Mars Interactive: Exploring the Immersive Potential of Browser Based Extended Reality

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Abstract

The Covid-19 pandemic has resulted in an increased demand for online collaborative tools, one such area which has seen a surge in interest has been in eXtended Reality (XR). Though tools such as Zoom and Skype have existed to simulate the environment of professional meetings there has been an absence of an online alternative to kinaesthetic tasks. Extended reality has seen a wide range of uses both professionally and for entertainment, the value of which comes from the immersive capabilities of extended reality applications. This project seeks to explore the implementation of extended reality within a web browser environment with the aim of understanding the limits and capabilities of immersive experiences in comparison to similar applications which rely on local installations. To achieve this goal this project will focus on the implementation of a Virtual Reality environment which seeks to emulate the experience of exploration of the Mars surface. This project will also explore an additional technology under the extended reality umbrella term known as augmented reality in the form of a digital Mars rover which will be controllable in the real world environment through a camera lens. The desired end result of this investigation will be a greater understanding of the current capabilities of web browsers to support immersive extended reality experiences.

Declaration

I, Kyle Dick confirm that this work submitted for assessment is my own and is expressed in my own words. Any uses made within it of the works of other authors in any form (e.g., ideas, equations, figures, text, tables, programs) are properly acknowledged at any point of their use. A list of the references employed is included.

Signed: Kyle Dick

Date: 22/11/2021.

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1. Introduction

In the past XR experiences have been limited mostly to systems which can support their installation and operations. Recently there has been a push to integrate this technology into web development such that similar experiences are accessible through a standard web browser. A forerunner in this regard was the WebVR API which is currently deprecated, replaced instead with WebXR that expands its focus from just Virtual Reality to the entire spectrum of Extended Reality [1]. Presently VR has been identified as a desirable solution to the problem of training students for practicing surgery in the medical field with benefits associated with the innate advantages of virtual environments and the improvement to real world abilities [2]. The problem presented with these applications however is the reliance on the systems which they run with VR applications sometimes requiring demanding hardware in order to support the rendering of their 3D assets. The strength of XR based training is the ability to construct scenarios which would be either dangerous or costly to implement in the real world and part of the identified benefits of this medium is the immersive capabilities innate to the technology which has shown positive results in current use [3].

The aim of this project is to engineer an immersive experience using the WebXR API for hardware integration into a web browser environment. The importance of this system would be in the benefits to real world training applications where immersive experiences are valuable in attaining experience while protecting trainees and providing a low cost alternative. One of the aspects of this project which would provide challenge is in the management of different aspects of XR as this encompasses both VR, AR and MR. The goal would be to explore the immersive capabilities of at least two of these technologies, namely VR and AR. A further breakdown of the objectives that were outlined to achieve the aim are included below. These were constructed with the explicit goal to answer the question of whether the web browser is a suitable environment for immersive extended reality experiences.

1.1 Objective A: Mars Exploration Scenario

To explore the capabilities of web browser based VR this project will attempt to engineer an immersive experience modelled after the planet Mars. This virtual environment would allow for many demonstrations of how the technology could support immersive experiences.
An overview of the steps involved in this process are discussed below. This objective was developed using an Oculus Quest 2 headset.

Objective A.1 Construct a 3D environment which supports a user's movement through the terrain.
- Allow for the loading of 3D models to act as terrain.
- A lighting system which mimics the presence of the Sun.

Objective A.2 Implement a model of Mars' physics into the environment.
- Basic capabilities for the user to pick up objects and put them back down in the environment.

- Objects in the environment move in a manner expected of the environment's gravity.

Objective A.3 Attach correct textures to the environment that displays correctly while the viewpoint is moved.

- The viewpoint refers to the areas which are currently in view for the user.
- Due to memory constraints for browser based applications this area must handle the ability to manipulate resolution such that the textures do not break immersion by being too low quality when the user is close but will also not cause problems with memory by loading high quality textures where the user cannot perceive them.

Objective A.4 The addition of interactive elements to the environment.

- Small goal based objectives for the user to engage in within their surroundings.
- This will involve interacting with the surroundings; picking up objects or other users.

Objective A.5 Integrating internet related functions

- Allow for multiple users to inhabit the same environment and interact with the same objects.
- A ‘tag’ system such that objects in the environment can offer to redirect the user to other locations within the web.

1.1 Objective B: Mars Rover Controller

To explore the capability of browser based AR this project will remain with the theme of Mars and implement a virtual replica of a Mars Rover which users can place in their real world environment and control. When developing this objective the hardware involved is assumed to be a mobile phone with AR capabilities.

Objective B.1 Implement the placing of virtual objects within the real world environment.

- In the early stages of this objective multiple objects should be loaded into the environment to determine the capabilities of different sizes

Objective B.2 Implement the movement of an object in the real world environment.

- An object should be able to move around in the real world environment in a believable way.
- This section will contribute to an immersive experience with accurately moving the Mars Rover in the following section.

Objective B.3 Implement control of the Mars Rover through the web browser.

- Multiple forms of control should be explored which can include using on screen buttons or drawing a path through the camera.

2. Background

This section is dedicated to the discussion of the concepts underlying the solution to our aims. Within this section Extended Reality and the related areas will be further explored as this will aid in the discussion of the solutions later within this document.

2.1 Discussion of Extended Reality (XR)

XR is an umbrella term which encapsulates Virtual Reality, Augmented Reality, Mixed Reality and other forms of using rendered graphics to alter the perception of an individual's surroundings. The scope of the solutions discussed in this report refer primarily to the applications of Virtual Reality and Augmented Reality within the web browser however the other areas of Extended Reality are valuable to include due to the potential for future work based on the outcomes of this project to incorporate these other applications.

2.1.1 Virtual Reality (VR)

VR involves creating a virtual environment through entirely 3D rendered components that is displayed to the user through appropriate hardware, commonly known as visors. Most of these visors are paired with a set of controllers which will communicate with the WebXR API in this solution to interact with the virtual components of the environment. VR has seen a demand within fields in which training scenarios are either too dangerous or expensive to recreate in a real world case. The company VR-Interactive has already presented virtual reality solutions to the demands of industry for VR training tools, one such case being a crude oil burner simulation [4].

2.1.2 Augmented Reality (AR)

AR involves capturing the real world through devices such as the camera of a mobile phone and rendering virtual elements which are able to maintain a consistent position in the environment. These objects can persist within the environment when the camera is not currently pointing in its direction, using the real world surfaces and environment to track the positions of virtual objects. A popular example of this technology being used is the early implementations present within the Nintendo 3DS which used physical cards to initialise the virtual objects in the environment. Since then this technology has progressed such that the virtual objects no longer need any specialised real world objects to initialise the virtual elements, this can be seen in the recent google AR & VR experiments where AR is used to provide directions with google maps [5].

2.1.3 Mixed Reality (MR)

MR technology lies between the extremes of both VR and AR. While one method focuses on replacing the real world with a virtually rendered one and the other relies on rendered graphics which overlay the users surroundings, MR seeks to blend both in order to combine the virtual components with the real world. The Microsoft Hololens is an early adopter of this type of extended reality, a visor which resembles the hardware which is known to support virtual reality however replacing a digital screen with a clear panel through which rendered graphics are drawn [6].

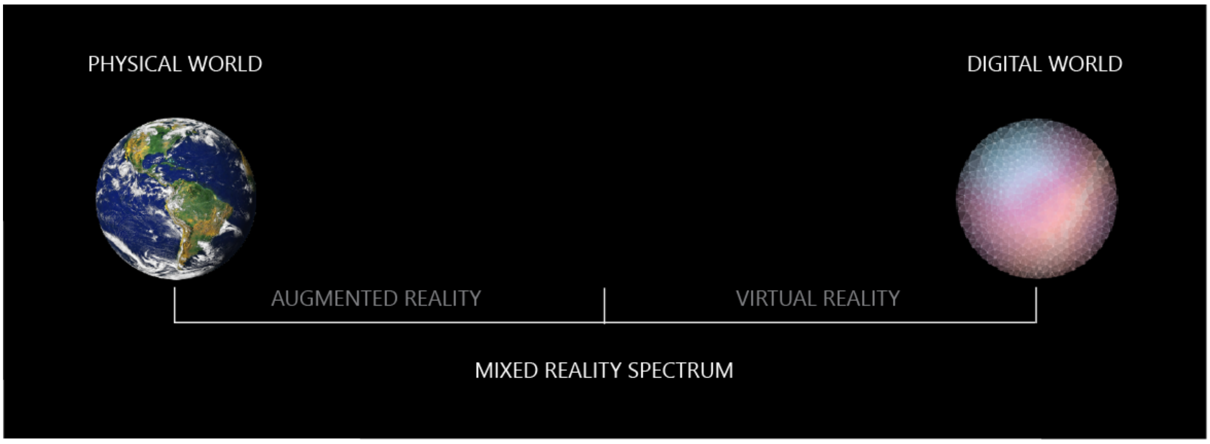

Figure 1: The Mixed Reality Spectrum [6]

3. Review of Related Literature

To assess the achievability of the objective given earlier in the introduction this section will examine similar work which deals with areas related to the aim. Through examining the conclusions that previous research has arrived at the stronger the case for the proposed aim will be. The literature which has been collated below has been organised into sections related to aspects of the development process.

3.1 Virtual Environments

Objective A which was outlined in an earlier section is rooted in the idea of engineering a virtual environment which the user is able to interact with through exploration and manipulation of objects. In the past there have been investigations into using virtual environments for a wide array of uses, one of which is its applications within education. Analysis of the applications of virtual environments has shown there to be a benefit to the ability of an individual to learn new skills which would normally require for a real world experience to develop naturally. The implementation of virtual reality for this has the additional benefit of decreasing the risk of damage to the individual and reducing costs associated[2][3]. The benefits of VR specifically have also shown benefits to the development of knowledge where practical kinesthetic learning methods would not traditionally be incorporated.

3.1.1 Collaborative Virtual Environments

Outside of training scenarios virtual reality and virtual worlds have seen popular use in the entertainment industry. One particular case is the social application VRChat which allows for users to assume the role of 3D avatars in a virtual world and interact with others users through the use of either VR hardware or a standard computer desktop configuration [6].

Figure 2: Virtual avatars greet a user within a virtual world through the application VRChat [7].

The application, while built for entertainment purposes, has relevance to our goals as it provides evidence that there are implementations for collaborative experiences within XR which are accessible through the use of internet access. The application itself requires an installation which is where the implementation differs from the stated goal of allowing the user to access from the web browser.

3.1.2 Immersive Experiences and XR

The strength of XR lies in the immersive potential that it contains which is an important role especially for any application which incorporates VR. The technical requirements of the engineered solution should be grounded in an attempt to create an immersive experience and as such the success that previous attempts with immersive systems have attained should be examined. A study which examined the effect that a Virtual Reality Learning Environment (VRLE) had on a students understanding of English paragraph structure found that the benefits that immersion was most suited as an exogenous variable in regards to how beneficial it showed to be in the outcome [8].

3.1.2 Interaction with Virtual Environments

A core component to the engineering of an immersive virtual experience is how the user is able to interact with the different objects present within the environment. A study was conducted to investigate how Fitts' Law applies to the 3D control methods of virtual reality [9]. The study found that Fitts' Law extended into applications involving stereoscopic displays however the methodology used is currently in need of validation through further research. The results of this study however provide evidence that interaction with virtual objects is possible as Fitts' Law can be extended to the possibility of a user moving a virtual appendage to a target location in order to interact with virtual components within the target area.

3.1 Hardware Devices

There is currently a large range of devices available both in research and to the public which allow for interacting with the virtual world. The devices can be separated by whether they are output devices or input devices.

3.1.1 Output Devices

Output devices are responsible for displaying the virtual elements of extended reality. They are available in a range of forms, each catering to a different section of the XR spectrum. In the objectives previously it was stated that the focus of this project would be in the realms of VR and AR. The main output devices that are concerned with these areas are those which are able to replace the real world environment with a virtual substitute and those which are able to capture the real world while rendering graphical components within that environment often overlaying the presence of real objects.

The desire to implement AR solutions to ongoing problems in education has been under research with one particular study exploring its application in university laboratory exercises

[10]. This particular study also investigated the attitudes towards the technology by those who interacted with the devices. One particular attitude which this implementation seeks to resolve was the attitude that the technology would prevent a student from studying the material at home due to the systems required being located within the university. The solution this project proposes would be entirely hosted within a web browser meaning the AR technology could be experienced by any individual with access to a web browser and a mobile device capable of AR support. An additional point shown by this study was the evidence that interaction with virtual elements within an AR experience has a grounded possibility.

Virtual Reality Visors are the most common method of displaying VR to a user however there are concerns inherent to this medium, one notable example is the phenomenon of Virtual Reality Sickness. This is a form of motion sickness which an individual can experience through the use of VR visors, research was conducted which attempted to create an index for this form of motion sickness through the use of a VR motion sickness simulator.

3.2 Web Based Extended Reality

The current landscape of support for web based extended reality is currently still in its relative infancy compared to the other forms available commercially however there has been exploration into the topic by previous researchers. One particular study explored the applications of A-Frame for use in collaborative virtual reality solutions to training scenarios. This implementation found that the systems involved would begin to see negative impacts on the performance as the quantity of users within a scene increased, however the methodology provided evidence that a virtual environment capable of supporting multiple users is possible within a web browser environment [11].

4. Requirements Analysis

Previously in the introduction the aim and objectives of this project were briefly outlined. This section will take an in depth analysis of those objectives and the steps taken to achieve them.

4.1 Aim and Objectives

The aim of this project which was defined earlier is to explore the immersive potential of extended reality within a web browser environment. The approach taken when creating the objectives set to achieve this aim was to define the manner in which immersion would be explored. For each of the two main objectives immersion was defined as being the ability for the user to interact with the rendered elements of the virtual world as if they were physical objects within the environment. Examples of this in practice would be the user picking up a virtual representation of a rock within the virtual world of Mars and tossing it into the air, they would observe the rock to leave their grip and travel in a trajectory expected of the Mars environment. A similar example which applies to the AR objective is the ability to remotely control the virtual rover through the use of the browser, similar to a remote control car.

4.1.1 Objective A: Mars Exploration Scenario

The main objective of this section is to construct a VR simulation of the planets Mars which users can visit through a standard web browser. As stated previously the experience should be immersive so when breaking down the steps involved to achieve this main objective, referred to as the sub-objectives in this context, a particular focus is situated on features which allow the user to interact with the virtual elements.

Objective A.1
This objective is centered on creating a generic 3D VR environment which will be accessible through the web browser. For the purposes of hosting it was decided that Github Pages would be the most optimal method for the purposes of achieving the aim, the extended reasons for this will be discussed in a later section. The main reason for this decision however is due to Github being used for version control of the project which made Github Pages an ideal solution compared to employing a paid service or creating a server which may detract time from the goals of the project.

The result of this objective should be for a featureless 3D VR environment in which the user can access through the web browser and explore through movement across the terrain. Within this environment will be several objects which exist as a means of testing the interactions between the user's movement and the environment. The terrain itself and the objects within it will primarily be objects imported into the environment which originate as assets developed specifically for this project or properly sourced assets located from third party sources. In the early stages of the project there were considerations made as to which framework would be best suited for rendered the 3D graphics required for this project, the results of this comparison were that A-Frame would be the ideal choice due to its simplistic nature compared to the other available frameworks and it's relation to Three.js which would allow for a greater degree of control. A-Frame also contains the benefit of importing glTF models which will act as the objects in the virtual world [12].

Lighting is an important aspect to the virtual world as it allows for the objects present to be seen by the user. In the case of this objective the light should be present as a representation of the Sun, as is the case on the real Mars. The minimal requirement would be for a single static placement of the light source however the most ideal result would be a dynamic light source which moves through the environment as time progresses as this will result in a greater degree of immersion.

The virtual world is intended to be rendered through the use of a VR Visor which will be operated by the user and due to this there are unavoidable restrictions in how the movement system will operate in the system. The vast majority of users will have restrictions in regards to the available real world space in which they can inhabit, due to this it is inevitable that a user will try to move in the virtual world but will be prevented as a barrier in the real world prevents the movement. It is of great importance that an alternate movement option is available to the user, the proposed solution is for the user to have the ability to move their position in the world through the use of a placed marker to which they will be relocated. The exception to this would be users who are experiencing the virtual world through a computer screen in which case their movement is not limited.

The benefits this objective will contribute to the immersive experience will be observed in the movement capabilities of the user. The result of this object should allow the user to move freely within the environment and explore a featureless terrain.

Objective A.2

This objective will focus on improving the ways in which the user will be able to interact with the virtual environment. At this stage the interaction the user should have with the environment is restricted to movement around the virtual space which this objective will seek to expand.

The first step that will be taken in regards to expanding interaction is the implementation of features which will allow the user to use input devices such as touch controllers to manipulate objects in the environment. A simple example of this which was mentioned earlier is the ability to pick up a rock and toss it back out into the environment. In order for this to work however there must be a system in place to handle the physics of objects within the environment. Defined more exactly, this means that the system should handle the displacement of objects in the environment in such a way that it mimics how objects in our real world behave as a result of gravity. An additional effort should be made to model the way that the physics engine treats the objects to reflect the gravity of objects on Mars rather than Earth.

The benefits this objective will contribute to the immersive experience will be observed in the ability the user gains to manipulate the objects in the environment. The user will be able to gain an understanding for how their environment behaves and through such an immersive understanding of the Mars environment.

Objective A.3

At this stage the virtual world will consist of a generic VR environment with an implemented physics engine with which a user can enter into and interact with objects in the environment. The current environment will however reflect Mars in only the physics which this object seeks to remedy. This section will give an overview of how this environment will be transformed to more closely resemble the Mars surface.

The challenge of this section was in finding a way to provide the user with an accurate visual representation of the Mars surface while balancing the ability to interact with the environment. The initial plan for this section involved using images as a texture for the meshes which the 3D models would use, however this introduced a problem in which pictures for certain geography would feature objects which the user should expect to be able to interact with but would be unable. The solution that was devised to solve this problem was to select one of the quadrangles of Mars and instead model the environment to reflect this smaller area of Mars for the user to explore. The final decision was made to base the setting of the experience within the Jezero Crater due to this being the current location being surveyed as a part of NASA's Mars 2020 project [13].

The constraints which will affect the progress of this objective result from the web browsers limits on memory. This is in direct conflict with one of the ways that the project hopes to achieve its aim as memory will be important in displaying high resolution textures to the objects in the virtual environment. During this section care must be taken to allow the system to manipulate the resolutions at which textures appear such that the immersion is not broken for the user when faced with a low resolution image at a close distance, low resolution imagery however may find utility in allowing the rendering of vast distances without placing strain on the memory limits of the web browser.

The benefits this objective will contribute to the immersive experience will be observed in the users ability to recognise their surroundings as being on the planet Mars. Previously the terrain would be a bland textureless environment, with the addition of the contributions from this objective it should resemble the Mars environment closely.

Objective A.4

The current progress of the virtual world should provide the user with an environment which is recognisable as Mars with possibilities for interaction with the environment. This section aims to demonstrate the possible activities the user could partake in while within the virtual world. The method to be used to achieve this goal will be through the introduction of goal based objectives for the user to complete. Each of these should reflect the previous efforts of the objectives until this point.

This stage of the project will also introduce the Mars Rover which will roam freely through the environment with the possibility available for the user to interact with the object. This will be encouraged through an objective to guide the object through the use of the controllers. The exact objectives will be determined after review of the previously implemented objectives to account for complications which may arise during the development process, however the following objectives should be included at a minimum:

1. An objective for the user to walk from one point within the virtual world to another. This may involve a change in altitude. This objective should also account for the different movement types (marker based relocation or free movement) and as such should include both variants in their completion conditions.
2. An objective to interact with an object in the environment. This could be with a simple rock on the surface or by guiding the rover to a point within the virtual world.

The benefits this objective will contribute to the immersive experience will be observed in the user having a greater understanding of the way the system allows them to have a degree of control over the environment they exist within.

Objective A.5

At this stage of development the virtual world should be completed with the user presented with opportunities to interact with their environment in ways which are perceived as being immersive. The system until this point has neglected the advantages to the experience which could be contributed as a result of the web browser environment that it is hosted within.

One of the main additions to the system that will be contributed within this objective will be the support to a collaborative experience. This will take the form of allowing users to share the same virtual world and interact with the environment simultaneously. This would require the avatars of each player to be visible to all others within the session with some form of unique identification for each player through the introduction of giving the user an identification string which they could change from within the experience.

The final addition which will be made in this section is the introduction of a ‘tag’ system in which attachments could be made to objects in the virtual world which can be interacted with to redirect the player to other locations on the web. There is a high risk for this addition to contradict with the players immersion however if they are pulled from the experience by a redirect which will require experimentation to find the best method of achieving a smooth transition with this system. The currently presented solution is for the ‘tags’ to instead open a new tab within the user's browser which will result in them staying present in the virtual world instead of being extracted from it.

4.1.2 Objective B: Mars Rover Controller

The main objective of this section is to explore the immersive potential of extended reality through the use of the WebXR API to support hardware which allows for AR experiences.

The resulting goal from the steps in this objective will be the creation of a virtual Mars rover which the user can pilot in the real world environment viewable from the camera of a device which supports AR content. The hardware used in the exploration of this objective would be a standard mobile phone which is able to support AR content.

Objective B.1

The goal of this objective is to utilise AR supporting hardware to render virtual objects in the real world environment captured through the camera. The main challenge in this area is creating the system such that it is able to identify surfaces within the real world environment and render the objects on these surfaces correctly. An object should not float above the surrounding scene and instead sit on surfaces in the environment whether these are the floor, a table or some other flat surface captured by the hardware.

The objects rendered should consist of simple 3D shapes to test the capabilities of the system. The ability to resize the models used to render the shapes should be explored as this will benefit the immersive experience through the simulation of depth. When the angle in which the object is viewed through is moved the object should also retain its position within the scene and not move with the camera.

An important distinction to be made in this section due to the range of experiences that Extended Reality can support is to clarify that the virtual objects will only be viewed through a digital display attached to the device capturing this environment. The reason for this clarification is due to the fact that extended reality can include the implementation of holographic imagery which this project does not include in its scope.

Objective B.2

The goal of this objective is to implement the movement of virtual objects within a real world environment as presented through a digital display. This means that the objects displayed will have the ability to move in the environment independent of the angle at which they are being viewed. The object's movement should incorporate the resizing feature previously implemented in order to gain a sense of depth as objects further away from the camera are displayed smaller than objects closer to the camera. A possible inclusion to this objective is the ability for the system to determine separate surfaces and prevent the movement across surfaces which would result in a drastic change in elevation. Example, the object attempts to move from a table to the floor below and ceases movement at the table edge.

The movement which objects perform should be issued by the system as instructions instead of being the result of any input from the system's user. The implementations contributed by this objective are to provide support for the following objective in which the movement should be dictated by the user.

Objective B.3

The goal of this objective is to achieve the rendering of a virtual mars rover which possesses the ability to move in the environment instructed by the user.

The first step in achieving this goal is the loading of an object which acts as the rover. The object should be supported by all of the earlier systems implementation in this main objective. The additional feature which this objective seeks to implement is the movement of the virtual object through instructions given by the user. These instructions will be determined by buttons which can be selected within the web page.

A possible feature within this section would be the ability to connect a mobile device to the web page on a desktop such that the mobile device could act as a camera for displaying the virtual objects while the desktop acts as a medium for control.

4.2. Textual Requirements

4.2.1 Requirements Key

This section details the requirements for the system. The following key is used to track the requirements with each requirement marked with either an A or B to indicate which objective the requirement encompasses. If a requirement lacks this indicator then the requirement is assumed to encompass both objectives.

ID	Requirement	Priority
FR(A/B)-U/S-No.	Textual description of the requirement.	MoSCoW priority of the requirement
NFR(A/B)-P/C/R/S/U-No.	Textual description of the requirement.	MoSCoW priority of the requirement

Functional Requirements (FR) are requirements which detail the system functionalities and how the function of the system will help achieve the overall goals. The types of functional requirements this system is concerned with are as follows:

1. User (U) - Requirements related to how the user interacts with the system.
2. System (S) - Requirements related to how the system behaves.

Nonfunctional Requirements (NFR) are requirements which detail issues related to the system's capabilities and its constraints. The types of nonfunctional requirements this system is concerned with are as follows:

1. Performance (P) - Requirements related to how the system is able to perform. This includes the ability to deliver a stable frame per second count when serving the graphical components.
2. Compatibility (C) - Requirements related to how well the system is able to perform when varying hardware, browser and the respective versions of both.
3. Reliability (R) - Requirements related to how prone the system is to both minor and critical failure.
4. Security (S) - Requirements related to the security of the system and the protections in place against malicious use. With the main focus of this system based within virtual

reality this area will also concern itself with protecting users from malicious imagery being injected into the user's vision.
5. Usability (U) - Requirements related to how easy the user can operate the system and navigate its functions.

Both functional and nonfunctional requirements have been prioritized using the Moscow method. Therefore each requirement has exactly one of the following priorities:

- Must Have (M) - The requirements with the highest level of priority. These requirements are fundamental to the operation of the system.
- Should Have (S) - The requirements which are not as fundamental to the system as the previous category but ideally should be present in the final version of the system.
- Could Have (C) - The requirements which are not important to achieving the goals of the system but would be beneficial to the system.
- Won't Have (W) - The requirements which will not be present within the system. This is either due to them not fitting the scope of the system or being ill suited but still worth noting.

4.2.2 Functional Requirements

Below a collection of the functional requirements are given. The order in which each appears correlates to the timeline in the sense that earlier objectives which involve the presence of a requirement will result in a higher position on the below table.

ID	**Requirement**	**Priority**
FR-S-01	The system must be accessible through a standard web browser.	M
FR-S-02	The system must allow for the loading of 3D models which will act as objects in the environment	M
FR-S-03	The system must support 3D models imported through the format glTF (gl Transmission Format).	M
FR-S-04	The system must utilise the WebXR API to integrate the XR hardware into the web application.	M
FR-S-05	The system must be able to render 3D graphical objects in the environment.	M
FR-S-06	The system must include lighting which illuminates the environment such that the rendered objects are visible to the user.	M
FR-S-07	The system should allow for the use of a digital screen to act as the visual output in the absence of XR hardware.	S
FR(A)-U-08	The user must be able to move in the real world while operating XR hardware and have this movement reflected by the system.	M

FR(A)-S-09	The system must support the placing of markers in the environment as an additional movement method	M
FR(A)-U-10	The user must be able to place markers in the environment which can be used to relocate their position.	M
FR(A)-S-11	The system must support a physics engine which handles the movement of objects in the virtual world which reflects the presence of gravity.	M
FR(A)-S-12	The system should resemble the gravity of the Mars environment in its application of the physics engine	S
FR(A)-U-13	The user must be able to interact with the surrounding environments by using controllers to pick up objects in the virtual world.	M
FR(A)-S-14	The system must process interactions made with the environmental objects to be handled with the physics engine after the user has ceased contact with the object.	M
FR(A)-S-15	The system should feature terrain which resembles the Jezero Crater geography.	S
FR(A)-S-16	The system must be able to display images in the environment as textures which are applied as meshes to the virtual objects.	M
FR(A)-S-17	The system must scale the resolution of textures in the virtual world with relation to the player's proximity.	M
FR(A)-S-18	The system should allow for the creation of objectives which will have a set of conditions for completion.	S
FR(A)-S-19	The system should display the current objective in an area which the user can view.	S
FR(A)-U-20	The user could be able to view the list of objectives in the environment on command.	C
FR(A)-S-21	The system should allow for objectives which have had their completion conditions reached to be archived as such.	S
FR(A)-U-22	The user could be able to reset an archived objective such that they could experience it once again.	C
FR(A)-S-23	The system should include the presence of a Mars Rover object in the environment.	S
FR(A)-S-24	The system should allow for the Mars Rover object to patrol the virtual environment along a set of predetermined paths.	S
FR(A)-S-25	The system could allow for the Mars Rover’s movement patterns	C

	to reflect that of the Perseverance rover.	
FR(A)-U-26	The user should be able to influence the movement of the Mars Rover through interaction with it.	S
FR(A)-U-27	The user should be able to use controllers to interact with the Mars Rover, ie. pushing buttons present on the object.	S
FR(A)-S-28	The system should allow for any interactions in the environment which require the presence of a physical controller such as an XR touch controller to be possible with a standard keyboard and mouse configuration.	S
FR(A)-S-29	The system must allow for users to join into the same session as other users.	M
FR(A)-S-30	The system must allow for the users to view the avatars of other users within their session.	M
FR(A)-U-31	The system should show a unique identifier for each user.	S
FR(A)-S-32	The user could be able to change their identifier.	C
FR(A)-U-33	The user could be able to create their own private sessions.	C
FR(A)-S-34	The system should allow for URL attachments to objects in the environment.	S
FR(A)-S-35	The system should be able to open a new tab within the user's browser when a URL attachment is interacted with.	S
FR(A)-U-36	The user could be able to disable URL attachments to prevent the opening of new tabs.	C
FR(B)-S-37	The system must be able to utilise the WebXR API to render virtual components into a captured scene of the real world.	M
FR(B)-S-38	The system must be able to delineate the separation of two different surfaces.	M
FR(B)-S-39	The system must place objects in the environment such that they appear to be on top of identified surfaces.	M
FR(B)-S-40	The system must be able to resize placed virtual objects in the scene.	M
FR(B)-S-41	The system must be able to retain the position of the objects within the 3D space.	M
FR(B)-U-42	The user must be able to move their camera within the real world to view the virtual objects at different angles.	M
FR(B)-S-43	The system must be able to instruct objects in the virtual world to	M

	move to a specific point.	
FR(B)-S-44	The system should instruct moving objects with specific paths in order to reach their destination.	S
FR(B)-S-45	The system should resize models in the environment as they move in order to maintain the illusion of depth.	S
FR(B)-S-46	The system could possess the ability to identify separate elevations between surfaces.	C
FR(B)-S-47	The system should instruct a moving object to stop if its path would take it to an area it would not be able to access if it were a real object.	S
FR(B)-S-48	The object placed within the environment must possess the model of a Mars Rover.	M
FR(B)-U-49	The user must be able to instruct the rover object with specific movement instructions.	M
FR(B)-S-50	The system must respond to any movement instructions issued by the user by parsing those instructions to move the object.	M
FR-U-51	The user should be able to select which experience they wish to partake in. The choices being either the Mars Exploration Scenario (VR) or the Mars Rover Controller (AR).	S

4.2.3 Non-Functional Requirements

ID	**Requirement**	**Priority**
NFR-P-01	The system must be able to render the environment while maintaining a stable fps (frames per second) count	M
NFR-S-02	The system must be protected from outside attacks which could affect the images displayed to users	M
NFR-R-03	The system must not suffer critical failures during normal operation	M
NFR-U-04	The system controls should	S

	be easily understood by the user	
NFR-C-05	The system should run on all the popular web browsers	S
NFR-C-06	The system should be able to fall back on the device screen in the absence of the appropriate hardware	S

5. Evaluation Strategy

This project will take an iterative approach to evaluating the progress of each objection with each iteration involving a review of the requirements involved to present a case for whether the requirements were implemented to a standard which is acceptable before progressing to the following objective. The methodology used for the evaluation will emulate the systemic review of the SCRUM method however with the amendment that the team will consist of a single member.

5.1 Requirements Assessment

The main indicator of the progress of the project is the progress made in achieving the requirements laid out earlier within the document. In the next section the requirements will be assigned to specific time frames at the end of which the progress of each requirement will be assessed to determine whether the produced result satisfies the needs of the requirement. Should a requirement which is crucial to the development of another requirement suffer from inadequate implementation then the project time plan will need to be revised to accommodate the time required to make changes.

5.2 Progress Review

At the conclusion of each week in order to assess the progress of the project a short document will be maintained which details the contributions made within that week. This will be used to compare the state of the project to the expected state as according to the Gantt Chart explained in the following section. These reviews will also be conducted at the conclusion of objectives.

In the final stages of the project the completed objectives will be assessed in their performance against similarly designed systems with the distinction that the systems compared will not be hosted within a web browser environment. Through this comparison the value of the produced applications will be assessed through examination of both the technical performance of the systems and their ability to convey the intended scenes to the user. The criteria by which the comparisons will be made relate to the previously defined non-functional requirements with particular importance given to the performance aspect. The reason that this area will be given special attention is due to the focus of this project on delivering an experience comparable to other solutions which means that the development process is focused on the technical abilities of the system.

Examples of comparisons that will be made between systems.

1. The quality of the models which each system is able to support.
2. The quantity of objects which each system is able to handle within a scene.
3. The reliability within the system for protections against system failure.

In future stages a comparison matrix will be devised which will assess the different aspects of each system in a numerical scale.

6. Project Management

6.1. Project Timetable

To achieve a smooth development process the project requirements were organised within their set objectives and allocated to a time frame. This involved creating a Gantt chart through which the planning of each objective could be mapped and planned for ahead of time. The Gantt Chart is currently available within this project's GitHub repository.
Below the Gantt Chart excerpts for objectives A.1 and A.2 are included to showcase the format of the planning.

4.1.1 Objective A: Mars Exploration Scenario Timetable

Objective A.1
The following Gantt Chart considers requirements with the suffix id -01 through -10.

Requirement(s) ID	TASK TITLE	START DATE	DUE DATE	DURATION	03/01/2022					10/01/2022				
					M	T	W	R	F	M	T	W	R	F
A	**Explorable Area**													
FR-S-01,02,03, 05,06,07	Initialise the scene with basic flat terrain and static lighting.			0										
FR-S-04	Integrate the WebXR API into the environment.			0										
FR-U-08	Implement basic movement within the system using real world positioning			0										
FR-S-09,U-10	Implement alternate movement style using the marker based positioning.			0										

Objective A.2
The following Gantt Chart considers requirements with the suffix id -01 through -10.

Requirement(s) ID	TASK TITLE	START DATE	DUE DATE	DURATION	17/01/2022					24/01/2022					31/01/2022				
					M	T	W	R	F	M	T	W	R	F	M	T	W	R	F
A	**Explorable Area**																		
FR-S-11	Implement a basic physics engine in the virtual world to simulate effects such as gravity	17/01/22	21/01/22	5															
FR-U-13,S-14	Implement features which allow the player to pick up objects in the environment and throw them	24/01/22	26/01/22	3															
FR-S-15	Replace the terrain with martian geography (Jezero Crater Modelled)	27/01/22	27/01/22	1															
FR-S-12	Tweak the physics engine to support a Mars-like gravity	28/01/22	28/01/22	1															
FR-S-16	Apply textures to the included models which appear natural for the environment	31/01/22	01/02/22	2															
FR-S-17	Implement handling for the scaling of textures	02/02/22	04/02/22	3															

6.2. Project Organisation

This section details the methods used for project management. This includes the systems used to monitor the progress of the project and to make sure that the related documents and work contributed are kept secure.

6.2.1 Version Control

To achieve a secure storage place for the work contributed to this project all files which pertain to the project will be hosted within a Github repository [14]. This will allow for the progress to be tracked using the features offered by the website in addition to the innate advantage of providing additional security to the files against loss or corruption.

6.3. Risk Analysis

6.3.1 Risk Classification

To manage the progress of this project efficiently it was important to identify possible risks that could prevent the realisation of the goals laid out earlier in this document. To aid in the identification of the risks the following key was used to classify the associated risks:

- People (P) - Risks which are the result of issues related to those individuals involved in the engineering of solutions.
- Technological (T) - Risks which result from the technology being used to engineer the solutions. This involves the software, hardware and frameworks used.
- Requirement (R) - Risks which result from changes to the requirements of the project. Examples of such being a requirement being dropped from the scope or a requirements priority undergoing a change.
- Estimation (E) - Risks which result from ill estimations of the project timing, capabilities of an individual or understanding of a certain technology.

ID	**Risk**	**Risk Type**	**Description**
R-P1	Textual Title of Risk	People	Textual Description of the Risk

7.2.2 Risk Identification

ID	**Risk**	**Risk Type**	**Description**
R-P1	Illness	People	Particularly important due to current events surrounding the Covid-19 pandemic. If an individual falls ill during the implementation of the solutions this could cause contributions to the project to cease temporarily.
R-P2	Conflict of Timing	People	Events within the personal lives of the contributors could cause a temporary cease in addition to the solutions. This could be due to requirements for other courses or

			personal emergencies.
R-P3	Lack of Experience	People	The technologies involved in the project may be unfamiliar to those involved in engineering the solutions. Time has been taken to familiarise the contributors with the tools however a lack of understanding could cause temporary problems in achieving objectives.
R-T1	Loss of Project Documents	Technology	Currently important documents pertaining to the project are being stored both locally and in multiple online cloud storage services. There is still a risk of some progress being lost even with the protections of version control however. This could range from either minor inconveniences to large setbacks.
R-T2	Service Downtime	Technology	The system currently relies on the services of Github for hosting the project. In the event of downtime with this service progress on the public web will be temporarily slowed.
R-R1	Requirement Changes	Requirements	The system as it is planned currently could undergo changes to its requirements set. This is a possibility in both the early and late stages of the project.
R-E1	Time Estimations	Estimations	The current planned timings for the project have a possibility to be found inaccurate. This can be beneficial to the project as areas may require less time to implement than intended however it is equally likely that not enough time is allocated. To counteract this the time given to each task is generous.

6.4 Consideration of Professional, Legal, Ethical and Social Issues

6.4.1 Ethical Issues and Health Concerns

One of the identified risks associated with virtual reality specifically has been the ability it has to induce a form of motion sickness in the user. A study was conducted in an attempt to create an index for levels of motion sickness experienced by those who used virtual reality equipment [15]. In acknowledgement of this, when deploying the project to a public domain a disclaimer will be present to warn the user of any possible adverse effects from interacting with the software.

As this system will be available within the public domain throughout its development cycle the standards and code of ethics devised by the IEEE organisation must be adhered to in order to protect the users. Though no personal information will be stored by the system, through the connection of personal devices to the web browser to access the system protections must be in place to protect any user from malicious intent from outside sources. In the possibility that the requirements of the project are altered the code of ethics must be consulted in order to assure the development of the solutions do not violate any tenets [16].

6.4.2 Legal Issues

The solution as it will be implemented showcases a demonstration of the system by constructing a replica of the Mars environment. In order for this to be achieved the use of 3D models is required and in the case of any included 3D model the correct copyright must be respected for any assets that were not created by those included in the creation of the solution.

References

1. Mozilla (October 6, 2021) *WebXR Device API*, Accessed on November 17th, 2021 from https://developer.mozilla.org/en-US/docs/Web/API/WebXR_Device_API
2. King, D., Tee, S., Falconer, L., Angell, C., Holley, D. and Mills, A. (2018) 'Virtual health education: Scaling practice to transform student learning: Using virtual reality learning environments in healthcare education to bridge the theory/practice gap and improve patient safety', Nurse education today, 71, pp. 7–9. doi:10.1016/j.nedt.2018.08.002.
3. Cooper, N., Millela, F., Cant, I., White, M.D. and Meyer, G. (2021) 'Transfer of training - Virtual reality training with augmented multisensory cues improves user experience during training and task performance in the real world', PloS one, 16(3), pp. e0248225–e0248225. doi:10.1371/journal.pone.0248225.
4. VR-Interactive. (n.d.). *Crude Oil Burner Simulation*, Accessed on November 16th, 2021, from https://vr-interactive.at/portfolio-item/crude-oil-burner-simulation/
5. Google (n.d.). *Augmented Reality*, Accessed on November 16th, 2021, from *https://arvr.google.com/ar/*
6. Microsoft (October 22, 2021). *What is Mixed Reality?*, Accessed on November 17th, 2021 from https://docs.microsoft.com/en-us/windows/mixed-reality/discover/mixed-reality
7. VRChat Inc. (n.d). *VRChat*, Accessed on November 18th, 2021, from https://hello.vrchat.com
8. Barrett, A.J., Pack, A. and Quaid, E.D. (2021) 'Understanding learners' acceptance of high-immersion virtual reality systems: Insights from confirmatory and exploratory PLS-SEM analyses', Computers and education, 169, p. 104214. doi:10.1016/j.compedu.2021.104214.
9. Fitts' Law states that when operating a pointer, such as a computer mouse, the resulting time to move the pointer to a target area is influenced by the distance to the target area and the size of the area.
10. Akçayır, M., Akçayır, G., Pektaş, H.M. and Ocak, M.A. (2016) 'Augmented reality in science laboratories: The effects of augmented reality on university students' laboratory skills and attitudes toward science laboratories', Computers in human behavior, 57, pp. 334–342. doi:10.1016/j.chb.2015.12.054.
11. Korečko, Štefan, Hudák, M., Sobota, B., Sivý, M., Pleva, M. and Steingartner, W. (2021) 'Experimental performance evaluation of enhanced user interaction components for web-based collaborative extended reality', Applied sciences, 11(9), p. 3811. doi:10.3390/app11093811.
12. Mozilla (October 8, 2018). *Gltf-model - A-Frame*, Accessed on November 17th, 2021 from https://aframe.io/docs/1.2.0/components/gltf-model.html
13. NASA (n.d). *Perseverance Rover's Landing Site: Jezero Crater*, Accessed on November 18th, 2021, from https://mars.nasa.gov/mars2020/mission/science/landing-site/
14. Github, inc (22.11.2021) *KoilDoch/WebXR-Mars-Simulation*, Accessed on November 22nd, 2021 from https://github.com/KoilDoch/WebXR-Mars-Simulation.

15. Kim, H.K., Park, J., Choi, Y. and Choe, M. (2018) ‘Virtual reality sickness questionnaire (VRSQ): Motion sickness measurement index in a virtual reality environment’, Applied ergonomics, 69, pp. 66–73. doi:10.1016/j.apergo.2017.12.016.
16. IEEE (June 2020) *IEEE Code of Ethics*, Accessed on November 19th, 2021 from https://www.ieee.org/about/corporate/governance/p7-8.html#top