UiT The Arctic University of Norway

Department of Industrial Engineering

Integration of HoloLens in XR-LAB

A study based on XR environment between two systems

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Abstract

Extended reality is experiencing rapid growth, in both hardware and software and the marked is expanding targeting consumers, businesses and industry. At UiT, Narvik there is established an extended reality laboratory that have a potential to have an impact on the future for education and industry. However, the virtual environment is challenging to operate and navigate with the current equipment. This project focuses on how to integrate a head mounted display, such as Microsoft HoloLens 2, and then use the device in the same environment in real-time. Both the system running the XR-LAB and the system that operates the HoloLens, support a common development software for creating application. This software is a game engine given the name Unity, and to this software there is toolkits provided to each respective system.

Results achieved during the project are designs of XR environment and templates for future work towards the XR-LAB. There has been developed an application which allows users of the laboratory to interact and control the virtual environment with a seamless integration of the HoloLens 2.

The project had a duration of total 30 weeks and were divided into two parts. The part one counted for 1/3 of the total time and initialized the project with introduction and literature review. Part two were started after the first part was approved, and as the main part it counted for 2/3 of the total time allocated to the project.

For the work done in part two and concluded within this report, it was scheduled to have a time usage of 817 hours. Total time consumption used is 825 hours in the 18 weeks of duration.

Keywords: *Extended Reality, virtual reality, augmented reality, mixed reality, OpenXR, XR-LAB, Unity, Microsoft HoloLens 2, Igloo Vision.*

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1 Introduction

Digitalization has become an essential part for the purpose of streamlining and more efficient way of working. Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) are examples of technologies that offer unique possibilities for visualizing physical objects and systems. These technologies have advantages and limitations. Extended Reality (XR) refers to the technology that being able to combine real-and-virtual environments and enabling human-machine interactions. XR serves as the term that orchestra VR, AR and MR in harmony and can be utilized with all benefits from the previous three concepts.

To take full advantage of what XR technology can offer, it is important to create a compatible software environment. More specifically, UiT has the ambition to integrate more AR technologies (i.e., AR headset etc.) to facilitate the ease of application.

This is a final report for the master thesis project, where the master thesis is divided into two parts. The first part of the master thesis was to perform a literature study, where information and research of the topic collected to gain basic knowledge needed in part two. In part one a study on topics within XR technologies was conducted and the most common methods and system. XR is a collective term for the technologies such as VR, AR and MR (?). VR systems uses head mounted displays (HMD) which blocks out the real world and only shows the virtual environment. AR systems supports multiple devices, such as HMD, smartphones, tablets, computers etc, and AR add a layer of digital content into the real world. MR is based on the AR technology but utilizes depth sensors to establish spatial awareness which allows interaction between the digital content and real world environment [1]. Further on, research of the opportunities of which software will best fit the mission of integration, was done. Here Unity game engine appeared to be the best choice since both the system inside the XR-LAB and Microsoft's MR headset, HoloLens 2, is supported. A fair amount of time where also spent on learning Unity to gain skills for the development.

The second part of the thesis is to create an XR environment in Unity, where the HoloLens 2 will control the environment operators want to show or present inside the XR-LAB and that is concluded within this report.

1.1 Background

XR is gaining huge interest within different sectors, such as construction, engineering, architecture etc. Especially within the industrial sector, with the fourth industry revolution Industry 4.0, AR is one of the main pillars. After working a few years with VR technology and XR environment, the development and integration seems like a good project. One other reason for selecting this project is that it is a hot topic when talking about digitalization, and this particular integration appears to not have been done before.

1.2 Problem statement

Today the system in XR-LAB uses different software to display content onto the canvas inside the room. To add and control content the operator must access the server in the backroom or through an external desktop, e.g., TeamViewer. However, there is a possibility to connect a tablet such as an iPad and navigate preloaded content without accessing the server. When displaying a real time XR environment there are no good solutions, at this date, that gives the operator the options to navigate and interact with it. With the HoloLens connected to the same environment, they could be used to improve the usability and enables more controls to the operator.

1.3 Project description

The description of the project is to create a XR environment where the HoloLens 2 is integrated towards the system in the XR-LAB. The HoloLens will display the same environment that are displayed onto the canvas, but work as an extension with control panels and ways for operator/users to interact with the environment. This will be done by using Unity as an editor and create a build that are installed on both the server and the headset.

1.4 Assumptions

Since the same software is used for both systems, the integration should be doable without setting up virtual servers to enable connection. I also assume that wireless connection over Wi-Fi should work with low input lag since the XR-LAB has its own network independent from the university's eduroam.

1.5 Scope

The scope of this project is to establish a connection between two systems, the XR-LAB and Microsoft HoloLens 2, and empower operators to use the HoloLens as a controller for the XR environment. The selected software, Unity, offers support to both systems and should provide a seamless integration.

This study will result in these concrete tasks:

1. Create a XR environment specifically for the XR-LAB.
2. Create a XR environment specifically for the HoloLens 2.
3. Establish a connection between the two systems and make the HoloLens control the XR environment displayed onto the canvas inside the XR-LAB.
4. Document the executed work in the form of a written report.
5. Prepare a PowerPoint presentation and present the performed work.

2 Theory

The XR-LAB is a new installation at the university as it's visualization room, the name given is shortened from Extended Reality Laboratory. The rooms' location is at the UiT campus in Narvik and was finalized in February 2021. This is an immersive workspace which is a product from Igloo Vision in the United Kingdom, and they are the providers of both the hardware and software to this installation.

2.1 XR-LAB

The room measures 10 x 7.6 meters and uses the wall as canvas with a height of 2.5 meters on to the walls and has additional floor projection. The projection is done with 12 laser projectors with 4K resolution, where 8 of them projects on the walls and 4 to the floor. All the projectors are powered with a powerful graphical server, the Igloo's Immersive Media Player (IMP), which allows for warping, blending, video processing and real time rendering. Figure 1 below shows an illustration of the room before it got built.

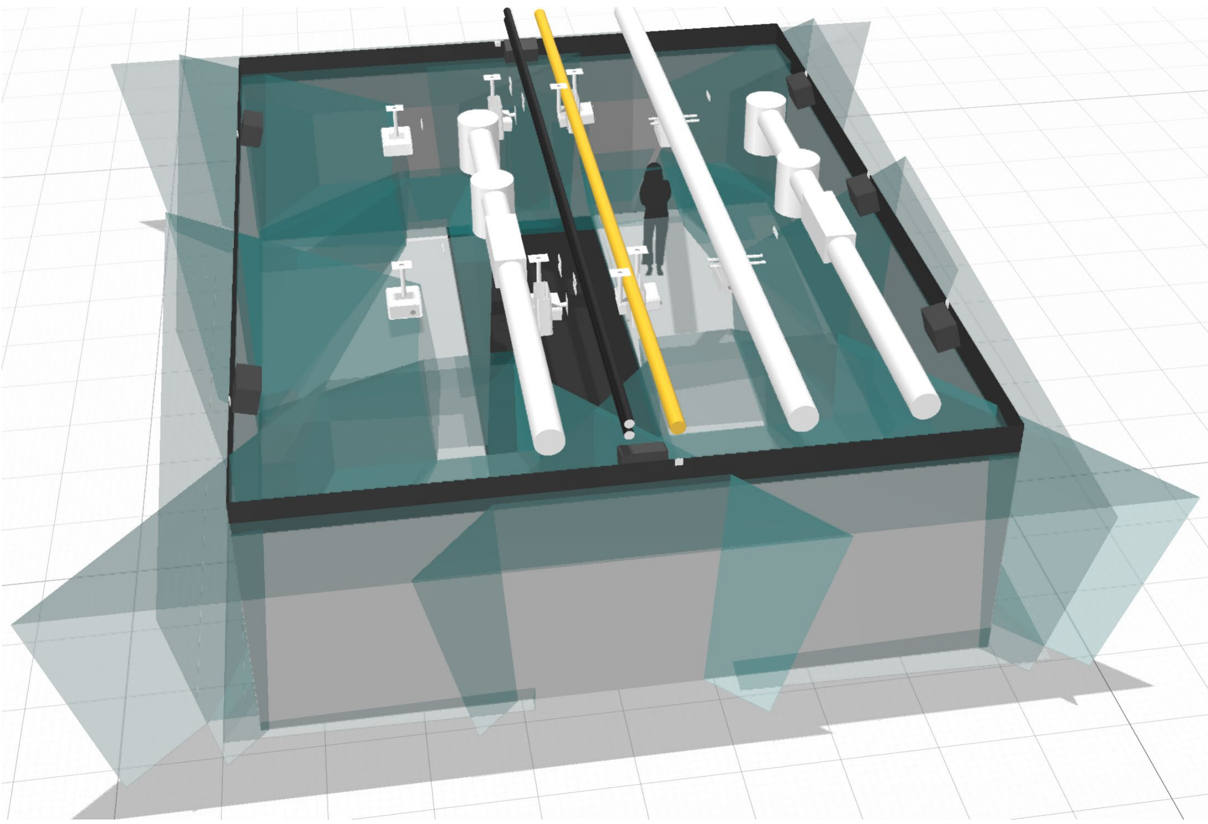


Figure 1 – Illustration XR-LAB (Screenshot from CAD model made by Igloo Vision)

2.1.1 Software

For being able to output a 360-projection, software plays an important role in this system installation. With the IMP and Igloo's layer-based visualization system the desired content can be displayed with flexible, scalable, and easy operation. Figure 2 illustrates the process when 360 or VR content are projected into the room.

Figure 2 – 360 or VR content process

Igloo Vision provides a full range of software application that are created to the system, Table 1 gives a brief overview of the application listed on their website [2].

	Igloo Home	The Igloo user interface, allow you to access all your content, data and applications from a single home-screen (a bit like a room-scale iPhone).	[3]
	Igloo Warper	Advanced geometry correction and edge-blending software, enabling any imagery to be projected across a seamless 360° horizon.	[4]
	Igloo Playback	360° media player application, enables you to play multimedia files like videos, Computer Generated Imagery (CGI) and panoramas, enhance them with surround sound, and project them in up to 20K.	[5]
	Igloo Control	An intuitive, easy-to-learn user interface, enabling you to set-up, scale and schedule your 360° content, switch between different channels, and program clip settings.	[6]
	Igloo Remote	Control the Igloo system easily and remotely on any iOS or Android device, including consumer-grade phones and tablets, as well as pro-level equivalents.	[7]
	Igloo Realtime	A set of software plug-ins and tools to integrate with a range of game engines (Unity and Unreal) and interactive simulation and visualization tools.	[8]
	Igloo Web	Display any website in 360° , like social media feeds, Google Slides presentations, 360° mapping systems (Esri, ArcGIS and Street View) and more.	[9]
	Igloo Capture	Display up to 12 channels of content from external sources (like YouTube, PDFs, PowerPoint, Teams, camera feeds, etc) via HDMI, NDI and RTMP.	[10]
	Igloo Encode	Drag and drop HAP encoding widget. Drag any 360° movie file onto the widget and it will automatically encode the file with optimal Igloo HAP settings.	[11]
	Igloo VR Spectator	Simultaneously play VR or 360° content both in headsets and Igloo Shared VR (enabling spectators and team members to see what is happening in the headset).	[12]

	Igloo Cast	Mirror your phone, tablet, or computer onto a 360° screen. Stream content directly from any device onto your immersive display.	[13]
	Igloo 3D	Project any 3D-ready imagery stereoscopically and/or more fully integrate the Igloo System with 3D visualization programs. Requires active 3D glasses and projectors.	[14]
	Igloo 4D	Schedule triggers for multi-sensory DMX / UDP hardware (e.g., fans, lights, aroma diffusers, heating and cooling devices, etc) to enhance audio visual experiences.	[15]
	Igloo Livestream	Stream 360° content in real-time, at full resolution, across standard RTMP and NDI networks, without the need to pre-render and upload.	[16]
	Igloo API	Take control of every aspect of your Igloo system using your own control interfaces and protocols.	[17]

Table 1 – Software application from Igloo Vision

The systems core application for projecting content on the canvas inside the room, is the Igloo Warper. The Warper enables the opportunity to blend multiple projectors outputs into one seamless and clear 360° picture around the entire room. The Warper support a whole variety of input from both Igloo's application and third-party applications that are desirable to use. Figure 3 gives a good overview of the different sources that can be used as input, where the Igloo applications such as Igloo Playback, Realtime, Web and Capture act as a support application. The input data is processed on the IMP using the Igloo Warper and then the processed picture is outputted on the canvas.

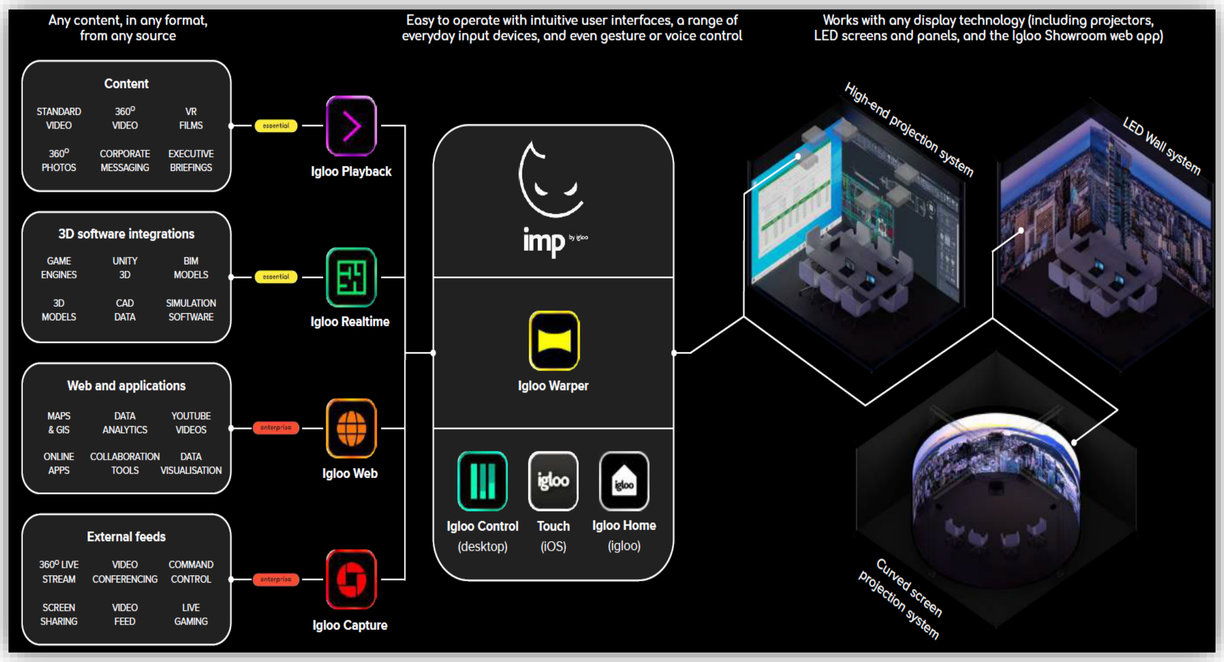


Figure 3 – From input to output in an Igloo system (Provided in a PDF from Igloo Vision)

2.1.2 Software integration

The system and software applications provided from Igloo enables the opportunity to use a large variety of third-party software, such as BIM, CAD, Simulation, 3D, game engines, etc. The game engine, Unity, has grown out of the gaming segment and now also provide solutions to other segments. Two of these are targeting the industry in modern age, and these two segments are the Automotive, Transportation & Manufacturing (ATM) and the Architecture, Engineering & Construction (AEC)[18, 19]. Unity AEC can be used to create immersive, interactive experiences for VR, AR and mobile. This can improve workflow in project management and teams, lower project cost, connect stakeholders etc. Figure 4 illustrates software integration that runs through Igloo Realtime and Igloo Warper.

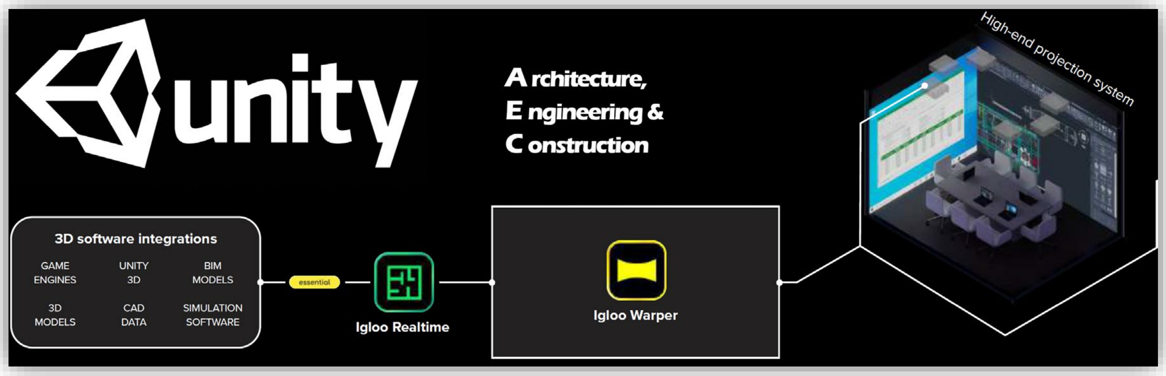


Figure 4 – Unity AEC integration (Self-made in Adobe Photoshop from Figure 3)

In addition to the integration, Igloo has developed a Unity toolkit which adds a 360-camera package into the XR environment. This makes it possible to render a scene in real time and then output this to different platforms such as desktop (Windows or Mac), VR, AR, mobile (Android and iOS) and to the XR-LAB.

This toolkit has been provided and successfully been implemented into Unity and tested inside the XR-LAB. It has been established a dialogue and a limited support with Igloo regarding exploring integration of AR (HoloLens) with Unity scene and multiplayer integration. Igloo have also provided technical documentation for the toolkit and to all of Igloo's software applications portfolio.

Igloo Vision have posted a case study of the XR-LAB [20].

2.2 Microsoft HoloLens

In March 2016 Microsoft introduced the first stand-alone mobile AR glasses, the HoloLens. When the HoloLens where released, it was not for regular consumers, but for developers and professional users as this technology was in an early stage [21].

The second generation, the HoloLens 2, was released as an enterprise edition in February 2019 and this version made it suitable for consumers due to the improvements in immersiveness, ergonomics and business/consumer friendliness [22].

Today, Microsoft have listed 5 different options of the HoloLens 2 on their webpage [23], comparison of these are illustrated in Table 2.

	HoloLens 2	HoloLens 2 Industrial Edition	Trimble XR10 with HoloLens 2	HoloLens 2 with Remote Assist	HoloLens 2 Development Edition
HoloLens 2 Device	√	√	√	√	√
Dynamics 365 Remote Assist				√	
ISO 14644-14 and Designated ISO Class 5.0		√			
Class 1, Devision 2 – Group A, B, C and D HAZLOC		√	√		
Rapid Replacement Program[1]		√			
Hardhat integrated (PPE compliant in 40+ countries)			√		
Noise-canceling Audio Output			√		
Developer entitlement[2]					√
Warranty	1 year	2 years	1 year	1 year	1 year

[1]Recive a replacement device overnight or expected shipping (faster of the available option) before defective HoloLens 2 is received by Microsoft
[2]Includes $500 Azure credit and 3-month trails to Unity Pro and Pizzy Plugin

Table 2 – HoloLens 2 option

2.2.1 Software integration

Microsoft provides a great portion of software, toolkits and technical documentation for mixed reality and their HoloLens 2 on their documentation website [24, 25]. Microsoft offers a toolkit, Mixed Reality Toolkit (MRTK), for Unity [26]. This contain necessary functions such as; cross-platform input system, wide range of support of platforms, building blocks for spatial interactions and unity interactable to create the integration towards the system installed in the XR-LAB [27]. Microsoft is providing documentation for where you can find release notes, MRTK overview and API references that are significant when using the toolkit in Unity [28-30]. The toolkit gives Unity opportunity to utilize many features that the HoloLens 2 have built-in, Table 3 gives a summary of some of the most important features.

Input system	Input system allows users to define abstract actions and have different inputs associate to them.	[31]
Hand Tracking	Hand tracking profiles, hand mesh prefab and scripting.	[32]
Eye Tracking	HoloLens 2 is equipped with eye tracking; this is a feature that enable users of the headset to engage with holograms in their view.	[33]
Profiles	MRTK are required to be managed and is done so with profile configuration. With this, users can navigate through settings such as camera-, experience-, input system-, speech settings etc.	[34]
UI Controls	Unity interactable (UI) controls is how to build users experience in the mixed reality and give control over it. It allows users of the headset interact with buttons, hand menu, app bar, system keyboard etc.	[35]
Solvers	Solvers enable calculations of an object's position and orientation given by a predefines algorithm. It offers behavior how to attach objects to each other, such as a menu that could either follow the users or hold its position in the environment.	[36]
Multi-Scene Manager	Multi-Scene Manager enables the opportunity to manage multiple scenes in a project, but if a project consists of one scene this is not required to use.	[37]
Spatial Awareness	Spatial awareness enables real-world environmental awareness in the augmented reality applications. The headset scans the environments and let users add holograms or 3D object on top of it.	[38]
Diagnostic tool	The MRTK diagnostic system runs within applications to analyze and log issues inside the applications.	[39]
MRTK Standard Shader	The shading system uses a shaded that are flexible which can attain visuals comparable to Unity's standard shader.	[40]
Speech & Dictation	Enables recognitions of speech input events with defined keywords and record audio to obtain a transcription, from speech-to-text.	[41, 42]
Boundary System	Enables support for visualizing virtual reality boundary to crate safe movement of the users.	[43]

Table 3 – Feature overview of the MRTK

2.3 Unity

Unity is a cross-platform game engine established by the company Unity Technologies, and the first engine was launched in June 2005 [44]. Unity claim that in 2020 to have five billion applications downloaded to 20+ different platforms, 71% of the top 1000 mobile games is made with Unity and 50%+ of games also were made with Unity [45]. With Unity Learn developers with all levels of experience, from beginners to professional, have access to over 750 hours of free training and tutorials to gain skills [46].

Another big advantage Unity brings is their asset store, where developers can explore 3D/2D models, add-on, templates tools etc, that they can buy or sell to use as content to use in projects [47].

Unity provides not only solutions for making games, but offers in total 12 solution to this day [48]. A brief overview of their solution is given in Table 4.

Games	Create and operate games.	[49]
Unity Gaming Service	Manage online servers for multiplayer, engagements, monetization, analytics etc.	[50]
Accelerate Solution for enterprise	Technology solution from Unity to help companies innovate faster.	[51]
Automotive, Transportation & Manufacturing	Advantage in competitive real-time 3D model in embryonic development within the industry.	[18]
Architecture, Engineering & Construction	Develop interactive and immersive 3D experiences for real-world applications.	[19]
Digital Twin	Create a model with real-time data to interact, analyze and visualize.	[52]
Film, Animation & Cinematics	Enables real-time rendering to accelerate production, workflow and raise creativity.	[53]
Government & Aerospace	Enables solutions for data visualization, 3D simulation, machine learning, artificial intelligence combined with XR.	[54]
Brand and Creative Agencies	Establish connection between brands and end-users with AR content that brings experiences and product to life.	[55]
Gambling	Bring gambling and casino into a interactive, real-time content for a improved experiences to the players.	[56]

EdTech	Develop applications, simulations and games for educational purposes.	[57]
Retail	Deliver a digital business model that provides consumers experiences that are immersive and interactive.	[58]

Table 4 – Unity solution overview

During the study, a large amount of the time has been used to learn the Unity editor, located scrips (API) and testing of all the plug-ins and toolkits required for the integration. The tests have been successful.

- Unity environment created towards XR-LAB is running as it should.
- MRTK is running on the HoloLens and has been tested on different persons to ensure that the interface is understandable and interactive.

2.3.1 Software integration

Unity support development to most of the platforms used in 2022, such as Windows, macOS, Linux, iOS, Android, WebGL and Lumin [59]. There is provided a complete list at Unity's documentation site, where all supported platforms and the systems requirements for each of them [60]. On Unity Documentation there is also supplied technical documents, manuals and scripting API related to any development in their editors [61, 62].

Unity's ability to integrate on multiple platforms and XR development, make this engine as a upright choice for developing an integrated connection between the XR-LAB, and Microsoft HoloLens (or other AR headsets/glasses, e.g. Oculus, HTC Vive Pro) [1, 63].

2.4 Extended Reality Technologies

XR is an umbrella term for systems that supports the interactive applications in VR, AR, and MR [1].

2.4.1 Virtual reality

VR is the system that uses a computer-generated 3D environment, hence virtual reality, inside a head mounted display (HMD), and that will not allow the user to see the real-world environment [1]. The HMD could be equipped with tracking that is either by external- or internal sensors, which let the users orientate and navigate inside the virtual environment. The HMD also demands that users pre-configure boundaries for safety purposes to avoid injuries [64]. In the packages when attaining HMD, there is usually included equipment such as hand controllers which allows users interact inside the environment.

Today, there is a variety of brands that offers different VR systems that either requires a computer or devices that are standalone. In Table 5 you will see a small collection of the most used VR systems.

		HTC	
Flow		Newest from HTC, is these VR glasses with a compact design which allows users to bring them along wherever they go. The HMD is equipped with internal tracking.	[65]
Vive Focus		The Vive Focus offers a system that can connect to a computer either over Wi-Fi or via cable. The HMD is equipped with internal tracking.	[66]
Vive Pro		The pro series are the professional grade VR headset that connect to a computer via cable. The HMD have external and high precision tracking. Also capable of AR.	[67]
Vive Cosmos		The Vive Cosmos was the first VR headset from HTC that was standalone, only connection needed is a smartphone. Cosmos is equipped with internal tracking.	[68]
		Meta Oculus	
Quest 2		The Quest 2 is the second generation in the Quest series. This headset is connected via a smartphone and Wi-Fi and have internal tracking.	[69]

Rift S		Rift S was the headset from Oculus that required a computer connection. It was equipped with internal tracking. This headset is no longer available from Oculus.	[70]

Valve

Index		The Index was made purely for the gaming marked with high refresh rate and precise tracking with external sensors.	[71]

HP

Reverb G2		This headset is developed in a collaboration with Microsoft and Valve and is claimed to be the the next level in immersion and hyper-realistic VR. The headset is equipped with internal tracking and requires a PC connection.	[72]

Table 5 – Examples of VR headsets from different brands.

2.4.2 Augmented reality

AR is the system that overlays digital content into the real world without any spatial awareness [1]. Most people are unaware that this exist in all smartphones and tablets today, there is applications on mobile devices that uses the camera and then input digital content along with what the camera captures. There are also a few dedicated devices for this purpose, see Table 6 for a few examples.

Microsoft

HoloLens 2		HoloLens 2 is considered the AR headset that defines the technology. It is a standalone headset with internal tracking of the environment as well as it uses hand tracking for controlling the environment. Is compatible with MR.	[23]

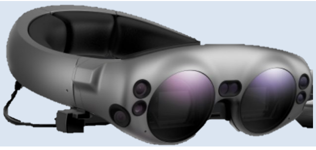
	Magic Leap		
One		The One is a standalone AR headset with internal tracking of both environment and hands for control.	[73]

Table 6 – Examples of AR headsets.

2.4.3 Mixed reality

MR is a combination of the user's real world environment with spatial awareness and digital content, and lets these two interact with each other [1]. MR demands a headset for users, and this headset is equipped with 3D cameras and sensors to scan the real-world environment. Due to this it is able to mix and combine it with the digital content [64].

2.5 Industrial application of XR

The industrial application of XR can offers endless opportunities towards businesses and different types of industry. The fourth industrial revolution, Industry 4.0 for example, is built on 9 pillars. These are:

1. Big data and Analytics
2. Autonomous Robots
3. Simulations
4. Horizontal and Vertical System Integration
5. Industrial Internet of Things (IIot)
6. The Cloud
7. Additive Manufacturing
8. **Augmented Reality (AR)**
9. Cyber Security

AR is considered as one of the main pillars, this indicates that XR plays a bigger role in the modern industry. The definition states that AR are the concept of human-machine interaction [74]. This topic has a potential of being huge and a bit out of the scope for this thesis.

3 Methodology

To perform an integration onto the system in XR-LAB with another device, Unity game engine have been the main approach in this project. Along with the game engine, the online documentation published by Unity and Microsoft have been a solid foundation to support the development.

The documentation that are published by Unity, includes manual of the game engine, assets workflow, inputs, graphics, scripting API, XR, and networking [61].

For development of an application towards this integration, most of the time in the project have been the work with Unity editor and

3.1 Unity

In this research work, different versions of editors have been used due to updates and improvements that had an impact on the integration. It has only been utilized released editors with Long Term Support (LTS) as they are recommended by Unity for best stability during development [75]. Table 7 lists the versions used during the thesis and their release dates.

LTS Release version	Release date
2020.3.23f1	19. November 2021
2020.3.24f1	2. December 2021
2020.3.26f1	13. January 2022
2020.3.33f1	7. April 2022

Table 7 – Unity Editors version used during the project.

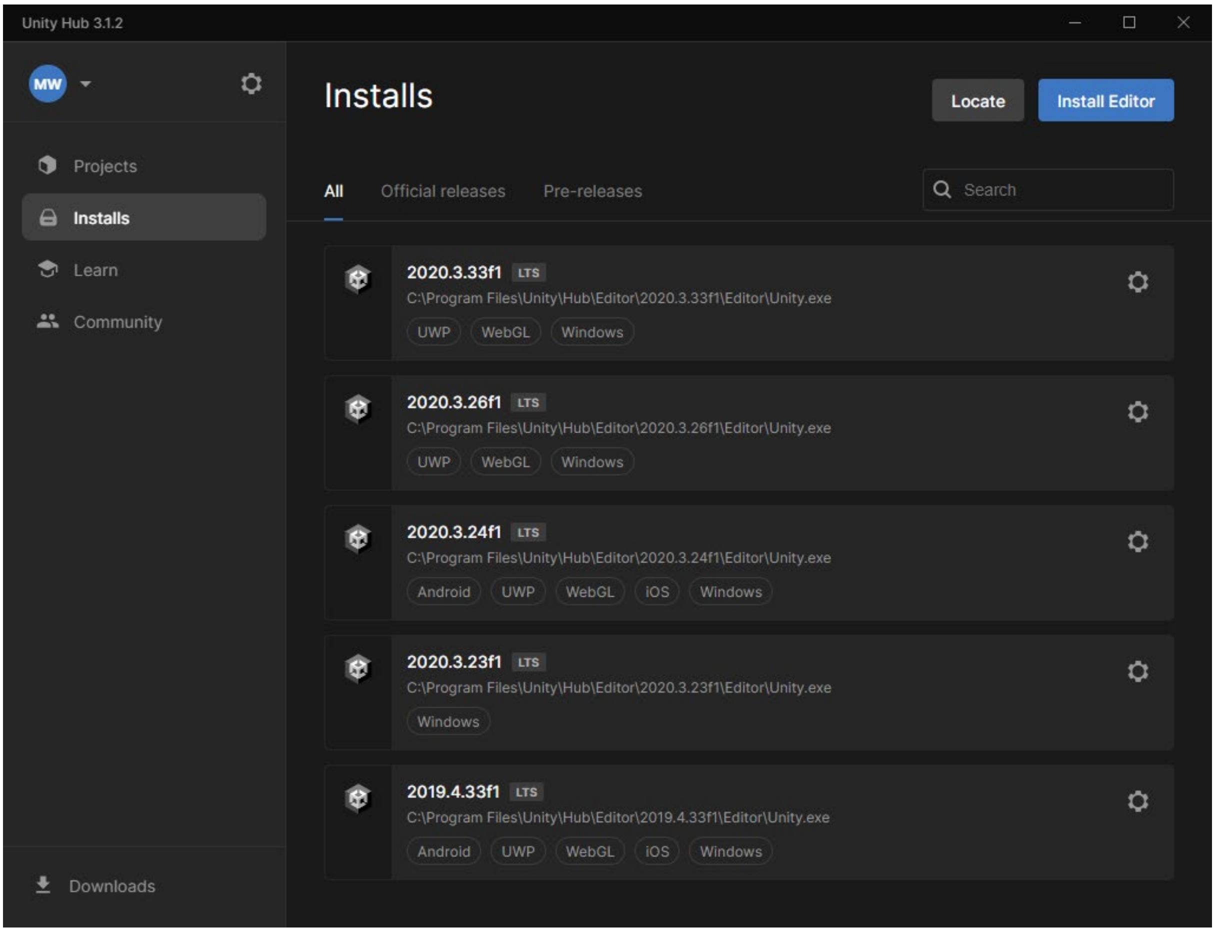


Figure 5 – Unity Hub with installed editors (Screenshot of Unity Hub)

3.2 XR environment for XR-LAB

The solution to develop and display real time XR content on the canvas inside the XR-LAB is given by Igloo Vision and their toolkit. This toolkit contains a camera package which allows applications to render and output 360-degree field of view (FOV). This camera package can either be configurated to be static or work as a player that can be moved around in the environment. Regarding this project the camera has been configurated to be static, and this is due to the focus on integration and the use of a pair of HoloLens in the same environment. There were also some concerns regarding that, with the additional inputs, it would have caused interference when using the HoloLens.

The toolkit is imported as a custom package into the project, and it contains prefabrications, scripts, settings, and examples how to configure the camera. Figure 6 shows the package when it is imported into the project.

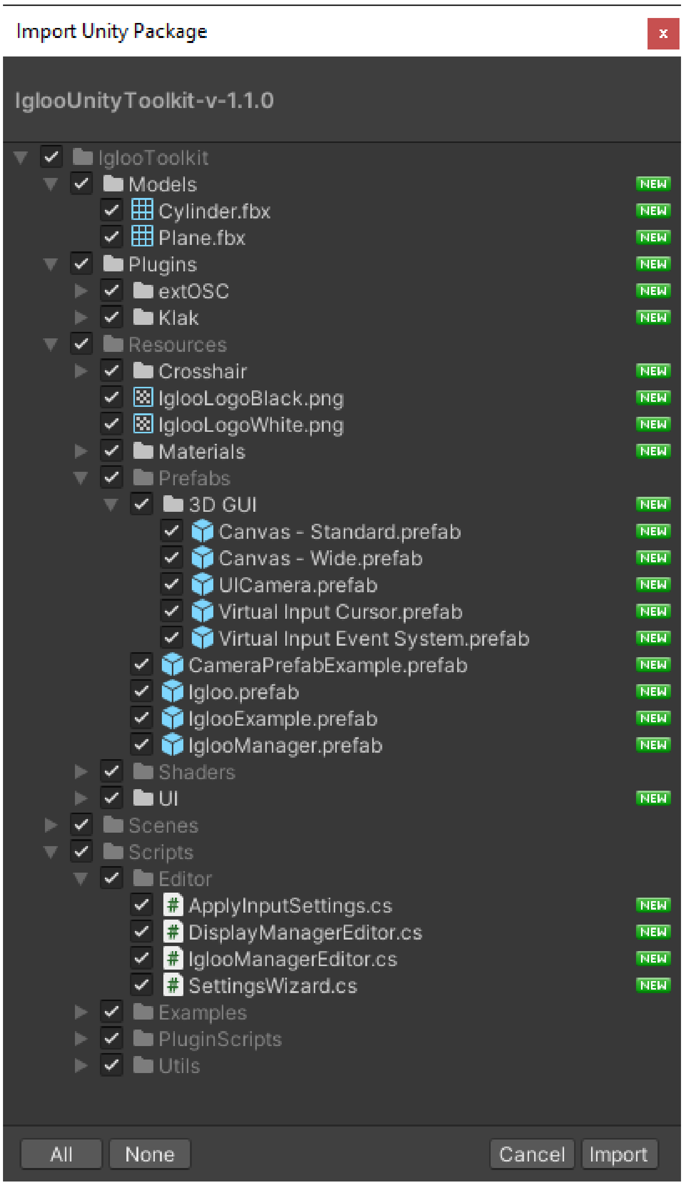


Figure 6 – Import Unity Package IglooUnityToolkit (Screenshot from Unity Editor)

3.3 XR environment for HoloLens 2

When starting the development of applications and installation of the toolkit, there were some prerequisites that had to be fulfilled first [76]:

- Windows 10 with developer mode enabled.
- Visual Studio 2019 with recommended workloads.
- Windows Software development kits (SDK).
- Unity Hub with Unity Editor 2020.3 LTS.
- Microsoft HoloLens 2 device with developer mode enabled.

After this the latest version of MRTK, could be downloaded and installed into Unity projects to build applications for the HoloLens 2 [77].

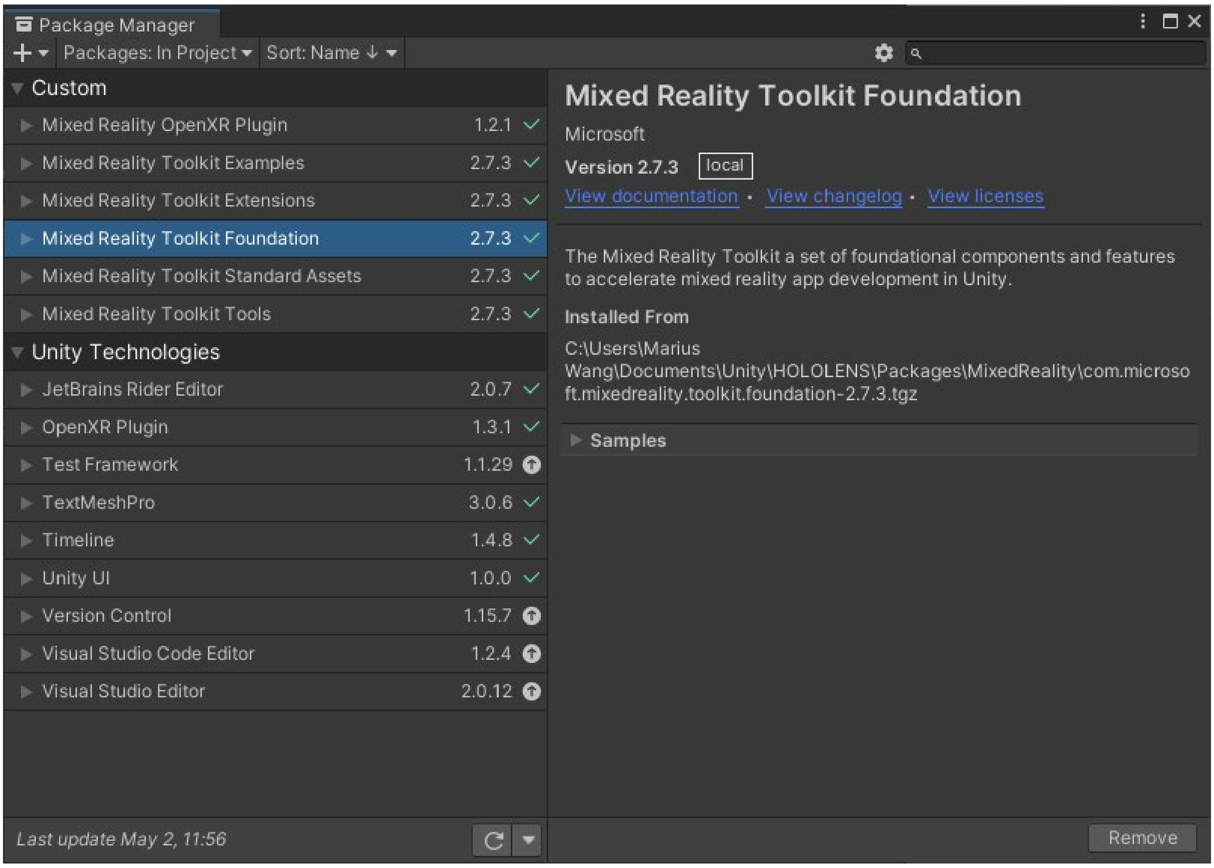


Figure 7 – MRTK installed in project

4 Concept

During the concept phase, it was created concepts for the XR environment for the two different systems and which feature they would contain. During the assessment of concept, it was connection and interface between them that was the focus. The idea was to keep them as simple as possible due to limited time.

Concept is given name for each respective system, where XRL is XR-LAB and XRH is for the HoloLens.

After this phase, two concepts were chosen for further work and development for an interactive XR environment. These two concepts are XRL 1 and XRH 2, and at a later stage these two will be combined into one integrated environment when connection is successful.

Criteria	Weighting	XRL 1	XRL 2	XRH 1	XRH 2
	(1-5)	Score (1-10)			
Complexity*	5	7	5	3	5
Functionality	3	9	8	8	6
User friendly	3	7	2	6	8
Performance	3	10	7	4	8
Inputs	2	8	5	3	8
Interactions	3	1	5	8	6
Resources	4	8	5	6	8
Support	5	7	6	8	8
Total Score		199	151	163	197

Table 8 – Concept decision

Weighting where 1 is lowest and 5 is highest. Score where 1 is lowest and 10 is highest.

*Higher score indicates opposite value

Largest total score directs the most appropriate concept.

4.1 XRL 1

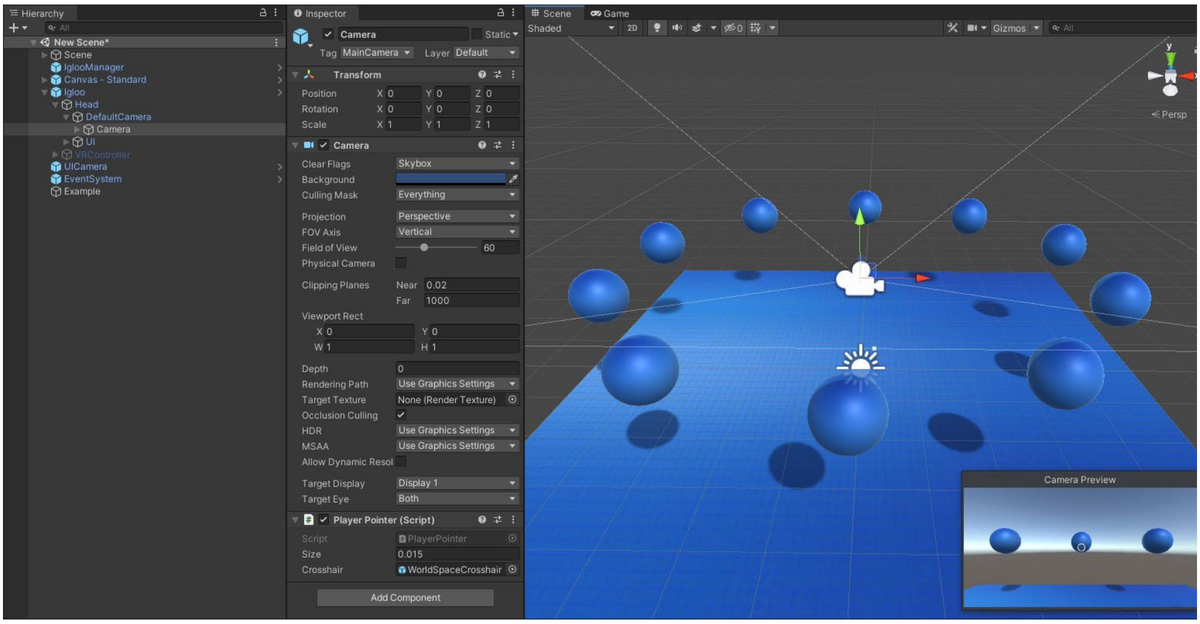
Project:	Date:	Revision:
Integration of HoloLens in XR-LAB	02.03.22	Rev_0 02.03.22
Concept sketch number: 1		Page: 1 of 2

Short about

Configure a scene with a static camera and only spectate the environment from a fixed position. With this, the focus will be at the person that are using the HoloLens and presenting content in the 3D world.

Pros	**Cons**
Fewer inputs to configure	Less immersive
Provides better performance for rendering	Not able to change view inside the XR-LAB
Lower level of complexity	

Pictures


Hierarchy
New Scene*
Scene
IglooManager
Canvas - Standard
Igloo
Head
DefaultCamera
Camera
UI
VRController
UICamera
EventSystem
Example
Inspector
Camera
Static
Tag MainCamera
Layer Default
Transform
Position X 0 Y 0 Z 0
Rotation X 0 Y 0 Z 0
Scale X 1 Y 1 Z 1
Camera
Clear Flags Skybox
Background
Culling Mask Everything
Projection Perspective
FOV Axis Vertical
Field of View 60
Physical Camera
Clipping Planes Near 0.02
Far 1000
Viewport Rect
X 0 Y 0
W 1 H 1
Depth 0
Rendering Path Use Graphics Settings
Target Texture None (Render Texture)
Occlusion Culling
HDR Use Graphics Settings
MSAA Use Graphics Settings
Allow Dynamic Resol
Target Display Display 1
Target Eye Both
Player Pointer (Script)
Script PlayerPointer
Size 0.015
Crosshair WorldSpaceCrosshair
Add Component
Scene
Game
Shaded
2D
Gizmos
Persp
Camera Preview

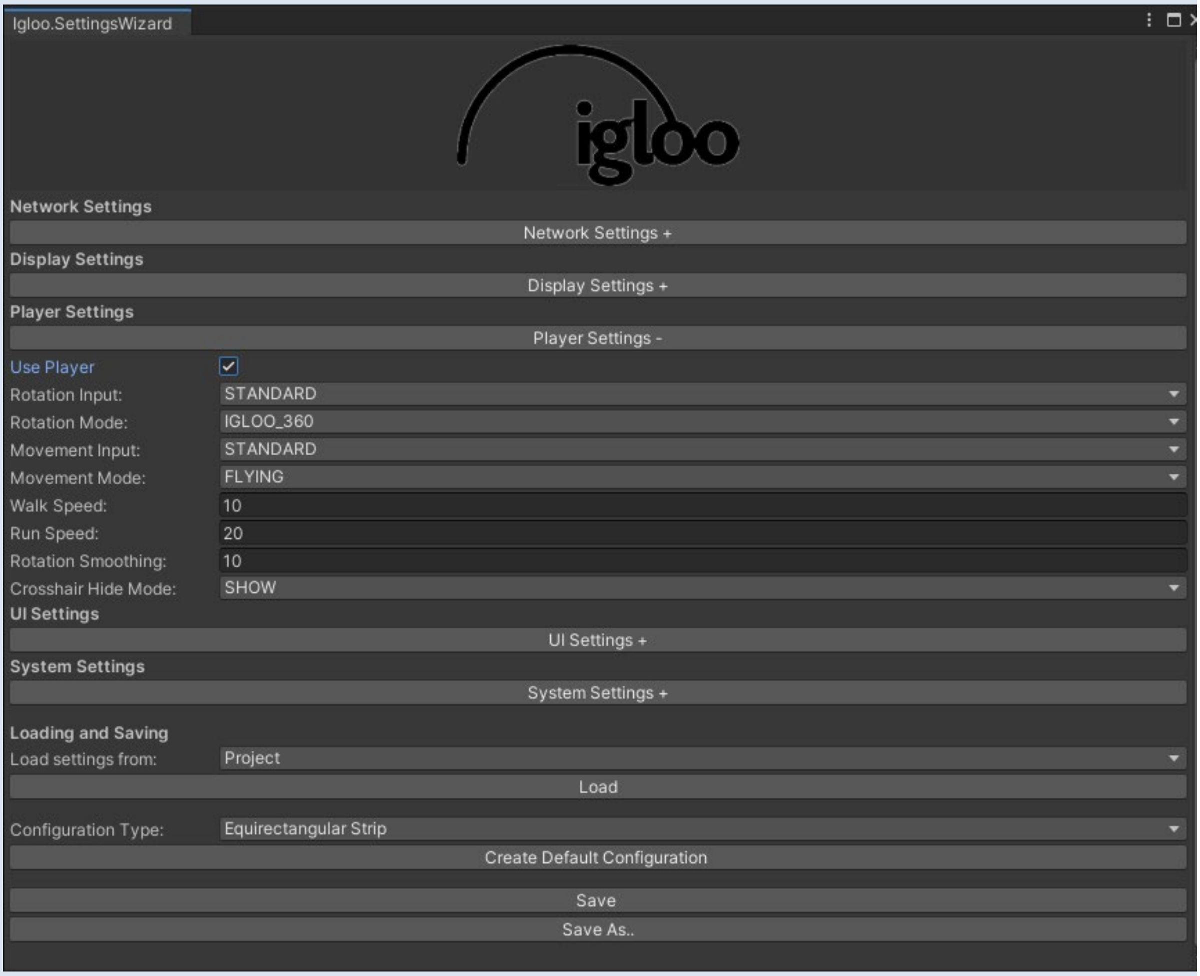
4.2 XRL 2

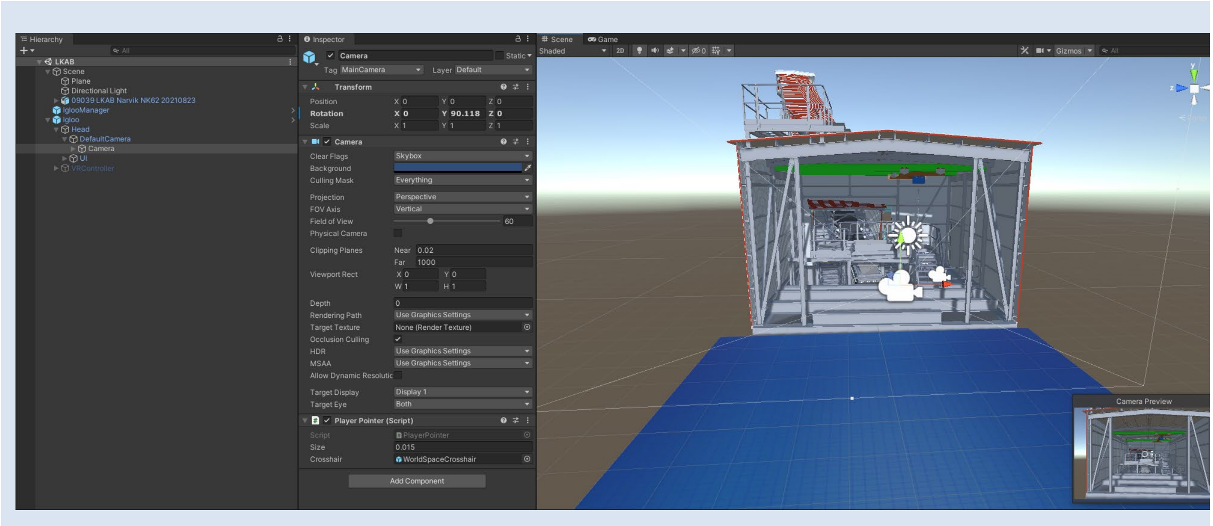
Project:	Date:	Revision:
Integration of HoloLens in XR-LAB	03.03.22	Rev_0 03.03.22
Concept sketch number: 2		Page: 1 of 2

Short about
Configure a scene with a camera that act as a player and move around in the environment.

Pros	**Cons**
Immersive	Time-consuming to configure
Able to navigate within the environment	Lower performance due to increased rendering

Picture




Hierarchy
LKAB
Scene
Plane
Directional Light
09039 LKAB Narvik NK62 20210823
IglooManager
Igloo
Head
DefaultCamera
Camera
UI
VRController
Inspector
Camera
Static
Tag MainCamera
Layer Default
Transform
Position
Rotation
Scale
X 0
Y 90.118
Z 0
Camera
Clear Flags
Skybox
Background
Culling Mask
Everything
Projection
Perspective
FOV Axis
Vertical
Field of View
60
Physical Camera
Clipping Planes
Near 0.02
Far 1000
Viewport Rect
Depth
Rendering Path
Use Graphics Settings
Target Texture
None (Render Texture)
Occlusion Culling
HDR
MSAA
Allow Dynamic Resolutio
Target Display
Display 1
Target Eye
Both
Player Pointer (Script)
Script
PlayerPointer
Size
0.015
Crosshair
WorldSpaceCrosshair
Add Component
Scene
Game
Shaded
2D
Gizmos
Camera Preview

4.3 XRH 1

Project:	Date:	Revision:
Integration of HoloLens in XR-LAB	07.03.22	Rev_0 07.03.22
Concept sketch number: 1		Page: 1 of 2

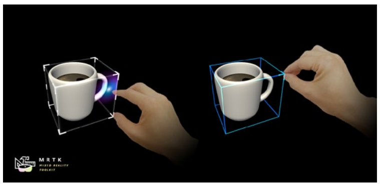
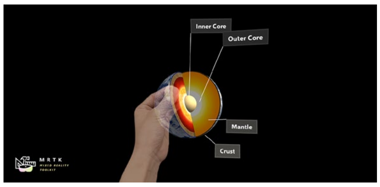
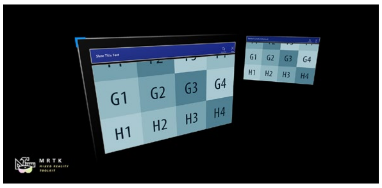
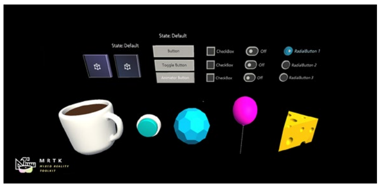
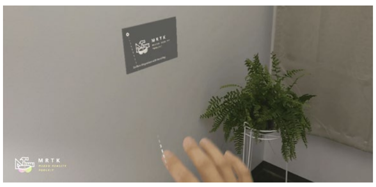
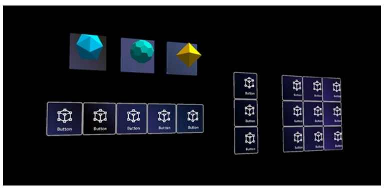
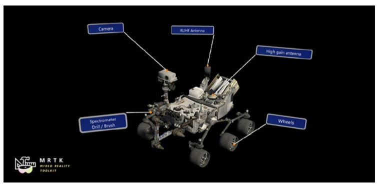
Short about

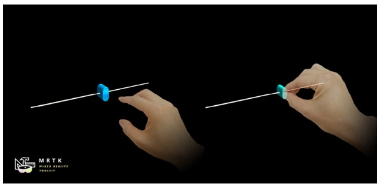
Configure an environment with multiple scenes and all the features the MRTK provides for the HoloLens 2. These features are listed in **Table 3**.

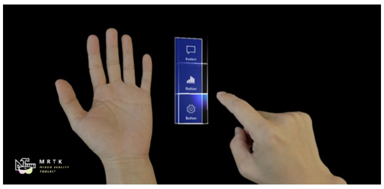
The way to navigate and interact with the environment will be to use UX building blocks that are available in the toolkit. To create a full experience of the operator, all the available UX building blocks will be utilized.

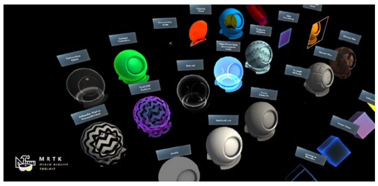
Pros	**Cons**
Immersive	Time-consuming to configure
Highly interactive	Complex
Loads of features	Impact on performance

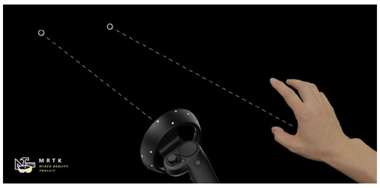
UX Building blocks

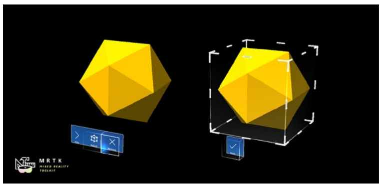
		
Buttons	Bound Control	Object manipulator
		
System Keybord	Slate	Interactable
		
Solver	Object Collection	Tooltip

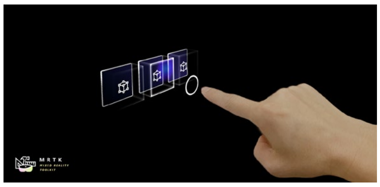

Slider


Hand menu

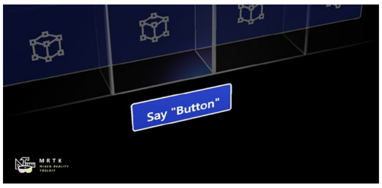

MRTK Standard shader


Pointer

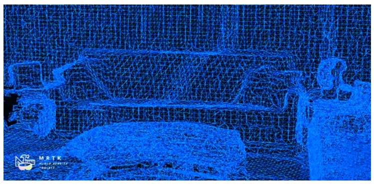

App bar

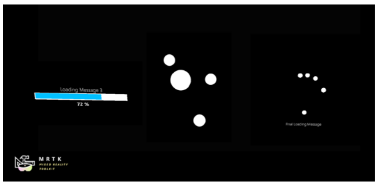

Fingertip visualization

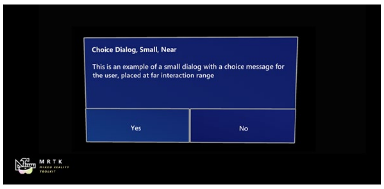

Near menu



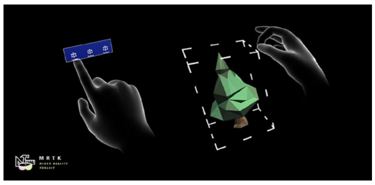
Voice command


Spatial awareness view

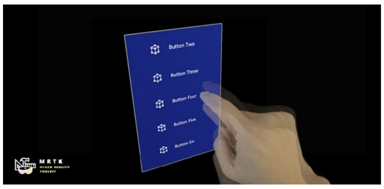

Progress indicator

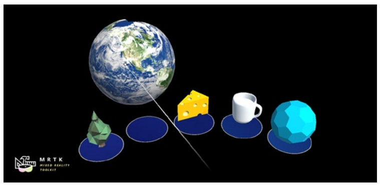


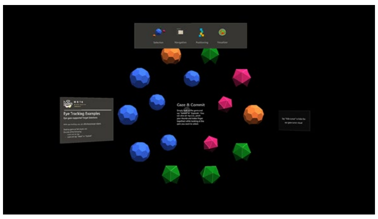
Dialog

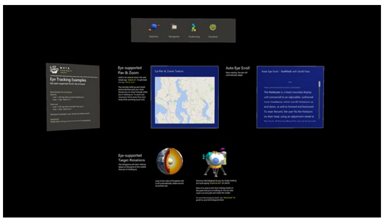

Hand coach

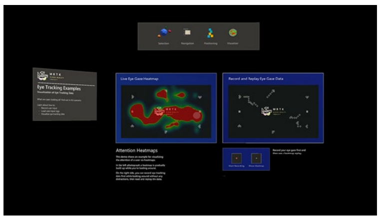

Hand physics service


Scrolling collection


Dock


Eye tracking: Selection


Eye Tracking: Navigation


Eye tracking: Heat map

4.4 XRH 2

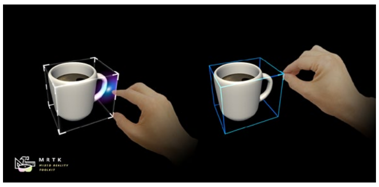
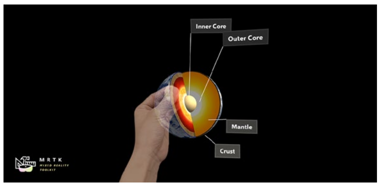
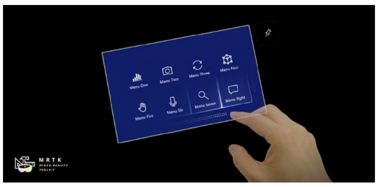
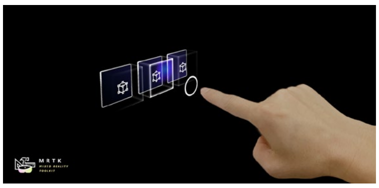
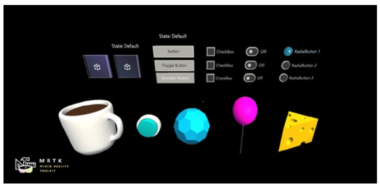
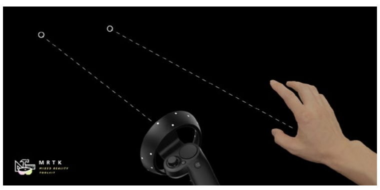
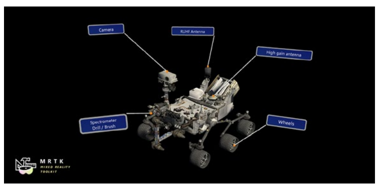
Project:	Date:	Revision:
Integration of HoloLens in XR-LAB	09.03.22	Rev_0 09.03.22
Concept sketch number: 2		Page: 1 of 1

Short about

Configure an environment with one scene and the most basic features from the MRTK provides for the HoloLens 2. The selected feature for this concept is: Input system, hand tracking, eye tracking, UI controls, spatial awareness, and diagnostic tool. The way to navigate and interact with the environment will be to use UX building blocks that are available in the toolkit. To create a good enough experience, a selection of the available UX building blocks will be utilized.

Pros	Cons
Fewer inputs to configure	Less immersive
Lower level of complexity	Less features
Interactive	

UX Building blocks

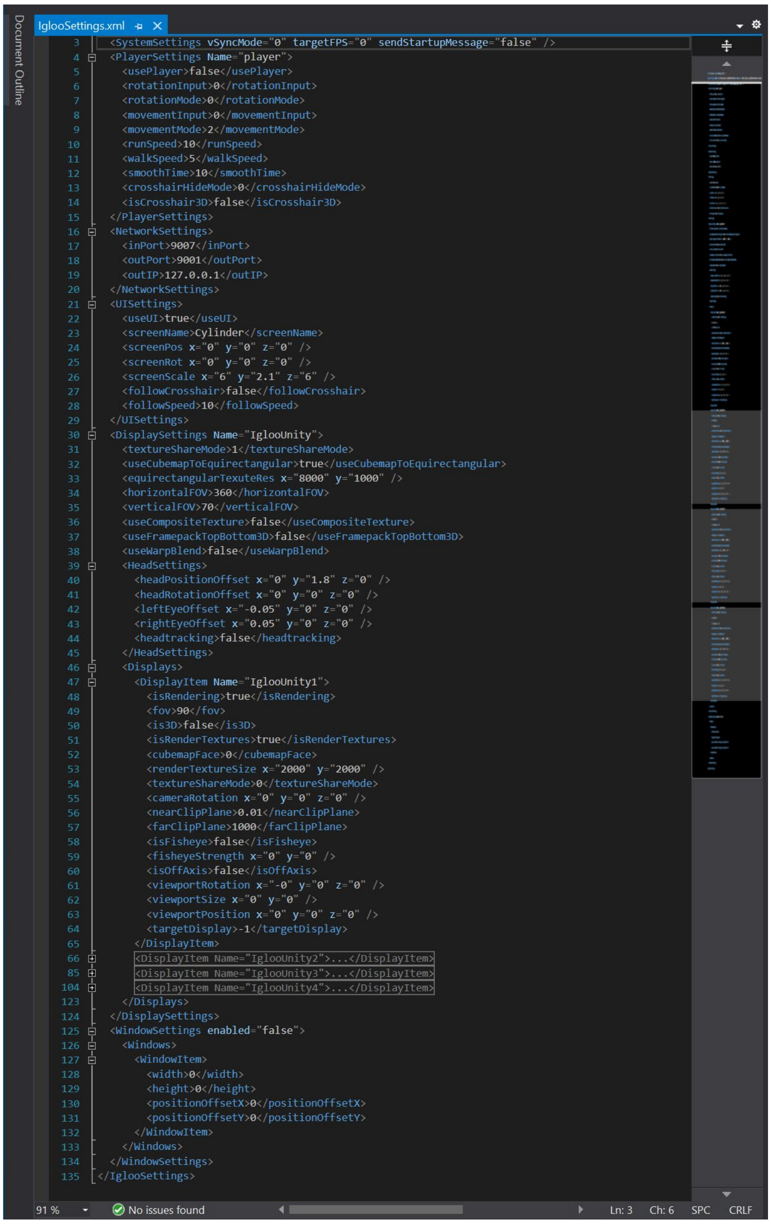
		
Buttons	Bound Control	Object manipulator
		
Near menu	Fingertip visualization	Interactable
		
Solver	Pointer	Tooltip

5 Design

After finalizing the concept phase, two concepts were chosen to establish the baseline for the design for this project. One concept is the environment inside XR-LAB and other is the HoloLens. During this phase, development of interactive environment was completed and successfully deployed on the respective system.

5.1 XR-LAB

Timeframe of thesis and to achieve the goal of thesis a simple design of the environment was chosen. There were only small changes and adjustments done from the concept and these are mainly just positions of the virtual camera and display /rendering settings. The sphere models used in the chosen concept were just temporary during testing and these was changed with other 3D models after working on the interactive environment for the HoloLens. Figure 8 shows the configuration script of the Igloo Vision's camera package, and important notes to take from this is that player is set to false (Line 5), resolution is set to x = 8000, y = 1000 (Line 33), horizontal and vertical FOV is set to 360 and 70 degrees respectively (Line 34-35). There are four displays (Line 46-122) that acts as outputs and render in real time from the application, and these are processed in Igloo Warper before outputted on the canvas inside the XR-LAB.



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3    <SystemSettings vSyncMode="0" targetFPS="0" sendStartupMessage="false" />
4    <PlayerSettings Name="player">
5      <usePlayer>false</usePlayer>
6      <rotationInput>0</rotationInput>
7      <rotationMode>0</rotationMode>
8      <movementInput>0</movementInput>
9      <movementMode>2</movementMode>
10     <runSpeed>10</runSpeed>
11     <walkSpeed>5</walkSpeed>
12     <smoothTime>10</smoothTime>
13     <crosshairHideMode>0</crosshairHideMode>
14     <isCrosshair3D>false</isCrosshair3D>
15   </PlayerSettings>
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17     <inPort>9007</inPort>
18     <outPort>9001</outPort>
19     <outIP>127.0.0.1</outIP>
20   </NetworkSettings>
21   <UISettings>
22     <useUI>true</useUI>
23     <screenName>Cylinder</screenName>
24     <screenPos x="0" y="0" z="0" />
25     <screenRot x="0" y="0" z="0" />
26     <screenScale x="6" y="2.1" z="6" />
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28     <followSpeed>10</followSpeed>
29   </UISettings>
30   <DisplaySettings Name="IglooUnity">
31     <textureShareMode>1</textureShareMode>
32     <useCubemapToEquirectangular>true</useCubemapToEquirectangular>
33     <equirectangularTexuteRes x="8000" y="1000" />
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37     <useFramepackTopBottom3D>false</useFramepackTopBottom3D>
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45     </HeadSettings>
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53         <renderTextureSize x="2000" y="2000" />
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57         <farClipPlane>1000</farClipPlane>
58         <isFisheye>false</isFisheye>
59         <fisheyeStrength x="0" y="0" />
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62         <viewportSize x="0" y="0" />
63         <viewportPosition x="0" y="0" z="0" />
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65       </DisplayItem>
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85       <DisplayItem Name="IglooUnity3">...</DisplayItem>
104      <DisplayItem Name="IglooUnity4">...</DisplayItem>
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124  </DisplaySettings>
125  <WindowSettings enabled="false">
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132      </WindowItem>
133    </Windows>
134  </WindowSettings>
135 </IglooSettings>
91 %   No issues found   Ln: 3   Ch: 6   SPC   CRLF
```

Figure 8 – Igloo settings script (Screenshot from Visual Studio 2019)

By default, when an application is built, in the player settings, resolution is set to be “Fullscreen Window” and the option of a resizable window is not checked. When launching the application on the XR-LAB server, this has proven to be inconvenient due to Igloo Warper also need to be accessed at the same time. Figure 9 shows the default player settings and here the tab for “Resolution and Presentation” is open.

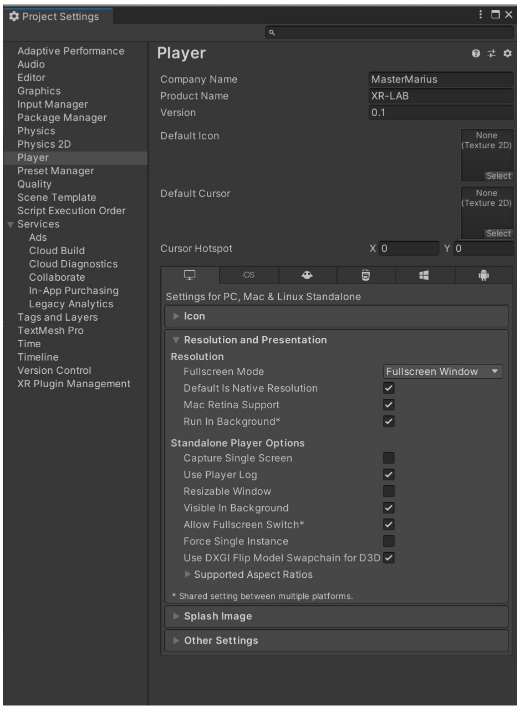


Figure 9 – Project settings, default. (Screenshot from Unity Editor)

In Figure 10 the application is running on the server, and in default settings it is running in fullscreen. In this scenario the user must manually bring the warper back. The warper with the application running in the background is shown in Figure 11.

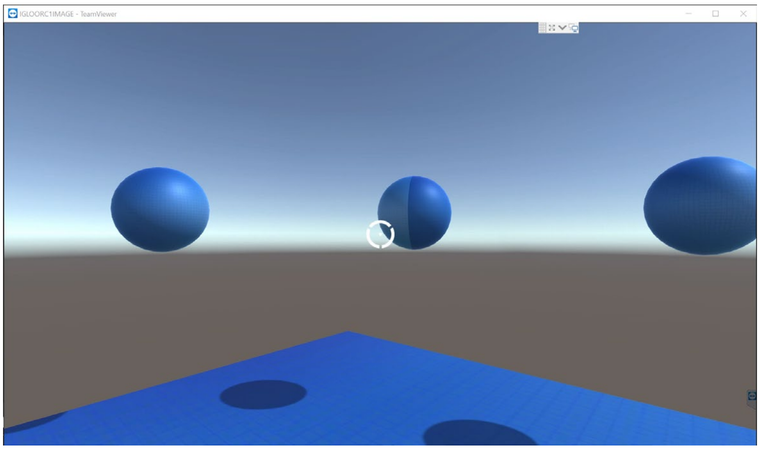


Figure 10 – Application running in fullscreen mode on (Screenshot via TeamViewer)

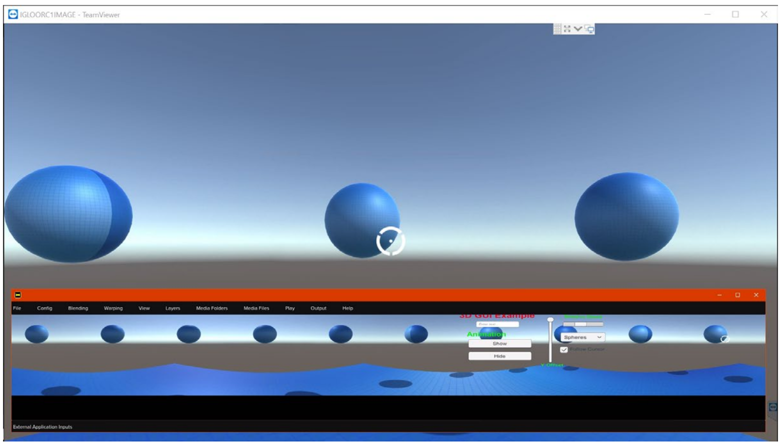


Figure 11 – Application and Igloo Warper (Screenshot via TeamViewer)

To avoid the application for launching in fullscreen, the setting for the “Fullscreen mode” were changed from “Fullscreen window” to “Windowed” with a default resolution of 1024 x 768 pixels. The option of having a resizable window is now checked as well to give the users the desired window size. Figure 12 shows the new setting applied for the player settings.

After creating the application again and deploying it on the server, the application will now open in a window and users can access other application simultaneously with ease. In Figure 13 XR application is running in window mode, and it still output the full 360-degree picture in the warper.

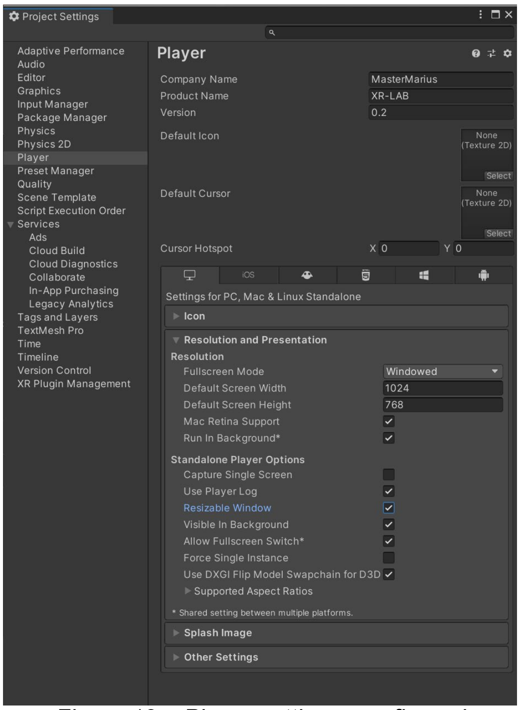


Figure 12 – Player settings, configured (Screenshot from Unity Editor)

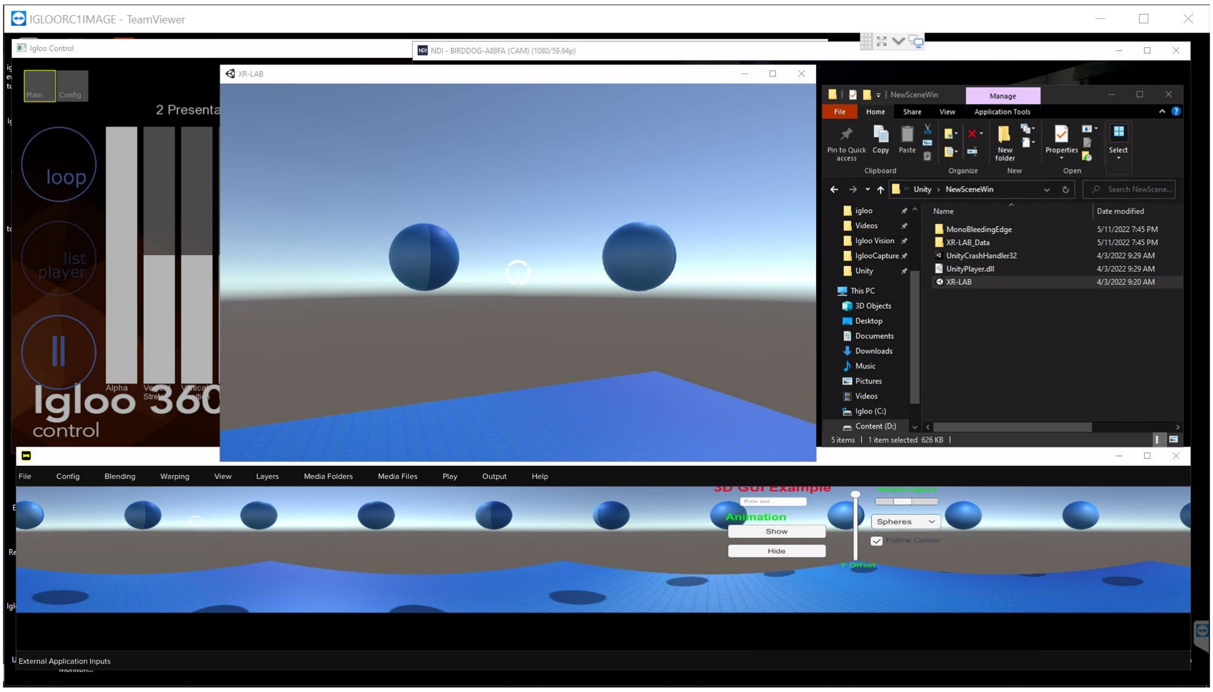


Figure 13 – Application in window mode and Igloo Warper (Screenshot via TeamViewer)

Next phase is prototyping where the content displayed here will be altered, in favor of interactive 3D models that are configurated during the design of the environment to the HoloLens.

5.2 HoloLens 2

When getting started with MRTK and development of an application to the HoloLens, the project had to be configurated and the toolkit offers a user-friendly setup process for new developers with a lower skill level.

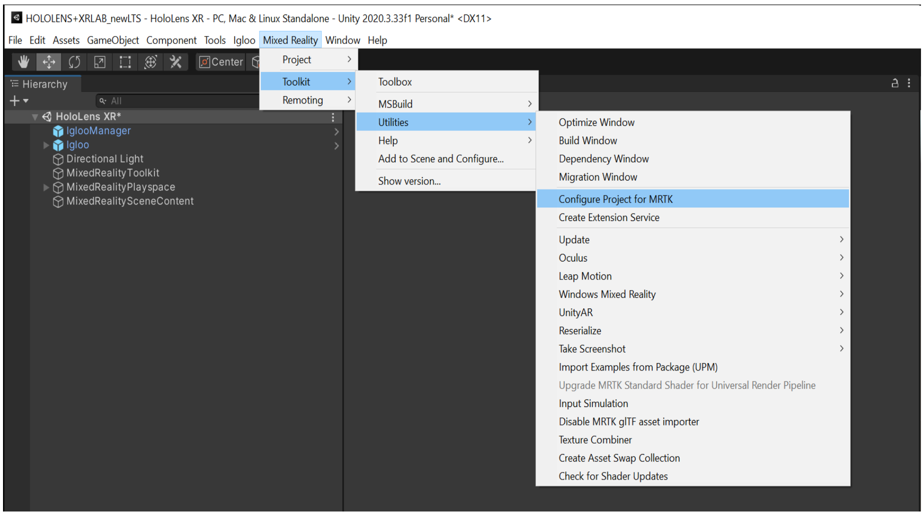


Figure 14 – Configure project for MRTK (Screenshot from Unity Editor)

Figure 14 shows a way to enter the configurator and then Unity will open another window that is a step-by-step process of project setup. Depending on the type of project that are developed, Microsoft provides good support on recommended setups.

Figure 15 – MRTK Project Configurator (Screenshot from Unity Editor)

In Figure 15 the configurator is open, and here it can be seen that the project is configured and the XR SDK pipeline along with the OpenXR plugins are installed in the project. Next step in the process is to enter the project setting under the section "XR Plug-in Management" to check the box named “Initialize on Startup”, change the “Depth Submission Mode” from “Depth 24 bit” to “Depth 16 bit”, and add interaction profiles. The profiles that are recommended to add are Microsoft hand interaction profile, eye gaze interaction profile, and Microsoft motion controller profile. They seemed to work good in this project. See figure 16 for illustration of the plug-in management and the added profiles..

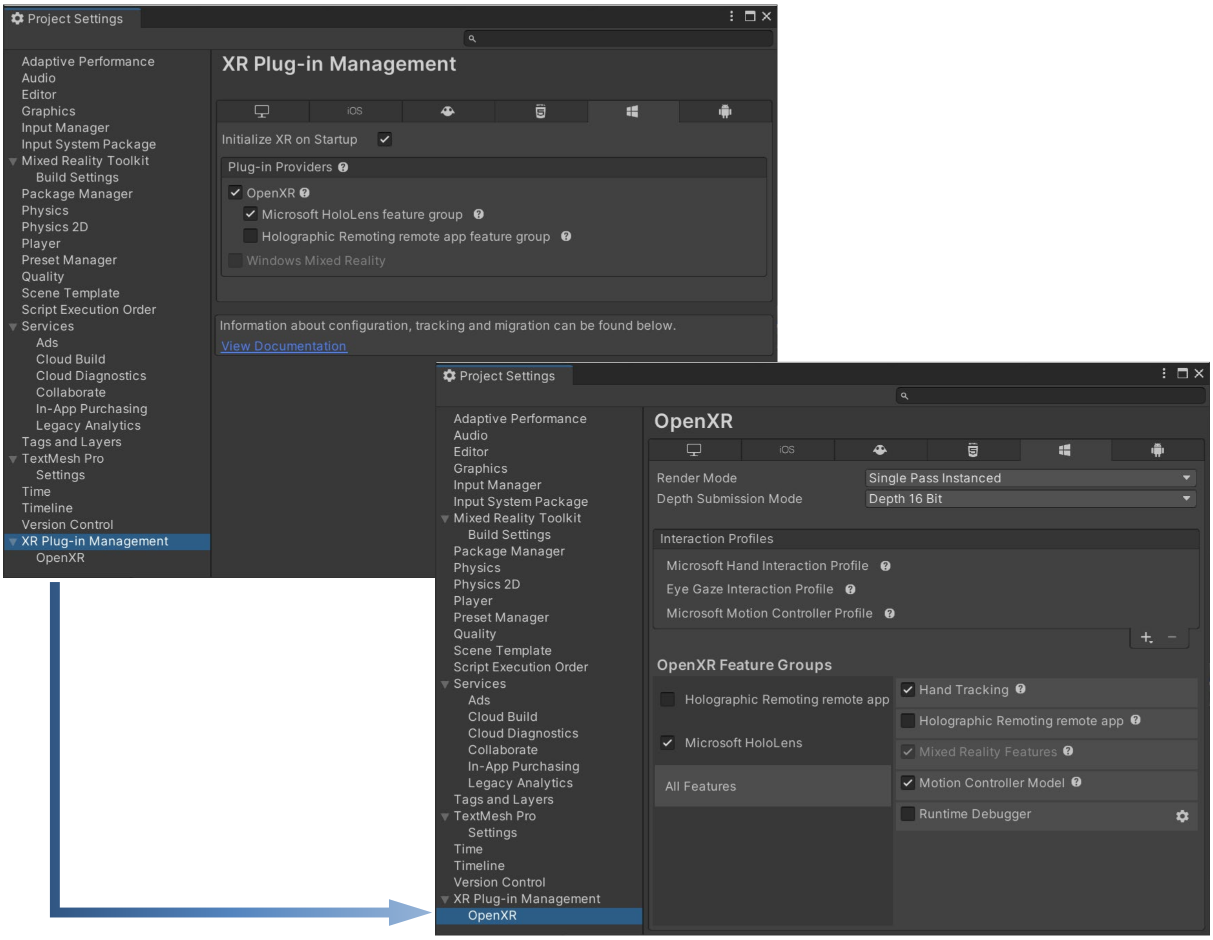


Figure 16 – XR Plug-in Management (Screenshot from Unity Editor)

Now with the MRTK and the plugins configurated, the wanted profiles and experience settings within the scene can be accessed and finetuned. This is how the user of the headset will interact with any objects in the environment, what kind of real-world environment the headset is used in, spatial awareness, inputs, boundary etc.

In this project, in total six profile were made to serve the applications purpose inside the XR-LAB.

In Figure 17 it is illustrated the main XR-LAB experience profile in the inspector window, and that the target experience scale is set to “Room”. In the project window below, the 5 other profiles that are configured into the experience is visible.

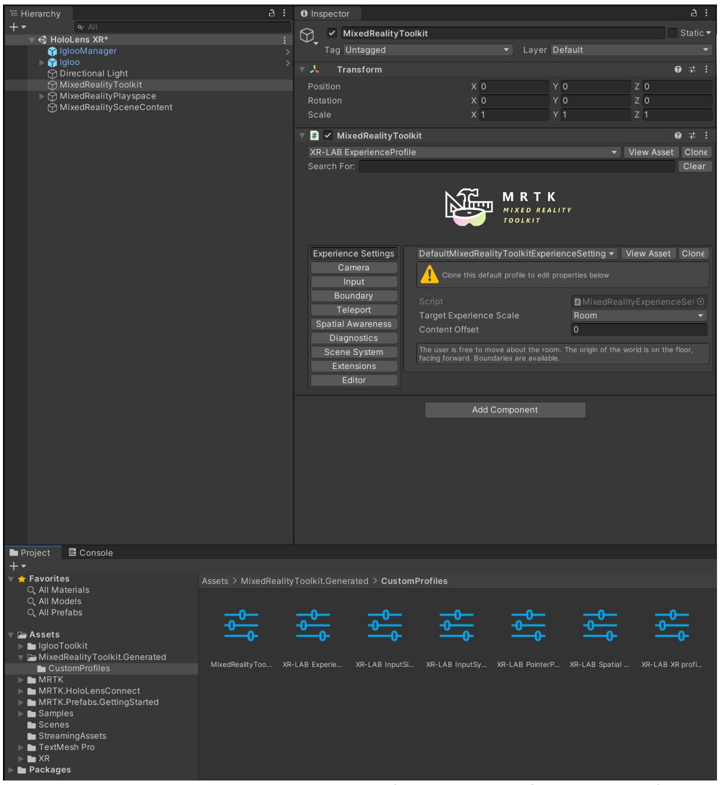


Figure 17 – MRTK Experience Profile settings (Screenshot from Unity Editor)

The custom profile for the input simulation setting is where the inputs and controls were configurated, the input simulation is used when the applications are running in play mode in the editor. This is a valuable feature where developers can emulate and test the application, before creating a build. You can define the key bindings, simulate eye gazing with controlling the camera, hand gesture and motion.

Figure 18 shows some of the setting that was chosen. These settings do not have any impact on applications but it is a preferable adjustment when developing and running tests.

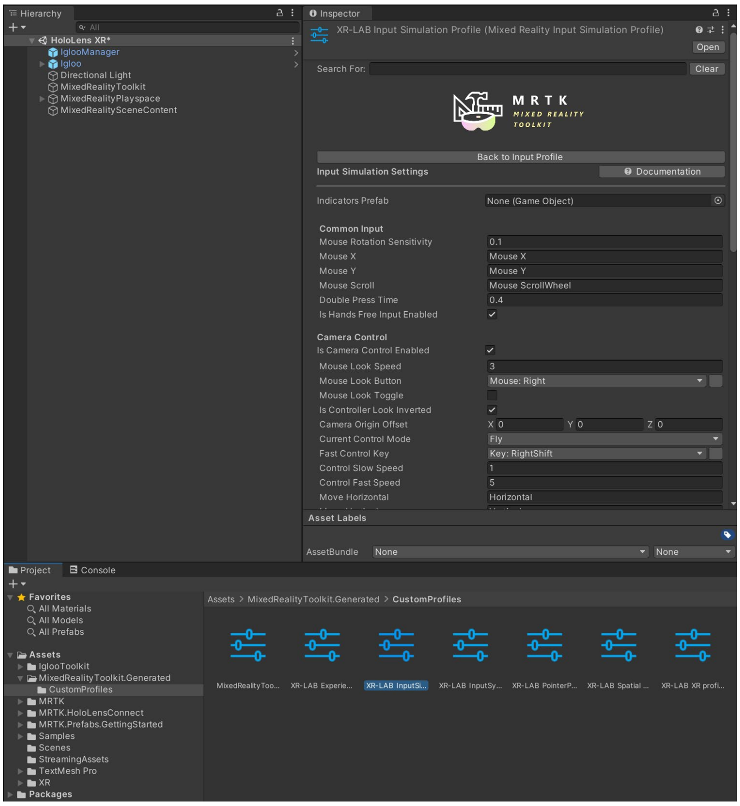


Figure 18 – XR-LAB Input Simulation Profile (Screenshot from Unity Editor)

Input system setting is for how users can use interactions with their hands, eyes, or speech. It also can be configuration of additional controllers, input action and pointers.

In this project, it uses default settings provided in the toolkit except for custom pointer profile, as illustrated in Figure 19.

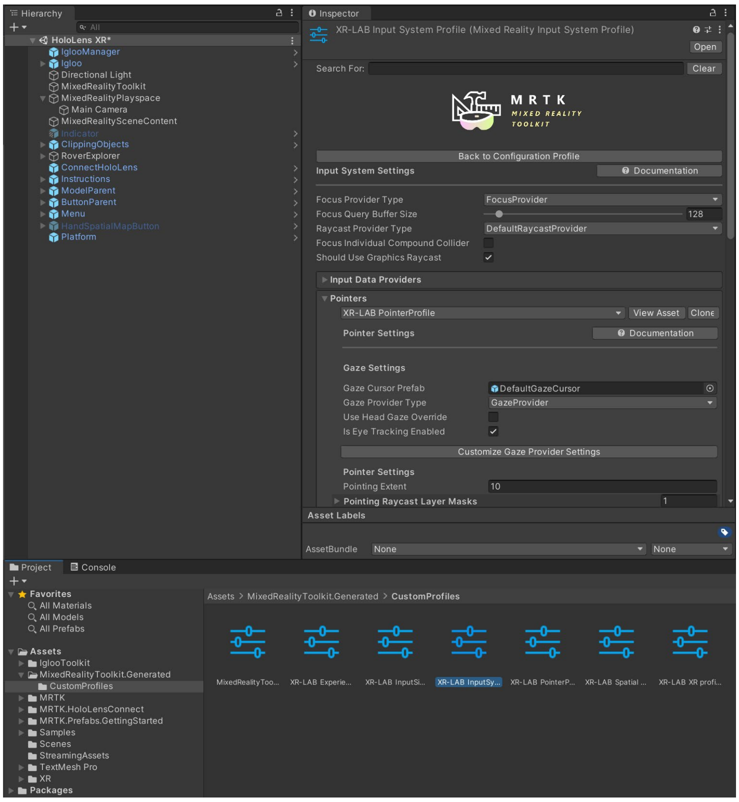


Figure 19 – XR-LAB Input System Profile (Screenshot from Unity Editor)

The pointer is divided into two groups, near pointer and far pointer. With the near pointer, you can either poke or grab objects to interact with them. The far pointer let users project a beam from their hand to interact with objects that are at a distance in the environment. For the pointer profile, the most important customization done is to activate the eye tracking, so it is possible to use this feature when the application is running on the headset. In Figure 20, the profile is illustrated. Other configurations that were done, was to add OpenXR and windows mixed reality as a controller type on all the different pointer options.

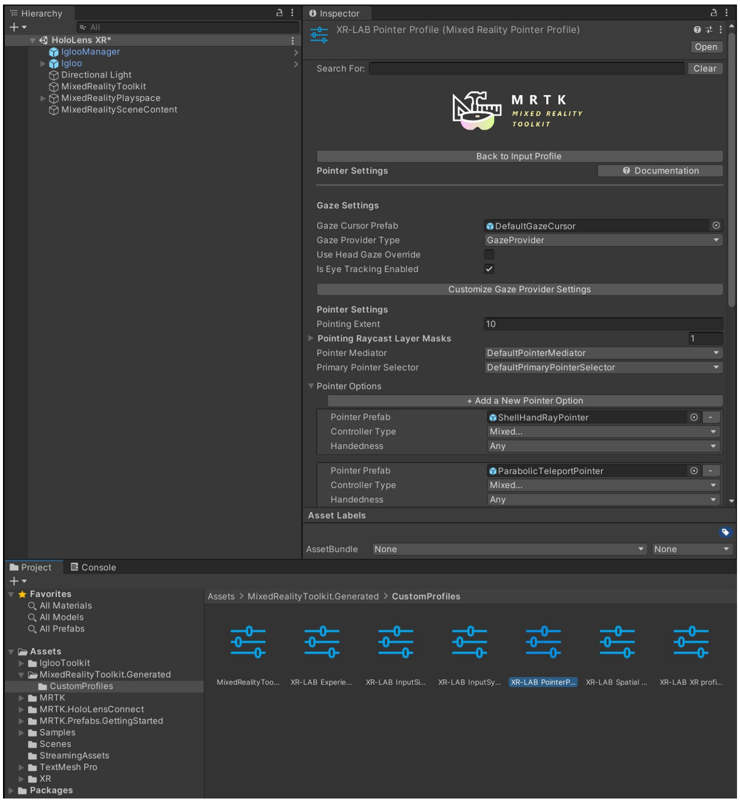


Figure 20 – XR-LAB Pointer Profile (Screenshot from Unity Editor)

In the spatial profile, configuration of how the headset will scan the real-world environment and how this is shown to the users. Here it is possible to change the mesh, update interval, change how it is displayed, and accuracy.

In Figure 21, an illustration is provided of how the settings and the options that can be chosen.

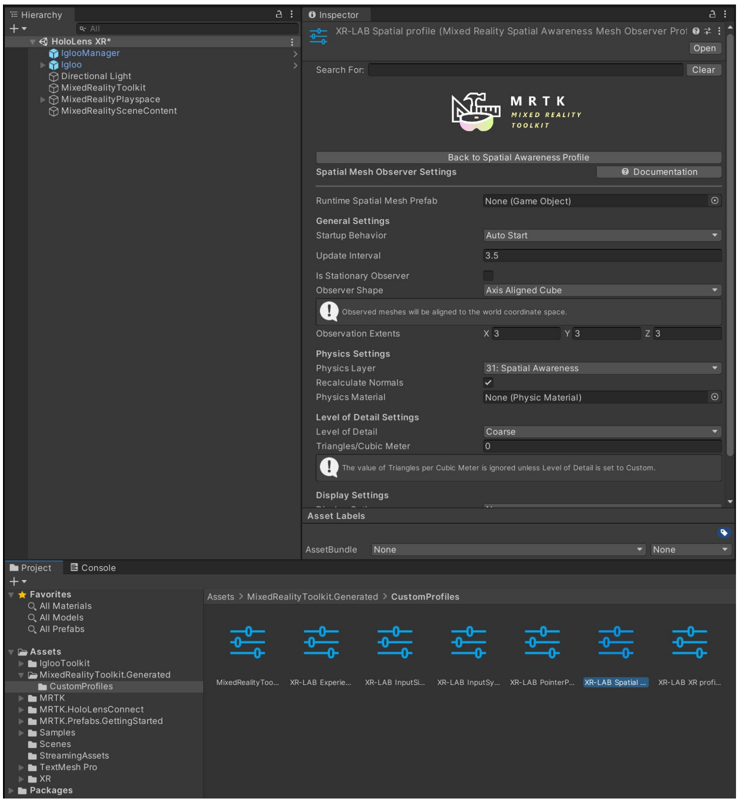


Figure 21 – XR-LAB Spatial Profile (Screenshot from Unity Editor)

For this project, the render of the mesh will not be displayed to the user as the display settings was set to “None”.

For setup and activation of spatial awareness, the spatial profile that was made must be defined in the spatial awareness system profile as a spatial observer.

In figure 22, the configuration that was done is illustrated.

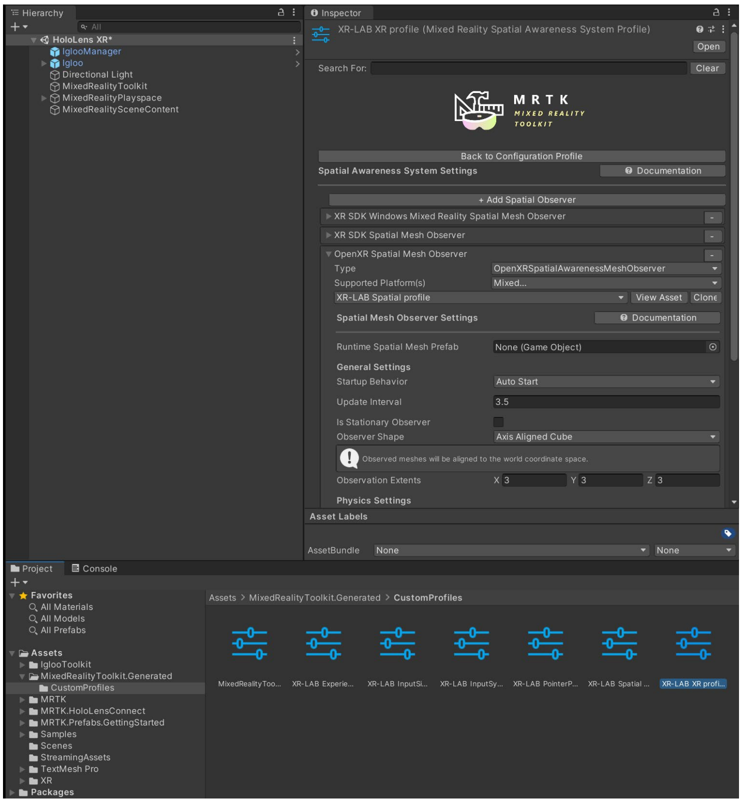


Figure 22 – XR-LAB XR Profile (Screenshot from Unity Editor)

After this point, all the required setups and configurations needed are completed and the work with the 3D models could start. In the toolkit there were provided prefabs, models, materials, and scrips to get started.

Reason for the custom spatial profile, was due to the spatial mesh was showing inside the headset at all time. This did not provide any good experience as the users would not be able to see the real-world witch is a key feature with an AR/MR headset. Figure 23 illustrate how this was experienced inside the headset during testing and configuration.

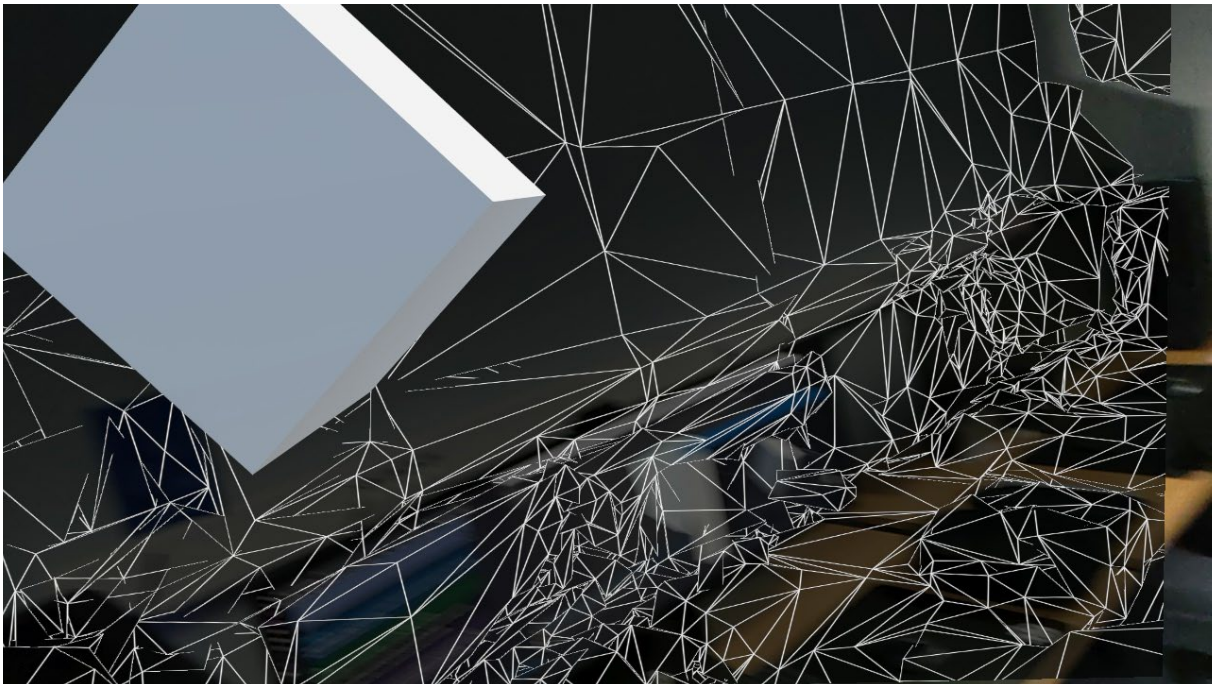


Figure 23 – Spatial Mesh always visible. (Screenshot from the HoloLens 2)

In the MRTK, prefabricated 3D models were provided, components, and scripts for behavior of them. And as the project had a limited duration these were used making the interactive environment. One of the assets provided was a "Rover, and with this asset a good number of features is being utilized. This were a good fit for the project as it could be designed and programmed to showcase the integration towards the XR-LAB.

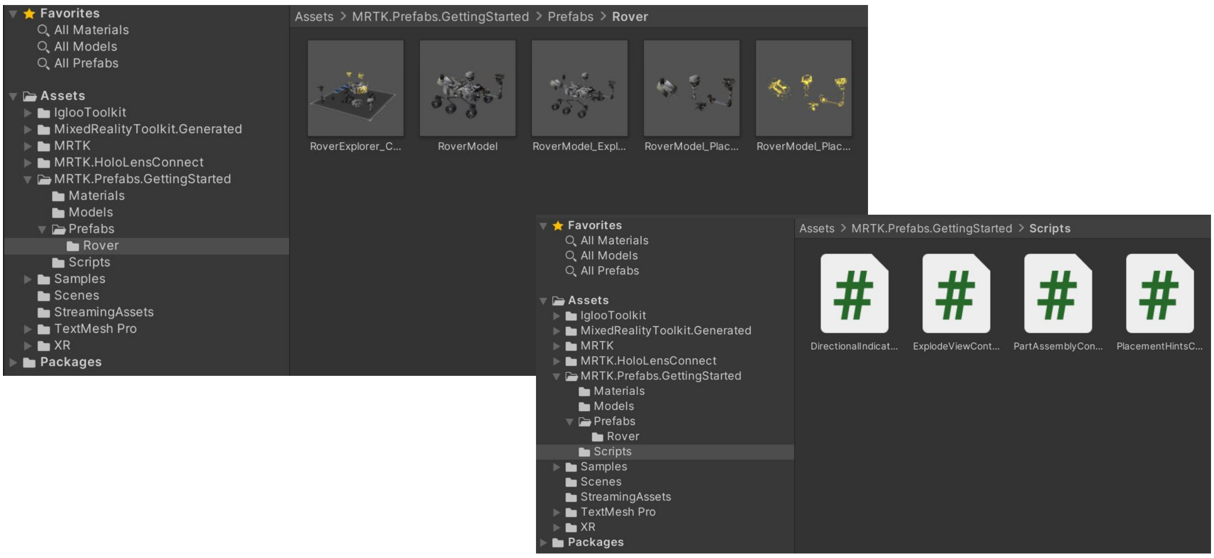


Figure 24 – MRTK Prefab (Screenshot from Unity Editor)

Even though these are prefabricated models and scripts, the models needed to be placed on the desired placement, named and all the featured needed to be programmed and the scripts needed to be assigned. Figure 25 illustrates the placement and all the components with names.

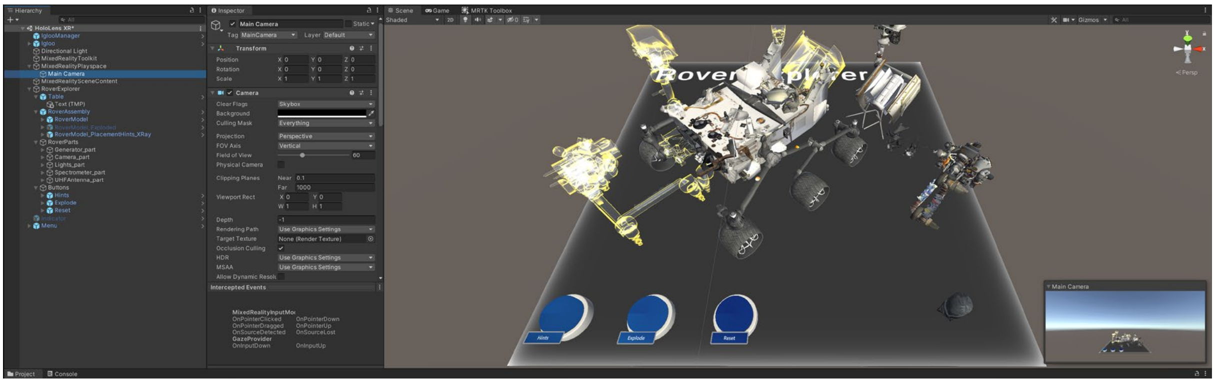


Figure 25 – Models placed in environment and components named. (Screenshot from Unity Editor)

With everything now placed inside the environment, the programming and the assigning the scripts is the next step. Keeping in mind that everything visible now would be interactable, this is divided into three levels. Level 1 is the virtual table that the rover, its belonging parts and the three interactive buttons is placed on. Level 2 would be the rover and the parts are level 3.

For level 1, all the assets were assigned as a component to the table, and this creates the opportunities to configure everything at once if the user want to move, rotate, or scale the models. To do this, bounds control component was added along with an object manipulator scripts. These scrips were so assigned to a menu panel that's follows the user where it easily can be turned on and off. In Figure 26 we can see that the bounds control is active for the table and the assets on it. The inspector tab shows all the components and how the buttons are assigned to functions within the bounds control script. When running the application in "Play Mode", the bounds could be activated or deactivated, by using the input simulation profile which allows for simulate hand gestures.

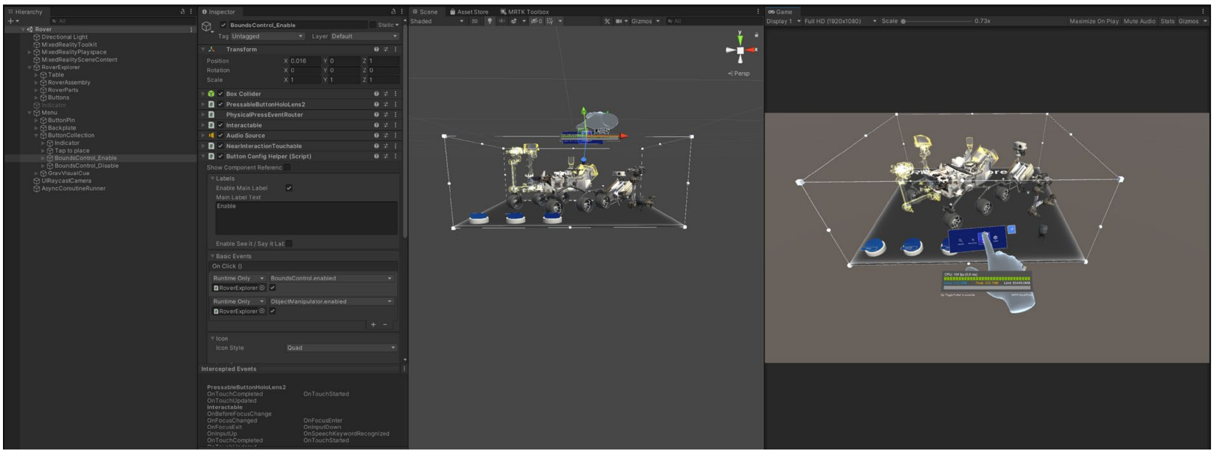


Figure 26 – Bounds control (Screenshot from Unity Editor)

In order to make rover interactive in level 2, we needed components and configure the scripts onto the 3D model. The main components to enable this, are the Object Manipulator, NearInteractionGrabbable, and SolverHandler. To create a good experience for the users, components such as placements hints controller, explode view controller, part assembly controller and audio were added as an addition. Figure 27 illustrate the scripts used.

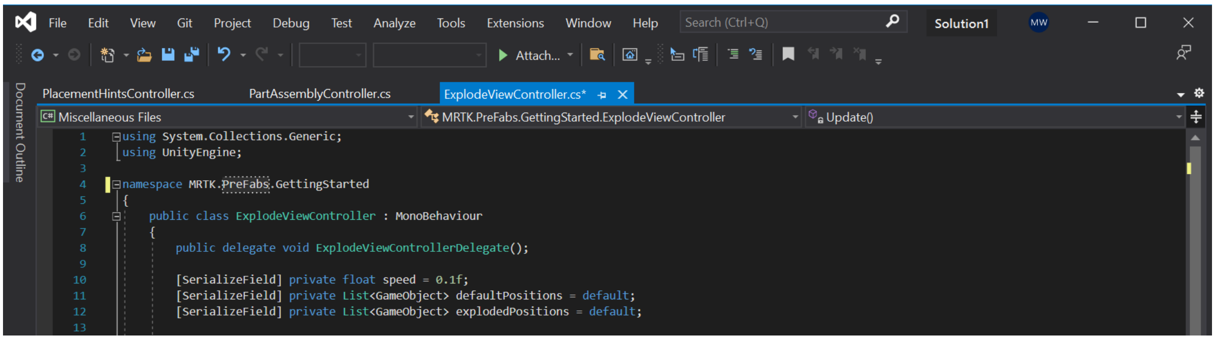


Figure 27 – Additional controller scripts. (Screenshot from Visual Studio 2019)

With the components in place and configured, we can now interact with the rover by using our hands while wearing the HoloLens 2. Figure 28 shows the rover and all the components that enables the interaction and manipulation in real-time when running the application.

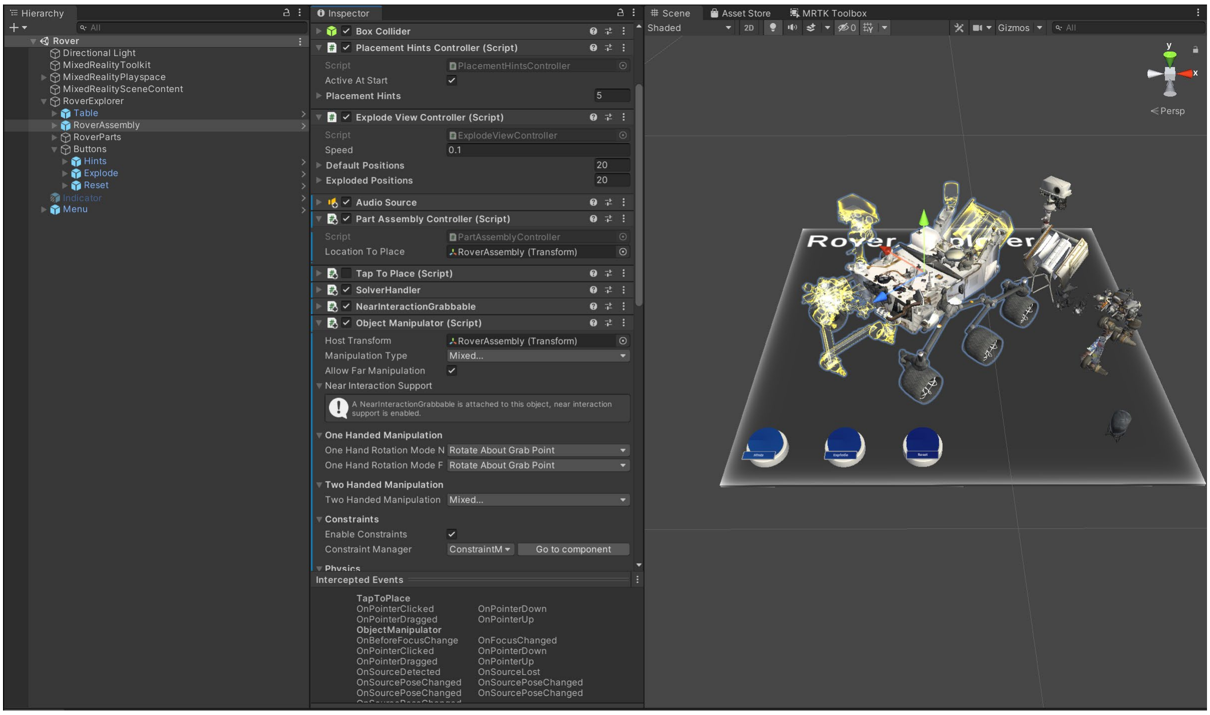


Figure 28 – Rover and its components. (Screenshot from Unity Editor)

On the last level, the parts belonging to the rover needed to be configured so they could be assembled on the rover by the user. To enable this, components were added to the individual parts, these were the Object Manipulator, Near Interaction Grabbable and the Part Assembly Controller. The part assembly were configured to the placement hint on the rover, and the controller script now lets the part snap on the correct placement when it is placed by the user. Figure 29 illustrate how the part assembly controller were configurated for one of the parts.

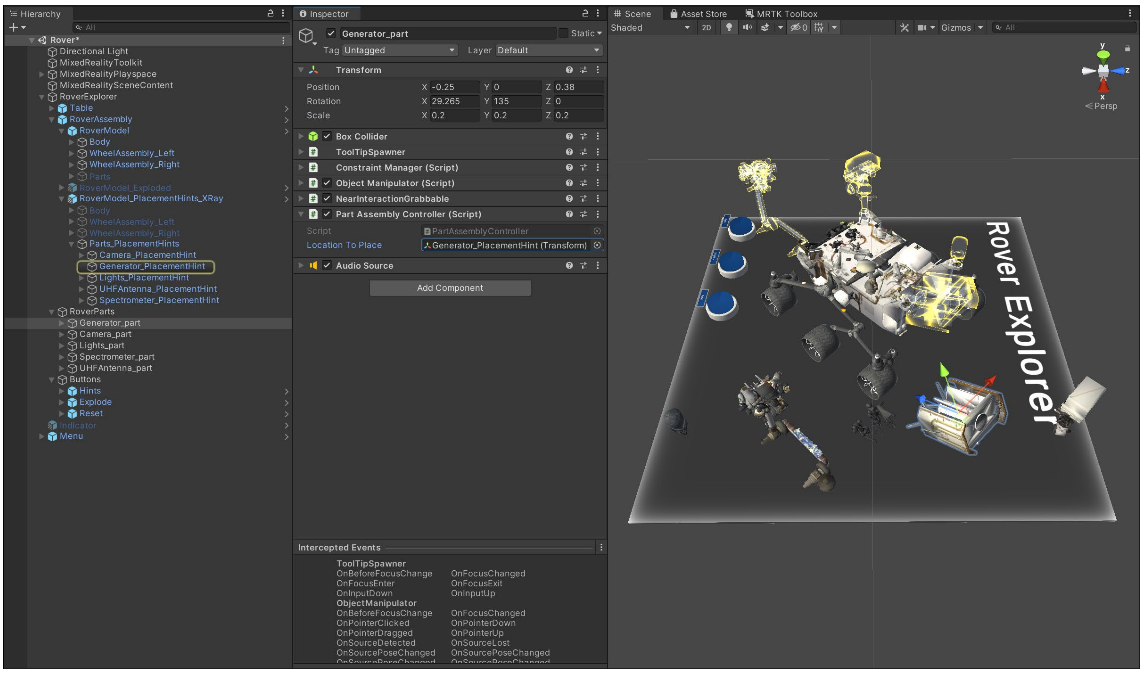


Figure 29 – Configuration of the parts to the rover. (Screenshot from Unity Editor)

To add extra information to the user, a ToolTip script were added as a component for the parts. With this the users can now see the name of the parts by either looking at them or when interacting with them. Figure 30 shows how the component were configured and how it looks then running the simulation.

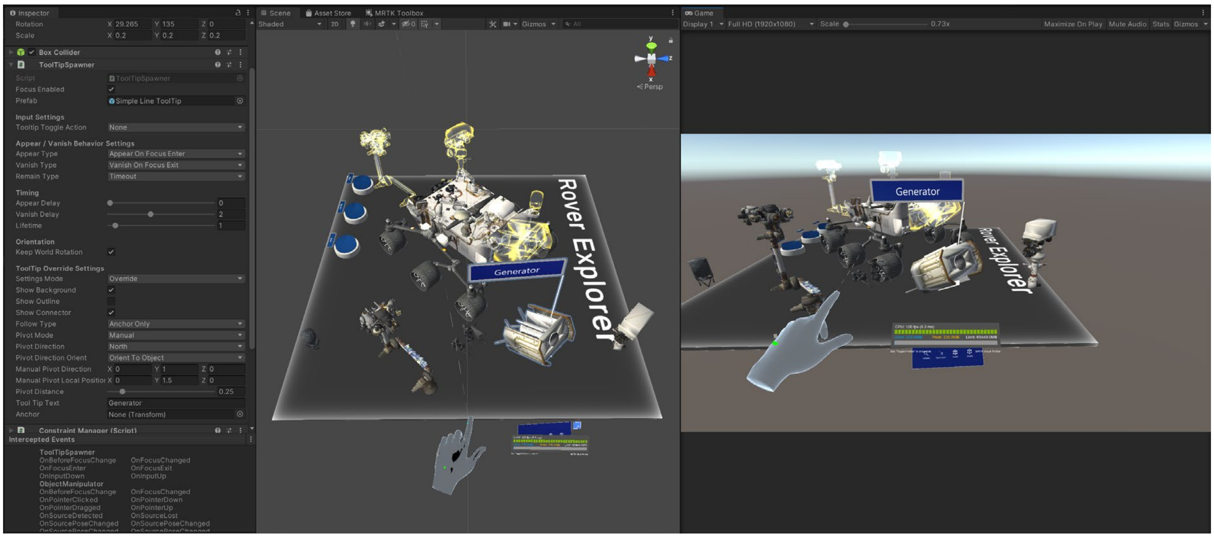


Figure 30 – ToolTip for addition information. (Screenshot from Unity Editor)

With all the three levels completed, the three buttons that are placed on the table were configurated. These buttons are named “Hints”, “Explode”, and “Reset”. Purpose of these button are to assist and add visibility for the users.

The first button, “Hints”, are used to turn on or off the placement hints on the rover.

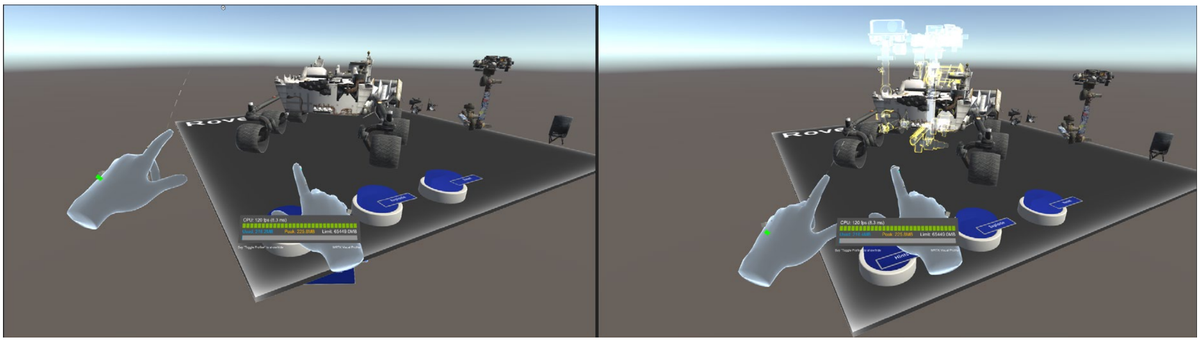


Figure 31 – Placement hints. (Screenshot from Unity Editor)

Second button are used to switch between normal view or exploded view of the model.

Figure 32 – Normal View (Screenshot from Unity Editor)

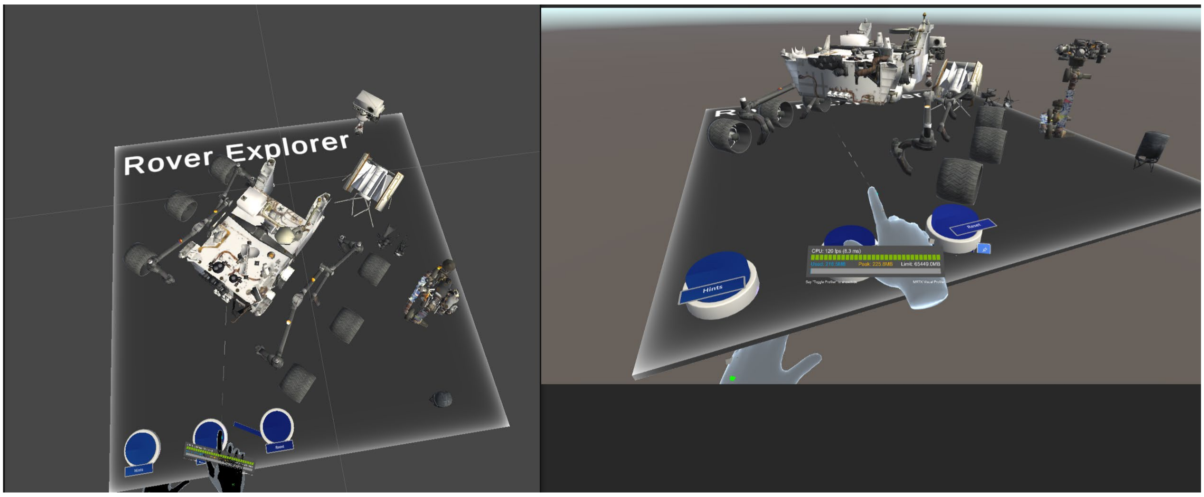


Figure 33 – Exploded View (Screenshot from Unity Editor)

The third button is to reset the rover and the parts to its original position.

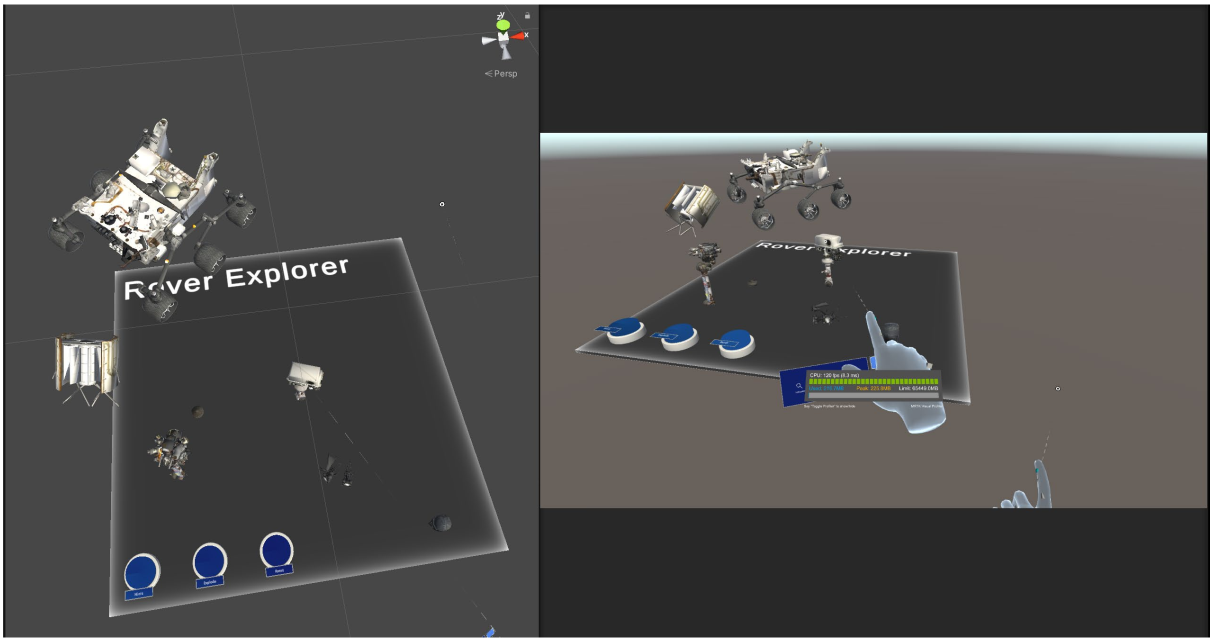


Figure 34 – Rover and parts moved out of position. (Screenshot from Unity Editor)

Figure 35 – Rover after pushing the reset button. (Screenshot from Unity Editor)

The desired design was now completed, a build was created and then deployed on the HoloLens 2 for testing of the performance and features. The application was running successfully on the device, with all the features working as intended. However, the framerate was not as expected, the target was 60 frames per second and only 30 were maintained. It was not taken any measurement to resolve the performance at this point as the implementation to the XR-LAB could impact this at a later stage.

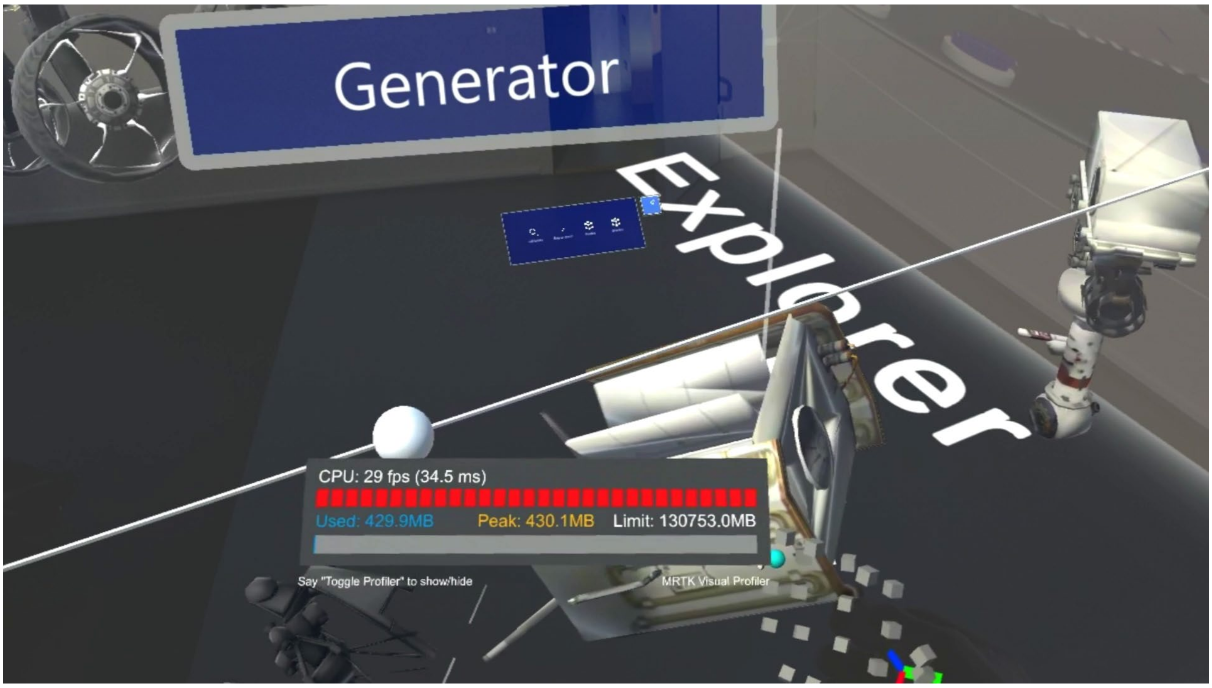


Figure 36 – Snapshot from the HoloLens 2 running the application first time.

Figure 37 – Snapshot from the HoloLens 2 with Rover assembled.

6 Prototype

With the design phase completed, the prototype phase with establishing a connection between the XR-LAB and the HoloLens could start.

The initial strategy was to use the built-in network settings that the Igloo toolkit provides and configure the connection direct to the HoloLens 2 using the device IP address.

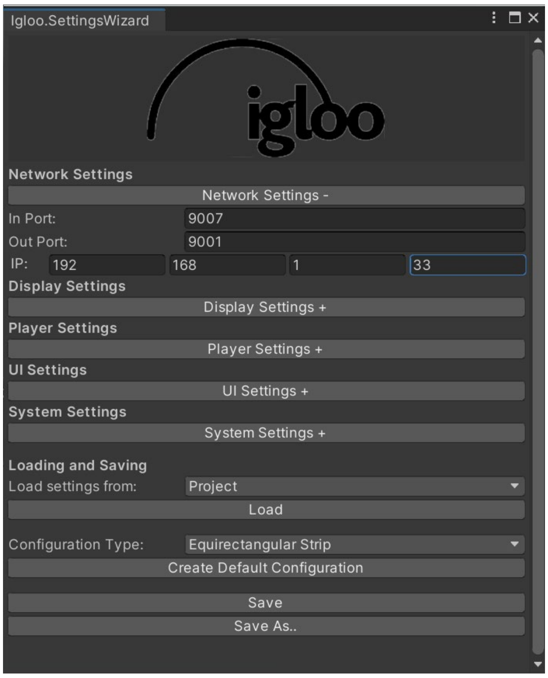


Figure 38 – Igloo network settings. (Screenshot from Unity Editor)

For this operation it was created two individual builds with predetermined network configuration. This was done because of the two different platforms, as the XR-LAB runs a Windows server, and the HoloLens 2 deploys through the Universal Windows Platform.

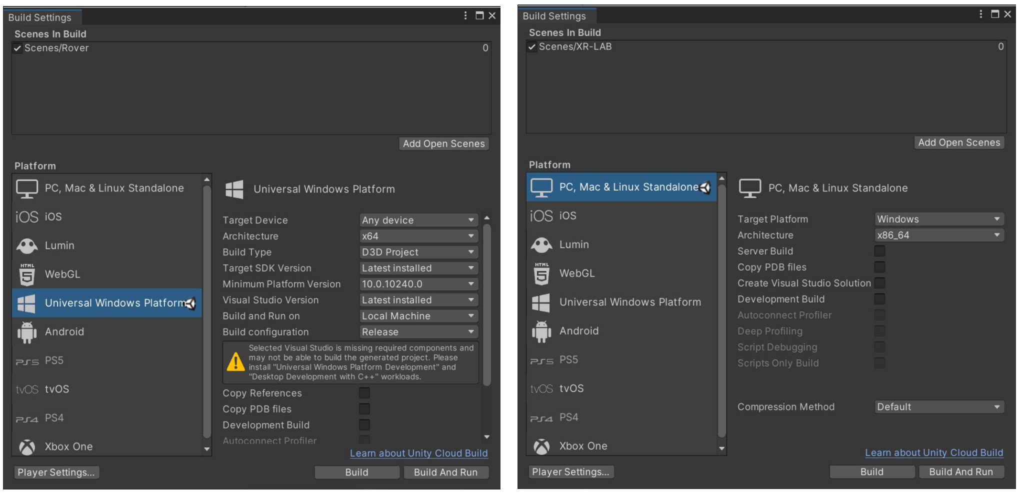


Figure 39 – Build settings of the two systems (Screenshot from Unity Editor)

The build was successfully created, but when tested only one of the applications would launch. The application made for the XR-LAB worked with outputting the correct environment, however when the application was deployed to the HoloLens 2 it failed. During the deployment, the application did not show any issues in the code but there was an error due to "Exception Thrown". Code and error are shown in Figure 40.

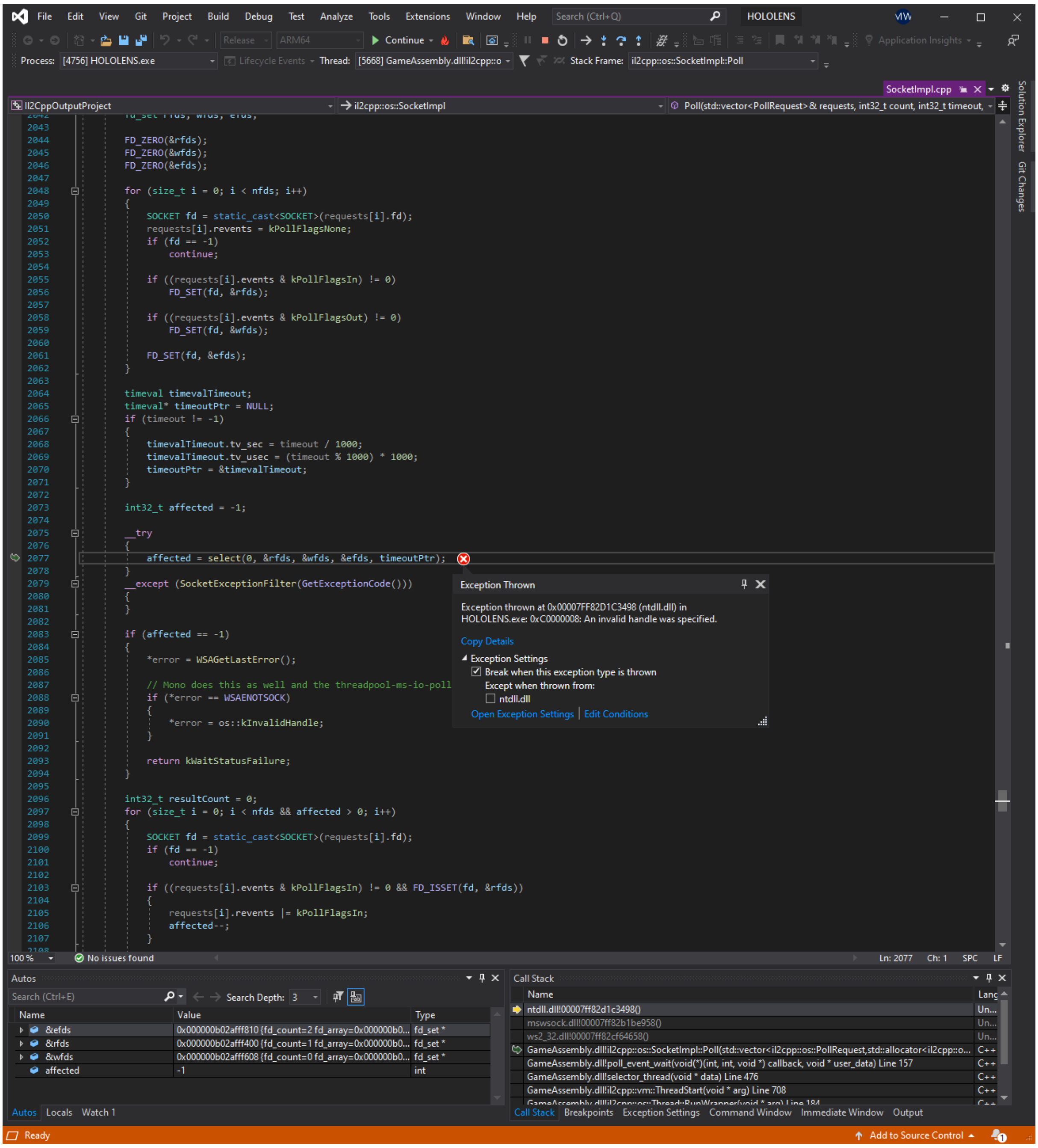


Figure 40 – Deployment to HoloLens failed. (Screenshot from Visual Studio 2019)

This was a complicated issue to troubleshoot for finding any resolution, and it was an attempt to rebuild the entire application, test different setting for the HoloLens and network. These attempts did not give any improvements or solutions to the issues that occurred, when deploying the application on the HoloLens 2.

During the troubleshooting and research for API or scripts that could resolve the issue, a second approach for establishing connection were discovered. This was a part of Microsoft's own solution for the mixed reality development and offered support for the HoloLens. This solution is an application made for the HoloLens and it is called Holographic Remoting Player. The application is a companion application that connects the HoloLens to a Windows application that supports Holographic Remoting [78]. By using Microsoft's resources to write a holographic application using the OpenXR API, a script was created to implement the support in the existing environment for the XR-LAB [79]. Figure 41 shows the component added to the environment, the script used can be seen in Figure 42.

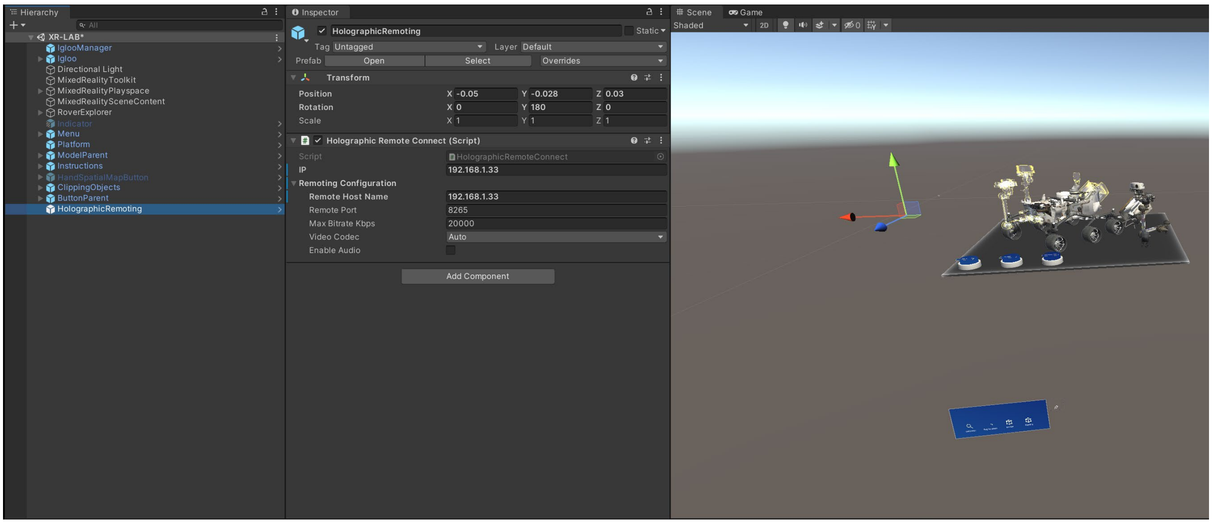


Figure 41 – Holographic Remote connect implemented (Screenshot from Unity Editor)

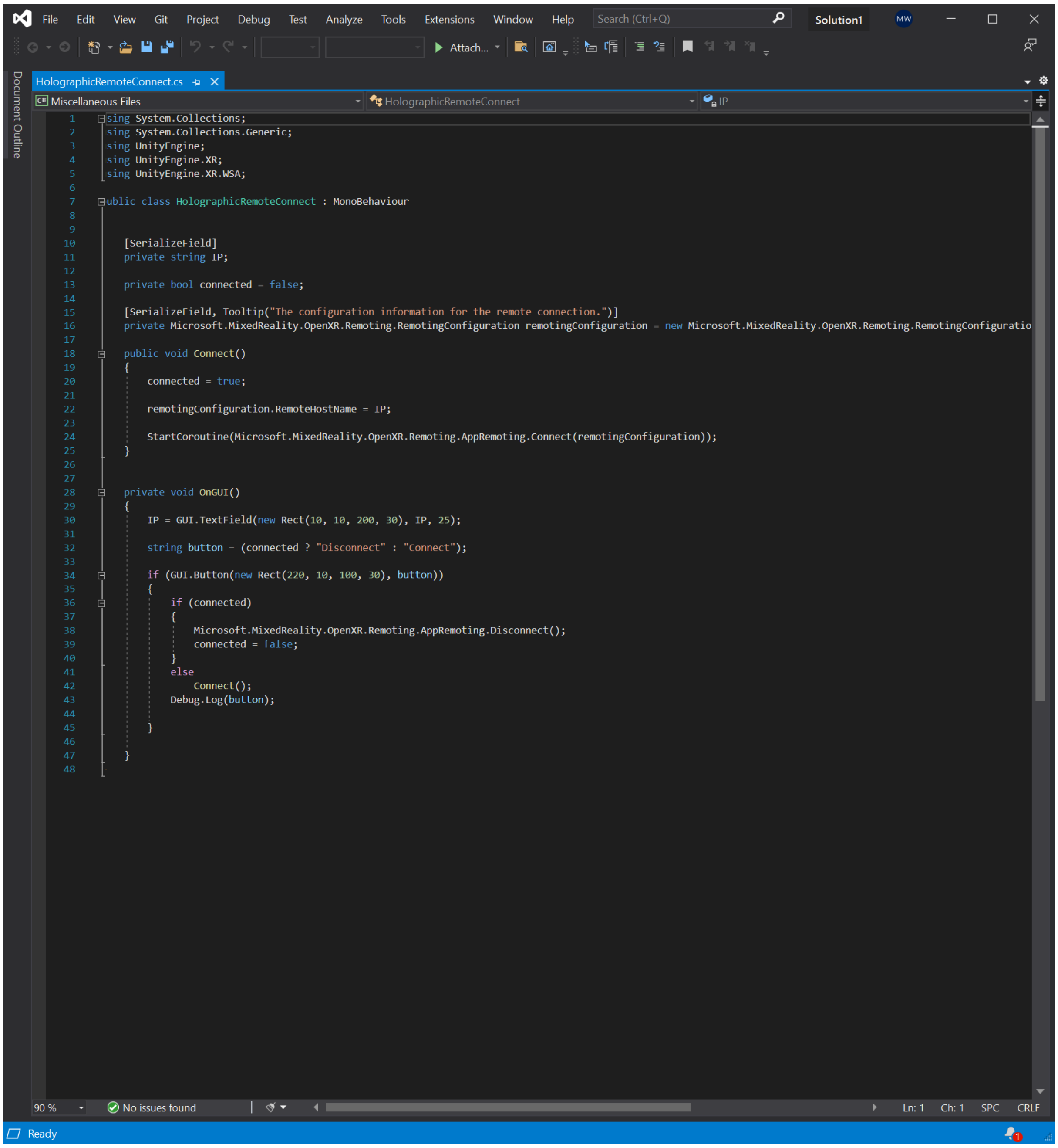


Figure 42 – Holographic Remote script (Screenshot from Visual Studio 2019)

After the implementation, it was attempted to create a build to test the application, but it failed due to a validation issue. Message displayed in Figure 43

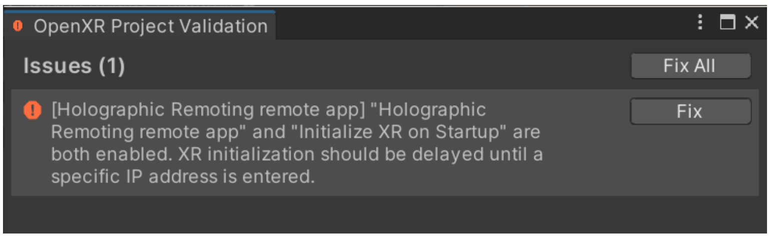


Figure 43 – Validation issue (Screenshot from Unity Editor)

Solution to this was to enter the project settings and perform changes under the section regarding the "XR Plug-in Management". After the MRTK configurated scene, it is by default selected that the OpenXR plugin will initialize on Startup. Figure 44 illustrate where to find the options for deactivate the initialization in startup.

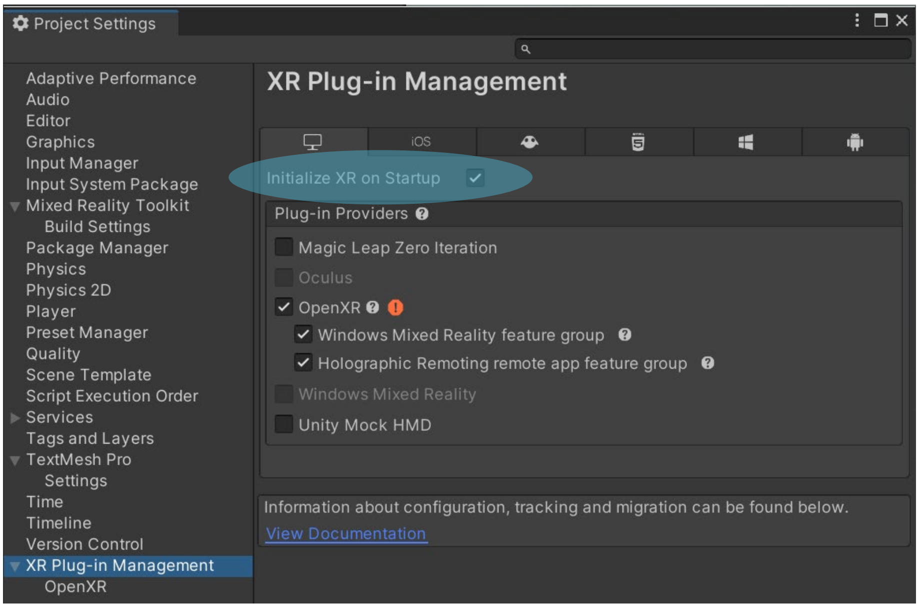


Figure 44 – Resolving the validation issue (Screenshot from Unity Editor)

After performing this step, the build was successfully created and then tested on the server powering the XR-LAB and at this point the application were running as intended.

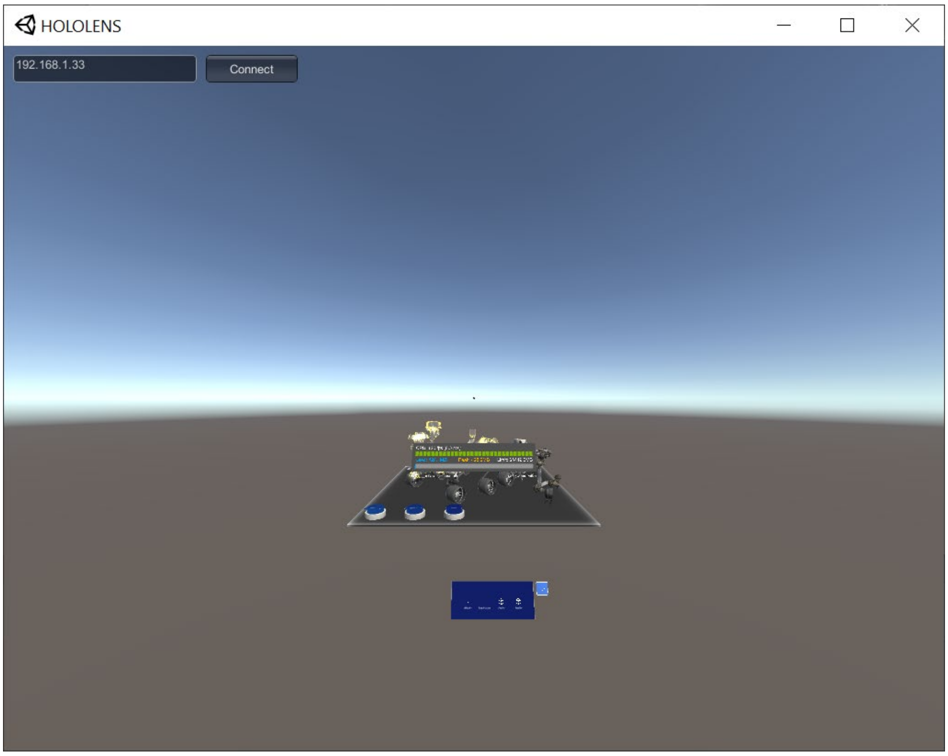


Figure 45 – Application running on the XR-LAB system (Screenshot of the application)

With the application running, next step was to connect the HoloLens 2. As the headset was at the same Wi-Fi network as the server, it was supposed to connect wireless directly. As the application are running on the server, the performance on the HoloLens was expected to be better than running the application on the headset. A connection was successfully established, and the headset now displayed the same environment that was outputted onto the canvas inside the XR-LAB. However, from the performance stats in the HoloLens, the framerate was still at 30 frames per second.

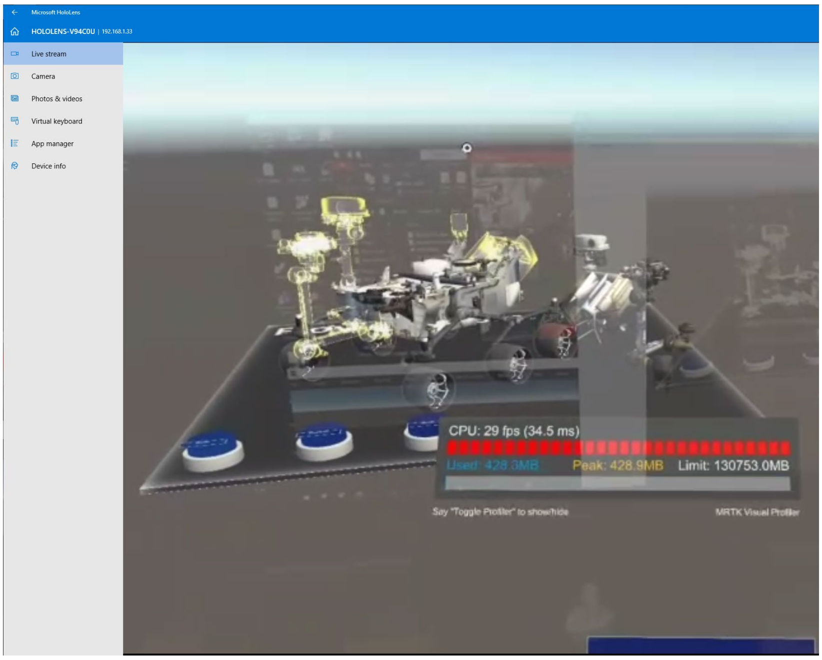


Figure 46 – Successful connection of the HoloLens (Screenshot from Microsoft HoloLens)

To improve the performance, the server, and the HoloLens 2, were rebooted before other measurement were done and that seemed to resolve the performance issue. After the performance was satisfying, the integration was tested by using all the features that the application had to offer and during the test there was one feature that did not work as intended. The feature that did not work, was the eye gazing. The eye gazing in the application were only to show the names of the parts when looking at them, at this point the impact of that is minimal for the experience.

The testing was executed in a longer period until the HoloLens were out of battery power, and the trough the test it was a stable connection and performance. During the test, another student got to test the headset and interact with the environment. Figure 47 shows a screenshot of the desktop running the test. Figure 48, and Figure 49 are photos taken inside the XR-LAB at the same test.

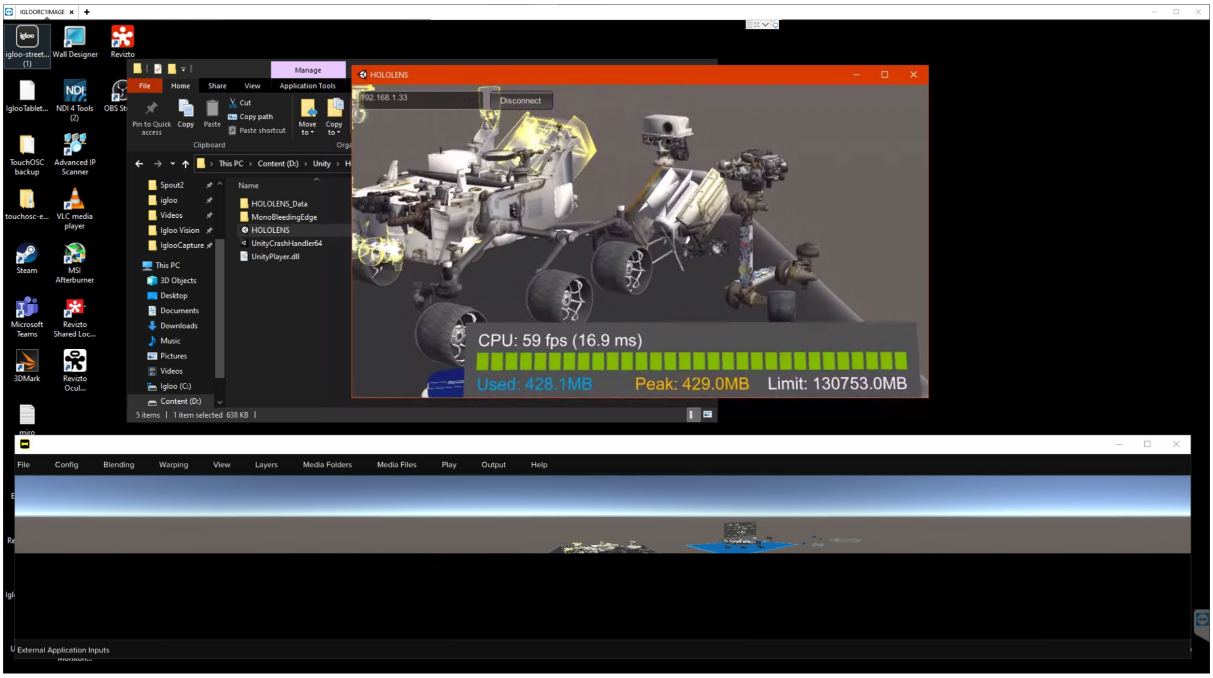


Figure 47 – HoloLens connected to the application running on the server. (Screenshot via TeamViewer)

Figure 48 – Picture taken inside XR-LAB when the HoloLens is connected.

Figure 49 – Picture taken inside the XR-LAB, displaying the environment onto the canvas.

6.1 Verification and Validation

The application has been launched multiple times, and it deploys on both systems without any issues. The connection has proven to be stable for the entire battery life of the HoloLens 2, approximately 2.5 hours of active usage.

All the features, except the eye gazing is working properly and the tracking of both the headset and the hands are quick and responsive.

It has been tested by other users, and all the users were able to interact with the environment, assemble the rover with the parts and manipulate the 3D object with hand gestures. Most of the persons have no experience of wearing a HoloLens or other AR headset, and the feedback of the experience were good.

The testing was executed over 4 days, and the application was running without any bugs. However, it has been done a few changes, such as adjustment of the height of the virtual camera, added extra content to interact with, and an additional table to display it on.

This was a good way to test how difficult it was to add more into the environment, and after doing so, it was no issues with creating the build or establish a connection with the HoloLens afterwards.

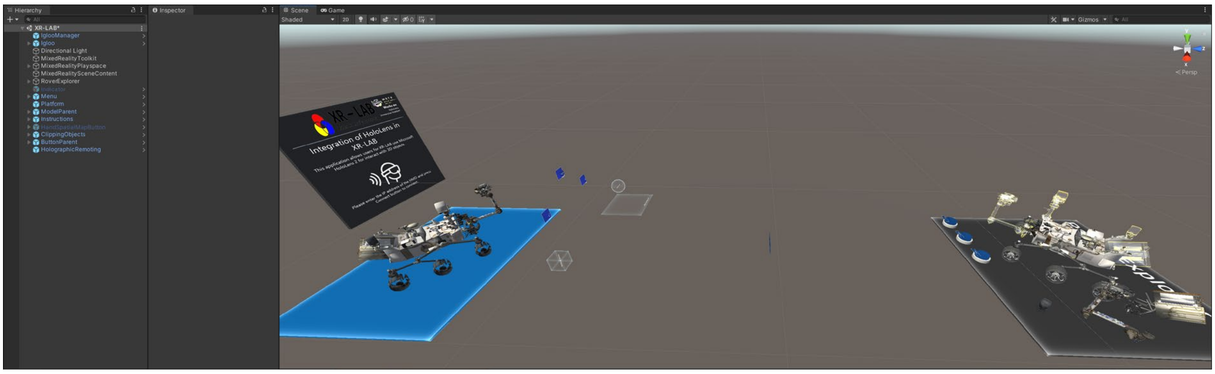
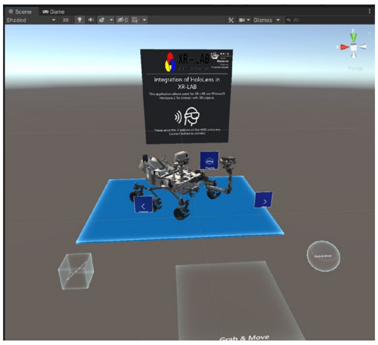
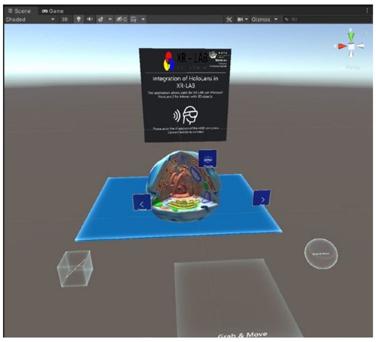
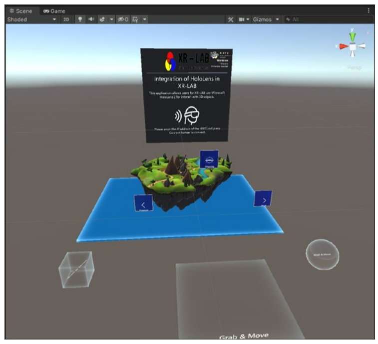
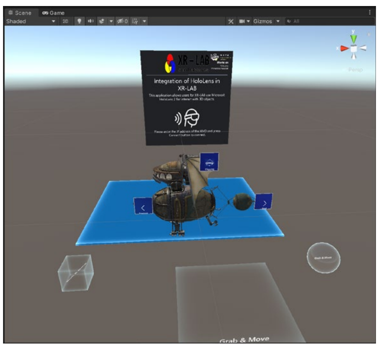
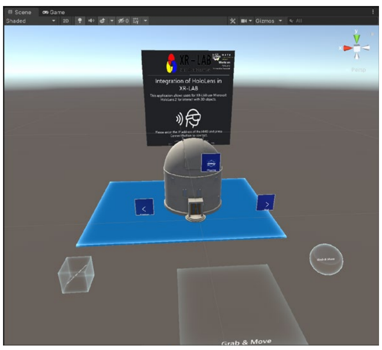
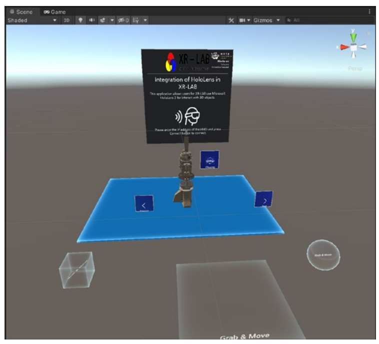


Figure 50 – Extra models added to the environment. (Screenshot from Unity Editor)

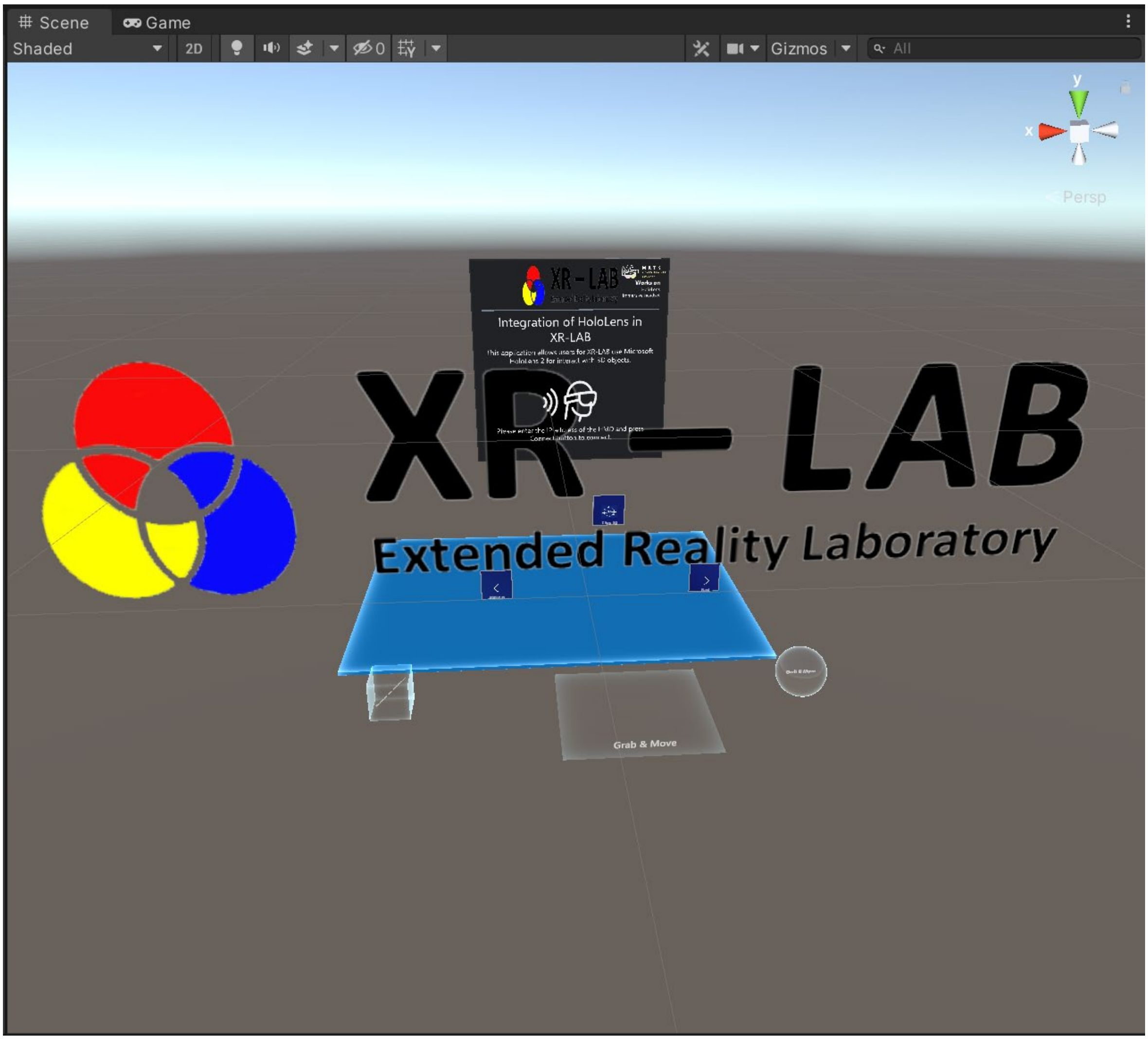
The added model contained a billboard with information how to connect the HoloLens, and a second table where users can navigate through different 3D models by pushing the next or previous buttons. There are three different geometric objects added that the users can move, rotate and scale by using one or two hands.

Rover	Cell	Nature

Aircraft	Telescope	Tower



XR-LAB logo

Table 9 – Added 3D models.

7 Conclusion

During this study, a contribution towards the future of XR technologies have been developed. As for the XR-LAB, the work performed in this thesis have ended in a development of a seamless integration of the Microsoft HoloLens 2, for navigation and control of the XR environment. Before ending the project, all the work was done and all the applications that were developed are stored at multiple locations, such as the server inside the XR-LAB, in a dedicated SharePoint, and on the development computer.

Also, the following tasks in the project have been completed.

1. XR environment specifically for the XR-LAB at UiT Narvik has been created and a template to work on different project in the future is also created.
2. XR environment specifically for the HoloLens 2 has been created, and there is a template created for future projects.
3. Connection between the two systems has been established, where the HoloLens 2 controls the XR environment displayed onto the canvas inside the XR-LAB.
4. Documentation of the executed work is presented in a written report.
5. The performed work has been presented.

7.1 Future work

For the future, the issue with the eye gazing feature should be resolved. The MRTK have also other useful features that can also be implemented into the environment, example of these could be hand menu, slider, voice commands. There is a full list of features provided in Table 3.

The application could be configurated in such way that it allows importing 3D objects and models without using the editor and development of new builds each time.

Furthermore, in this project the integration was on a local network inside the XR-LAB, as Unity offers online servers and with connectivity over internet, there could be a possibility to connect to the environment displayed in the XR-LAB from other locations and with multiple devices at the same time. So, in the future it could be a possibility to design a multiple input real-time system or interface that can lay the foundation of new master thesis or new research project.

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Appendix

Appendix A – Pre-study report

Appendix B – Gantt chart

Appendix C – Time schedule

Appendix D – S-curve

UiT The Arctic University of Norway

Department of Industrial Engineering

Integration of HoloLens in XR-LAB

Pre-study report

Marius Wang

Master's thesis in Industrial Engineering - INE-3900 - May 2022

UiT THE ARCTIC UNIVERSITY OF NORWAY

Faculty of Engineering Science and Technology

Department of Industrial Engineering

Title: *Integration of HoloLens in XR-LAB*	*Date:* 12.02.2022 *Classification:* Open
Author(s): Marius Wang	*Number of Pages:* 10 *Number of Attachments:* 5
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Supervisor: Wei Deng Solvang	
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Faculty of Engineering Science and Technology

Department of Industrial Engineering

Abstract (max 150 words):

This report is a pre-study for the master thesis second part. The report shows the approach for the project of an integrations with Microsoft's mixed reality headset, the HoloLens 2, into the XR-LAB at the university. The project has a duration of 17 weeks, and has a time cost of 817 hours.

Table of Contents

List of Tables

1 Introduction

This is a pre-study report for the master thesis project and the master thesis are divided into two parts. The first part of the master thesis was to perform a literature study, here are information and research of the topic collected to gain basic knowledge needed in part two. In part one it was conducted a study on topics within extended reality (XR) technologies and the most common methods and system. XR is a collective term for the technologies such as virtual reality (VR), augmented reality (AR) and mixed reality (MR). VR systems uses head mounted displays (HMD) which blocks out the real world and only shows the virtual environment. AR systems supports multiple devices, such as HMD, smartphones, tablets, computers etc, and AR add a layer of digital content into the real world. MR is based on the AR technology but utilizes depth sensors to establish spatial awareness witch allows interaction between the digital content and real world environment [1]. Further on, research of the opportunities of which software that would best fit the mission of integration, where done. Here Unity game engine appeared to be the best choice since both the system inside the XR-LAB and Microsoft's MR headset, HoloLens 2, is supported. A fair amount of time where also spent on learning Unity to gain skills for the development.

The second part of the thesis is to create an XR environment in Unity where the HoloLenses will be able to control the environment the operators want to show or present inside the XR-LAB.

1.1 Background

XR is gaining huge interest within different sectors, such as construction, engineering, architecture etc. Especially within the industrial sector, after the fourth industry revolution Industry 4.0, AR is one of the main pillars. After working a few years with VR technology and XR environment, the development and integration seems like a good project. One other reason for selecting this project is that it is a hot topic when talking about digitalization, and this particular integration appears to not have been done before.

2 Problem statement

Today the system in XR-LAB uses different software to display content onto the canvas inside the room. To add and control content the operator must access the server in the backroom or through an external desktop, e.g., TeamViewer. However, there is a possibility to connect a tablet such as a iPad, and navigate preloaded content without accessing the server. When displaying a real time XR environment there is no good solutions, at this date, that gives the operator the options to navigate and interact with it. With the HoloLens connected to the same environment, they could be used to improve the usability and enables more controls to the operator.

3 Project description

The description of the project is to create a XR environment where the HoloLens 2 is integrated towards the system in the XR-LAB. The HoloLens will not display the same environment that are displayed onto the canvas, be work as an extension with control panels and ways for operator/users to interact with the environment. This will be done by using Unity as an editor and create a build that are installed on both the server and the headset.

4 Theory

Unity will be used with plugins provided from Igloo Vision and Microsoft.

Igloo has a 360 degrees camera package that enables real time rendering of the XR environment around the room [2].

Microsoft have developed a toolkit for the HoloLens to be used in Unity, Mixed reality toolkit (MRTK). The toolkit targeting development of XR environments to the HoloLens with Unity [3].

5 Assumptions

Since I am using the same software for both systems, the integration should be doable without setting up virtual servers to enable connection. I also assume that wireless connection should work with low input lag since the XR-LAB has its own network independent from the university's eduroam.

6 Risk

As a part of the HSE work at UiT laboratories and for the project, a risk assessment is performed to map potential risks that could impact the project. The risk assessment has been made in accordance with the Norwegian Labor Inspection Authority's guidelines and three simple tips when performing it.

- What can go wrong?
- What can we do to prevent this?
- What can we do to reduce the consequences if this happens?

See Appendix 5 – Risk assessment for full details.

7 Scope

The scope of this project is to establish a connection between two systems, the XR-LAB and Microsoft HoloLens 2, and empower operators to use the HoloLens as a controller for the XR environment. The selected software, Unity, offers support to both systems and should provide a seamless integration.

This study will result in these concrete tasks:

1. Create a XR environment specifically for the XR-LAB.
2. Create a XR environment specifically for the HoloLens 2.
3. Establish a connection between the two systems and make the HoloLens control the XR environment displayed onto the canvas inside the XR-LAB.
4. Document the executed work in the form of a written report.
5. Prepare a PowerPoint presentation and present the performed work.

7.1 Time frames

The study report is to be expected done and delivered within May the 15th 2022, and the presentation presented May 10th.

8 Organization

8.1 Project phases / main activities

Overview over activities				
Main Activity	**Sub Activity**		**Description**	
	ID	**Name**	**ID**	**Name**
Planning	A	Project Management	A01	HSE
			A02	Quality Management
	B	Literature study	B01	XR Technology
			B02	Industrial application of XR

			B03	Unity
	C	Pre-study	C01	Planning the project
			C02	Risk assessment
			C03	Gantt chart
Implementation	D	Concept Phase	D01	Model in Unity
			D02	Selection
	E	Design	E01	XR-Lab
			E02	HoloLens 2
	F	Prototype	F01	Merge the two systems
			F02	Test
	G	Validation and verification	G01	Validation
			G02	Verification
Completion	H	Evaluation	H01	Evaluation
			H02	Revision
	I	Final report	I01	Report writing
			I02	Prepare presentation

Table 1 – Overview over activities.

8.2 Milestones

To be able to measure how far the project is coming along, milestones are made and listed in Table 2.

Milestone	ID	Date	Description
Pre-study report hand-in	MS1	12.02.22	Milestone is considered achieved when the pre-study report is handed in.
Technical specs	MS2	25.02.22	Milestone is considered achieved when a description of how the functionalities will be implemented to meet the needs of users.
Concept chosen	MS3	11.03.22	Milestone is considered achieved when concepts are presented and chosen.
Design completed	MS4	01.04.22	Milestone is considered achieved when the XR environment is completed for both the XR-LAB and the HoloLens.
Prototype completed	MS5	07.05.22	Milestone is considered achieved when the prototype is completed, merged and tested.
Report finalized	MS6	15.05.22	Milestone is achieved when the final report is completed and delivered.
Project closed	MS7	15.05.22	Milestone is achieved when the project is presented and delivered.

Table 2 – Milestones.

8.3 Decision points

ID	Date	Decision point
DP1	25.02.22	**Technical specs:** Specifications and functionality are made and validated.
DP2	11.03.22	**Concept:** Concepts are sketched from ideas and one final solution is chosen. Concept phases are finalized and design phase starts.
DP3	01.04.22	**Design:** After chosen concept, all necessary modeling and coding for the XR environment are done in Unity.
DP4	22.04.22	**Prototype:** Developed a build in Unity where the HoloLens are implemented in the system in the XR-LAB.
DP5	07.05.22	**Testing:** Test is completed when the system is running as intended and the build is validated and verified.
DP6	11.05.22	**Project completion** Start of the completion phase.

Table 3 – Decision points.

8.4 Submission- and status dates

During the project there are two status meeting where the performed work is presented and how the planned progress compares. The date is not set at the time this report is written, but there is scheduled one during March and one during April.

Event	Date	Description
Project start – Part II	15.02.22	Start of the Master Thesis Part II.
Task description part II	03.02.22	Delivery of the Master Thesis Task Description part II.
Pre-study report	12.02.22	Delivery of the Master Thesis Pre-study report.
Status meeting	03.22	Delivery and presentation of the Progress report of Master Thesis Part II.
Status meeting	04.22	Delivery and presentation of the Progress report of Master Thesis Part II.
Project presentation	10.05.22	Final presentation of the Master Thesis.
Final report	15.05.22	Delivery of the Master Thesis final report.

Table 4 – Submission- and status dates.

8.5 Progress monitoring

It is established a detailed plan for the project to monitor actual hours compared to scheduled hours for each week and activity. This is presented in a Gantt chart and in a time schedule with a S-curve where the relation is presented. The Gantt chart are based on the activities with start dates and their duration and the data are presented in a column chart. Time schedule shows all the activities and how many hours that are planned for each of them. In the end of every week during the project, actual hours will be updated.

See Appendix 2 – 4 for Gantt chart, time schedule and S-curve.

9 Cost

In this project there are no direct costs except the hours for the student, material and equipment the university provide at the laboratory.

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Appendix

Appendix 1 – Activity description

Appendix 2 – Gantt shart

Appendix 3 – Time schedule

Appendix 4 – S-curve

Appendix 5 – Risk assessment

Appendix 1 – Activity description

<table>
<tr><td colspan="2">Project title:
Integration of HoloLens in XR-LAB</td><td>Date:
10.02.2022</td><td>Sign:
MW</td></tr>
<tr><td>Activity no:
A</td><td colspan="3">Activity name:
Project Management</td></tr>
<tr><td colspan="4">Responsible:
Marius Wang</td></tr>
<tr><td colspan="4">Task description/intention:
Weekly planning and monitoring progression with quality management</td></tr>
<tr><td colspan="4">Scope:
In the end of every week 3 hours are used to monitor progressed work, update actual hours and compare them to the scheduled hours</td></tr>
<tr><td colspan="4">Method:
Excel in from of update the time schedule and S-curve</td></tr>
<tr><td colspan="4">Dependency:
On progressed work</td></tr>
<tr><td colspan="4">Documentation/results:
Documented in Excel</td></tr>
<tr><td colspan="2">Written by:
Marius Wang</td><td colspan="2">Duration (days/weeks):
17 weeks</td></tr>
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Integration of HoloLens in XR-LAB</td><td>Date:
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MW</td></tr>
<tr><td>Activity no:
C</td><td colspan="3">Activity name:
Pre-study</td></tr>
<tr><td colspan="4">Responsible:
Marius Wang</td></tr>
<tr><td colspan="4">Task description/intention:
A report that’s describe the scheduling and execution of the project</td></tr>
<tr><td colspan="4">Scope:
Plan the project with scope, activity list, gantt chart, time schedule and risk.</td></tr>
<tr><td colspan="4">Method:
Usage of MS Word and Excel</td></tr>
<tr><td colspan="4">Dependency:
Non</td></tr>
<tr><td colspan="4">Documentation/results:
A written report</td></tr>
<tr><td colspan="2">Written by:
Marius Wang</td><td colspan="2">Duration (days/weeks):
4 weeks</td></tr>
</table>

Project title: Integration of HoloLens in XR-LAB		*Date:* 10.02.2022	*Sign:* MW
Activity no: D	*Activity name:* Concept		
Responsible: Marius Wang			
Task description/intention: Develop a few concepts for the XR environment and features that's the HoloLenses should have.			
Scope: Create multiple environments and pick the one that could suit the needs for the XR-LAB			
Method: Using Unity			
Dependency: Pre-study			
Documentation/results: Concepts will be sketched and documented in final report. Best concept will be the foundation for the design			
Written by: Marius Wang		*Duration (days/weeks):* 4 weeks	

Project title: Integration of HoloLens in XR-LAB	*Date:* 10.02.2022	*Sign:* MW

Activity no: E	*Activity name:* Design

Responsible: Marius Wang
Task description/intention: Develop an interactive XR environment that deploys on the systems
Scope: Development of XR environment that lets users interact with the content in real time
Method: Using Unity
Dependency: Concept
Documentation/results: Documentation of how it is done in final report. Environment installed on server

Written by: Marius Wang	*Duration (days/weeks):* 3 weeks

Project title: Integration of HoloLens in XR-LAB	*Date:* 10.02.2022	*Sign:* MW

Activity no: F	*Activity name:* Prototype

Responsible: Marius Wang
Task description/intention: Establish connection between the XR-LAB and the HoloLens 2
Scope: Create a connection which allows users to interact with the content displayed onto the canvas inside XR-LAB using the HoloLens 2
Method: Using Unity
Dependency: Design
Documentation/results: Documentation on how it works. HoloLens is able to control the XR environment.

Written by: Marius Wang	*Duration (days/weeks):* 4 weeks

Project title: Integration of HoloLens in XR-LAB		*Date:* 10.02.2022	*Sign:* MW
Activity no: G	*Activity name:* Validation and Verification		
Responsible: Marius Wang			
Task description/intention: Fix bugs			
Scope: Ensure that everything works, stable connection and perform tests with other users			
Method: Testing			
Dependency: Design, Prototype			
Documentation/results: Documented bugs and fix.			
Written by: Marius Wang	*Duration (days/weeks):* 3 weeks		

<table>
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Integration of HoloLens in XR-LAB</td><td>Date:
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MW</td></tr>
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I01</td><td colspan="3">Activity name:
Report writing</td></tr>
<tr><td colspan="4">Responsible:
Marius Wang</td></tr>
<tr><td colspan="4">Task description/intention:
Documentation of the project and conclusion.</td></tr>
<tr><td colspan="4">Scope:
Create a written report of the performed work</td></tr>
<tr><td colspan="4">Method:
Using MS Word</td></tr>
<tr><td colspan="4">Dependency:
Non</td></tr>
<tr><td colspan="4">Documentation/results:
A written report</td></tr>
<tr><td colspan="2">Written by:
Marius Wang</td><td colspan="2">Duration (days/weeks):
5 weeks</td></tr>
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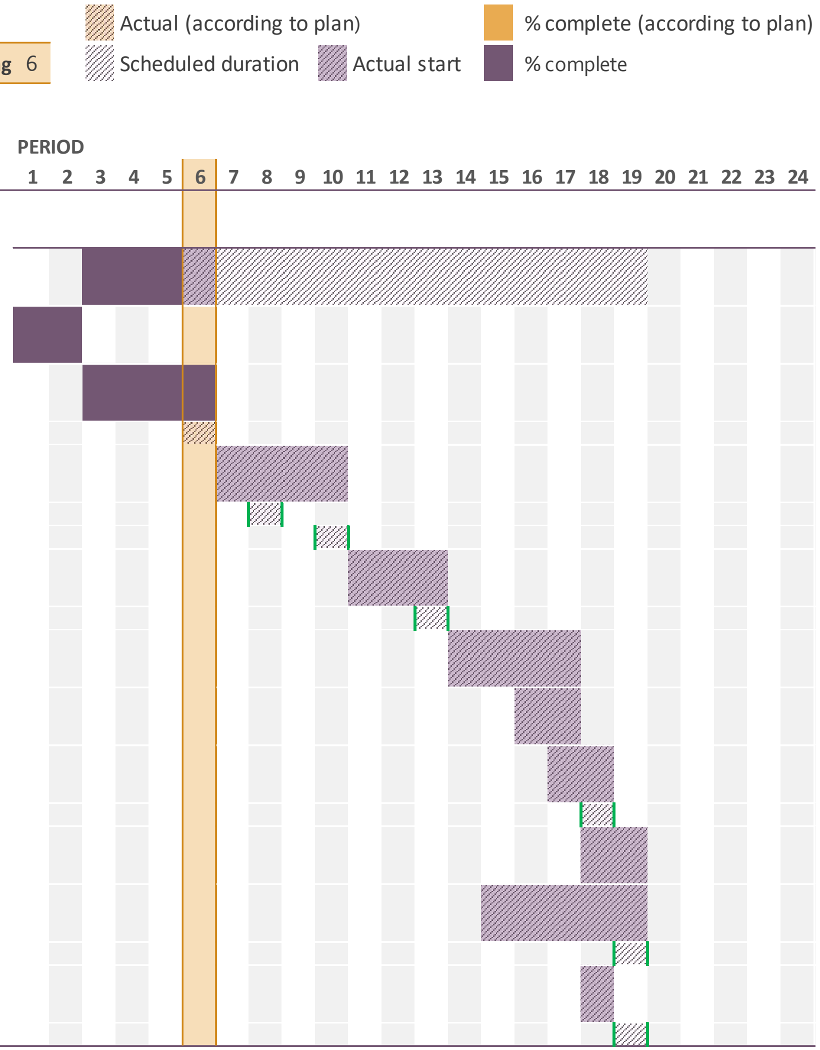
MW</td></tr>
<tr><td>Activity no:
I02</td><td colspan="3">Activity name:
Presentation</td></tr>
<tr><td colspan="4">Responsible:
Marius Wang</td></tr>
<tr><td colspan="4">Task description/intention:
Make a PowerPoint presentation and present the work</td></tr>
<tr><td colspan="4">Scope:
Present the performed work done during the project</td></tr>
<tr><td colspan="4">Method:
Using MS PowerPoint</td></tr>
<tr><td colspan="4">Dependency:
Earlier work</td></tr>
<tr><td colspan="4">Documentation/results:
A PowerPoint presentation</td></tr>
<tr><td colspan="2">Written by:
Marius Wang</td><td colspan="2">Duration (days/weeks):
1 week</td></tr>
</table>

Appendix 2 – Gantt chart

Project Schedule

Period highlighting 6

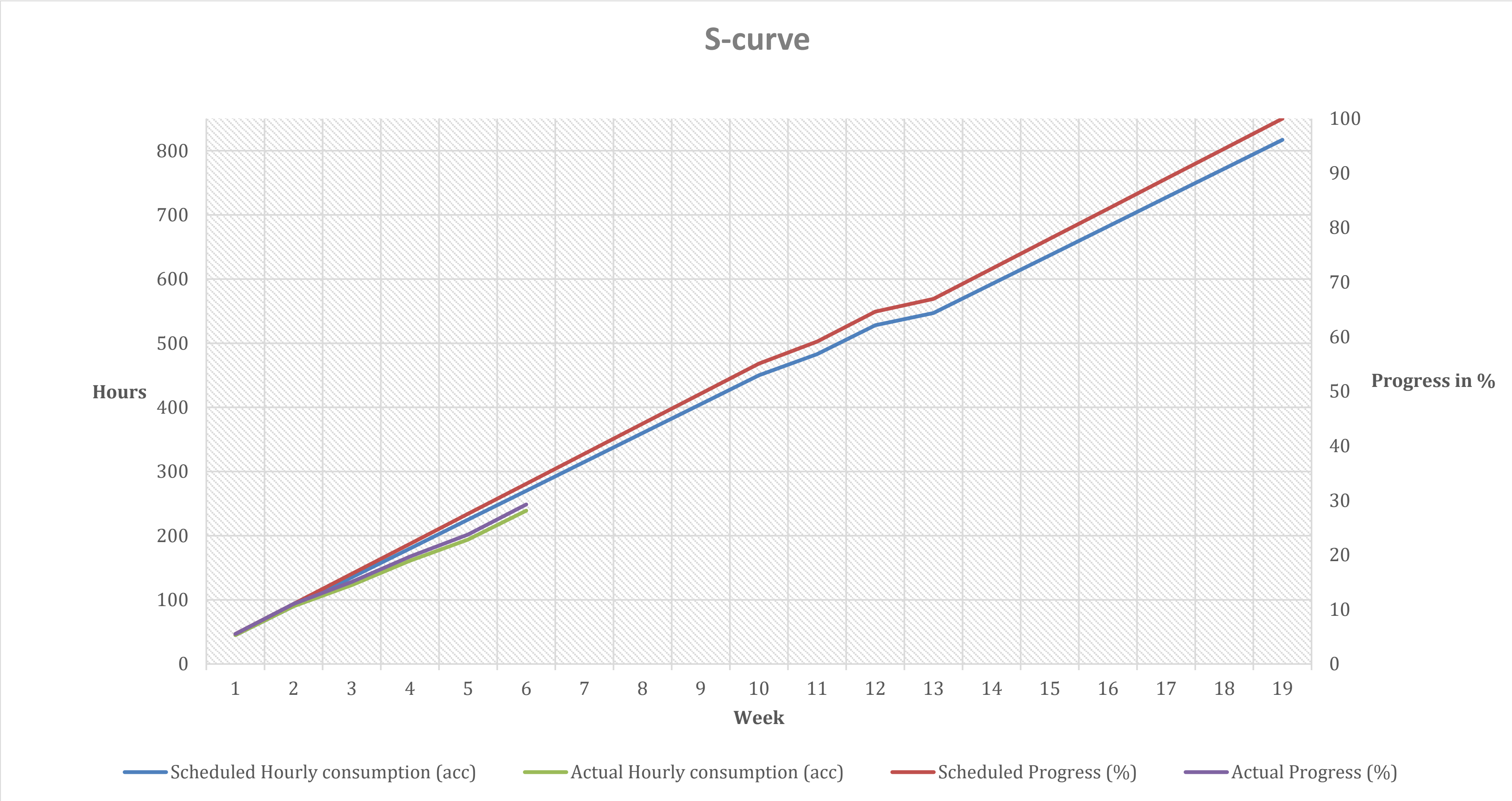
	ACTIVITY	SCHEDULED START	SCHEDULED DURATION	ACTUAL START	ACTUAL DURATION	PERCENTAGE COMPLETED
	Project start	3	1			
A	**Project Management**	3	17	3	4	75 %
B	**Literature study**	1	2	1	2	100 %
C	**Pre-study**	3	4	3	4	100 %
MS1	Pre-study report hand-in					
D	**Concept**	7	4	7	4	0 %
MS2	Technical specs					
MS3	Consept chosen					
E	**Design**	11	3	11	3	0 %
MS4	Design completed					
F	**Prototype**	14	4	14	4	0 %
Go1	**Validation**	16	2	16	2	0 %
Go2	**Verification**	17	2	17	2	0 %
MS5	Prototype completed					
H	**Evaluation**	18	2	18	2	0 %
Io1	**Report writing**	15	5	15	5	0 %
MS6	Report finalized					
Io2	**Presentation**	18	1	18	1	0 %
MS7	Project closed					



Appendix 3 – Time schedule

	Time schedule				Week																		
ID	Title	Start in week	Length in weeks	Hours	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Project start	5	1	0																			
A	Project Management	3	17	51			3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
B	Literature study	1	2	80	45	35																	
C	Pre-study	3	4	153			42	42	42	27													
D	Concept	7	4	158							42	42	42	32									
E	Design	11	3	88											30	42	16						
F	Prototype	14	4	94														32	32	15	15		
G01	Validation	16	2	15																10	5		
G02	Verification	17	2	10																	5	5	
H	Evaluation	18	2	10																		5	5
I01	Report writting	15	5	128						15				10				10	10	17	17	12	37
I02	Presentation	18	1	30		10																20	
	Totalt for prosjektet			817	45	45	45	45	45	45	45	45	45	45	33	45	19	45	45	45	45	45	45
Scheduled	Hourly consumption (acc)				45	90	135	180	225	270	315	360	405	450	483	528	547	592	637	682	727	772	817
Scheduled	Progress (%)				5,508	11,02	16,52	22,03	27,54	33,05	38,56	44,06	49,57	55,08	59,12	64,63	66,95	72,46	77,97	83,48	88,98	94,49	100
Actual	Hourly consumption (acc)				45	90	123	161	194	239													
Actual	Progress (%)				5,508	11,02	15,06	19,71	23,75	29,25													

Appendix 4 – S-curve



Appendix 5 – Risk assessment

Affiliation: Responsible:
Department of Industrial Engineering (IVT) ***Marius Wang***

The risk assessment has been made in accordance with the Norwegian Labor Inspection Authority's guidelines
https://www.arbeidstilsynet.no/hms/risikovurdering/

Prerequisites: Risk assessment applies to student projects at the Department of Industrial Engineering and is based on the problems that may arise and the impact on the implementation of the project

The risk assessment is made by looking at all the work processes involved in the project. Risk assessment is a basis for a good working environment and for minimizing the risk that the project will not be completed. The following risks have been identified:

1.1 Risk assessment

ID	Risk factors	Impact description	Consequence	Probability	Probability description	Risk
R1	COVID-19	If I get the virus, I will have to be put in a quarantine and might impact the project	Very High	Very High	This could have a great affect on the project since it require that gets work done.	Very High
R2	Closing of the campus	Closing of the campus will result in that activities will not be completed as planned.	Very High	Very High	If the coronavirus is spreading there is a chance that campus would have to be closed.	Very High
R3	Illness	If I gets sick, either by the coronavirus or the flu, it will have consequences for the project	Very High	High	Valuable time and resources will be lost, and the project could crash.	High
R4	Activities will not be completed	Consequence of uncompleted activities is that the result will not satisfy the goal of the project	High	Very High	Probability of that the activities will not be completed is high	High
R5	Lack of motivation	This risk will directly affect the overall scope of project; delaying activities, conflicts and reduced quality of work.	High	Medium	Probability that I will lose motivation in project	Medium
R6	Technical failure	If the digital platform lacks features or connection issues it will negatively impact the objectives of project	Very High	Medium	Probability that the project does not meet the required technical standards	High
R7	Lack of time	Tight timing constraints and little to no extra room for extra time.	High	Medium	Probability that project will require more time for its completion	Medium
R8	Lack of knowledge	Student don't have sufficient knowledge regarding the software or hardware.	Very High	Medium	Probability that the objectives of project are not finished.	Medium
R9	Project change	Forcing decisions will affect motivation and indirectly reduce the quality of the work.	High	Medium	Probability that the student would be forced to change the selection and execute another option.	Medium
R10	Competitors First	If the competitors reach out to industries and develop relations before us, industries will have to share their resources between two, thus less attention to us.	Medium	Medium	Probability that we are not the first one to present this idea to industries	Medium

R11	Interest less Industries	Industrial personnel might not be interested in this solution.	Very High	Medium	Probability that industries refuse to contribute.	Medium
R12	Poor maintenance	Digital platform and services require regular oversight and maintenance.	High	Medium	Probability that administration fails in properly overlooking and maintaining the system.	Medium
R13	Complex Design	In case of difficulties in understanding the platform, number of users may significantly reduce.	Medium	Low	Probability that users will find it difficult to use the platform	Medium

1.2 Measures

ID	Risk	Measures	Consequence after measures	Probability after measures	Remaining risk
R1	Very High	Carefully apply all standard operating procedures of Covid-19 while working and promote work from home and digital meetings.	Medium	Medium	Medium
R2	Very High	If work from home, and digital working environments like Zoom and teams have been promoted, closing of the campus will not have an impact.	Medium	Medium	Medium
R3	High	It has been planned to always have alternative workers and programmers to develop the system. Since IT department have a lot of human resource, contracting alternative programmers in case of mishap will reduce the impact.	Medium	Medium	Medium
R4	High	In further sections, contingency and project crashing strategies have been designed in case activities are lagging. So, the risk if activities are not getting completed is reduced.	Low	Low	Low
R5	Medium	Presenting regular progress reports, presenting the successes and statistics of project will reduce the impact.	Low	Low	Low
R6	High	There will be a written agreement with IT department finalizing the final technical specifications of platform. If some features cannot be completed by IT department, they can be outsourced, and we have extra budget which can be reduces.	Low	Low	Low
R7	Medium	Project scheduling has been performed to reducing the risk of delayed project schedule.	Low	Low	Low
R8	Medium	Limited support provided from Igloo Vision and Microsoft.	Low	Low	Low
R9	Medium	Projection selection will be done and written approval will be	Low	Low	Low

		obtained before the starting of project.			
R10	Medium	Planned delegations containing best negotiators within UiT will be sent to develop relations.	Low	Low	Low
R11	Medium	There are many potential companies that are interested in this technology, not only in Norway but also nearby countries as it is digital.	Low	Low	Low
R12	Medium	Regular progress reports must have to be delivered to upper management. So that if someone is being irresponsible of one's activities, upper management can force to make the things right.	Low	Low	Low
R13	Medium	Test users would be employed to check the usage complexity of digital platform. Recommendations would be actively heard, and all steps would be taken to improve the experience.	Low	Low	Low

1.3 Risk matrix

RISK MATRIX

Likelihood

	Low	Medium	High	Very High
Very high		R6	R4	R1 R2
High		R5	R7	R3
Medium		R10	R9 R12	R8 R11
Low		R13		

Consequence

1.4 Risk matrix after measure

	RISK MATRIX			
Likelihood				
Very high				
High				
Medium		R1 R2 R3		
Low	RR			
	Low	**Medium**	**High**	**Very High**
	Consequence			

RR	R4 R5 R6 R7 R8 R10 R11 R12 R13

Appendix B – Gantt chart

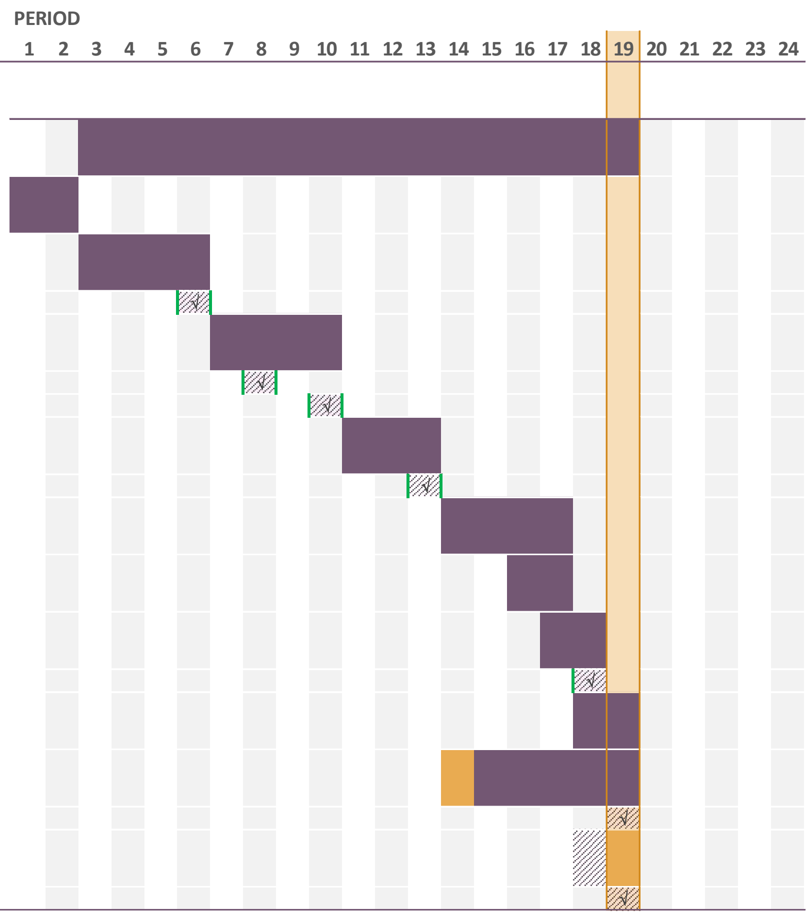
Project Schedule

MS = Milestones

Period highlighting: 19

Actual (according to plan) · Scheduled duration · Actual start · % complete (according to plan) · % complete

	ACTIVITY	SCHEDULED START	SCHEDULED DURATION	ACTUAL START	ACTUAL DURATION	PERCENTAGE COMPLETED
	Project start	3	1			
A	**Project Management**	3	17	3	17	100 %
B	**Literature study**	1	2	1	2	100 %
C	**Pre-study**	3	4	3	4	100 %
MS1	Pre-study report hand-in					
D	**Concept**	7	4	7	4	100 %
MS2	Technical specs					
MS3	Consept chosen					
E	**Design**	11	3	11	3	100 %
MS4	Design completed					
F	**Prototype**	14	4	14	4	100 %
Go1	**Validation**	16	2	16	2	100 %
Go2	**Verification**	17	2	17	2	100 %
MS5	Prototype completed					
H	**Evaluation**	18	2	18	2	100 %
Io1	**Report writing**	15	5	14	6	100 %
MS6	Report finalized					
Io2	**Presentation**	18	1	19	1	100 %
MS7	Project closed					



Appendix C – Time schedule

	Time schedule				Week																		
ID	Title	Start in week	Length in weeks	Hours	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Project start	5	1	0																			
A	Project Management	3	17	51			3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
B	Literature study	1	2	80	45	35																	
C	Pre-study	3	4	153			42	42	42	27													
D	Concept	7	4	158							42	42	42	32									
E	Design	11	3	88											30	42	16						
F	Prototype	14	4	94														32	32	15	15		
G01	Validation	16	2	15																10	5		
G02	Verification	17	2	10																	5	5	
H	Evaluation	18	2	10																		5	5
I01	Report writting	15	5	128						15				10				10	10	17	17	12	37
I02	Presentation	18	1	30		10																20	
	Total for project			817	45	45	45	45	45	45	45	45	45	45	33	45	19	45	45	45	45	45	45
Scheduled	Hourly consumption (acc)				45	90	135	180	225	270	315	360	405	450	483	528	547	592	637	682	727	772	817
Scheduled	Progress (%)				5,508	11,02	16,52	22,03	27,54	33,05	38,56	44,06	49,57	55,08	59,12	64,63	66,95	72,46	77,97	83,48	88,98	94,49	100
Actual	Hourly consumption (acc)				45	90	123	161	194	242	287	332	377	427	472	517	550	598	646	696	754	792	825
Actual	Progress (%)				5,508	11,02	15,06	19,71	23,75	29,62	35,13	40,64	46,14	52,26	57,77	63,28	67,32	73,19	79,07	85,19	92,29	96,94	100

	Actual																						
	Tittel		Progress %	Hours																			
A	Project Management		100	51			3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
B	Literature study		100	80	45	35																	
C	Pre-study		100	115			30	35	30	20													
D	Concept phase		100	158							42	42	42	32									
E	Design		100	104											42	42	20						
F	Prototype		100	110														35	35	20	20		
G01	Validation		100	15																10	5		
G02	Verification		100	10																	5	5	
H	Evaluation		100	10																		5	5
I01	Report writting		100	162						25				15			10	10	10	17	25	25	25
I02	Presentation		100	10		10																	
	Total per week				45	45	33	38	33	48	45	45	45	50	45	45	33	48	48	50	58	38	33
	Total time consumption			825																			

Appendix D – S-curve