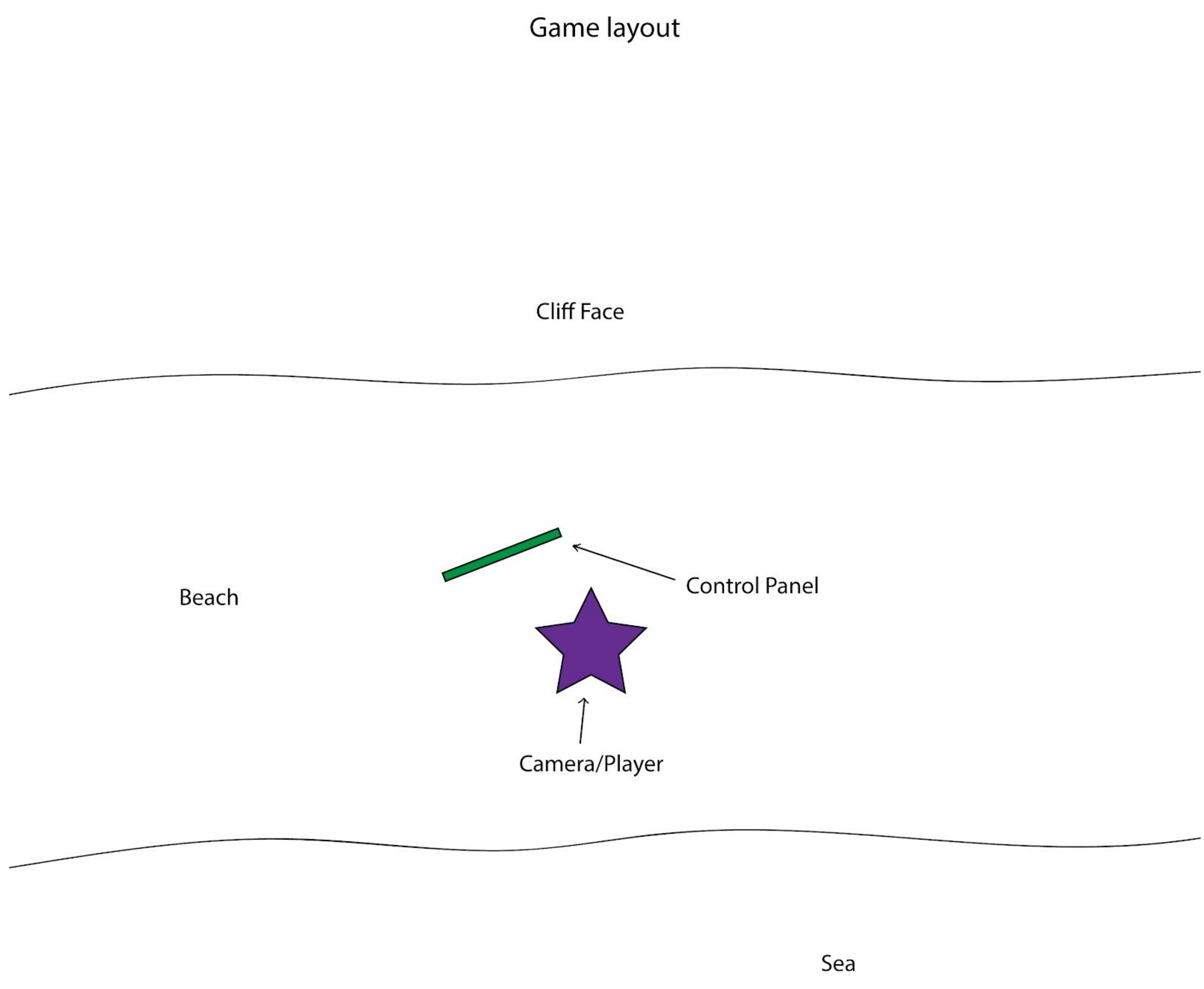


Fig 3.7 - Game Layout

The game element consists of a panel that displays an image of a fossil, along with its name. There is a large cliff face in front of the player. Upon the cliff face are a number of various images of fossils. The player must match the fossil displayed on the panel with the same fossil on the cliff face. The idea is that the game will help players to memorise the different fossils and their names.

3.4 Navigation

In order for users to be able to move between the different experiences in the application it was necessary to implement some form of navigation. I considered different possible methods of implementing a navigation system and how they would fit in with the overall design of the application. It was important to bear in mind that it would be necessary to cater for two different interaction methods: users experiencing the application on a desktop PC with a mouse and keyboard, and users who were using a mobile device. The users on PC would be able to freely move around the scene using the mouse and WASD keys, and be able to click the left mouse button to activate certain elements. Meanwhile, users on mobile devices would have to rely on their gaze in order to navigate the scene. During my review of existing WebVR applications I had noted that in some applications, navigation was handled by using a time-based interaction where users were required to focus their gaze upon an element for a set duration, in order to activate a “click” event. I decided to use this method of interaction in the application, however it was still necessary to determine how the user would move from point A to point B. One option was to teleport the user from one point to another when they clicked on a navigation element in the scene. Another possibility was to animate the movement of the user along a path from their current position to the intended location. This could be done either in a straight line, from one point to another, or along a predefined path.

I felt it would be more beneficial for the user experience if I implemented the functionality that allowed for the animation of the camera movement through the scene. Teleporting the user from one location to another had the potential to be jarring and could result in the user being disoriented by the sudden change in location.

The navigation would be handled by including navigation “nodes” within the scene. These would take the shape of spheres that were designed to be visually distinct from other elements in the application. To help them stand out I decided to give them bright colours and to animate some of their properties. The spheres would be positioned at an appropriate location relative to the position of each distinct educational experience in the scene. When a user clicked upon a node they would gently move towards it at a walking pace.

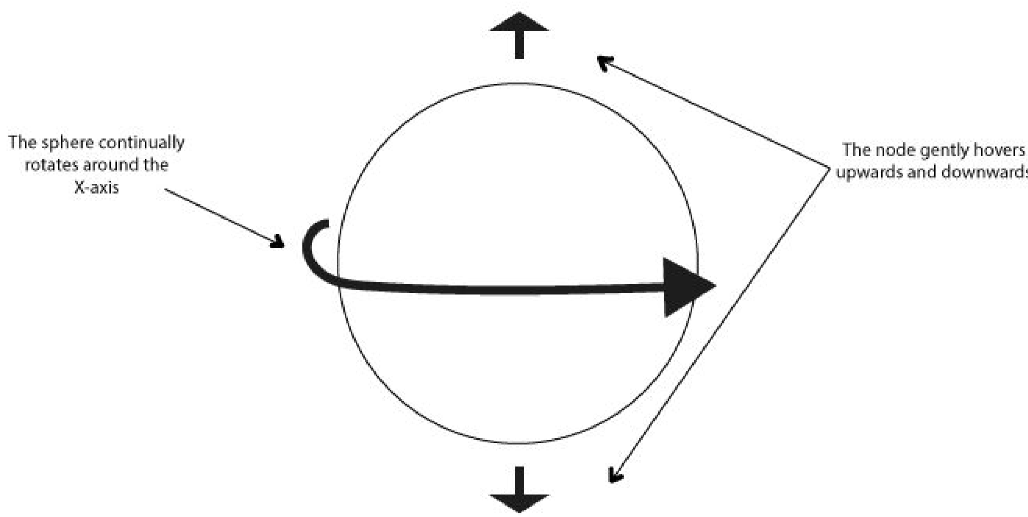


Fig 3.8 - Navigation Node

To make the user aware of the navigation method, the welcome panel in the start scene would need to display information about how the navigation worked to the user. There would also need to be navigational elements within the scene that were clearly visible distinct from their surroundings.

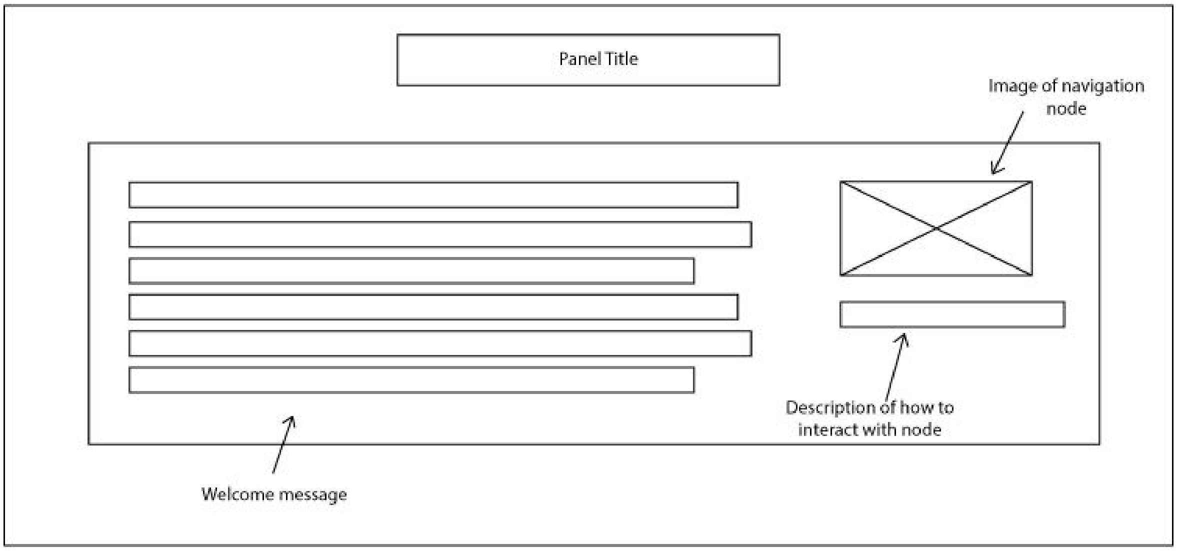


Fig 3.9 - Welcome Panel

The information panel in the start point location would inform the user of what to expect from the application and how to move around within the scene. The panel included an image of a navigation node and a description of how to interact with it.

3.5 Cognitive Walkthroughs

In order to ascertain whether or not the application's design would be usable, I performed a cognitive walkthrough. Cognitive walkthroughs are usually conducted by defining a usability goal or task to be performed within the application and then creating a set of subtasks that must be completed in order to achieve that task (Blackmon, M. et al 2002). While conducting the cognitive walkthrough it is necessary to evaluate the task from the perspective of the user and to decide whether or not the steps involved are sufficiently clear and intuitive to users. It is also useful to include wireframes with annotations when performing a cognitive walkthrough. I defined a number of tasks that I wanted to evaluate and performed a cognitive walkthrough on each.

Task 1: The user must navigate to, and begin, the virtual tour experience.

Subtasks:

1. The user enters the scene and reads the welcome panel.
2. The user activates the navigation node that will take them to the location of the Virtual Tour.
3. The user reads the Virtual Tour information panel.
4. The user begins the Virtual Tour by performing a “click” event on the “begin tour” panel.

Evaluation:

1. The welcome panel is clearly visible and provides sufficient information to guide the user towards taking the appropriate action.
2. The navigation node draws the user’s attention through its animated properties and bright colours. Placing the cursor over the node is also aided by the fact that the cursor crosshair stands out well against the background environment.
3. The tour information panel is positioned in front of the navigation node. This means that when the user arrives at the location of the node, the panel will be the first thing that that they see.
4. The “start tour” panel is embedded within the information panel making it straightforward for the user to click on it once they have read the information about the virtual tour.

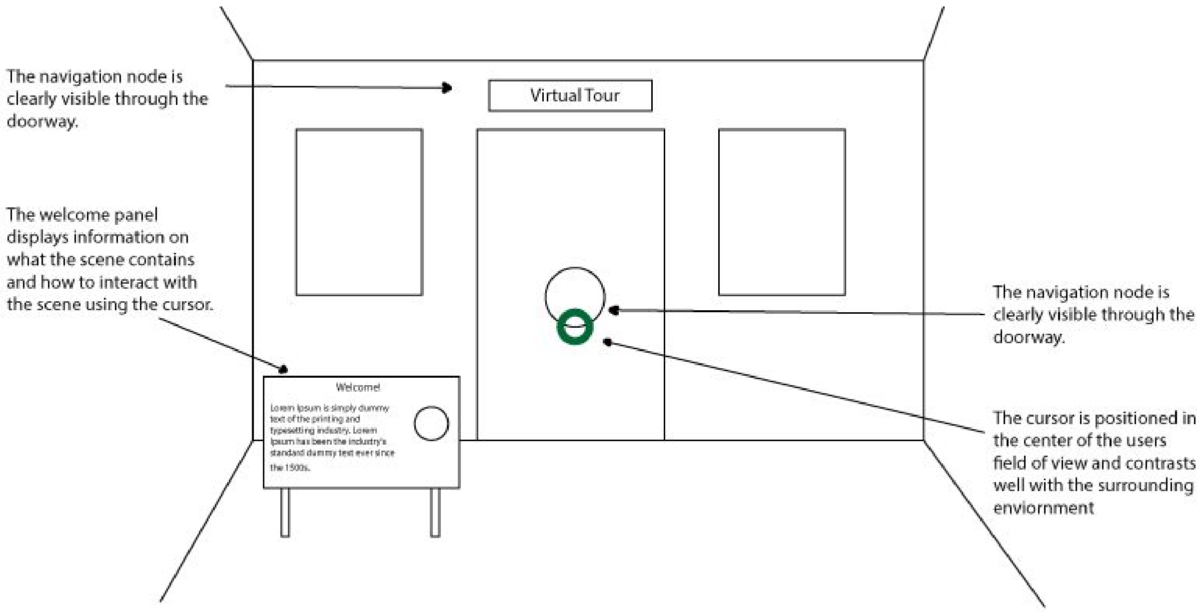


Fig 3.10 - Task 1, Wireframe 1

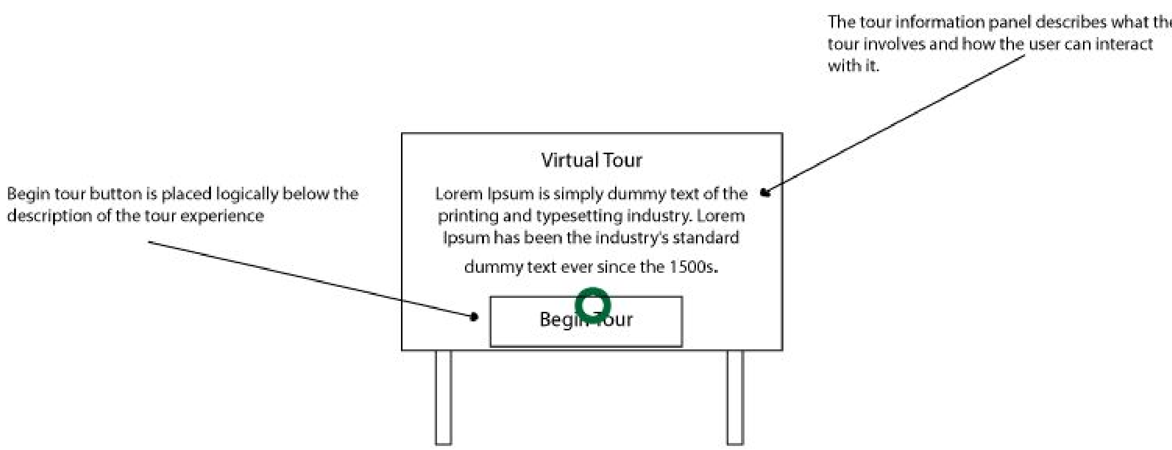


Fig 3.11 - Task 1, Wireframe 2

Task 2: The user must navigate to the data visualisation experience and interact with the bar chart.

Subtasks:

1. The user enters the scene and reads the welcome panel.

2. The user must turn to face the correct doorway which leads to the Data Visualisation element.
3. The user activates the navigation node that will take them to the location of the Data Visualisation.
4. The user reads the Data Visualisation information and control panel.
5. The user must look at the bar chart in order to activate the labels for each data point.
6. The user must return to the control panel to change the data being displayed.

Evaluation:

1. The welcome panel is clearly visible and provides sufficient information to guide the user towards taking the appropriate action.
2. The default position of the camera is looking towards the doorway leading to the Virtual Tour. The doorway leading to the Data Visualisation also falls within the user's field of view. As they naturally gaze around the scene they will come across the correct doorway.
3. The navigation node draws the user's attention through its animated properties and bright colours. Placing the cursor over the node is also aided by the fact that the cursor crosshair stands out well against the background environment.
4. As the user arrives at the bar chart the control panel is positioned naturally in front of the bar chart. The panel provides a description of what the user can see before them and informs them of how to interact with the bar chart.
5. When the user gazes upon a data point in the chart, the bar changes its visual appearance and a text label appears providing information about the data represented by the bar.
6. The two buttons at the bottom of the panel are clearly labelled and contrast well with the panel background. The user has read the information on the panel and is already aware of how to interact with elements in the scene. The data set that is currently active is shown through a visual effect applied to the button.

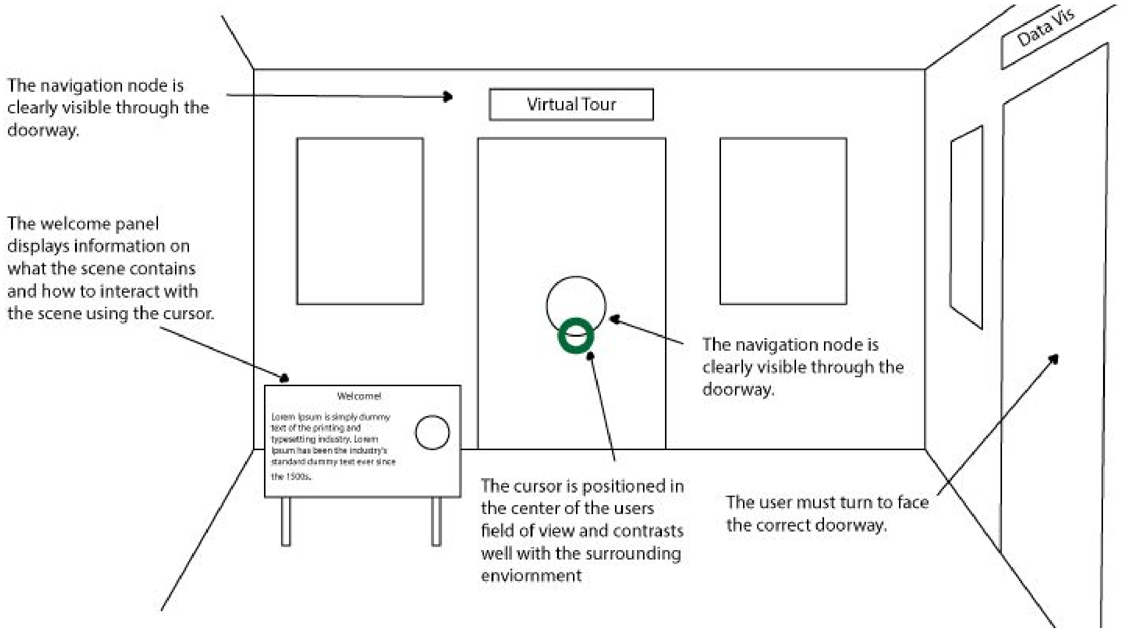


Fig 3.12 - Task 2, Wireframe 1

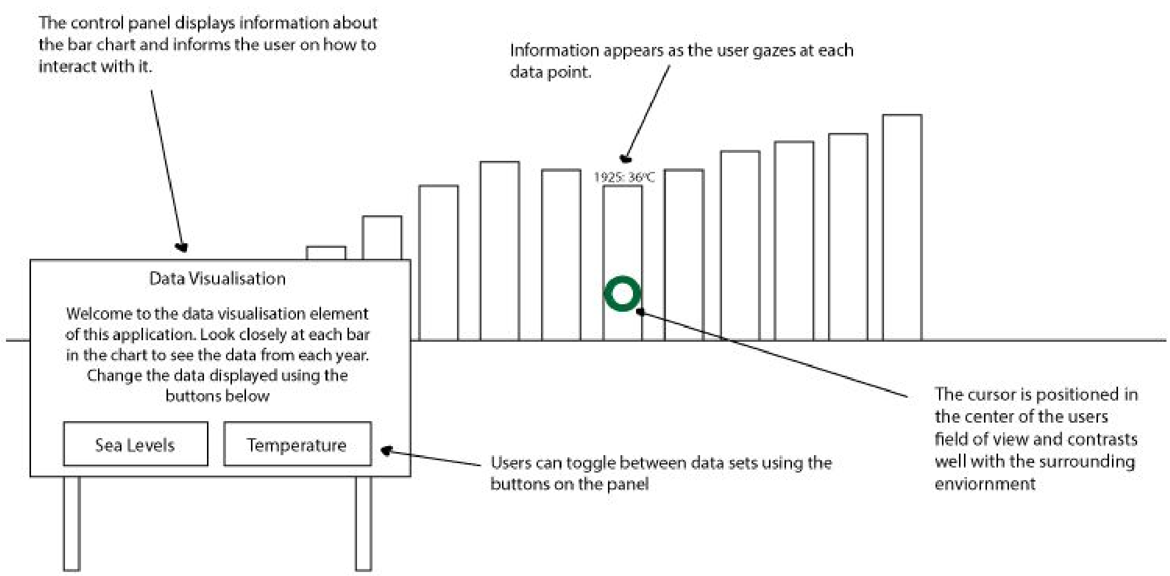


Fig 3.13 - Task 2, Wireframe 2

4. Implementation

In this section I discuss the implementation phase of the project. This was definitely a very challenging part of the project and it took the longest time to complete. Implementing some of the features of the design had seemed straightforward in the beginning, but soon became much more challenging and complex as I learned exactly what was involved. In fact, I was not able to implement all of the features that I had hoped to. Most notably, the game element is missing from the final version of the project. I also omitted the 3D models I had created from the final version of the project artefact. This was because they were causing the experience to lag on mobile devices. I have however, included descriptions of the models in the section below and discussed this further in the testing and evaluation chapter.

4.1 Asset Creation

The implementation phase began with the process of creating any assets that would be necessary to complete the development of the final WebVR experience. These were created using a variety of software tools and equipment. The assets required for the scene included 3D models, images and audio clips.

4.1.1 3D Modelling Using Magika Voxel

The software I used to create the 3D models required for the application was Magika Voxel. Magika Voxel is a free to use, lightweight, 8-bit voxel editor. Models can be exported along with textures in .obj and .mtl formats. Creating models in this fashion is useful because the file formats are supported by A-Frame. An added benefit to using voxel-based models is that they are inherently low-poly, meaning that the browser is required to render fewer polygons and vertices, resulting in an increase in performance in terms of metrics like frames per second.

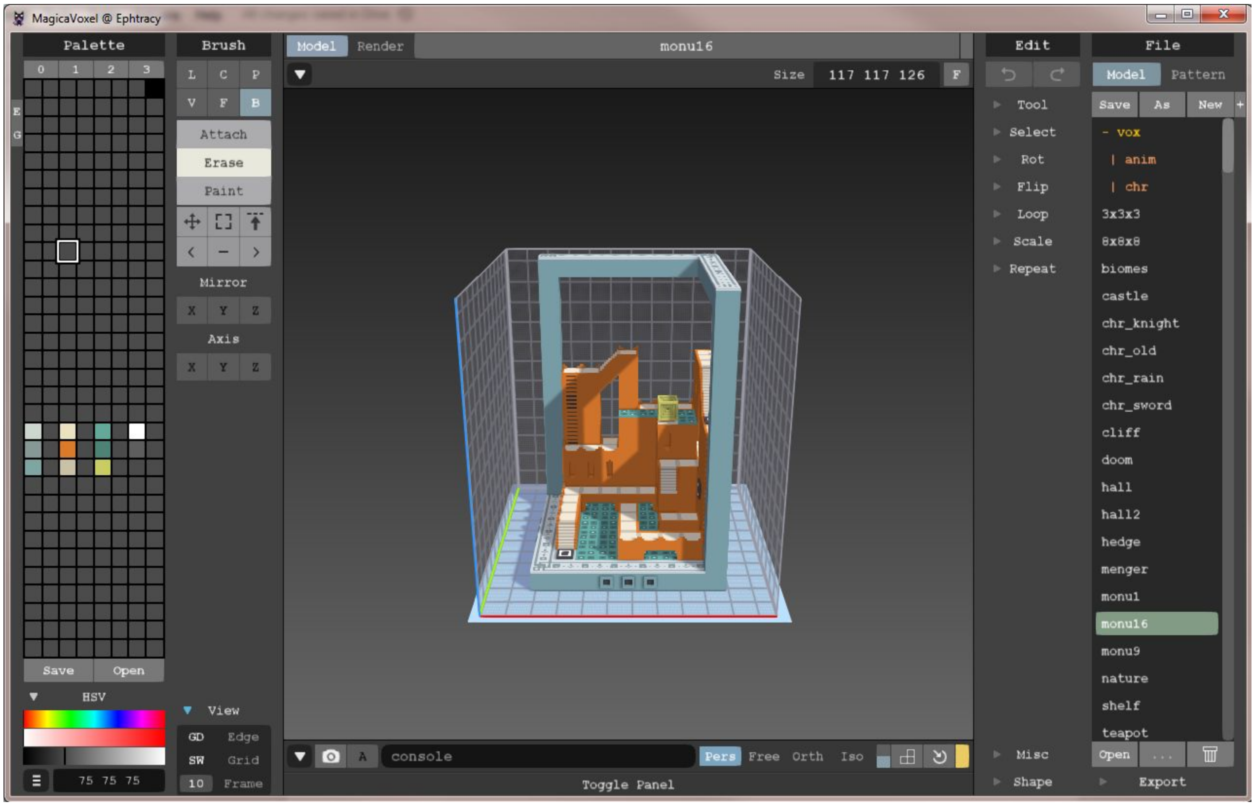


Fig. 4.1 - Magika Voxel Interface

I created a number of 3D models that I would incorporate into the scene.

Start Location

I modeled a small building that would serve as a container for the starting location, the place where the user would arrive when they entered the application.

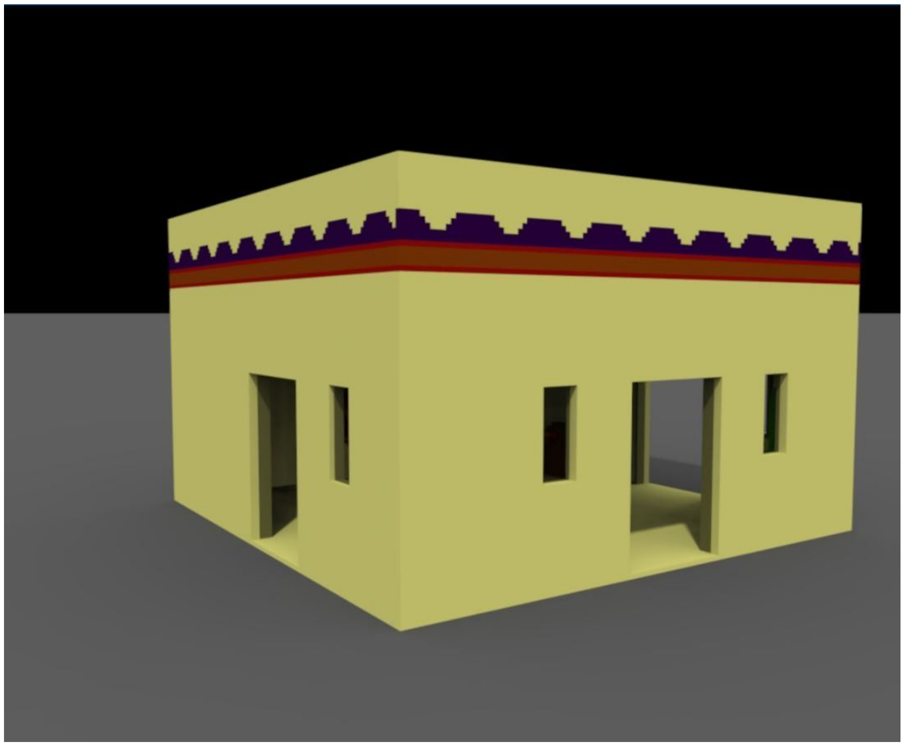


Fig. 4.2 - Start Point Model, View 1

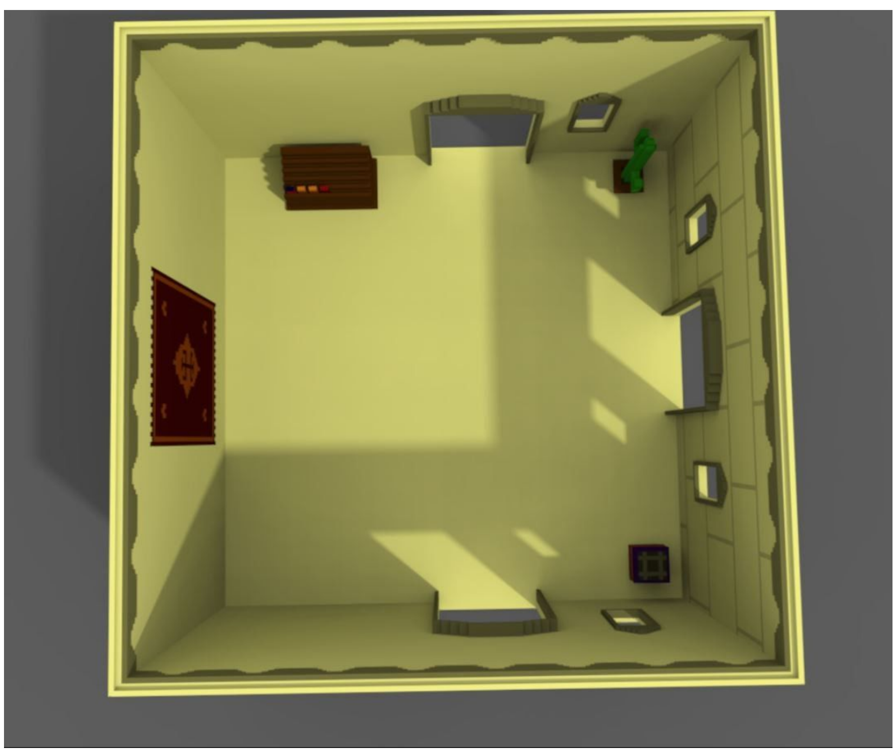


Fig. 4.3 - Start Point Model, View 2

I created some decorative models to add character to the scene and aid with immersion for the user.

Fig 4.4 - Cactus Model

Fig. 4.5 - Basket Model

Data Visualisation

I created another smaller courtyard location in which I would position the data visualisation element of the application.

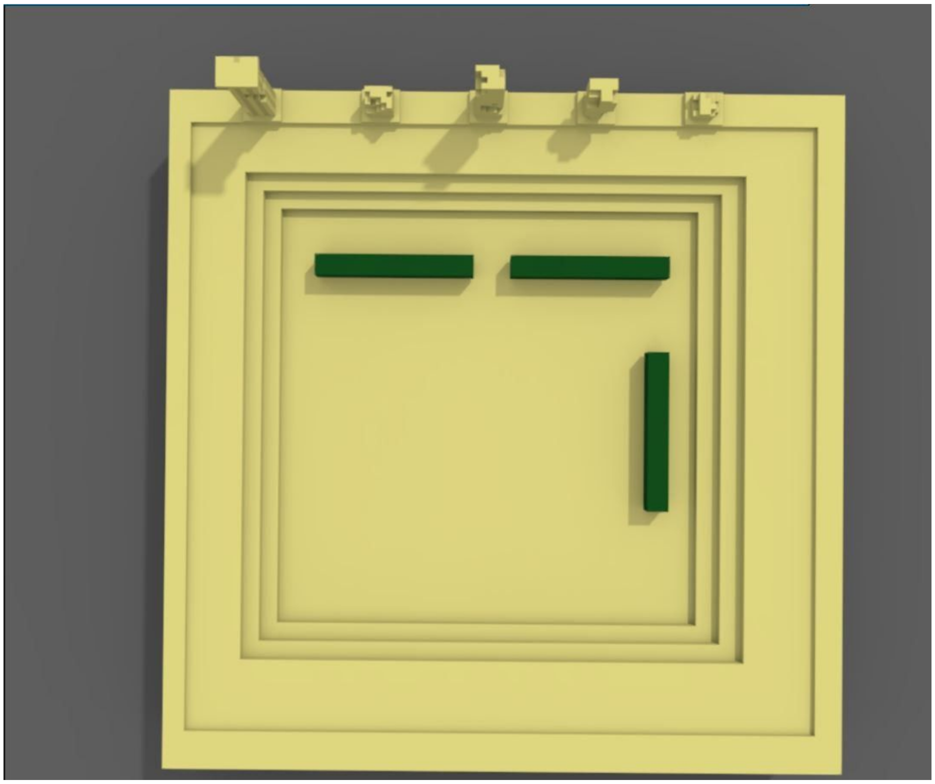


Fig 4.6 - Courtyard Model, View 1

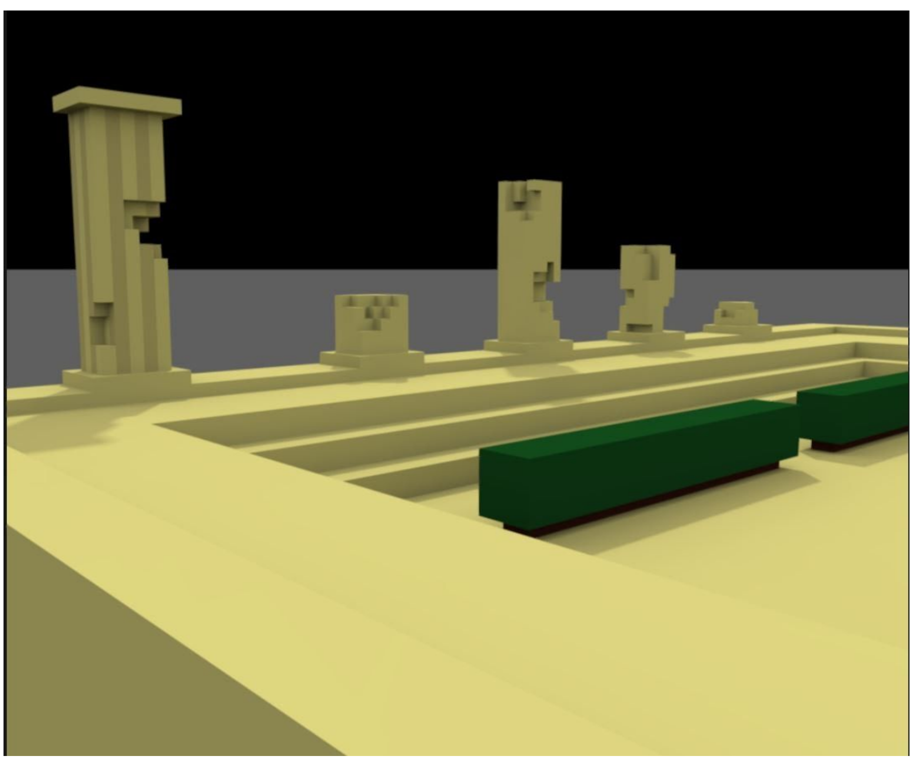


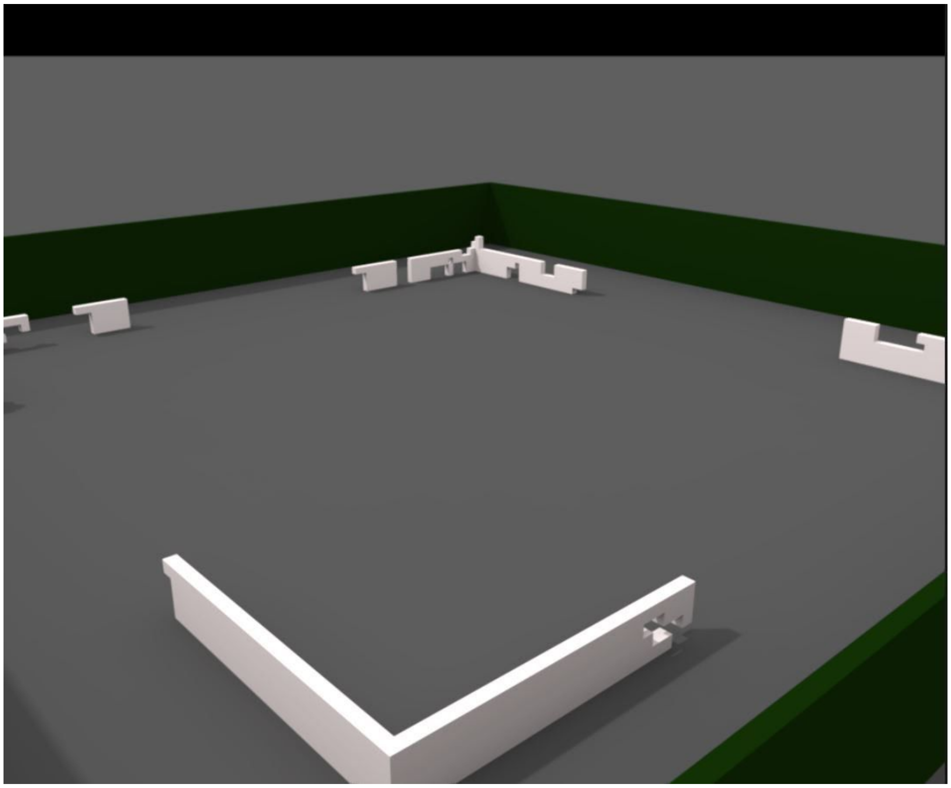
Fig 4.7 - Courtyard Model, View 2

Game

I modelled the cliffside location for the game element of the application.

Border Walls

I modelled a set of walls and hedges that would contain the entire scene.



4.1.2 Images

The Virtual Tour element required an equirectangular 360° image in order to function properly. There were examples of these from various sources online, however in order to create the experience I wanted for the application, it was necessary to produce my own images. This involved travelling to the location and taking the images myself. The Virtual Tour was designed to provide information about landscape-forming processes such as Glacial Erosion and Deposition. I was aware of evidence of these processes at Glen Muick, Aberdeenshire, and so I took a trip there to capture some images. My mobile phone, a Google Pixel, has a camera app that enables the capture of 360° photospheres. I created a number of these in the field and then imported them to Adobe Photoshop later for optimisation. Below are some examples of the images I created.

Although these images may seem to be distorted when viewed from a flat 2D perspective, once they have been applied to spherical entities as textures, the scale and proportions should appear more natural.

4.1.3 Audio

The virtual tour would require audio narration in order to fulfill the requirements of the design brief. I recorded two short audio clips to supplement this element. The content was derived from sections of geography and geology textbooks. I recorded and edited the clips in Audacity before exporting them as .mp3 files. I have included the script for each of the audio narrations below.

Audio Clip 1 - "As glaciers advanced across the terrain the U-shaped valleys you see before you were carved into the landscape."

Audio Clip 2 - "The boulders and rock you see before you were deposited here around 10 000 years ago at the end of the last ice age. The rock was eroded and uplifted further up the valley and carried along by the action of glaciers - in a process known as Glacial Motion. The large rocks deposited here are referred to as Erratic Boulders."

4.2 Setting up the scene

The first step involved in creating a WebVR experience with A-Frame is to create the appropriate HTML structure, and to include the A-Frame library via <script> tags in the head section.

```
<!DOCTYPE html>
<html lang="en">
<head>
<script src="https://aframe.io/releases/0.5.0/aframe.min.js"></script>
</head>
<body>
  <a-scene>

    <a-assets>
    </a-assets>

  </a-scene>
</body>
</html>
```

All A-Frame entities must be contained within the <a-scene> tags. Any assets drawn from the project directory or content delivery networks should be contained within the <a-assets> tags.

4.2.1 Including libraries and scripts

In order to implement the desired functionality of the application it was necessary to create custom A-Frame components and to also include a number of third-party components. These were contained within <script> tags in the <head> section of the html document. Here I also included other frameworks such as jQuery and d3.js, which would be used for the data visualisation element.

```
<head>

<script src="https://aframe.io/releases/0.5.0/aframe.min.js"></script>
<script src="https://rawgit.com/ngokevin/.../aframe-animation-component.min.js"></script>
<script src="https://rawgit.com/ryanbetts.../aframe-daydream-controller-component.min.js"></script>
<script src="https://rawgit.com/ngokevin.../aframe-event-set-component.min.js"></script>
<script src="https://cdnjs.cloudflare.com/ajax/libs/d3/3.5.5/d3.min.js"></script>
<script src="https://code.jquery.com/jquery-3.1.1.min.js"></script>
<script src="moveComponent.js"></script>
<script src="turnOff.js"></script>

</head>
```

4.2.2 Creating the basic layout and cursor element

The A-Frame library comes with some predefined primitive entities and components. I used these to create a basic scene with a ground and sky.

```
<a-sky color="#4fd8ea"></a-sky>
<a-plane id="floor" color="#c1af45" height="100" width="100" rotation="-90 0 0"></a-plane>
```

The <a-sky> entity is essentially a large sphere with a colour or texture mapped to the inside face. In this case I defined the colour attribute with the hex value of a light, sky blue colour.

The <a-plane> primitive is used to create flat surfaces with the predefined “Geometry” component. By default the plane is positioned perpendicular to what would naturally be considered the ground. I used the rotation component to rotate the plane by 90^o along the x-axis, forming the ground. I gave the plane a colour that resembled the colour of sand.

The next step was to create a crosshair shape that would act as the cursor. It was essential that the cursor remained in the center of the screen at all times, as it would represent the direction in which the user was looking. Or in other words, where their attention was focused. In order to achieve this it was necessary to specify the <a-camera> entity in HTML. The <a-camera> entity is attached to the scene by default, however should you wish to make any changes to its behaviour or properties, it must be added between the <a-scene> tags. To create a cursor that followed the camera, I added the <a-cursor> entity as a child of the <a-camera> element.

```
<a-camera position="8.3 0 8.7" rotation="0 90 0">
  <a-cursor id="cursor" fuse="true" fuseTimeout="500">
    <a-animation begin="click" easing="ease-in" attribute="scale"
                 fill="backwards" from="0.1 0.1 0.1" to="1 1 1" dur="500"></a-animation>
    <a-animation begin="cursor-fusing" easing="ease-in" attribute="scale"
                 from="1 1 1" to="0.1 0.1 0.1" dur="3000"></a-animation>
  </a-cursor>
```

By adding the fuse and fuseTimeout components to the cursor I was able to control its behaviour. The fuse component allows for gaze-based interactions, whereby the cursor will produce a click event after focusing on an entity for a set amount of time - specified by fuseTimeout. I set the fuseTimeout property to half a second.

To provide the user with visual feedback and to make them aware that the cursor was focused on an entity. I added the animation system as a child element of the cursor. The cursor shrinks to 1/10th of its size as an element in the scene is focused upon, this process was set to take 3 seconds. At the end of the three seconds the click event is activated and the cursor returns to normal.

4.3 Importing Assets

To be able to import assets into the scene they should be specified in the <a-assets> tags. It is also possible to set an asset as a property of an entity e.g.

```
<a-entity geometry="primitive: box" material="src:imgs/arrow1.png"></a-entity>
```

This method is not very efficient as I would have to retype the same code repeatedly if I wanted to use the same asset multiple times in the scene. It also means that the browser has to load the asset each time it is called upon, resulting in poorer performance. By using the asset management system instead, the browser will cache all of the assets and ensure that they are ready before rendering the scene.

```html
<a-assets>
  <!-- Audio Assets -->

  <audio id="click-sound" src="audio/click.wav"></audio>
  <audio id="audio1" src="audio/audio1.mp3"></audio>
  <audio id="audio2" src="audio/audio2.mp3"></audio>

  <!-- Image assets -->

  <img id="arrow1" src="imgs/arrow1.png"></img>
  <img id="sphereBG" src="imgs/sphere1.jpg"></img>
  <img id="play" src="imgs/playBtn.png"></img>
  <img id="stone" src="imgs/sandstone.jpg"></img>
</a-assets>
```

I specified each asset and gave each a unique id. I could then call upon the assets as and when I needed them by referring to the asset’s id, rather than specifying its URL each time.

4.4 Navigation

In order to implement the navigation functionality I wanted in the scene, I utilised a third party component and adapted it slightly to meet my needs. The component defines a set of behaviours and it allowed for the positioning of nodes that would trigger the movement of the user from one location to another. I added the component to the sphere entities I created for the navigation nodes in the scene.

```html
<!-- NAVIGATION NODES -->

<a-sphere id="node-move"
position="-2.5 0.5 9.5"
radius=".5"
color="green"
travel-node="transition: move"></a-sphere>
<a-sphere id="node-move"
position="20 0.5 9"
radius=".5"
color="green"
travel-node="transition: move"></a-sphere>
<a-sphere id="node-move"
position="8.3 0.5 8.7"
radius=".5"
color="green"
travel-node="transition: move"></a-sphere>
```

The component was written to target the <a-scene> entity,

```javascript
var scene = document.querySelector('a-scene');
```

and so I had to set the default behaviours of the navigation component through the <a-scene> entity in HTML.

```html
<a-scene
  stats
  travel-node-defaults="axis: x,y,z; offsetY: 0.75; animationDur: 3000">
```

Once this had been set up I could now click on the nodes in the scene and the camera would move towards them over a period of three seconds. It took some experimenting to arrive at this number, and I had to ensure that the nodes were spaced equal distances apart, as the animation would occur too slowly if they were close together and far too quickly if they were too far apart.

4.5 The Virtual Tour

To set up the virtual tour element of the application I created a second <a-sky> entity within the scene. I set the radius of the <a-sky> and positioned it in the correct location. I added the 360° image I had created previously as the <a-sky>'s material component.

```
<a-sky id="image-360" radius="10" src="#sphereBG"></a-sky>
```

Within the sphere I created two planes that would act as the triggers for the audio narration.

```
<a-entity id="rock-plane"
  geometry="primitive: plane; height: 1; width: 2"
  material="color: #b57727"
  position="-2.5 -0.1 0"
  rotation="-22 90 0"
  text="align: center; color: white; value: Play Audio"
  sound="src: #audio1; on: click"></a-entity>


<a-entity id="glacer-plane"
  geometry="primitive: plane; height: 1; width: 2"
  material="color: #b57727"
  position="1.5 -0.1 -1.2"
  rotation="-22 -60 0"
  text="align: center; color: white; value: Play Audio"
  sound="src: #audio2; on: click"></a-entity>
```

I placed all of the Virtual tour elements inside an entity that would serve as a wrapper. I then set the wrapper's visibility to false by default, thereby rendering all of the Virtual tour elements invisible.

```
<a-entity id="vTour" visible="false" position="0 0 -11.2">
```

The player would arrive at the navigation node and be greeted with a message and a button that would start the virtual tour experience. The button would set the component's "visible" property to "true" while also setting the visibility of the unnecessary elements like the navigation node, and the ground plane, to "false".

```
<a-entity id="vtStartPanel"
event-set__1="_event: click; visible: true; _target: #vTour"
event-set__2="_event: click; visible: false; _target: #vTWelcome"
event-set__3="_event: click; visible: false; _target: #floor"
geometry="primitive: plane; height :1; width: 1;"
material="color: #b57727"
position="-2.3 1 -12"
rotation="0 40  0"
text="align:center; color: white; value: Start VT"></a-entity>
```

Through this entity I could control the behaviour of other entities by referring to their unique #id tags. There was another button created inside the virtual tour that would reverse these changes allowing the player to return to the main scene, when they were finished with the Virtual Tour.

```
<a-entity id="exit-plane"
  event-set__1="_event: click; visible: false; _target: #vTour"
  event-set__2="_event: click; visible: true; _target: #vTWelcome"
  event-set__3="_event: click; visible: true; _target: #floor"
  geometry="primitive: plane; height: 1; width: 2"
  material="color: #b57727"
  position="0 -0.1 3.8"
  rotation="-22 180 0"
  text="align: center; color: white; value: EXIT"
  sound="src: #click-sound; on: click"></a-entity>
```

4.6 The Data Visualisation Element

The bar chart for the data visualisation was created using the d3.js library. I modified a demo created by Scott Little in order to implement this into the scene. The bar chart drew data from two arrays, one to hold the data and the other to hold the labels.

```
var data = [ 19, 80, 30, 15, 55, 35, 40,
            45, 50, 70, 109, 35, 78,
           87, 76, 22, 2, 33, 44, 59, 200]

 var animals = [ 'Bobcat', 'Dog', 'Cat', 'Boar', 'Cheetah', 'Chimp', 'Dragon',
            'Elephant', 'Human', 'Elf', '1989', 'Batman', 'Donkey',
           'Henry', 'Face', 'Funny', 'Kitty', 'Doggy', 'Joker', 'Alf', 'Earth']
```

I had originally intended to represent data relating to the environment, but struggled to find an appropriate source during the course of the project. The arrays were instead filled with arbitrary data that was intended to illustrate the functionality and interactivity of the bar chart.

5. Testing and Evaluation

In this section I discuss the different testing and evaluation methodologies I applied during the course of the project. It also contains a section on self evaluation where I discuss my thoughts on aspects of the project - what went well and what could be improved. The testing phase of the project sought to determine whether the project had achieved its goals in terms of meeting the requirements specification, described in section 2.5 of the report. It was also necessary to test the final application in terms of the user experience. I conducted a user experience evaluation with a group of potential users.

5.1 Testing against requirements specification

The requirements specification, defined in section 2.5, stipulated a number of requirements for the project artefact. The requirements were both functional and non-functional in nature, with some relating to the application itself and the material contained within. In order to test these requirements I created a set of tables. The tables described a test case, which of the project requirements the test related to, the results of the test, and finally any action that was taken to rectify situations where the application had failed to meet a requirement.

Table name: Test ID 1

Test ID:	1
Test Description:	Application should maintain a frame rate of at least 60fps
Requirement satisfied:	1.2, 1.13
Expected Result:	The frame rate remains consistently above 60fps
Test result:	The frame rate was dropping below 60fps, even as low as 40 on occasion.
Action taken:	I removed the 3D assets from the project and the frame rate returned to a rate that was consistently above 60fps. 

Table name: Test ID 2

Test ID:	2
Test Description:	The user can navigate through the scene.
Requirement satisfied:	1.7, 1.13, 1.5, 1.6
Expected Result:	The user can "click" on a navigation node and move to its location or use the mouse and keyboard to move.
Test result:	WASD keys working as expected. The user can move to the node but it is either too fast or two slow. One node not responding to cursor fuse.
Action taken:	Repositioned nodes to be equidistant from each other and the issue was solved. Also, repositioned a panel element that was interfering with the node that wasn't responding.

Table name: Test ID 3

Test ID:	3

Test Description:	Instructional panel elements all display relevant text
Requirement satisfied:	1.1, 1.11
Expected Result:	Text is relevant, clear and legible
Test result:	As expected
Action taken:	None

Table name: Test ID 4

Test ID:	4
Test Description:	Data visualisation element displays labels for data
Requirement satisfied:	1.0, 1.5, 1.10, 2.3
Expected Result:	The bar chart displays data on climate change and labels are activated when the cursor is hovered over the chart.
Test result:	The bar chart displays data, however it is not relevant to the subject material.
Action taken:	Tried to find a good source of environmental data but could not, replaced with arbitrary data instead.

Table name: Test ID 5

Test ID:	5
Test Description:	Virtual tour element contains audio narration that the user can control.
Requirement satisfied:	1.0, 1.8, 1.5, 2.2
Expected Result:	Panels activate audio narration with click event.
Test result:	As expected
Action taken:	None

5.2 User experience evaluation

Testing the application with users was an important aspect of the project. The nature of the project meant that testing with a large number of users would be problematic. The application requires specific hardware in order to be experienced properly. This is one of the reasons why I chose to focus on qualitative evaluation methods. I recruited a group of five users who would each spend time using the application and then participating in user experience evaluation activities afterwards. Prior to testing the application, users were given brief instructions on how to use the headset and were told to feel free to ask questions if they were having any difficulties as they were using the application.

5.2.1 Thinking Aloud

During their time spent interacting with the device and application, users were encouraged to vocalise their thoughts and emotional responses to the experience. This approach was discussed during the literature review, and I decided to include this methodology in the testing phase of the project. As the users interacted with the experience I noted down any remarks that were made. Below are some quotes taken from the users as they experienced the application.

User A:

- "Wow cool"
- "I wasn't expecting this"
- "I like the bar chart"
- "Oh, it moves when you look at it"
- "What's over here?"
- "It looks a bit like the beach or something."

User B:

- "This looks fun"
- "I didn't know you could do that"
- "So I just look at the circles?"
- "Oh, I'm moving!"
- "I'm in the Highlands now"
- "I can hear your voice"
- "Ah, I'd never thought about that before."

User C:

- "I've got something like this at home"
- "The graph thing is nice"
- "I like how you can look at the bars and the information comes up"
- "This looks like a cool place to visit"
- "It's almost like I'm there."
- "That was fun"

User D:

- "OK, I'm reading a sign now."
- "So I just look at things to make them work?"
- "OK, I think I get it."
- "I'm looking at the bar-graph thing now."
- "Oh yeah, it changes when I look at it."
- "OK I'm moving."
- "What does this thing say?"
- "Oh that's nice, the picture appeared around me."
- "Looks good"

User E:

- “It feels quite comfortable.”
- “It’s a bit blurry round the edges but apart from that it’s fine.”
- “I’m just reading the welcome message now.”
- “It’s not quite like real-life, is it?”
- “The bar chart could be useful though.”
- “This is more like it.”
- “I’m glad you included the voice overs.”

Based on the comments made during the user’s experience, I would say the overall reception to the application was positive. Users generally seemed to find the experience quite novel and most were engaged in the experience throughout the process. Some of the users took a few moments to adjust to the experience and required a small amount of guidance, while others who were more familiar with the technology, picked it up relatively quickly. One user commented on the fact that their view of the scene seemed a bit blurry around the edges. Unfortunately this is simply a result of the limitations of the mobile based VR experience. Cardboard headsets have a limited field of view and narrow area of focus, I don’t believe however, that this was too much of a detriment to their overall experience of the application.

5.2.2 Semi-Structured Experience Interview

The semi-structured experience interview is a usability experience evaluation method that is intended to produce meaningful, qualitative results. It involves a discussion with users on their thoughts and feelings towards the experience they had with the product or software in question. On the surface, the idea of having conversation with a user may seem like a straightforward, simple method to implement. However, in order to conduct a successful and meaningful interview careful planning and consideration is required. I referred to the textbook “*Qualitative Researching*” (Mason, J. 2002) while planning out the interview process. When planning an interview of this type, it should be considered what it is that the interview is intended to achieve. The original aims of the research question should provide guidance for the structure of the interview. The role of the researcher is to dictate the course of the conversation, while at the same time trying to avoid leading the interviewees to conclusions that suit the research aims of the interviewer. The conversation should feel natural and the interviewees encouraged to provide honest answers and feedback. With this in mind I planned out a loose structure for the interview process. I knew there were certain topics that I needed to cover in order to determine if the goals of the project had been met in terms of the user experience and educational value of the technology. The topics for discussion I decided to include in the interview were:

- How the application compared to other VR experiences.
- Whether the interaction methods were easy to understand and implement for the user.
- Whether or not the WebVR experience was something they felt could provide a useful learning experience.
- Any other thoughts or feelings they had towards the application.

It could be said that on the whole, participants had a positive experience when using the application. They made reference to the fact that it was a new development in terms of media and technology and were therefore generally quite forgiving of the low-fidelity aesthetics of the application. They all remarked positively on the Virtual Tour element, this seemed to be the most popular aspect of the application. The audio narration especially, was brought up by several of the participants as being one of the features they enjoyed the most. The data visualisation element was also generally received well. Most agreed that navigating around the scene wasn't too difficult. Some users did remark that they had some difficulties getting their bearings at the beginning but as they grew more familiar with the application this became less of an issue.

5.2.3 Overall User Experience and Recommendations

Overall I feel that the application has achieved a good standard in terms of the user experience. Providing guidance to the users from within the application was an important aspect in making the user experience more positive. I do believe though, that the way in which instruction is delivered within the application can be improved. During the testing phase some users remarked that they had to pause to read the text before continuing with the experience. The text panel elements are better than not having any instructions, but they also appeared to be a distraction in some regards, drawing the focus of the user away from other elements within the application. Instead I would propose that using audio to guide the user rather than relying on text alone would be a better solution. Of course, it would still be wise to keep the text elements within the application in order to aid with accessibility for users who do not have a great sense of hearing. Therefore I suggest a combination of both text and audio would be the best method of delivering instructions in an application of this type.

5.3 Personal Evaluation

I have enjoyed working on this project. It was interesting to me from a number of perspectives. I was glad to be able to bring together many of the skills I have learned during my time at university. The research phase of the project allowed me to gain insight into a number of new concepts and technologies, whilst also improving my skills in academic writing. The final implementation of the project was not exactly what I had envisioned at the beginning. I think the biggest challenge during this project was narrowing down the scope. I had initially thought that I would be able to design an application that would work well on all VR device types, from Cardboard all the way up to devices like the Oculus Rift and HTC Vive. It soon became apparent that this would be far outwith the realms of the project, as I learned more about exactly what was involved. The design of the application itself, I feel, was also quite ambitious. Deciding to include three separate engagement methodologies was perhaps too much of a challenge. Instead, were I to start this project again, I would rather focus on just one of these and develop it more fully. For example, creating a more expansive Virtual Tour or a much more detailed Data Visualisation. Again, this relates to narrowing down the focus and scope of the project and its goals, something with which I did struggle somewhat. It was unfortunate that I had to remove the 3D assets in the final version. While testing them on my local machine everything seemed to be working fine, however once the project was hosted live on GitHub pages, I discovered that it wasn’t working in quite the same way as it was on my local machine. It did help me to appreciate the value and importance of testing however. The sheer amount of time required in order to produce each element of the design was something that challenged me also, many of the techniques required had to be learned before they could be implemented. The experience I have gained however, will hopefully serve me well in the future should I continue to work in these areas.

6. Conclusions

The project has demonstrated, at the very least, the possibility that WebVR could be a useful tool for learning and is worth investigating further. The people who participated in the testing of the prototype application all agreed that it wasn’t too hard to imaging using such technologies to learn something new. The work undertaken during the research and design stages of such a project must have a clear objective in mind, in order to produce a meaningful outcome in terms of the implementation.

WebVR is definitely an exciting and interesting field in which to study. The possibilities of this new technology are interesting from both a pedagogical perspective and an entertainment perspective. The ability to deliver VR content through the web will no doubt be a contributing factor to the enhancement and development of the VR medium as a whole. The research and findings of the project suggest that this technology is only beginning to show what it’s true capabilities are. If we look to the future, concepts such as the “metaverse” and entire virtual worlds are becoming ever closer to being realised.

6.1 Future Work

I shall continue to work on this project in the future and I hope to reach a stage where the project itself becomes more complete. The experience will no doubt serve me well in whatever route I take in the future, be it professional or academic. The A-Frame library is something I will continue to use and hope to become more familiar with it. This project has inspired me and I already have some ideas for new projects I intend to develop in the near future.

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7.3 Figures

Some of the figures used in the report were created by myself, while others were drawn from various sources. Here I have listed the sources for the relevant figures.

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https://atomicsupermen.files.wordpress.com/2016/01/screendooreffect.jpg

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7.4 Script References

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Appendix A: Project Log

Week 1 (03/10/2016)
- Work on project began
- Defining project title and questions to address

Week 2 (10/10/2016)
- Began to source reference material for project proposal
- Work on project proposal commenced

Week 3 (17/10/2016)
- Continued to work on project proposal.
- Continued research into relevant subject areas: VR, E-learning, A-Frame
- Worked on initial, condensed literature review.

Week 4 (24/10/2016)
- Finalisation of project proposal and initial literature review
- Submitted project proposal.

Week 5 (31/10/2016)
- Began research phase of project.
- Continued to expand upon source materials, adding more material to library of sources.

Week 6 (7/11/2016)
- Worked on literature review component of the Research phase.

- Investigated various examples to include in Critical Review component.

Week 7 (14/11/2016)

- Continued working on literature review - finding sources, making notes, writing review.
- Continued with Critical Review - investigating examples, comparing to findings of research.

Week 8 (21/11/2016)

- Continued work on literature review

Week 9 (28/11/2016)

- First draft of literature review completed
- Began considering design phase

Week 10 (5/12/2016)

- Initial ideas and sketches
- Began creating mind map

Week 11 (12/12/2016)

- Worked on some wireframes and sketches
- Looked at critical review again for more relevant sources

Week 12 (19/12/2016)

- Continued working on design phase.
- Ideas for navigation and interaction were developed

Week 13 (30/01/2017)

- Resumed work
- Finalising research phase
- Continue with design work

Week 14 (6/02/2017)

- Seeing what was possible in A-Frame
- Small test scenes of techniques

Week 15 (13/02/2017)

- Returned to design work
- Made alterations based on experimenting with A-frame

Week 16 (20/02/2017)

- Came up with idea for navigation nodes
- Worked on design for nodes

Week 17 (27/02/2017)

- Seeing what was possible in A-Frame
- Small test scenes of techniques

Week 18 (13/02/2017)

- Returned to design work
- Made alterations based on experiments with A-frame

Week 19 (20/02/2017)

- Finished up wireframes
- Worked on cognitive walkthroughs

Week 20 (27/02/2017)

- Began implementation

- Set up basic scene

Week 21 (06/03/2017)
- Continued to work on implementation
- Created 3D assets

Week 17 (13/03/2017)
- Finishing up 3D assets
- Incorporated 3D work into project

Week 18 (20/03/2017)
- Worked on Virtual Tour element
- Took pictures
- Edit and optimised pictures
- Incorporated into scene

Week 19 (27/03/2017)
- Worked on information panels
- Recorded audio

Week 20 (03/04/2017)
- Created buttons to toggle on/off of the virtual tour
- Worked on ideas for data vis

Week 21 (10/04/2017)
- Began data vis implementation
- Worked on tweaking aspects of the scene

Week 22 (17/04/2017)
- Scene was not functioning correctly, removed 3d assets
- No more lag. Continued with implementation

Week 23 (24/04/2017)
- Finishing up data vis element
- Thinking about testing methods

Week 24 (01/05/2017)
- Settled on thinking aloud and interviews
- Began to recruit participants

Week 25 (08/05/2017)
- Conducted testing with participants
- Finished up presentation slides
- Gave presentation
- Finishing up report
- Submitted report

Appendix B: Project Code

Index.html

```
<!DOCTYPE html>
<html lang="en-gb">
<head>

<script src="https://aframe.io/releases/0.5.0/aframe.min.js"></script>
<script src="https://bitbucket.org/realitylab_ruben/aframe-travel-node.git"></script>
<script
src="https://rawgit.com/ngokevin/aframe-animation-component/master/dist/aframe-animation-compo
nent.min.js"></script>
<script
src="https://rawgit.com/ryanbetts/aframe-daydream-controller-component/master/dist/aframe-daydr
eam-controller-component.min.js"></script>
<script
src="https://rawgit.com/ngokevin/aframe-event-set-component/master/dist/aframe-event-set-compon
ent.min.js"></script>
<script src="https://cdnjs.cloudflare.com/ajax/libs/d3/3.5.5/d3.min.js"></script>
<script src="https://code.jquery.com/jquery-3.1.1.min.js"></script>
<script src="moveComponent.js"></script>
<script src="turnOff.js"></script>

</head>

<body>

  <a-scene
        stats
        travel-node-defaults="axis: x,y,z; offsetY: 0.75; animationDur: 3000">

        <a-assets>
```

```
<!-- Audio Assets -->

<audio id="click-sound" src="audio/click.wav"></audio>
<audio id="audio1" src="audio/audio1.mp3"></audio>
<audio id="audio2" src="audio/audio2.mp3"></audio>

<!-- Image assets -->

<img id="arrow1" src="imgs/arrow1.png">
<img id="sphereBG" src="imgs/sphere1.jpg"></img>
<img id="play" src="imgs/playBtn.png"></img>
<img id="stone" src="imgs/sandstone.jpg">

<!-- Model assets -->

</a-assets>

<!-- SKY AND GROUND -->

<a-sky color="#4fd8ea"></a-sky>
<a-plane id="floor" color="#c1af45" height="100" width="100" rotation="-90 0 0"></a-plane>

<!-- CAMERA AND CURSOR -->

<a-camera position="8.3 0 8.7" rotation="0 90 0">
<a-cursor id="cursor" fuse="true" fuseTimeout="500">
<a-animation begin="click" easing="ease-in" attribute="scale"
        fill="backwards" from="0.1 0.1 0.1" to="1 1 1" dur="500"></a-animation>
<a-animation begin="cursor-fusing" easing="ease-in" attribute="scale"
        from="1 1 1" to="0.1 0.1 0.1" dur="3000"></a-animation>
</a-cursor>
</a-camera>
```

```
<a-entity id="remote" daydream-controller raycaster="objects: .selectable">
<a-cone id="ray" color="cyan" position="0 0 -2" rotation="-90 0 0" radius-bottom="0.005"
radius-top="0.001" height="4"></a-cone>
<a-box id="position-guide" visible="false" position="0 0 -2"></a-box>
</a-entity>

<!-- NAVIGATION NODES -->

<a-sphere id="node-move" position="-2.5 0.5 9.5" radius=".5" color="green"
travel-node="transition: move"></a-sphere>
<a-sphere id="node-move" position="20 0.5 9" radius=".5" color="green"
travel-node="transition: move"></a-sphere>
<a-sphere id="node-move" position="8.3 0.5 8.7" radius=".5" color="green"
travel-node="transition: move"></a-sphere>

<!-- EXPERIENCE ELEMENTS -->

<!-- START AREA -->
<a-entity id="wrap" position = "7 0 9.5" rotation = "0 90 0">
<a-entity id="welcomePanel"
geometry="primitive: plane; height :1; width: 3;"
material="color: #739122"
position="-2 2 -1"
rotation="0 45 0"
text="align:center; color: white; value: Welcome, please have a look around and enjoy your stay.
\n Use the cursor in the center of your screen to interact with objects."></a-entity>


<!-- VIRTUAL TOUR -->
<a-entity id="vTWelcome">
<a-entity id="vtWelcomePanel"
geometry="primitive: plane; height :1; width: 3;"
material="color: #739122"
```

```
        position="0 1 -12.3"
        text="align:center; color: white; value: Welcome to the Virtual Tour of Glen Muick.\n Look
around and learn about the environmental processes that shaped this landscape"></a-entity>

        <a-entity id="vtStartPanel"
        event-set__1="_event: click; visible: true; _target: #vTour"
        event-set__2="_event: click; visible: false; _target: #vTWelcome"
        event-set__3="_event: click; visible: false; _target: #floor"
        geometry="primitive: plane; height :1; width: 1;"
        material="color: #b57727"
        position="-2.3 1 -12"
        rotation="0 40  0"
        text="align:center; color: white; value: Start VT"></a-entity>
        </a-entity>

        <a-entity id="vTour" visible="false" position="0 0 -11.2">
        <!-- 360-degree image. -->
        <a-sky id="image-360" radius="10" src="#sphereBG"></a-sky>

        <!-- Planes -->

        <a-entity id="rock-plane"
        geometry="primitive: plane; height: 1; width: 2"
        material="color: #b57727"
        position="-2.5 -0.1 0"
        rotation="-22 90 0"
        text="align: center; color: white; value: Play Audio"
        sound="src: #audio1; on: click"></a-entity>


        <a-entity id="glacer-plane"
        geometry="primitive: plane; height: 1; width: 2"
        material="color: #b57727"
```

```
position="1.5 -0.1 -1.2"
rotation="-22 -60 0"
text="align: center; color: white; value: Play Audio"
sound="src: #audio2; on: click"></a-entity>

<a-entity id="exit-plane"
event-set__1="_event: click; visible: false; _target: #vTour"
event-set__2="_event: click; visible: true; _target: #vTWelcome"
event-set__3="_event: click; visible: true; _target: #floor"
geometry="primitive: plane; height: 1; width: 2"
material="color: #b57727"
position="0 -0.1 3.8"
rotation="-22 180 0"
text="align: center; color: white; value: EXIT"
sound="src: #click-sound; on: click"></a-entity>



<!-- Images -->

<a-image id="glacier-arrow"
src="#arrow1"
position="6 0.5 -6"
rotation="0 112 0"
geometry="height: 1; width: 2"></a-image>

</a-entity><!-- end of VT -->

<!-- GAME -->
<a-entity id="gamePanel"
geometry="primitive: plane; height :3; width: 4;"
material="src: #stone"
position="0 1 16.3"
rotation="0 180 0"></a-entity>
```

```
<a-entity id="gamePane2"
geometry="primitive: plane; height :1; width: 2;"
material="color: #b57727"
position="2 0.5 15"
rotation="0 220 0"
text="align: center; color: white; value: GAME"></a-entity>




</a-entity>

  </a-scene>

 <!-- DATA VISUALISATION -->

  <script>

    var alpha = 0.6


            var data = [ 19, 80, 30, 15, 55, 35, 40,
            45, 50, 70, 109, 35, 78,
            87, 76, 22, 2, 33, 44, 59, 200]

            var animals = [ 'Bobcat', 'Dog', 'Cat', 'Boar', 'Cheetah', 'Chimp', 'Dragon',
            'Elephant', 'Human', 'Elf', 'Giant', 'Batman', 'Donkey',
            'Henry', 'Face', 'Funny', 'Kitty', 'Doggy', 'Joker', 'Alf', 'Earth']


            var hscale = d3.scale.linear()
```

```
 .domain([0, d3.max(data)])
 .range([0, 3])


var scene = d3.select("a-scene")


var bars = scene.selectAll("a-box.bar").data(data)
bars.enter().append("a-box").classed("bar", true)

$( ".bar" ).append( "<a-text> </a-text>" );

bars.attr({
position: function(d,i) {
var x =  i*.75
var y = hscale(d)/2;
var z = 1
return x + " " + y + " " + z
},
width: function(d) { return 0.5},
depth: function(d) { return 0.5},
height: function(d) { return hscale(d)},
opacity: alpha,
color: 'blue'
})
.on("click", function(d,i) {
console.log("click", i,d)
})
.on("mouseenter", function(d,i) {

if(this.hovering) return;
console.log("hover", i,d)
this.hovering = true;
```

```
d3.select(this).transition().duration(10)
.attr({
metalness: 0.8,
opacity: .9
})
d3.select(this).select("a-text")
.attr({
	'color':'hsla(240, 100%, 25%, 0.6)',
	'align':'center',
	'position':'0 '+ (hscale(d)/2+.5) + ' 0',
	'scale':'1 1 1',
	'value': animals[i]+', '+d
})
})
.on("mouseleave", function(d,i) {
console.log("leave",i,d)
this.hovering = false;
d3.select(this).transition().duration(500)
.attr({
metalness: 0,
opacity: alpha
})
d3.select(this).select("a-text")
.attr({
	'color':'blue',
	'align':'center',
	'position':'0 '+ (hscale(d)/2+.5) + ' 0',
	'scale':'.01 .01 .01',
	'value': d
})
})
```

```
  </script>

  <script>

        $(".bar").each(function() {
        this.components.material.material.alphaTest = 0.5;
        this.components.material.material.depthWrite = false;
        this.components.material.material.needsUpdate = true;;
        });

   </script>
</body>
</html>
```

moveComponent.js - (van der Leun, R. 2016)

```
AFRAME.registerComponent("travel-node", {
        schema: {
        axis: {
        type: 'string',
        default: null
        },
        offsetX: {
        type: 'number',
        default: null
        },
        offsetY: {
        type: 'number',
        default: null
        },
        offsetZ: {
```

```
type: 'number',
default: null
},
transition: {
type: 'string',
default: null
},
animationDur: {
type: 'number',
default: null
},
animationEasing: {
type: 'number',
default: null
},
travelTarget: {
type: "selector"
}
},

axises: null,
clickEventRegistered: false,
travelTarget: null,

update: function () {
var scene = document.querySelector('a-scene');
if (scene.hasLoaded) {
this.setupVariables();
} else {
scene.addEventListener('loaded', function () {
this.setupVariables();
}.bind(this));
}
```

```
},

setupVariables: function () {
var scene = document.querySelector('a-scene');
var defaults = scene.components["travel-node-defaults"];

if(defaults === undefined) {
scene.setAttribute("travel-node-defaults", "");
setTimeout(this.setupVariables.bind(this), 10);
return;
}

for (var i in this.data) {
if (
this.schema[i].type === 'number' && isNaN(this.data[i]) ||
this.data[i] === null
) {
this.data[i] = defaults.data[i];
}
}

this.axises = {};
var axisData = this.data.axis.toLowerCase().split(",");
var possibleAxises = ["x", "y", "z"];

for (var i in possibleAxises) {
var axis = possibleAxises[i];
if (axisData.indexOf(axis) >= 0) {
this.axises[axis] = true;
}
}

this.travelTarget = this.data.travelTarget;
```

```
if(this.travelTarget === null) {
console.warn("Can't determine travel target.");
}

if (!this.clickEventRegistered) {
this.el.addEventListener("click", this.onClick.bind(this))
this.clickEventRegistered = true;
}

},

onClick: function () {
var newPosition = new THREE.Vector3();;
var targetPosition = new THREE.Vector3();
newPosition.setFromMatrixPosition(this.el.object3D.matrixWorld);
targetPosition.setFromMatrixPosition(this.travelTarget.object3D.matrixWorld);

for (var axis in this.axises) {
targetPosition[axis] = newPosition[axis];
}

targetPosition.x += this.data.offsetX;
targetPosition.y += this.data.offsetY;
targetPosition.z += this.data.offsetZ;

this.targetPosition = targetPosition;

switch (this.data.transition) {
case "fade":
this.fadeToTarget();
break;

case "move":
```

```
	if(AFRAME.components["animation"]) {
		this.moveToTarget();
	} else {
		console.warn("To use the 'move' transition, you will need to add the
aframe-animation-component component, available at
https://github.com/ngokevin/aframe-animation-component");
		this.jumpToTarget();
	}
	break;

	default:
	console.warn("Unknown travel mode: " + this.data.mode);

	case "jump":
	this.jumpToTarget();
	break;
	}
	},

	fadeToTarget: function () {
	var scene = document.querySelector("a-scene");
	var camera = scene.camera.el;

	var plane = document.createElement("a-plane");
	plane.setAttribute("position", "0 0 -0.1");
	plane.setAttribute("material", "color: black; transparent: true; opacity: 0");

	var fadeOut = document.createElement("a-animation");
	fadeOut.setAttribute("attribute", "material.opacity");
	fadeOut.setAttribute("from", "0");
	fadeOut.setAttribute("to", "1");
	fadeOut.setAttribute("dur", this.data.animationDur);
	fadeOut.setAttribute("easing", this.data.animationEasing);
```

```
var fadeIn = fadeOut.cloneNode(true);
fadeIn.setAttribute("from", "1");
fadeIn.setAttribute("to", "0");
fadeIn.setAttribute("delay", this.data.animationDur + 100);

fadeOut.addEventListener("animationend", function() {
this.jumpToTarget();
}.bind(this));

fadeIn.addEventListener("animationend", function() {
plane.removeChild(fadeIn);
plane.removeChild(fadeOut);
camera.removeChild(plane);
});

plane.appendChild(fadeIn);
plane.appendChild(fadeOut);
camera.appendChild(plane);
},

moveToTarget: function () {
var attribute = "property: position; to: " + this.targetPosition.x + " " + this.targetPosition.y + " " +
this.targetPosition.z + "; dur: " + this.data.animationDur + "; easing: " + this.data.animationEasing;
this.travelTarget.setAttribute("animation__travel-node_movetotarget", attribute);

this.travelTarget.addEventListener("animation__travel-node_movetotarget-complete",
function() {
this.travelTarget.removeAttribute("animation__travel-node_movetotarget");
}.bind(this));
},

jumpToTarget: function () {
```

```
this.travelTarget.setAttribute("position", this.targetPosition);
}
});

AFRAME.registerComponent("travel-node-defaults", {
schema: {
axis: {
type: 'string',
default: 'x,z'
},
offsetX: {
type: 'number',
default: 0
},
offsetY: {
type: 'number',
default: 0
},
offsetZ: {
type: 'number',
default: 0
},
transition: {
type: 'string',
default: 'fade'
},
animationDur: {
type: 'number',
default: 100
},
animationEasing: {
type: 'string',
default: 'linear'
```

```
    },
    travelTarget: {
    type: "selector",
    default: "[camera]"
    }
    },

    init: function() {
    var scene = document.querySelector('a-scene');
    if (scene.hasLoaded) {
    this.checkElement();
    } else {
    scene.addEventListener('loaded', function () {
    this.checkElement();
    }.bind(this));
    }
    },

    checkElement: function() {
    if(this.el.tagName !== "A-SCENE") {
    console.warn("travel-node-defaults should be placed on the a-scene element.");
    }
    }
});
```

turnOff.js -

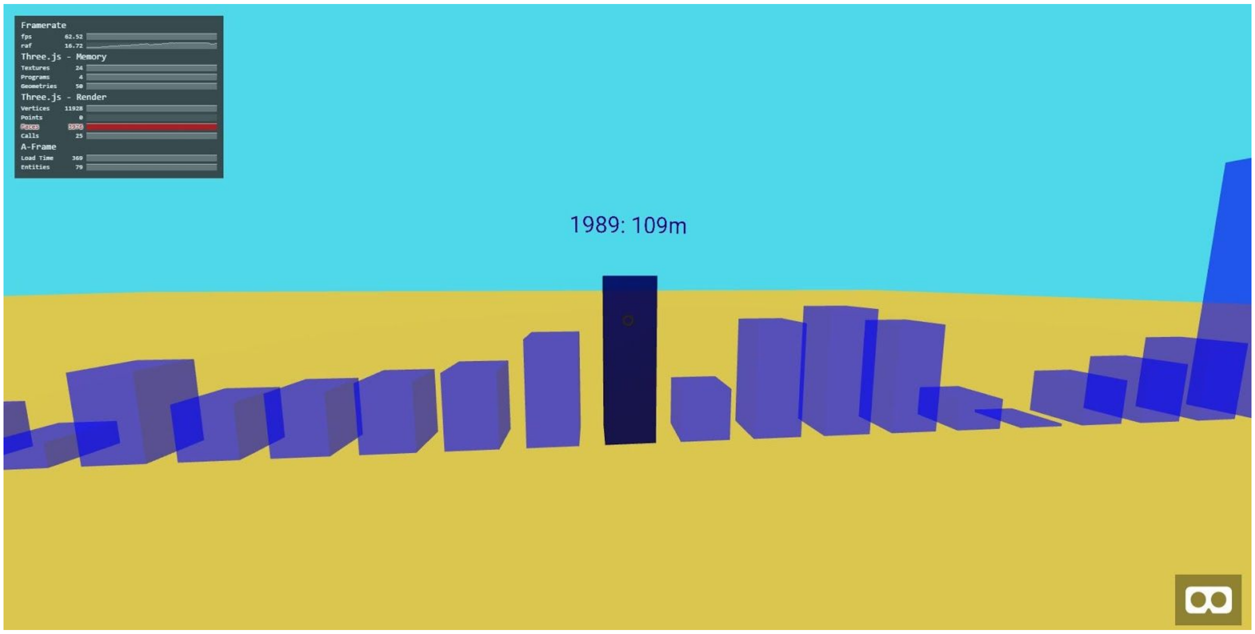
```
AFRAME.registerComponent('turnOff',{
 init: function(){
    var el = this.el;
    el.addEventListener('click', function(evt){
    el.setAttribute('visible', false);
```

```
            });
  }
});
```

Appendix C: Screenshots

Screenshot 1: Welcome

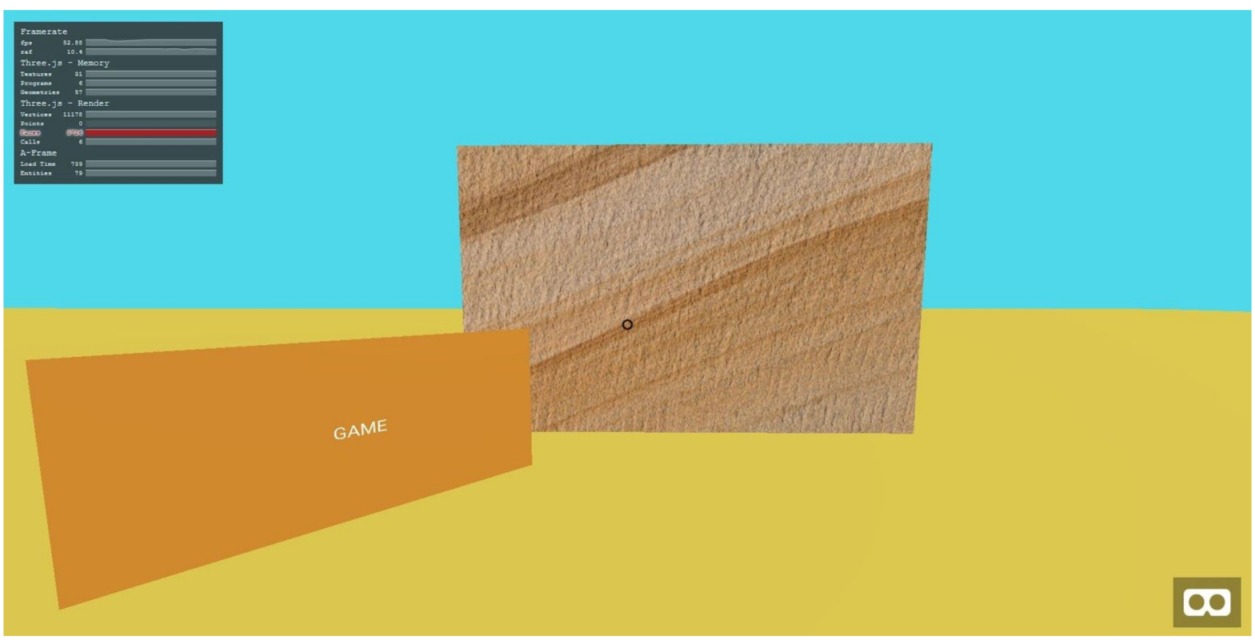
Screenshot 2: BarChart



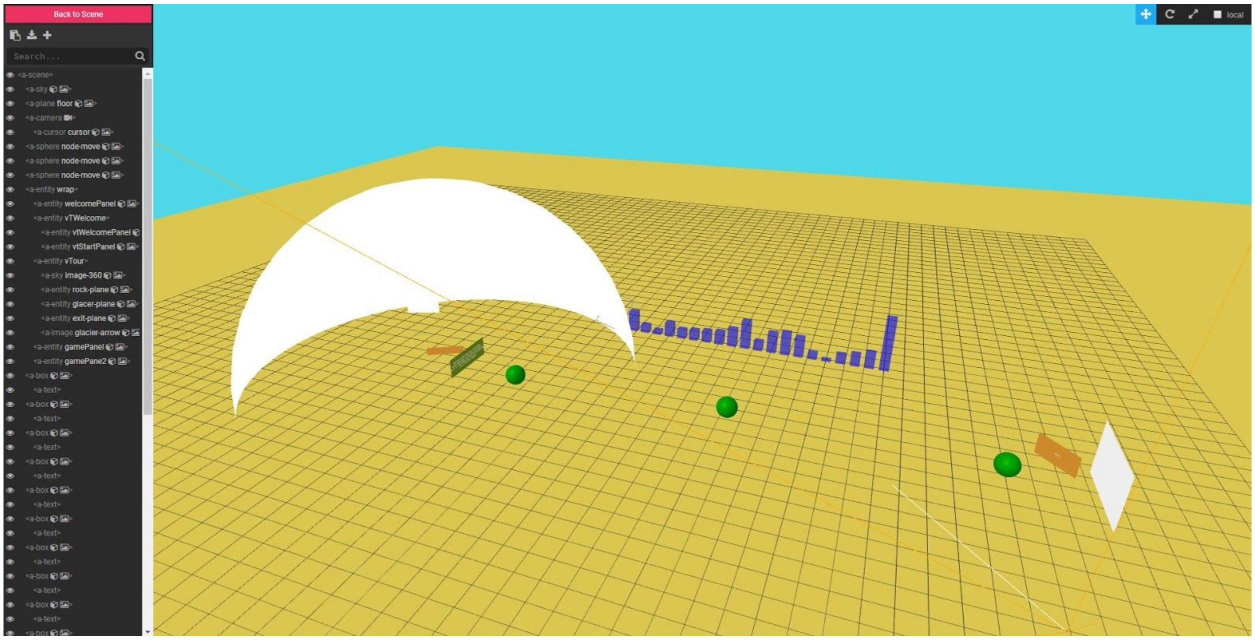
Screenshot 3: Virtual tour audio panel and arrow annotation

Screenshot 4: Virtual tour exit

Screenshot 5: Game Element



Screenshot 6: Scene View



Appendix D: Presentation Slides

CM4018 - Honours Individual Project

Project Presentation and Demonstration - Maxwell Knox 1507205

Introduction

- What is the potential for WebVR as a tool for learning?
- WebVR is an experimental JavaScript API.
- It allows devices to access VR content through a web browser.
- It is therefore compatible with a wide variety of device types.
- When deciding upon the direction I wanted the project to take, I looked to my past experience and areas of interest.
- User Experience focused, Web-based, Educational, Cutting-Edge.

Research

- Began by reading and sourcing reference material.
- Two major components within the research phase of the project.
- Literature review
  - Timeline and current state of VR
  - Education and 3d/multimedia.
  - Combining the two.
  - WebVR and tools for creating experiences.
  - Best practices to follow when developing for VR.
  - Best practices for pedagogy.

  Requirements
- Critical review
  - What is out there?
  - How does it relate?
- A-Frame

Design

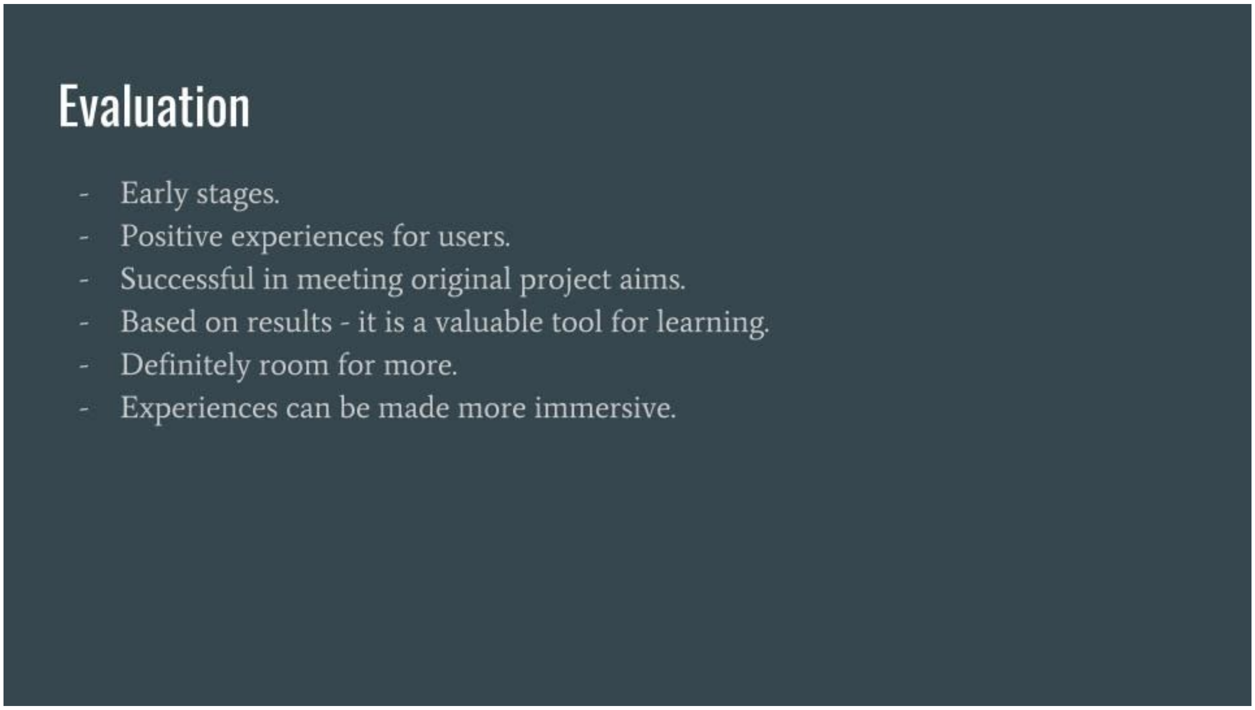
- The educational context
- Choosing a theme and aesthetic
- Design process
  - Initial ideas
  - Storyboards/Interactions
  - The user experience
  - Narrowing down the scope - prototyping
  - Focusing on entry-level hardware
- End results
  - Courtyard concept
  - Three distinct experiences within the prototype
  - Two main methods of interaction

Implementation

- Resource creation
  - 3D Modelling
  - Photography
  - Audio
- Locations/Experiences
  - Start/Tutorial Area
  - The Virtual Tour
  - Game
  - Data Visualisation
- Version control and deployment.

Testing

- Testing of functional requirements
  - Agile development allowed for greater freedom.
  - Unit testing.
  - Local vs Live.
- Usability
  - Users given brief instructions prior to engaging with the application.
- Qualitative testing methodologies
  - Thinking aloud
  - Questionnaire
  - Cognitive Walkthroughs/Personas



Appendix E: Social, Legal and Ethical Issues

Social Issues

The democratisation of educational technologies was an important focus of this project. The idea that everyone should have a right to an education is an important one. This project sought to explore the possibility that VR learning experiences could be made available to as many people as possible. The elimination of the need for expensive proprietary technology and software could help to remove the barriers to education delivered through this medium. More and more people worldwide are connecting to the web and the prevalence of smartphones is a large factor in this increase in access. Especially in less developed countries where many do not have access to desktop PCs, yet may be more likely to have the chance to own or at least have access to a smartphone.

Legal Issues

I do not believe that there were any considerable legal implications or considerations relating to this project. Most of the materials used within the project were created by myself, and any materials created by other parties that have been used in the project have been done so with permission and referenced accordingly.

Ethical Issues

While conducting the user experience evaluations it was important to maintain a professional and ethically sound demeanour. The questions asked of the interviewees were considered during the planning of the interview, and designed in such as way so as not to be intrusive or relating to any subjects which participants might find objectionable or offensive. Study participants were advised of the correct way to use any equipment that was involved and were made aware that they could ask for any assistance they required and were free to leave at any time.