

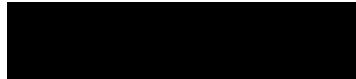
**HOCHSCHULE FÜR ANGEWANDTE  
WISSENSCHAFTEN HAMBURG**

Hamburg University of Applied Sciences

**Master Thesis**

**Development of a Training Module for Process Operation based  
on Mixed-Reality Technology**

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Juli, 2022

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## **Affidavit**

I hereby declare that I have written this thesis independently and have fully acknowledged all sources and aids. Passages taken literally from other works or passages borrowed in meaning are indicated by references.

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Derya Kara

## Abstract

The aim of this master thesis is to create a training module with the use of mixed reality glasses in process engineering plant operation. The HoloLens 2 which is developed by Microsoft is utilized for this project, as well as 3D model of plant drawn in AutoCAD is transferred to Unity to design a training module which can be experienced in HoloLens 2 after the deployment in Visual Studio.

The major target of this master thesis is to reveal the feasibility of making training scenario with HoloLens 2 and present an alternative which leads the hybrid education formed by the integration of the training module created by mixed reality technology and the classical way of the process engineering education. The creation of this training module is explained in detail, emphasizing important point to make all the information enable for the reader in order to make the training module in line with the current aim. The experimental phase of the master thesis presents how to transfer the AutoCAD file including the 3D plant model to Unity program where features linked with the training aim are added on 3D plant model in Unity and the visualization of this 3D plant model with training units on HoloLens 2. In addition, since these programs are open source for private individual, this master thesis shows that a training module can be created by interested user who are not a professional programmer. Besides that, the problems which can be confronted during using Unity and trying to deploy the project in HoloLens 2 are clarified in detail with giving the possible solutions.

One of the most crucial implications is the problems that can be encountered when using Mixed Reality Tool Kit feature tools together with the objects used in Unity when making a mixed reality-based project. In addition to manually ensuring the shader compatibility in the materials of the objects placed in the project, it was tried to prevent incompatibilities that may arise from the template selection of the project. The template which is selected in Unity in the beginning of the project is important to set up correctly to make Unity render the material that is upgraded by Mixed Reality Tool Kit. It is also advised to use the last version of the programs in order to prevent incoordination of the version.

The factors which affect the performance of the HoloLens 2 during deploying the training module in Unity are also discussed toward the observations from the tracking of HoloLens 2 performance from Windows Device Portal. The performance has been evaluated in aspect of GPU performance, power of HoloLens 2, I/O values, and the network. As a result of these factors, it is concluded that the framerate of the vision in HoloLens 2 during deployment should remain constant at 60 FPS for good performance. This stability mainly depends on the stable internet connectivity and minimizing the effect of external factors such as lightning condition of the environment.

In the context of this work, the training scenario was prototypically implemented on the HoloLens 2 for evaluation. The observations that are obtained through successive trials are discussed in the result of the master thesis. Furthermore, suggestions for improvements and alternative solutions for the user's benefits are described in the discussion chapter.

In this developing world, the augmented reality in the process plant engineering is going to be inseparable part of the Industry 4.0 and the integration of the training including augmented reality becomes an inevitable part of the plant engineering education.

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**List of Abbreviations**

AR	=	Augmented Reality
CPU	=	Central Processing Unit
CPS	=	Cyber-Physical System
FPS	=	Frames per Second
GPU	=	Graphics Processing Unit
HMD	=	Head-Mounted-Display
LTS	=	Long Term Support
MR	=	Mixed Reality
MRTK	=	Mixed Reality Tool Kit
MRFT	=	Mixed Reality Feature Tool
PC	=	Personal Computer
URP	=	Universal Render Pipeline
UWP	=	Universal Windows Platform
VR	=	Virtual Reality
SDK	=	Software Development Kit
WDP	=	Windows Device Portal

### 3.Theoretical Background

In this chapter, while the definitions of virtual, augmented and mixed reality are mentioned along with the developments in Industry 4.0 in general, the place of virtual and augmented reality in education is also mentioned. The programs used to create the training module which can be deployed in HoloLens 2 are named and explained. The HoloLens 2 developed by Microsoft and its technical data are also discussed, as well as the influences on the performance of the HoloLens 2.

#### 3.1. Industry 4.0 Elements

Industry 4.0 is associated in this debate with a vision of completely new factory and value-added structures based on the comprehensive use of "intelligent" information and communication technologies as well as robotics, so that there is also expectation of a fourth industrial revolution [1]. On the other hand, this vision follows on from the incremental development of computerization and automation of production processes and products that has been going on for several decades [1]. On the other hand, a qualitative leap in the development of the computerization of production processes can currently be expected [2]. The main reason for this is that the massive increase in performance and dramatic reduction in price of the new digital technologies are opening up completely new fields of application for the technologies compared to a few years ago [2].

The Industry 4.0 vision is based on two main components technologically. First of all, a highly flexible and largely autonomous networking between physical systems and components of various kinds (production and products) with distributed and intelligent software systems and global data networks is targeted. On the other hand, the vision aims at the intelligent and targeted use of the data accumulating in production and sales through the use of sensors and advanced evaluation methods. [3]. The Industry 4.0 elements are described by the basic technologies which are based on the ground of the Industry 4.0. Cyber-physical system (CPS) is the first and inevitable concept for the definition of Industry 4.0 elements. In the concept of CPS, concrete devices which are interconnected via Internet have been located in various tools in order to collect, process and exchange data. Therefore, this constitutes the basis for the Internet of Things [2]. The communication through CPS systems is represented as Men to Men (M2M) communication. The integration of CPS, advanced software and sophisticated user interfaces forms totally new ways of system use which have been already used in manufacturing, warehousing, modern robotics, transport and logistic management etc [2]. The Figure 1 indicates the relationship between the human-interconnection-machine relationships in the aspect of the Industry 4.0 elements [4].

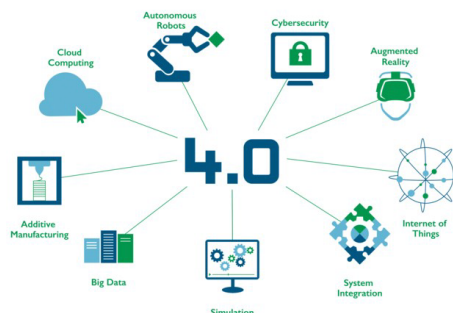


Figure 1. Industry 4.0 elements [4]

## 1. Internet of Things (IoT)

In the industrial sector, it is mainly about connecting machines and systems in such a way that entire industrial processes can be automated which makes the production process more efficient and cheaper. The IoT is an elementary component of the so-called Industry 4.0 [4]. Moreover, the self-organisation of industrial processes becomes possible through the direct communication of machines, plants, goods and people with the IoT and Industry 4.0.

The term Internet of Things is used for the networking of everyday objects or machines in an industrial environment via the Internet. Devices are given a unique identity (address) in the network and are equipped with electronic intelligence. This enables them to communicate via the internet and perform tasks in a fully automated way [4]. The intelligent devices are often also referred to as smart devices. In addition to the possibility of the devices communicating with each other (machine-to-machine communication, M2M), many of the networked objects provide an interface via the internet through which the devices can be operated and controlled by a user from any location [5]. IoT which is based on the technology of Radio-Frequency Identification (RFID) can be conceived as a comprehensive network framework. This involves various connected real-world objects that depend on sensory, communication, networking, and information processing technologies. RFID allows microchips to transfer identifying data to the reader via wireless medium, and consequently any person analyze, trace, and monitor the objects connected with RFID tags [5].

## 2. Big Data

The concept of Big Data is based on the use of analyses or methods which separate data from a data file. It is used to handle for a for capaciously and complexly datasets in the common applications which has deficiency in required technological level. The accuracy of the data selection is linked with the decision-making processes, increases production efficiency, reduces costs and levels of risk [2].

## 3. Cloud Computing

Cloud computing is an approach to the dynamic provision of IT resources. The internet is often used as a network, but internal company networks can also function as a cloud. Cloud computing follows the outsourcing approach and enables the outsourcing of computing capacities [2]. For example, IT services such as storage space, software or computing power can be outsourced via cloud services. With this approach, the corresponding resources no longer have to be available on the local device and can be accessed with an existing network connection. The required services are accessed with the help of corresponding applications or via interfaces (APIs) [6].

## 4. Cyber Security

Cyber security is the totality of all technologies, processes and procedures designed to protect networks, computers, programs and data from attack, damage or unauthorized access [2]. In aspect of information technology, overall IT security consists of cyber security and physical protection of property. The term is used in a variety of contexts, from business applications to mobile computing, and can be grouped into a number of general categories [4]. Cybersecurity is a constantly changing area of IT. New technologies usually bring with them new opportunities for cyber attack. Security incidents at well-known companies or institutions

usually attract media and public attention. In fact, all users and companies of all sizes have to deal intensively with the threats, as they too are often the target of malware or phishing attacks. Therefore, cyber protection should be integrated as a permanent part of the design and operations which are part of the development of any Industry 4.0 innovation [6].

## 5. Autonomous Robots

An autonomous robot is a robot that is designed and engineered to handle its environment autonomously and operate for extended periods of time without human intervention. Autonomous robots often have sophisticated features that allow them to better understand their physical environment, automate parts of their maintenance and control that were previously performed by humans. In Industry 4.0, it is aimed that they will be able to work independently or collaborate with people [2].

## 6. System Connectivity

System connectivity refers to the interconnection of new technologies such as intelligent robots, sensor technology, artificial intelligence, nanotechnology etc which transform traditional production into data-drive. In the Industry 4.0, the linked factory is aimed where all equipment is available online and have ability of making its own decisions [7].

## 7. Simulation (digital win)

A simulation imitates the functioning of real processes or systems with the help of models. The model represents the key behaviors and characteristics of the selected process or system, while the simulation shows how the model evolves over time under different conditions [7]. The sensor that are installed in objects makes data transmitted to optimize the operation. The target of the simulation is creating, testing and producing in a digital environment [2].

## 8. Additive technologies (3D printing)

The popularity of these technologies is increasing rapidly in the industrial production and there is notable increment in productivity and usability in products with higher repeatability [2].

## 9. Augmented Reality

Augmented reality, or AR for short, is a method of "extending" reality with virtual effects by means of computer-assisted devices such as smartphones or glasses. AR is a medium that consists of a virtual extension of reality by three-dimensional registered and real-time interactive elements [6]. AR works computer-aided and offers the user additional information to the currently perceived reality. The insertion of virtual elements or additional information takes place in real time and in consideration of three-dimensional references [4]. These are to be presented to the user as if they were part of the real world by means of suitable systems that address one or more senses. Extension elements are, for example, texts, animations, images, videos or graphics. For the viewer, there is a mixing or overlapping of real and virtual representations. The user often has the option of accessing the extended content via gesture control or touch screens [6]. Thus, it is the combination of real world with virtual environment. In contrast to virtual reality (VR), however, the real world always remains the starting point of the representation and is not replaced by a purely virtual world.

### 3.2. Virtual Reality, Augmented Reality, Mixed Reality

Virtual reality and augmented reality (VR/AR) are the basis for the technology of virtual engineering. Virtual prototyping which enables engineers to analyze the shape, form and functional feature of future products in an immersive and interactive virtual environment are provided by these technologies. The good application of them develops the product design and production innovation by reducing the number of physical prototypes, increasing awareness in design errors in early stages of the development process and preventing wasting money and costs for enterprises. Therefore, VR/AR are considered as crucial tools which accelerates product and process development in the industry [8]. In Figure 2, the VR, AR and MR is clarified according to the features that the technology provide.

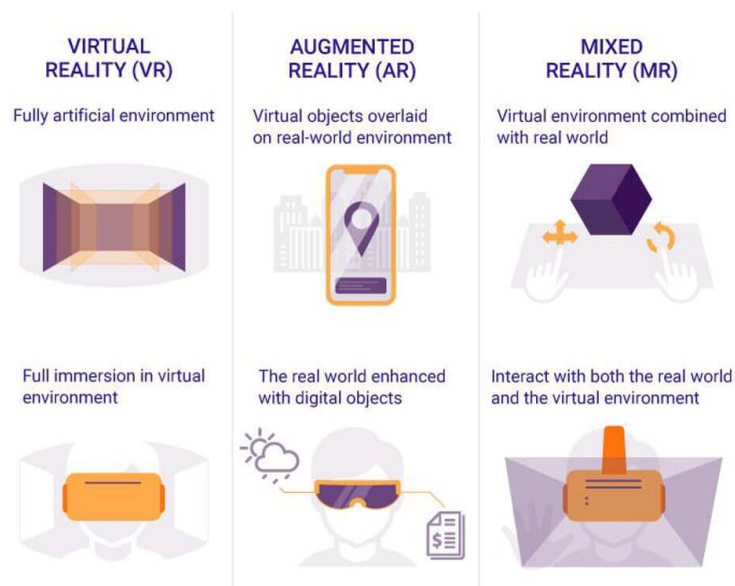


Figure 2. Virtual Reality, Augmented Reality, Mixed Reality [9]

#### 3.2.1. Virtual Reality

There are many definitions of the term "Virtual Reality" (VR). One reason for this is the different environments, areas of application and ergonomic aspects in which technologies are used. Sherman and Craig define the (1) effect of immersion of virtual reality as one of the four core elements for creating a virtual reality. Other requirements exist for an immersive effect: (2) the virtual world itself, (3) sensory feedback, and (4) interaction between elements of virtual reality and the end user [10]. The user is immersed in a completely computer-generated, three-dimensional environment which is a completely virtual environment created by a computer. In contrast to real perception, virtual reality allows the user to choose his or her own point-of-view (PoV). This allows events within the virtual world to be influenced. The most advanced virtual reality experiences can even provide freedom of movement which provides that users can move around and hear sounds in a digital environment. Special handheld controllers can also be used to enhance virtual reality experiences [8].

To experience virtual reality, you need to wear a special virtual reality glasses. An overview of the products currently available on the market is shown in Table 1. The end devices can be divided into the areas of full-feature, mobile and low-budget VR glasses [11]. Most virtual

reality glasses connect to a computer (Oculus Rift) or a game console (PlayStation VR); however, there are also standalone devices (Google Cardboard is one of the most popular). Most standalone virtual reality glasses work with smartphones [12].

Table 1. Devices for Virtual Reality [12]

Produkt	VR			Mixed Reality
	VR-Brillen			
	Full-Feature	Mobile	Low-Budget	
Oculus Rift	x			
HTC Vive	x			
Playstation VR	x			
LG 360 VR	(x)	x		
Samsung Gear VR		x		
Google Daydream View		x		
Huawei VR		x		
Google Cardboard				x
Homido				x

The main features of VR glasses as opposed to AR products are the completely closed housing and the lenses that are attached in front of the screen. Only in this way can the user be completely immersed in a virtual world and perceive it without the disturbing light effects of the real world [11]. The aspherical lenses in front of the OLED screen are designed to enable sharp vision in this unusually close range [12]. In the Table 2, there are common terms that are used to indicate VR and AR technologies [13] [14].

Table 2. Key VR/AR Terms [13] [14]

Term	Description
Frames per second (FPS)	The number of frames per second (fps) displayed by a pair of glasses. Depends on the Hz number of the installed display [13]. The more, the better. In order to maintain a pleasant and realistic illusion, a VR headset should be able to display at least 60 frames per second per eye, even during fast movements in complex 3-D environments [14]. In case of not having high and constant frame rate (greater than fps), the motion cannot look right and stable which disturb the user [14].
Field of View (FoV)	Field of view or field of vision. Refers to the size of the area that is visible to the user. This depends on the lenses and the display of the VR goggles. The larger the FoV, the better the immersion [14].
Avatar	An avatar is a virtual proxy, an artificially created figure assigned to a user in a virtual reality [13].
Latency	Describes the delay between user movement and VR reaction. The lower the latency, the more realistic the VR experience [13].
Immersion	Immersion describes the transfer into a state of consciousness (impression) in which the perception of oneself in the real world is reduced and the identification with the "I" (the avatar) in the virtual world is increased [13].
Degrees of Freedom (DoF)	This term corresponds with the number of directions which object can move or rotate. There are six degrees of freedom; pitch, roll, yaw, left and right, forward and backward, up and down [13].
Chaperone system	The Chaperone system is a safety system developed by Valve that uses a camera integrated into the VR headset to recognize the player's surroundings and warns him or her with the help of holographic grid lines if he or she gets too close to objects, animals or walls. This significantly reduces the danger of colliding with objects in the real world [14].

Eye tracking	Eye tracking is the recording of the exact focus and eye movement of a person. Sensors detect exactly what the person is focusing on [14]. In VR glasses, special sensors recognize the eye movement and transmit it to virtual reality [14].
Foveated rendering	Thanks to eye tracking and this method, only the part of the virtual world where the VR glasses wearer is looking at the moment is displayed in detail and sharpness, as the human eye can only see everything sharply in the center of the focal point. Outer areas of the field of vision are rendered with a lower resolution to save computing power [13].
Gyro sensors	With the help of these sensors (magnetometer, gyroscope, accelerometer), electronic devices such as smartphones can measure position, orientation in space, acceleration and movement. VR glasses can translate the movements of the user's head into VR, see Head Tracking by the help of these sensors [14].
Haptic feedback	Devices and controllers can let the user feel with the haptic function when they interact with the virtual world. This can be done with the help of simple vibrations to harmless electric pulses [14].
HMD	HMD is the abbreviation for Head-Mounted Display. These can be video glasses or VR glasses [14]. The video glasses show images on a screen directly in front of the eyes. A VR headset has both additional sensors to detect the movements of the head and lenses that create the largest possible Field of View [14].
Presence / Telepresence	Describes the state of feeling present in a remote environment. The higher the degree of immersion, the more the user feels in the remote environment [13].

### 3.2.2. Augmented Reality

In augmented reality, users can see and interact with the real world while adding digital content to the environment. The real, visual world is enriched with virtual, computer-generated content (images, videos, virtual objects) in real time. These are optionally superimposed on our reality via AR glasses or mobile devices (smartphones, tablets) and overlay or supplement real perception [14]. For instance, the game, "Pokemon Go" is the most impressive example of augmented reality which leads millions of people around the world rush with their phones in search of tiny virtual creatures. This is a kind of smartphone scavenger hunt outdoors (location-based game). The app asks the player to go to "real" places, hold the smartphone in front of them and see the pocket monsters virtually superimposed on the image of the rear camera. Now the player has to throw a virtual Pokéball (the "cage" of a Pokémon) in a targeted manner in order to catch it. This reality supplemented by virtual elements is called "augmented reality" [15].

### 3.2.3. Augmented Reality and 360° Videos

The term "augmented reality" often appears together with virtual reality. This means something like "augmented reality". On the other hand, in 360° Videos, there is not a completely new environment, but the surroundings around the user are expanded by

individual aspects. For example, the user can see navigation instructions or information about buildings on the image captured by his/her smartphone camera [16].

360° video and virtual reality are often not accurately separated in everyday life, although both techniques differ greatly, and each has its strengths and weaknesses. While virtual reality is created entirely on the computer and is suitable for interactions and visualizations, the strength of 360° videos and photos is the documentation of real events and places [16]. When creating and using 360° videos, a lot must be taken into account and various limitations have to be accepted in order for the result to have the desired effect. 360° representations cannot necessarily be integrated into a digital production, but it can support and complement it. Visualization of places that are difficult to access, education and training as well as documentation of facilities can be implemented well with 360° recordings [16].

In brief, in 360° Videos, there is not a completely new environment, but the surroundings around the user are expanded by individual aspects. For example, the user can see navigation instructions or information about buildings on the image captured by his/her smartphone camera. 360° videos also have a certain similarity to VR but, there are some certain differences between these two terms. Although the user can feel his/her existence in the place provided by the 360° video by the recorded environment with special cameras, the user cannot interact with it and usually do not have the feeling of being completely immersed in the world of the video.

#### 3.2.4. Augmented Reality Software Development Kit

The abbreviation SDK stands for Software Development Kit and means software development kit. A software development kit contains different programming tools or libraries, depending on the intended use. A distinction is made as to whether the SDK is offered for a programming language or for an operating system. A software development kit can contain different tools and augmented reality simulation requires the proper tools to be developed. It can contain a runtime environment, a compiler, a debugger, documentation and various interfaces. The runtime environment ensures that the written source code can be executed accordingly [17]. The compiler translates the written source code into the appropriate intermediate code and the debugger allows debugging of the running application. On the other hand, the main advantage of SDKs is giving the opportunity to developers to implement typical and time-tested solutions and shortcuts at the development stage which provides the developer not spending time solving and addressing all common and typical problems one by one [17]. The six most used augmented reality development tools are described in the below.

##### 1. Unity and Vuforia

Unity is a video game development tool developed by Unity Technologies. The Vuforia Engine allows developers to add augmented reality and virtual reality features to an application so that it can recognize images and objects and interact with spaces in the real world. An AR application based on the Vuforia SDK consists of the camera that captures frames and transmits the content to the tracker, the image converter that converts the image captured by the camera into a format suitable for OpenGL ES processing and internal tracking, and the tracker that can load and activate multiple data sets [17]. With Vuforia, the user does not only create the AR experiences, the user also display them on a wide range of



devices with different operating systems: iOS, Android and UWP, the universal Windows platform. Vision-based computing is not out of reach. Today, Vuforia is already connecting real and digital worlds with digital experiences that delight users [17].

The Vuforia Engine platform supports AR app development for Android, iOS and UWP devices, as well as a variety of optical and video stereo rendering displays, including HoloLens [17]. Vuforia Engine is based on the ARCore and ARKit software development kits (SDK) developed by Apple and Google [17].

## 2. Unreal Engine

Unreal Engine is a game engine developed by Epic Games and used in the first-person shooter Unreal, first published in 1998 [18]. Although it was originally developed for first-person shooters, it was later used in games of various genres. Since its code written in C++, it has a high degree of portability and has become a tool used by many game developers today. It includes components shared by many video games, such as a game engine, rendering code, and design tools. Games built using a game engine combine components from the engine with game logic and 3D models. Thus, making changes to a game engine can affect all games built on it [18].

## 3. Wikitude

Wikitude is a mobile augmented reality (AR) technology provider based in Salzburg, Austria. Wikitude was founded in 2008 and initially focused on delivering location-based augmented reality experiences through the Wikitude World browser app [19]. In 2012, the company restructured its offering by introducing the Wikitude SDK, a development framework with image recognition and tracking and geolocation technologies [19]. Wikitude is available for developing AR applications for iOS, Android and Smart Glasses devices. Similar to most of the best AR development tools, Various tracking methods and technologies are supported by Wikitude. In addition, it includes geolocation, cloud discovery and distance-based scaling features [19].

## 4. ARKit

Apple released iOS 11 some time ago and now everyone in the industry is talking about Apple's SDK ARKit, which allows developers to create AR apps. ARKit helps app developers go beyond simple 2D camera overlays while being easier to use than complex solutions [20]. Apps developed using ARKit bring 3D images into the real world using what is known as visual inertial odometry. Visual odometry estimates the position of a moving camera in three dimensions relative to its initial position. This typically involves tracking a series of points of interest across images in a video and then using 3D projection geometry to estimate their relative positions [20].

The software is cooperated with the camera sensor data and additional data (e.g. from a gyroscope and accelerometer) to detect and analyze the user's environment for AR visualization. Features include the core building blocks of "finding horizontal surfaces such as floors or tabletops", "placing virtual objects in real size" and "approximating the lighting situation / illumination of virtual objects to the real environment" [20].

## 5.ARCore

Augmented reality simulation is not an easy task when done from scratch. For this reason, there are suitable tools available in the market that help a developer to create apps as desired easily and efficiently. There are a lot of software development kits to create augmented reality-based apps and one of the most popular SDKs that is highly appreciated in the AR development community is Google's ARCore [21].

ARCore is a platform developed by Google , released on 1 March 2018 for creating augmented reality experiences. ARCore allows a person's phone to sense and understand their surroundings in order to interact with information. It essentially uses three key features, namely motion tracking, environment understanding and light estimation (all described below), which help bring virtual objects into the real world environment as seen through your phone's camera [21]

## 6.ARToolkit

When developing an augmented reality application, one almost inevitably comes across the ARToolkit during the planning stage, since it provides a freely usable marker-based tracking procedure for non-commercial purposes. The functions required for this are all found in a library that can be easily linked to. To make it as easy as possible to realise simple AR applications, however, the developers have designed the toolkit as a so-called "out-of-the-box" solution. This means that the user can simply connect a camera and compile the project on the respective operating system. From this point of view, it is already possible to start a small AR application ("simple test"), where a printed marker is tracked and a small virtual cube is drawn on it (this programme can then be extended as desired). In addition to the tracking routines, the ARToolkit also provides functions for the video connection and for the display of the scenes and objects [22].

It is also platform-independent, i.e. with the right drivers it runs on the operating systems Windows, MacOSX and Linux. Since it was already defined in the requirements that the Windows operating system should be used, the ARToolkit was only tested with this operating system [22].

### 3.2.5. Difference between Virtual Reality and Augmented Reality

In Table 2, the difference between the two technologies, VR and AR is clarified according to the user's target, the required devices, technical features and provided environment by these technologies in substance.

*Table 3. Differences between VR and AR*

<b>Virtual Reality</b>	<b>Augmented Reality</b>
The user no longer perceives the real environment	The user sees the real world and is also shown information.
The user can only experience the digital 3D world with aids such as VR glasses	A smartphone, tablet, head-up display, holography system or augmented reality

	glasses such as the Microsoft HoloLens are needed to experience the game.
The better and more powerful the computer, the better the experience in virtual reality	Pokemon Go is currently the AR hype
The virtual world can be seen, heard and felt	There are AR games, interior design planners, navigation apps, workshop manuals and much more.
VR is used for industrial applications, training, 3D games, real estate marketing and much more	The first AR display deep frame was presented at the CES which enables Augmented Reality without glasses.
There are 360 degree images, 360 degree videos and completely created 3D worlds	Developed 3D animation or 3D visualization is also extremely important for AR.
Only with the right 3D animation or 3D visualization does VR look real to the viewer.	

### 3.2.6. Mixed Reality

The next stage of evolution is the so-called Mixed Reality. Of all the terms, this is the most ambiguous, as it has already been used by different entities with different meanings. For example, Microsoft initially titled the HoloLens as Mixed Reality, but has since moved away from this [23]. It will be more accurate to define Mixed Reality as a connection of the real world with the technology of VR, which is accordingly strongly based on it.

Mixed reality is a mixture of real environment and virtual reality. In addition to a purely virtual environment, there is also augmented reality (AR) and augmented virtuality (AV). The term "mixed reality" was first introduced by Milgram & Kishino (1994) in an attempt to describe various mixed forms of computer-generated reality (virtual reality) and the real world [23]. It is a construct from science and basically encompasses the entire spectrum between VR and the real world. Mixed reality merges the real and virtual worlds, creating an environment in which physical and digital objects interact. It is conceivable not only to enrich the real world with digital content (AR), but also to superimpose real people into virtual worlds (augmented virtuality). Microsoft in particular has helped the term Mixed Reality gain new popularity in connection with its "Windows Mixed Reality" product series. While in traditional virtual reality the virtual environment is not connected to the real world around the user, in this form digital objects overlap with real objects. As already mentioned, the terms mixed reality and augmented reality are now mostly used synonymously. According to the original definition, however, mixed reality covers many more aspects than augmented reality by focusing on the interaction between reality and virtual objects. Accordingly, objects or subjects of the real world can interact with objects or subjects of the virtual world, for example. For example, if you place a virtual object on a real table, mixed reality applications register this and move the virtual element with it when you move the table. Ordinary augmented reality apps do not react to such changes, so the virtual object typically floats in the air or disappears altogether [23].

Mixed reality refers - at least theoretically - to all the senses, i.e. in addition to the sense of sight, also to hearing, smelling and touching. In practice so far, however, the visual aspect of Mixed Reality is clearly in the foreground.

### 3.2.7. Summary: Microsoft's Mixed Reality

As already mentioned in the introduction, Microsoft also re-established the buzzword Mixed Reality together with the HoloLens. Mixed reality not only describes the entire reality-virtuality continuum, but also focuses in particular on the interaction between the real and the physical world.

Since the definitions of MR, VR and AR are not clear in the literature, but the interaction between the physical and the real world is given special significance in the context of this work, the definition from Microsoft's point of view is summarized again here and also used for mixed reality applications in the context of this work.



Figure 3. Differences between the three technologies: In AR, the image is not correctly fitted into the environment in comparison only MR [24]

The best way to explain this definition is to look at Figure 3. On the far left, a virtual object is shown in VR. In an AR, on the other hand, the virtual object is mapped onto the real world. Just like in the AR game Pokemon GO, the object is initially simply mapped onto reality. In mixed reality, on the other hand, the object interacts with the real environment, which means that the sofa shown in Figure 3 represents a natural barrier for the virtual object as well as for the human being and can therefore only be located behind or in front of it. Moreover, the object in the MR stands correctly on the ground and no longer floats in the air like the AR, so gravity is active in the MR just as in the physical world.

### 3.3. Virtual Reality and Augmented Reality in Digital Production

Virtual reality and augmented reality have been used in numerous applications in the production environment since the beginning of the 1990s [25]. VR and AR contribute the Industry 4.0 concept by supporting manufacturing companies in meeting the increasing demands in terms of flexibility, quality, time and complexity. The newly created Industry 4.0 production paradigm postulates, among other things, the comprehensive networking of production systems, the real-time digitalization of production processes and states, and assistance through intelligent work systems. VR applications are based on post-processing of data from physical simulation in many cases. For instance, from the fields of computational fluid dynamics (CFD) or finite element analysis (FEM) [25]. The metaphors commonly used there, such as false color representation, are adopted; at the same time, further techniques are used in VR. Large projection systems can be used to support group discussions even across disciplinary boundaries. If physical prototypes are already available, on the basis of which the

production process has been tested, the use of augmented reality (AR) for superposition is conceivable [25].

In recent years, a number of VR and AR applications have been established that deal with manufacturing processes. According to DIN 8580 [25], manufacturing processes are divided into six main groups: forming, forming, cutting, joining, coating and changing material properties. The design of manufacturing processes is often a complex three-dimensional task. VR can be usefully applied wherever spatial-geometric tasks are to be solved by humans as decision-makers. This applies in numerous aspects to factory planning: building planning, layout planning, production plant planning or realization monitoring are possible fields of application for VR in this sense. There are four major fields of factory planning (phase of factory planning), production (division of production processes), assembly and service. Factory planning is a multifaceted, complex and extensive planning field in which the various subtasks are combined into a cohesive whole by means of a uniform objective [25]. It is a sub-area of corporate planning and essentially has the following tasks the optimal design and rational realization of investment projects. Therefore, there are four phases in factory planning according to including processes [25].

Phase 1 (goal setting): Here, corporate and project goals are determined, evaluation criteria are established and work packages are defined. No meaningful VR use can be identified in this phase [25].

Phase 2 (basic evaluation) [25]: Within the framework of the basic determination, information is procured and evaluated that forms the basis for the following planning. In this phase, the quantity structure for the subsequent process simulation must be created. In the case of rescheduling (brown field projects), it is important to document the current realization status (via evaluation of CAD plans, 3D documentation, laser scans) and to validate it (via target/actual comparisons, augmented reality). Manufacturing processes that are suitable in principle can be determined via simulative feasibility studies with reference to the planned product [25].

Phase 3 (concept planning) [25]: Concept planning includes structuring and dimensioning - for example of areas or warehouses - and ideal planning, followed by real planning. The use of VR for the visualisation of variants of the general development, the factory building, the building infrastructure (e.g. media systems) and the rough layout is interesting. Material flow and logistics concepts can be simulated [25].

Phase 4 (detailed planning) [25]: Whereas until the end of the 1990s computer-based planning was only possible "up to 5 metres to the assembly line", simulation and visualisation techniques have long since made it possible to design manual and automated assembly systems, robotics, automation technology and conveyor technology in detail according to the requirements of efficiency, safety and ergonomics, and to integrate the partial trade results in factory DMUs (digital mock-ups). These factory DMUs pursue a total of three integrations which are geometric integration where all building services are bought together as 3D objects in an overall model, functional integration that people, systems and other components are integrated into the flows (material, people, information) of the factory with regard to their function and production integration which prevents geometric or process-related collisions of the product in the factory structure [25].

Phase 5 (preparation for implementation) [25]: The preparation for realisation deals with the procurement of offers, awarding of contracts and monitoring of the implementation planning, but there is no meaningful VR use which can be identified in this phase [25].

Phase 6 (realization monitoring) [25]: Aspects of realization monitoring are the coordination, monitoring and documentation of the realization. Virtual technologies can help here to check the implemented status of the factory conversion or new construction within the framework of target-actual comparisons by means of mixed data processing (laser scans versus 3D construction) or augmented reality (superimposition of target planning over real perspective) [25].

Phase 7 (ramp-up support) [25]: To support ramp-up, control code created through offline programming can be transferred to physical plants. Such simulation-based pre-testing thus shortens the ramp-up time while greatly improving the maturity of the planning of robotics and automation systems. But it is not only machines that can be prepared early on via a simulated dry run: Operator training simulators offer the possibility of training personnel in advance without risk and at low cost (since no real resources are occupied). Virtual environments can map the four types of knowledge for this purpose. These are positional knowledge ("Where is what?"), structural knowledge ("What is related to what?"), behavioural knowledge ("How does the system behave? How do I behave?") and procedural knowledge ("What action triggers what?"). The trainee can thus explore spatially, learn conceptually, acquire motor skills and learn procedurally. This suitability of virtual environments to be used in knowledge management is also significant for the last phase 8 of factory planning [25].

Phase 8 (project closure) [25]: The project conclusion is about evaluating the past project and securing the achieved knowledge. Important in this context are the 3D geometry data that were collected in the basic evaluation (phase 2) and in the realization monitoring (phase 6). The factory DMU model and all simulation models that were already used in phase 4 (detailed planning) are also part of a 3D knowledge management system. Its possible use was outlined in the previous explanations for phase 7. The greatest, directly visible benefit of VR for factory planning can be achieved when standardized models are used according to standardized methods. However, the associated repetition effects are only realistic either for large companies with frequent planning events or for planning offices. Honest consequential error cost considerations can, however, lead to even smaller factory planning projects being carried out with intensive use of virtual techniques be carried out [25].

### 3.4. Virtual and Augmented Reality in Education

Through various developments under the catchwords digitalization or Industry 4.0, innovative technologies are reaching market maturity that can play a supporting role in the training and further education of technical employees. One promising technological development is represented by various types of augmented reality and virtual reality. Although the development in these technologies seems in a primitive level, the exiting opportunities which are existed by VR/AR are quite remarkable in order to support teaching and learning nowadays. Beside digitalization in production line, there are numerous examples to use VR/AR in education contexts that leads success in the implementations [26]. The advantage of VR/AR as an experimental and educational tool increase the comprehensibility of the subject by placing the participant inside of any scene with high degree of immersion [26]. The application area in education is quite extensive such as creating a training model for the

operator in the plan, the use of 3D anatomy models in medical education or skill transfer in VR based microsurgery training [26]. In the Figure 4, it is represented the percentages that which areas are currently using the VR/AR technology in education.

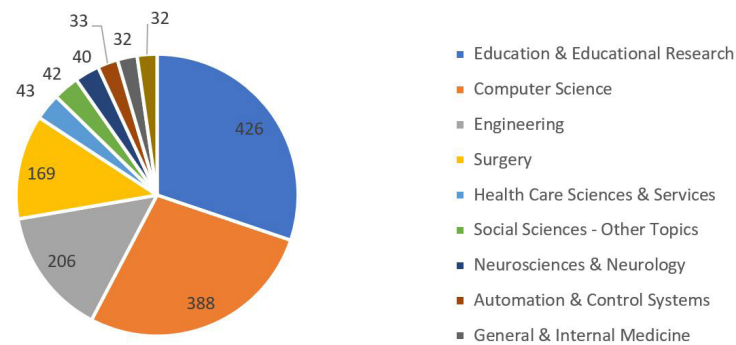


Figure 4. Areas of using VR/AR technology in education [27]

### 3.3.1. Classification of VR/AR in Education

One of the most important things in the usage of VR/AR technologies in education is the knowledge of the features of VR/AR which is conducive to the targeted educational area. In line with the purpose, function and design of the training model, the classification of the tools is clarified and selected to use. Classification of VR/AR education can be summarized with seven points in general [28]: (1) Purpose of the application, (2) User experience, (3) Technology of the delivery, (4) Production technology, (5) Gamification type, (6) User interaction and (7) System interaction [28].

The most crucial category in the taxonomy is linked with the type of information retrieved and the intended use of that information. The goal can include training purpose, teaching purpose, and observing purpose. The purpose of the educational application is to provide information on how to do this. Using a specific real device (especially in the case of AR) or its digitized equivalent (as in the case of model-based VR and cinematic VR) [27]. It is often very specific and focuses on training for the operation of devices, machines, or processes rather than understanding the underlying principles of the design. For teaching purpose, the main target is leading the student comprehensive the knowledge. The student is supported by transferring knowledge from environment and other situations via VR/AR technologies during exposing to the theory and underlying principles. Since the development of success on effective integration and feedback, there are low successful examples in this area. The main goal of observing purpose is to show or transfer information without having to pursue or understand it. In other words, it serves display purposes. The development of 3D printer or 3D videos are the bases for this purpose [28].

In addition, two terms which are called user experience and delivery technology are closely related. The taxonomy for AR/VR identifies three distinct user experiences as VR experience, AR experience and display experience. VR experience isolates the user from the outside environment to immersive world by creating reality-simulated and hypothetical environment. In AR systems, the training module is occurred in real time when the user connects with the system with the aspect of the other real-world surroundings in 3D [28]. The AR technology is aimed to enhance the real world interaction and learning experience by creating an

environment to make interaction between the user and education tools. On the other hand, the standard 2D screen / display is used for presenting the virtual world through 3D visualization. The standard display provides experience which offers advantages over 3D immersion. For instance, there can be the relative clarity of text and general reading experience, and much less prone to causing user dizziness, headache or eyestrain [29]. The user experience is supported by two different hardware devices: a stereoscopic head mounted display (HMD) and the screen.

#### A. HMD

The importance of virtual and augmented realities is increasing for a variety of application areas, such as product development, but also service and production. A prominent example are smart glasses and related mobile devices, which are also being integrated into existing processes of companies under the keywords Industry 4.0 or Internet of Things, thus structuring the workplace of the future. Smart glasses are associated with great potential benefits in professional use. However, the technology smart glasses are assigned to different areas in the literature. It corresponds to the definition of HMD, wearable computing as well as ubiquitous computing or an augmented reality system. HMDs comprise head-mounted screens that expand the reality perceived by the user by displaying information [11]. The meaning of stereoscopic vision shows up when two views of the same scene with binocular disparity are presented to each eye. Achieving the maximum yield perception of depth depend on the effect in binocular fusion [28]. Due to the extension of the user's reality, corresponding technologies are also classified as AR.

#### B. Screen

The user can prefer devices such as a stationery which can be desktop computer etc. or hand-held like tablet etc. or there can be a surrounded screen which is used as CAVE (Cave Automatic Virtual Environment) system [28].

The visual experience and the delivery technology forms the VR/AR technology which is shown in the Table 4. The delivery and experience are related with each other according to the type of experience identified by delivery technology and to some extent its production [28]. In this table, it can be testified that definition of AR can cause a confusion. For instance, Google Glass is classified as display experience in line with the taxonomy although its technology reminds of AR experience which is defined as a 3D registered system. Google Glass does not have necessary sensors that show information related to what is in front of the user and basically gives information on the screen by strapping onto the user's head [28].

*Table 4. VR/AR Equipment in User's experience vs. delivery technology [28]*

	Screen	HMD
Display	Computer monitor	Google Glass
VR	Simulators; panoramic videos	Vive, Oculus
AR	iPad	Meta, HoloLens



### 3.5. Difference between Virtual Reality and Augmented Reality in Education Scenarios

The functional differences between augmented and virtual reality glasses lie in the degree of integration of the end device into the user's reality. While AR glasses superimpose virtual objects into the user's field of vision and thus create an augmented reality, VR glasses completely hide the user's reality in order to create a detailed virtual reality. However, with both technologies, the user can interact with the digital objects. These features make these eyewear technologies suitable for different training and education scenarios [12]. The Figure 5 shows a delimitation between AR and VR. Here, the middle point depicts reality, i.e. mostly the actual state of the current education system. Conventional media that thus have no connection to AR or VR include, for example, textbooks, workbooks, printed instructions, training material in the form of presentation slides and much more.

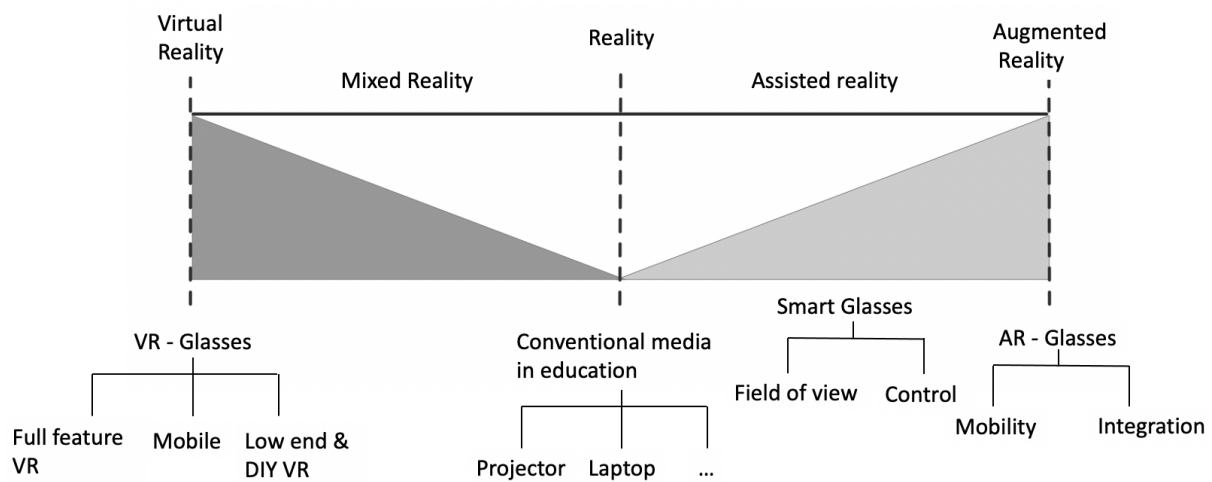


Figure 5. Classification of Virtual Reality and Augmented Reality [12]

AR glasses and also smart glasses superimpose context-sensitive information into the user's field of vision. In this way, information-intensive processes can be supported during execution. The mobility of AR systems also makes it possible to support the user regardless of location. AR glasses are thus an adequate assistance system for supporting technicians during service provision at the point of service. Technicians are thus enabled to be trained in processes while they are performing them, also called "training on the job" [30]. While this previously required intensive supervision by an experienced employee, AR glasses enable the employee to receive independent support in order to compensate for a lack of process knowledge on an individual basis.

With a view to the industrial environment, however, the VR technology group has to contend with significantly greater issues than AR technology, since here real perception is only partially overlaid, and the user is not completely immersed in virtual reality. Nevertheless, VR has the potential to revolutionize vocational education and training. While technical customer service has so far maintained training centers where training is given on real products, the virtual trainer enables flexible training independent of location, so-called "training off the job" [12]. This saves time, as several people can practice processes at the same time and travel distances are eliminated. Furthermore, costs are reduced as no expensive facilities must

be provided for training purposes [12]. Furthermore, the virtual trainer offers safety, so demanding tasks with chemical substances can be trained without taking health risks.

VR systems are thus an ideal complement to AR systems for an individual and autonomous learning concept. Employees are trained in advance in the relevant processes and then supported by the AR goggles during service delivery in the real process. When VR is used for commercial activities, for example, a larger number of problems and questions quickly arise that need to be addressed. In the short to medium term, forecasts therefore assume that the VR market has already got off to a good start, but that the AR market will soon catch up with it due to its industrial relevance [31].

### 3.6. Virtual and Augmented Reality Application in Production Engineering Teaching-Learning Process

The popularity of virtual and augmented reality is increasing in the teaching-learning processes because of providing a learning condition in virtual environment and enhance cognitive performance of the students. There are some notable applications increasing for the engineering education and in production engineering applications.

The research paper, “Virtual and augmented reality application in production engineering teaching-learning processes” [27], examines the guidelines of ABEPRO (Brazilian Association in Production Engineering) which has developed a Production Engineering curriculum reference document. In this document, F.Anjos, L.Rocha and D. Silva have recognized that “there is gaps in the application of virtual and augmented reality in the Production Systems Management, Production Planning and Control areas, Material Handling, Production Simulation, Productive Process Management, Metrological Quality Organization, Work Organization, Accident Risk Analysis and Prevention, Work Safety, Product and Process Ergonomics. These gaps can cause a negative effect on production engineer training which linked with the lack of opportunity to learn in a teaching environment that closer to the reality. Graduates enter the labor market with many gaps in the application of theories studied, and consequently this impact brings the reduction in organizational competitiveness” [27].

The graph in the Figure 6 shows the ratios of VR/AR technologies of teaching-learning processes in engineering categories [27]. The four engineering courses which are mechanical engineering, civil engineering, computer and production engineering has ratios of 30.0%, 25% and 9% (computer and production engineering) respectively [27]. Therefore, it can be determined that the implementation of VR/AR technologies generate a much more interactive environment, provides more realistic learning area for students which is closer to the real industry.

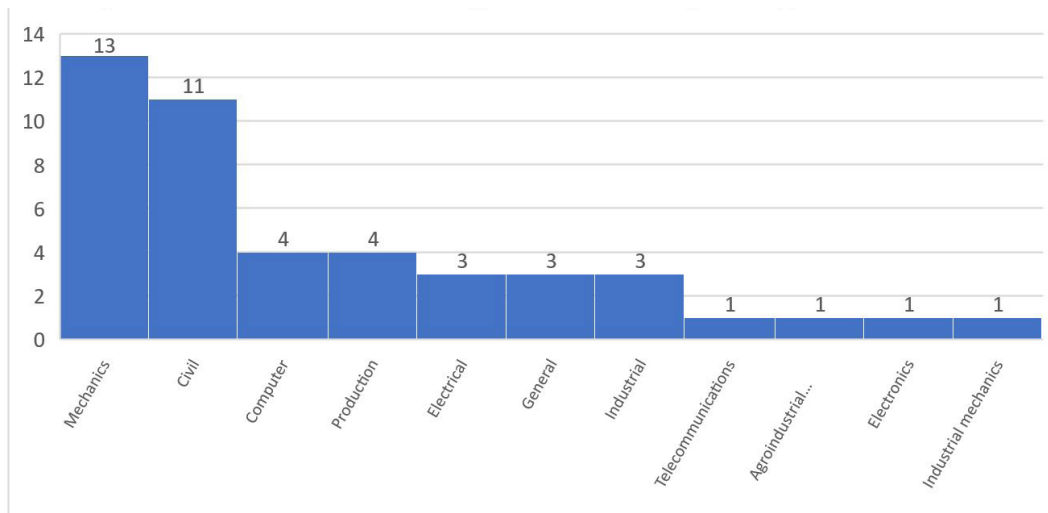


Figure 6. Proportion of Application of VR and AR Technologies in Engineering [27]

### 3.6.1. Learning Mode of Augmented Reality

Training in industrial-technical occupations often focuses on complex machines, the operation, maintenance and servicing of which is learned in the course of initial vocational training. In the course of the digital transformation, the initial vocational training is not only becoming increasingly complex, but the complete accessibility of the machines concerned (in terms of space and content) is no longer guaranteed in every case with increasing automation and networking. Augmented reality makes it possible to overcome the media break between learning on real machines (which is still possible only to a limited extent) and digital, interactive and dynamic learning content. Through the risk-free augmentation of machines, e.g. with authentic 3D models of the machine interior, not only can otherwise hidden assemblies be visualized, but also the associated processes and cause-and-effect relationships can be made accessible again for learning activities [32].

In order to offer learners, the easiest possible access to the learning content of social augmented learning, two strategies are pursued [32]: The 3D visualization of embedded 3D models and the augmentation of printing presses available at the learning location. To extend existing learning locations, real machines are augmented by digital models of the components hidden inside. By aligning these 3D models in a precise position, an extended learning world is created in which trainees can interactively explore the components of a machine without having to intervene in ongoing production processes [32].

In the Augmented Reality learning mode, the camera of a mobile device is activated, and the recorded video image is shown in real time on the display. If the device is now pointed at a printing press marked with an image marker, a virtual window into the interior of the press is opened, precisely positioned. Through this window, the individual components of the machine, which have been stored in the form of the embedded 3D model, can be seen. This overlaying of the real machine with digital subject content not only enables the direct identification and position recognition of otherwise inaccessible components, but also supports trainees in developing complex interrelationships [32]. Furthermore, the exploration of the learning object takes place in a natural way, as the learners can move freely around the machine.

### 3.6.2. Teaching Modes for Industrial Augmented Reality Learning

The use of augmented reality in the classroom is accompanied by two major challenges: not only must the infrastructure for successful use be available in the form of mobile devices and accessible internet connections, but the implementation in existing teaching concepts on the basis of didactic and pedagogical considerations must also be carried out carefully [26]. The machines that are to be expanded by means of augmented reality must first be marked with image markers. Furthermore, a usable and accessible internet connection is required for the synchronization of the users - and thus for the presentation tools based on it. Practical user studies in social augmented learning have shown that the use of augmented reality in the classroom has a positive effect on learning outcomes, for example, when teachers have had the opportunity to individually integrate the technology into their existing teaching concepts [26]. In addition, it was found that there is still a need to catch up in two critical factors in particular: In many cases, no mobile devices are available for teaching, as neither a tablet pool is maintained nor are private devices allowed to be used. In addition, trainees are often not allowed to access internet connections - insofar as these are available at all at the place of learning [32].

As designers of augmented learning worlds, teachers support trainees in self-directed and explorative learning activities, which goes hand in hand with a changed understanding of their role: in learning with augmented reality, learners have more freedom to engage with learning content themselves than is the case in conventional learning. For teachers, this means that they have to create the appropriate framework conditions for the learners' constructive learning processes in which successful augmented reality teaching can take place [33]. During augmented reality lessons, teachers can decide for themselves to what extent they want to influence the lesson. From the point of training at a production system, future training systems are going to become more popular and more interactive by a spatial link between the real object and the associated information because of dealing with complexity systems based on Industry 4.0 [33]. Furthermore, it is keep going on developing these kind of interactive training modules. For instance, in the article named, "Exploring Training Modes for Industrial Augmented Reality Learning" [33], a prototype of a mobile training system has been developed for non-expert users with helpful information about the functionality of complex automated industrial systems. The system are created to visualize information about internal processes, sensor states, settings and hidden parts of a production system directly in the field of view of a user by a AR tablet application which the whole system is illustrated in the Figure 6. This AR application can be accessible via different methods that involves step by step tutorials and promote exploration. In the prototype as it is showed in the Figure 6, mini-computer, a tablet with augmented reality functionality and a wireless router which provides a wireless network to make connection for both the computer and the tablet are used. In aspect of hardware, the computer acts as a local server and the computer also connected to the folding machine via a wired network to gain access to status information, messages and data of sensor. Moreover, a software application is implemented to form a platform for the training information such as object positions and media files. Thee experience level of augmented reality content is stabilized for tracking during the training. After scanning QR code on the machine, the different procedures appear as an accessible via four buttons at the button of the tablet display [33]. In the Figure 7, the visualization of an animation for the longitudinal folding process is showed. Also, different virtual objects and animations are developed to provide the provision of information to the user beside the textual description in the AR application.

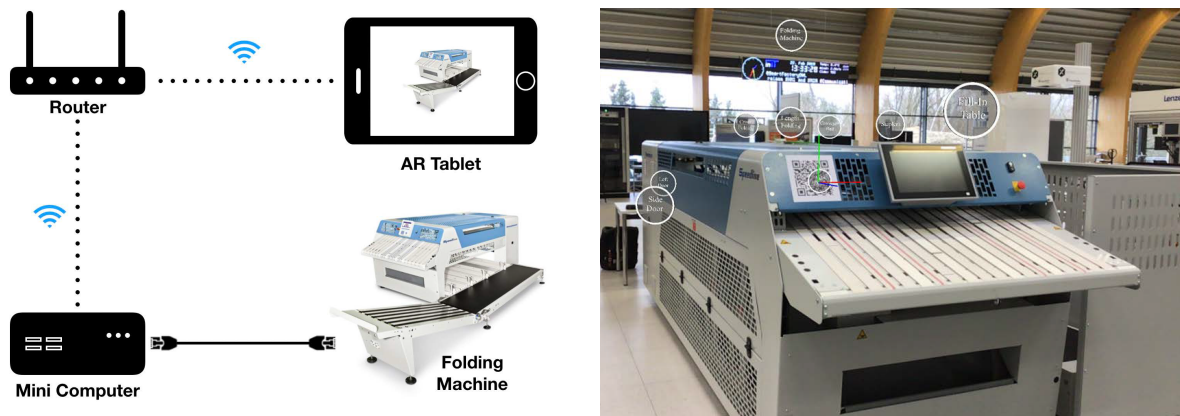


Figure 7. Hardware and communication system of the prototypical implementation [33]

The prototype in this article is an example of an augmented reality- based application to support the induction and training of workers at complex industrial systems and testify the feasibility of such systems training in AR technology [33].

### 3.7. The Utilized Software in 3D Training Module

In order to be able to visualize a 3D model created on the PC in the real environment through a user interface attached to mixed reality glasses, it is usually not possible to use the program that was originally used to create this model. This is because, on the one hand, the file format does not correspond to that which the glasses can read and, on the other hand, not all software is compatible with the glasses. Therefore, the file format must be imported into a format that can be used by the MR glasses, which is done by using several 3D software programs. The programs and tools used for this are presented in this chapter.

#### 3.7.1. Unity

Unity is the name for a development environment called Unity Editor and at the same time for the cross-platform computer game engine of the same name by the company Unity Technologies and released in June, 2005 at Apple Worldwide Developers Conference. Along with Unreal and CryEngine, it is one of the most frequently used 3D engines, which are also available to developers free of charge according to the purpose [34].

Although Unity is primarily a game engine, it is also used outside the computer games industry. In addition to the possibility of using it for complex 3D simulations, it is also used in particular for applications in the field of VR, AR and MR.

Unity itself already offers a variety of features for the development of MR applications, computer games and other 3D applications, including its own physics engine. In principle, however, Unity is not a professional program for modelling 3D objects. It offers good support for developers with its integrated functions, especially for 2D and 3D programs. This allows the developer to focus more on the content of the program. Unity already offers an included

physics, rendering, network and animation system. The extensibility with many frameworks and plug-ins is also a great advantage of this development environment. In principle, this is possible with Unity, since the possibilities for creating simple basic objects (cuboids, spheres, etc.) are included, but for more complex models one should resort to tools that are especially designed for this purpose (e.g. Blender or Rhinoceros) [35]. Since the modelling of more complex 3D models is not in the foreground in this work, but only a prototype is being developed, the use of further software for 3D model development was dispensed with and recourse was made to the primitives that is how the basic 3D objects are referred to in Unity [35].

The following sections will briefly introduce the Unity development environment. However, before this is introduced, some terminology will first be introduced [36]:

- Scene: Each scene describes a level or section in a game or application. Game or application.
- GameObject: This is the core element in Unity, as almost all types and classes are derived from it. almost all types and classes are derived from it. Every 3D object and also all other objects within a scene (e.g. the camera26). Each A GameObject is comparable to the superclass Object in Java or the "System.Object" in the .NET Framework.
- Component: Every GameObject in Unity consists at least of the "Transform" component. This describes the position of the GameObject in space (position, rotation and scale). In addition, objects can contain other components, e.g. the behaviour or a GameObject. In addition, the game object can be extended by script components.
- Frame: A frame is an update of the display screen. The average frame rate of HoloLens is between 30 and 60 FPS.

In Unity C# is used in particular as script language around the behavior of GameObjects to describe. A special feature of C# scripts is that each script is derived from MonoBehaviour, which is a derivative of GameObject. MonoBehaviour describes here the core behavior of each GameObjects, in particular by the following two methods [37]:

Start(): A method that is executed once in the lifetime of the script when it is activated, before the update method is executed. This is used later, for example, to assign a created GameObject to which custom messages it should receive.

Update(): This method called when updating any frame. For MR applications the movement of an object could be implemented here.

#### 3.7.1.1. Unity Development Areas

The development environment of Unity is modelled on that of a 3D animation program and is divided into the following core areas which is shown in the Figure 8 [35].

Scene View (1): Here the current scene and MR world can be designed. Optionally, a Game View can also be displayed, which offers a preview of the finished application. This is only

useful to a limited extent for MR applications, since the physical reality cannot be depicted [35].

Hierarchy (2): The structure of all existing GameObjects is displayed here. Inheritance relationships can also be created here simply by dragging and dropping, also called "parenting" in Unity. This means that objects can be grouped together. The top object is called the "parent object" and all subordinate objects are called "child objects". Changes to the parent object (e.g. the position in space) then inevitably affect the child objects as well [35].

Inspector (3): The components of the currently selected GameObject are displayed here. These can be assigned to other components such as a C# script by dragging and dropping [35].

Project Browser (4): Is used to display and manage all digital content (also called assets in Unity). More complex 3D objects from other programs or framework parts can be saved here [35].

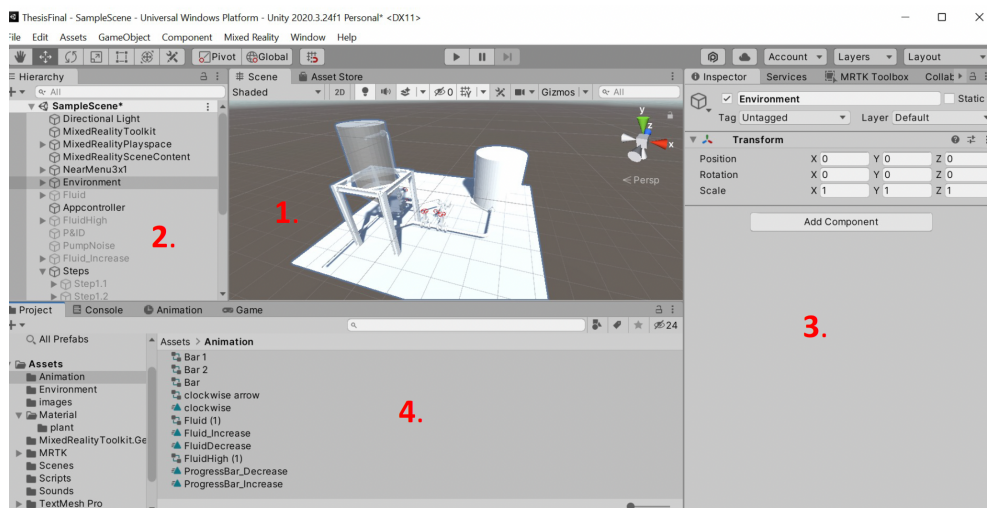


Figure 8. Extract from the Unity 2020.3.24f1 development environment [own recording]

### 3.7.1.2. Unity Dashboard

Unity Dashboard is the primary point of managing and organizing the Unity project by including tools to develop more. The Dashboard provides the user to configure Placements, filters, test devices, IAP Promos, and revenue reports to maximize the earning potential [38]. There are many tools to edit the Unity project in the Unity Dashboard page. From the Organization in Dashboard, the user can view the list of Organization's Project such as involving information like Project's Total Revenue, Ad Revenue, New Users, DAU, and ARPDAU (average revenue per daily active user) [38, 39]. Therefore, while the user can navigate and edit the project's settings from here as giving the authority to another Unity user to organize the project, it can be possible to arrange the monetization of the Unity app [39]. In order to perform all these operations on the Unity project, it is necessary to configure the project with Unity Dashboard in Unity such as editing, transferring, archiving. In this process, in the Project Settings section in Unity [39].

### 3.7.2. Mixed Reality Feature Tools

The Mixed Reality Feature Tool for Unity is a new application designed to serve as a simplification for learning new MR features, such as Microsoft's MRTK. By selecting the desired features, the Mixed Reality Feature Tool determines the required dependencies, downloads the needed packages, and helps update the Unity project to include those features. Windows Mixed Reality Feature Tool is a special operating system from Microsoft based on Windows 10 operating system with a focus on the display of virtual content and it requires the .NET 5.0 Runtime software platform [40].

All apps for Windows Mixed Reality are Universal Windows Platform apps (UWP apps). On the one hand, these can be apps with 3-D content developed specifically for Windows Mixed Reality, but on the other hand they can also be general Windows 10 UWP apps that also run on any Windows 10 PC or laptop. While the special 3-D apps display their content in a 3-D mode, the general UWP apps are displayed as flat 2-D windows that can be distributed and used as desired in the room. One of the important emphasis is that the Mixed Reality feature tool is currently only available for Unity. If the simulation is developed in Unreal or other, other options should be investigated [41].

### 3.7.3. Mixed Reality ToolKit

The MixedRealityToolkit-Unity (MRTK for short) is a collection of scripts and components for developing applications for HoloLens. The MRTK was initially published by Microsoft under the name HoloToolkit specifically for the HoloLens and later renamed MRTK. The toolkit is also designed to develop applications for MR headsets. Additionally, after the renaming to MRT, it was also expanded to include support for other Windows MR headsets. Microsoft refers to MR headsets as the non-transparent headsets that use the Windows Mixed Reality Platform. The latter does not receive any further attention in this work, as the focus is on applications for the HoloLens. The change in the name of the toolkit shows that Microsoft is trying to establish a uniform software solution for all devices that are located in the Mixed Reality spectrum [40].

In the Asset package called "Getting Started", assets are objects of various kinds, such as an image or even a complete 3D model, which can be imported into Unity. The Getting Started package is used for the manual positioning of a three-dimensional object.

The MRTK is divided into the following APIs which are mentioned in the Table 5 [40] [42].

*Table 5. Explanations of the APIs in Microsoft MRTK [40] [42]*

APIs	Explanation
Input	It includes methods around gesture input. This can be used to capture input within the MR. The augmented operator could use this to control a factory part using virtual buttons.
Spatial Mapping	This is the name for environment recognition and solving the SLAM problem with the HoloLens. The scripts in this API include methods to relate the digital and physical worlds. One example is "TapToPlace."



	This script allows the user to move an already created MR object in the MR world and place it on a physical object, just like a virtual image on a real wall. In contrast to the problem dealt with in this thesis, however, only objects that have already been created can be moved, i.e. it is not suitable for object recognition, but can be used as an auxiliary method for placing static objects.
Spatial Understanding:	It is prefabricated methods for environmental evaluation or also for changing the spatial mapping. There are also methods for environmental evaluation based on the generated mesh30 of the spatial mapping. For example, a couch can be identified in a room based on its shape.
Spatial Sound	Scripts for integrating spatial sound.
UX Controls	Auxiliary methods for improving the user experience.
Build, Boundary, Utilities	These are comprehensive support methods for building and debugging MR applications.
Sharing	Methods that allow communication with other MR devices, but also servers and databases.

For the implementation of the prototype, the libraries around spatial mapping as well as input and sharing are of particular importance.

#### 3.7.4. Windows 10 SDK

The Windows SDK for Windows 10 is a software development kit from Windows which is all-in-one package for developers. The Windows SDK contains headers, libraries and tools that allow the user to develop universal Windows apps and desktop apps that run on Windows operating systems [43].

The Windows 10 platform is a significant upgrade over previous versions of Windows. Besides the point on more intuitive user interface, performance improvements and the digital assistant Cortana, it offers developers cross-platform working for their apps. Additionally, it is possible to choose which components to use and where to install them. Through the integration in Visual Studio, the components available in both programs are not duplicated [43].

#### 3.7.5. .NET Framework

.NET Framework is a software platform developed by Microsoft for the development and the meaning of the software corresponds "framework work". This means that the .NET Framework serves as a basic program for other software and programs. The .NET Framework, which is part of the system, is a type of .NET that ensures the compatibility of the prepared programs with the Windows operating system. It consists of a runtime

environment (also called Common Language Runtime, or CLR for short), class library and compiler. The programs that have been programmed using the .NET Framework are executed in the runtime environment [44]. For writing larger programs, the use of Visual Studio is helpful. The version used in this project is .NET 5.0 Runtime.

### 3.7.6. Visual Studio 2022

Visual Studio is an IDE, an integrated development environment where you can make programs, applications or websites using many programming languages. It is used to develop computer programs, websites, web applications, web services and mobile applications for Microsoft Windows. Visual Studio uses Microsoft software development platforms such as Windows API, Windows Forms, Windows Presentation Foundation, Windows Store and Microsoft Silverlight. It can generate both native code and managed code [45].

Visual Studio includes IntelliSense (code completion component) and a code editor that supports code refactoring. The integrated debugger works both as a source-level debugger and a machine-level debugger. Other built-in tools include a code profiler, form designer for building GUI applications, web designer, class designer and database schema designer. It accepts plugins that enhance functionality at almost any level [45].

There are currently two different versions in Visual Studio 2022. One is the community version, the other is the professional version. The community version is free of charge and still contains all the tools required to create an executable app for the AR glasses. In both program versions, it is possible to select and install the workloads, individual components and language packages required for a project [37] [45].

## 3.8. Microsoft HoloLens 2

The term "mixed reality" is often used in connection with HoloLens. This buzzword, which was also established by Microsoft, describes an AR in which not only virtual objects are displayed in the real environment, but also relate to it and interact with it. At the beginning of 2015, Microsoft also entered the market and introduced the HoloLens, a pair of data glasses which, in addition to a normal camera, also has a depth scanner to create a more accurate image of its environment [46].

### 3.8.1. Historical Development of the Microsoft HoloLens

The precursors of modern VR and AR data glasses date back to the first half of the 19th century. The topic of VR and AR is currently one of the popular topics in information technology. This applies to the use of corresponding data glasses in the business-to-consumer (B2C) environment as well as the business-to-business (B2B) environment. According to the study, one third of all consumers worldwide will be using VR devices by 2020 - and a total of 3.5 billion active AR devices are expected around the globe by 2022. Yet the technology of virtual reality and data glasses goes back far further than one might generally assume as early as 1957, the Californian pioneer Morton Heilig developed the first functioning VR glasses with the futuristic Telesphere mask, which he even applied for a patent for his invention in 1960 [47].

The precursors date back even more than a century before that: In 1838, the Briton Charles Wheatstone developed the first stereoscope which is a device for viewing a pair of separate images that create a three-dimensional image by superimposing them in the right and left eyes of the viewer. This is an optical illusion - consequently also a kind of virtual reality [47]

On 21 January 2015, Microsoft showed off HoloLens during the Windows 10 presentation, where it was used for the Minecraft game and Windows 10 features. At Mobile World Congress 2019, Microsoft unveiled the upgraded HoloLens 2. This went on sale in the US, Japan, China, Germany, Canada, the UK, Ireland, France, Australia and New Zealand during 2019 for around US\$3500. Here, the field of view was doubled, while the resolution of 47 pixels per degree was retained. The wearing comfort has also been improved [48].

### 3.8.2. Hardware of Microsoft HoloLens 2

In 2016, Microsoft launched the first mixed reality glasses under the name HoloLens. Three years later, the improved successor appeared as the HoloLens 2. Microsoft does not call the HoloLens device as VR or AR although it includes elements from both of them. It is preferred to call as mixed reality technology. HoloLens experience blends the two realities together to create a new mixed reality which is an instance of the combination that is greater than the sum of VR and AR. HoloLens creates an amped-up world by cooperation of the real and virtual work which allows the user interacts with it in unprecedented ways. The virtual part of this world interacts and can be controlled by the user's hand gestures and voice commands. On the other hand, the real world is there to anchor the user's perceptions [43]. Microsoft has improved the HoloLens (1<sup>st</sup> gen) to develop more comfortable and immersive experience paired with more options for collaborating in mixed reality. The new version brings some changes that do not only concern the optics. Also, it runs on the Windows Holographic OS which has robust performance and secure [49]. In the Table 5, the HoloLens components are described in detail and the components of HoloLens 2 is illustrated in the Figure 9.

*Table 6. Components of HoloLens 2 [49]*

Visor	It involves HoloLens sensors and displays. You can turn the visor upwards while wearing HoloLens.
Headband	It is the adjustment wheel to expand the headband while wearing the HoloLens. It is needed to tighten the adjustment wheel by turning to the right to make the headband suitable and comfortable for the head.
Brightness buttons	These buttons are located on the left side of the visor near the user's temple while wearing the HoloLens.
Volume Buttons	The volume buttons are found on the right side of the visor near the user's temple during wearing the HoloLens
Power button	While wearing the HoloLens, this button is on the right side of the rear outer cover.
USB-C port	This entrance is found on the right side of the rear outer cover below the Power button.

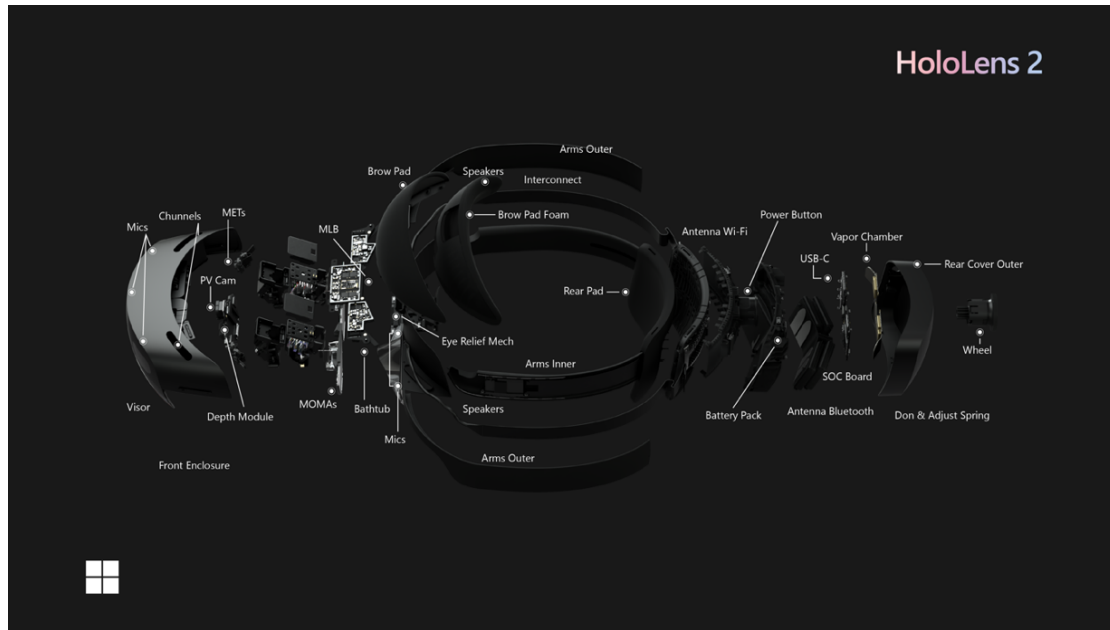


Figure 9. HoloLens 2 Components [49]

HoloLens is regarded as a pioneering device in the field of smart edge. This refers to technologies that can collect data without a reliable internet connection and process it where it is generated. However, they can also share some or all of the data with the intelligent cloud when connected. Thus, based on artificial intelligence and cloud computing, the device enables instinctive collaboration and knowledge sharing via holograms, independent of space and time [46]. There is a difference between the HoloLens and other Windows Mixed Reality headsets from the other popular headsets is the ability to providing the performance of inside-out tracking [40]. It is the ability for the headset to monitor its environment without the need for external sensors. In Outside-in tracking headset, the user has to set up the sensors around an area that allows the user to know where the headset is when the user moves around. Inside-out monitoring eliminates the cumbersome installation of external sensors, and virtually all environments [50].

Some basic VR headsets such as Google Cardboard, Samsung Gear VR do not have position tracking, only the ability to 'look around'. The HoloLens has eight cameras on the headset. Five of them are used to track the environment which involves four environment tracking cameras and one depth camera, two of cameras are for eye tracking and one regular camera is for recording videos and photograph. The environment is constantly tracked by the HoloLens 2 and 3D model of the area is built in it. This is called spatial mapping [50]. The spatial mapping which is comprise of mesh made of triangle to form a digital version of the surrounding where the user wears the HoloLens is crucial for several reason [50]. First of all, the spatial mapping directs the HoloLens about the holograms which need to hide from view. It increases the realism of the experience by the feature of occlusion. For instance, in the situation of placing of hologram in the user's hallway during walking into another room, the spatial map of that room's wall will hinder from seeing the hologram in the hallway. This feature is important effect on the comprehended naturalism of holograms [46].

Another special feature, which is currently unique compared to the competition, is the architecture. In addition to the classic components such as the CPU, GPU and RAM, the HoloLens also contains a Holographic Processing Unit (HPU). Compared to conventional CPUs, this chip is designed to process large quantities of incoming digital signals that are delivered by the sensors and the various HoloLens cameras and is only used to calculate the projections and place them correctly in real space [46].

Furthermore, the spatial map provides the interaction between the user and the other objects such as walls, sofas etc. in the surrounding. On the other hand, after turning off the HoloLens, the location of holograms is stable where the user locates them for the other usage period [50]. Therefore, the HoloLens is able to remember the user's space and restore any holograms which the user has seen and used during wearing the HoloLens.

### 3.8.3. Overview of the HoloLens Features

**Optics:** The optical unit of the HoloLens contains two transparent, holographic lenses (waveguides), two HD 16:9 light generators, and an automatic automatic pupil distance calibration, which enables a holographic resolution of resolution with a total of 2.3 million light points [43].

**Sensors:** Four environmental sensing cameras, a depth camera, an inertial element, a 2-megapixel photo/HD video camera, an ambient light sensor, four microphones and a mixed reality sensing unit provide enough data to enable accurate tracking HoloLens is controlled by sensing head orientation, gestures and the user's voice. In addition, HoloLens is able to mimic the spatial sound image of the user's environment [43].

**Gaze:** Gaze is the first and simplest form of input offered by HoloLens. The Gaze is comparable to the mouse cursor used to navigate and interact on the desktop. The HoloLens uses the position and orientation of the user's head as navigation input. Here, an invisible beam is sent horizontally into the world from the position between the user's eyes. The depth value at which this beam hits the real environment provides the position of the gaze. In most cases, this is visualized with a small white dot. In contrast to the real world, in which an object of interest is fixed with the eyes, with HoloLens the object is fixed with the gaze. The user must therefore move their head to fixate an object of interest and thus select it for further interaction [51].

**Gestures:** Gestures, or hand gestures, are used by the HoloLens to interact with virtual objects or holograms. They offer the advantage that the user does not need any other technical devices to interact with holograms. The HoloLens is able to capture either one or both hands simultaneously. The hand must be in the so-called gesture frame so that it can be captured by the HoloLens. The gesture frame is a rectangular volume in the lower in the front, lower area of the HoloLens which is shown in the Figure 10 [51].



Figure 10. The gesture frame in which the HoloLens recognizes the hand is shown. [51]

The user's hands are then considered for possible interaction if they fulfil one of two states. One state is the ready state, where the back of the hand is facing the HoloLens and the index finger is pointing up. The other state is the pressed state, where the back of the hand is facing the HoloLens and the index finger is pointing down. For each hand that the HoloLens recognizes, the status and its position can be queried. In addition, the HoloLens can indicate the direction in which the hand must move if it is at the edge of the gesture frame or outside of it [51].

**Voice Input:** VoiceInput or voice control is another type of input. The HoloLens only offers English voice control, which is optimized for U.S. American pronunciation. As with Gesture, the hologram is first targeted using gaze and then manipulated with an associated voice command [43]. The associated voice commands should appear in the user's visual field of view when the holograms are targeted. HoloLens uses a "see it, say it" model for voice control, where the label of a button is also the voice command to execute it. Voice control allows the user to interact with the system without using gestures or other technical controls which is the main target of this feature [52].

**Spatial Sound:** The HoloLens offers the developer the possibility to design applications in which the user can perceive a three-dimensional soundscape around him. While the visual radius of a human being is approximately 217 and the visual effects of the HoloLens are only between 30 and 40, the user can perceive his entire environment with his hearing [40]. Spatial Sound allows the user to make out holograms in their vicinity without seeing them. This creates greater immersion and makes the virtual objects seem more real. So instead of a visual warning, an auditory warning could now be used for the new orientation of the head [43].

By means of the orientation of the head, the distances to the sounds as well as a simulation of the environment, the Spatial Sound is determined. The Head Related Transfer Function (HRTF) simulates how sound travels from a source through a room to both ears. Between 10 and 12 spatial sound sources can be used for an application. This takes up about 12% of the CPU [43].

**Spatial Mapping:** This is the name for environmental recognition and solving the SLAM problem with HoloLens. The scripts in this API include methods to relate the digital and physical worlds. One example is "TapToPlace." This script allows the user to move an already created MR object in the MR and place it on a physical object (for example, a virtual image on a real wall) [46].

It is used by HoloLens to create a virtual replica of a real space. It consists of two basic components. One component is the spatial surface observer, which contains one or more bounding volumes that represent the space in which the spatial map is created. The bounding volumes can be stationary, i.e. they are at an absolute position in the real world, or they are bound to the position of the HoloLens [40]. In the second case, they are oriented to the position of the HoloLens and move with it through space, but they cannot be rotated. If the real world is now captured by the HoloLens, the bounding volumes provided for this purpose are filled with so-called spatial mapping surfaces, which represent parts of real surfaces. On the one hand, the data for a room or an environment can be recorded and stored once. On the other hand, the data for a space can be recorded dynamically so that it is permanently recorded, and changes are included in the spatial map [43].

Spatial mapping provides are many possibilities to process holograms in the real world. They can now be fixed to real objects so that they permanently maintain their position. This means that holograms and real objects can now cover each other and contribute to the most immersive experience possible for the user. Holograms covered by real objects can also be visualized so that the user can detect them at any time. However, they should be displayed differently so that the user can distinguish between covered and uncovered holograms [43].

Spatial Understanding: Predefined methods for environmental evaluation or for changing the spatial mapping. There are also methods for environmental evaluation based on the generated mesh of the spatial mapping. For example, a couch can be identified in a room based on its shape [46]. If holograms are to be positioned in the real environment to create immersive applications, a better understanding of the real environment is of great advantage. Spatial understanding first extends spatial mapping by creating a uniform, flat mesh from the roughness of the spatial map data [43]. This makes it much easier to detect flat surfaces that belong together.

#### 3.8.4. The HoloLens Performance from a Technical Point of View

The HoloLens, however, is the first device that connects the real world with a virtual 3D space without projecting the real world over a display again. By inserting three-dimensional content directly into the user's field of vision, the range of applications is significantly expanded compared to two-dimensional augmented reality glasses, and the hands remain free when viewing the three-dimensional objects, unlike with smartphone AR applications.

First of all, the combination of various objects has an influence on the performance. In the article written by A. Hauswald, [53] model had about 50,000 polygons was initially displayed without combining individual objects. After performance problems occurred, several hundred individual objects were merged. After merging, there were no more performance problems. It follows that objects should be merged if possible. This is only an advantage if the joined objects also have the same material. An object with two materials must first be disassembled into its individual parts with the different materials in order to be rendered [53]. This in turn makes for poorer performance than with objects that are not joined together.

Another issue is the use of inappropriate shaders. The HoloLens contains almost the same technology as smartphones. These are not particularly powerful compared to PCs, which are often used for 3D applications. For this reason, there are already specially written shaders for mobile devices, which usually offer fewer options, but are also significantly more performant.

This was already the case in previous work [43]. The Unity standard shader have an important impact on the frame rate. The crucial first step is utilizing the recommended environment settings for Unity during the optimization performance of mixed reality apps in the Unity. Shaders are used that are designed for the relevant work which can be provided by Unity Standard Shader from Mixed Reality Tool Kit [54].

It should also be noted that the HoloLens has a frame rate limit of 60 fps for calculation reasons. These 60Fps are necessary to ensure a stable display of the content. In the table, the performant framerate values for each target platform have been listed [55].

*Table 7. Framerate values for the platforms [55]*

Platform	Target Frame Rate
HoloLens	60 FPS
Windows Mixed Reality Ultra PCs	90 FPS
Windows Mixed Reality PCs	60 FPS

A frame rate of 60Fps is therefore an important goal when creating applications on the HoloLens. The HoloLens has roughly the performance of a smartphone, as it is equipped with an Intel Atom x5 processor, 2GB of RAM and 114MB of graphics memory [43].

#### 3.8.4.1. Analyze of Performance Bottlenecks

In case of having a low framerate on HoloLens, the computational place of holographic app intensity should be analyzed and understood. The CPU and the GPU are the two primary processors responsible to render the scene in Mixed Reality app. While the CPU acts as the brain in the HoloLens, the GPU is a processor that undertakes the brain's task of seeing and calculating images and they have different duties in MR app [56]. HoloLens applications generally bounds by GPU, and consequently it is important to figure out the bottlenecks in the app by using tools and techniques [55]. The three key places of bottlenecks are described in the below:

1. App Thread – CPU: It has the main task on the app logic which involves processing input, animations, physics and other app logic [55].
2. Render Thread- CPU to GPU: The main duty is sending the draw calls to the GPU. This submits a request to the GPU to do the operations while rendering an object such as cube [55].
3. GPU: After transforming 3D data (models, textures etc.) from the graphics into pixels, it generates a 2D images to submit the screen of the device [55].



#### 3.8.4.2. Light Conditions on HoloLens Performance

Mixed Reality experiences can be affected by different light conditions which are caused by environmental circumstances. The problems can be exited without proper tracking in case of not being comprehended the environment by the HoloLens [57]. Since the tracking performance is strongly influenced by the user's environment, lightening of the environment needs to be tune in stability [57]. Otherwise, holograms can be seen completely and found in wrong places by the same user, not appear in the same points every time while wearing the HoloLens. Therefore, the light intensity should be stable in whole environment to prevent the device to get lost [58].

The HoloLens devices know how to place a 3D model stable and accurate holograms by tracking users in a pace with the combination of Time-off light IR cameras and visible light cameras [58]. The task of the Time-of-flight IR cameras is coping with noise from ambient light which involves light at the same wavelengths from the system usage [58]. To prove the stability of light for the cameras of the HoloLens, the light can be measured during the operation. The metric utilized to measure light conditions in quantify method is illuminance which is a measurement of how much light falls on a surface. The sources of the light can be different in the same environment just like artificial or natural sources. The lux or lumens per square meter are used as SI-derived units for measuring illuminance which is prescribed by the International System of the Units [58]. Day and night light can also be different, and the intensity and amount of light varies according to the seasons. When using a luxmeter to understand the constancy of the light and to provide a better environment for HoloLens, a constant 500-1000 lux will create the ideal environment for a start [57].

Different types of ambient light can also affect viewing. Light bulbs flicker with AC electricity passing through them, so if the AC frequency is 50 Hz, the light will flicker at 50 Hz. For humans, this flicker is not noticeable, but HoloLens' 30 fps camera sees these changes [57]. As the camera tries to compensate for some light pulses, some frames will be well lit, some poorly lit, and some overexposed. Bulb pulses in the US are compatible with the frame rate of the HoloLens because the electrical frequency standard is 60 Hz. 60 Hz pulses are aligned with the HoloLens frame rate of 30 FPS [57]. In addition, in many countries the AC frequency standard is 50 Hz, so some of the HoloLens frames are taken during pulses. Fluorescent lighting in Europe is also known to cause problems [57].

There are several methods to solve flicker problems. Temperature, warm-up cycles and bulb age are among the causes of fluorescent flicker, which can be prevented by bulb replacement. In addition, tightening the bulbs and making sure the current draw is constant can help [57].

#### 3.8.4.3. Other Effects on the HoloLens Performance

In addition to the effects mentioned in the above chapter, HoloLens 2 performance is also affected by other details that may be overlooked. The memory performance has also impact on the consistency of HoloLens 2 performance while running the holographic app. Excessive memory allocation and deallocation operations in HoloLens 2 can cause problems such as frozen frames, instability of performance and other detrimental actions [55]. In order to eliminate the side effects caused by the memory performance, the object pooling in Unity can be a solution for it. Instead of destroying an object after the user are done with an object, it is to keep the object in a place called a pool and then when it is needed an object of the same type, reuse the object in the pool instead of creating a new object [59].

On the other hand, it is also necessary to check the battery when the app is running. As the power level in the battery decreases, the proportion of LEDs used decreases and this causes the image to become darker. For every 20 per cent decrease, one more LED is switched off [55]. Moreover, voice command can be confusable for the HoloLens 2 and it should be avoided giving commands which sound similar and the user should also prefer choosing phonetically rich words to prevent false actions [55]. While running holographic app on HoloLens 2, the user should be sure that all the other are closed in the background. Sometimes the user may notice that although user is sure about closing all running apps in the background, they are not closed outside the HoloLens 2 field of view. This can also lower the performance [55].

## 4. Experimental Part

This section describes what software installations and settings are required to create a training module application that can run on HoloLens 2. This experimental part can be divided under three main processes which are determination of the software and versions to use with successful installation of them (Process A), main development in Unity (Process B) and postprocessor including mainly the deployment of Unity project in HoloLens 2 via Visual Studio 2022 (Process C). The processes are explained in detail in the following chapters such as the installation and suitable versions of the software used in the training module application process, the purpose for which they are used, how the steps are followed for the desired training module, what is paid attention to and the details of transferring to HoloLens 2 are explained. The workflow of the thesis is summarized in the figure below.

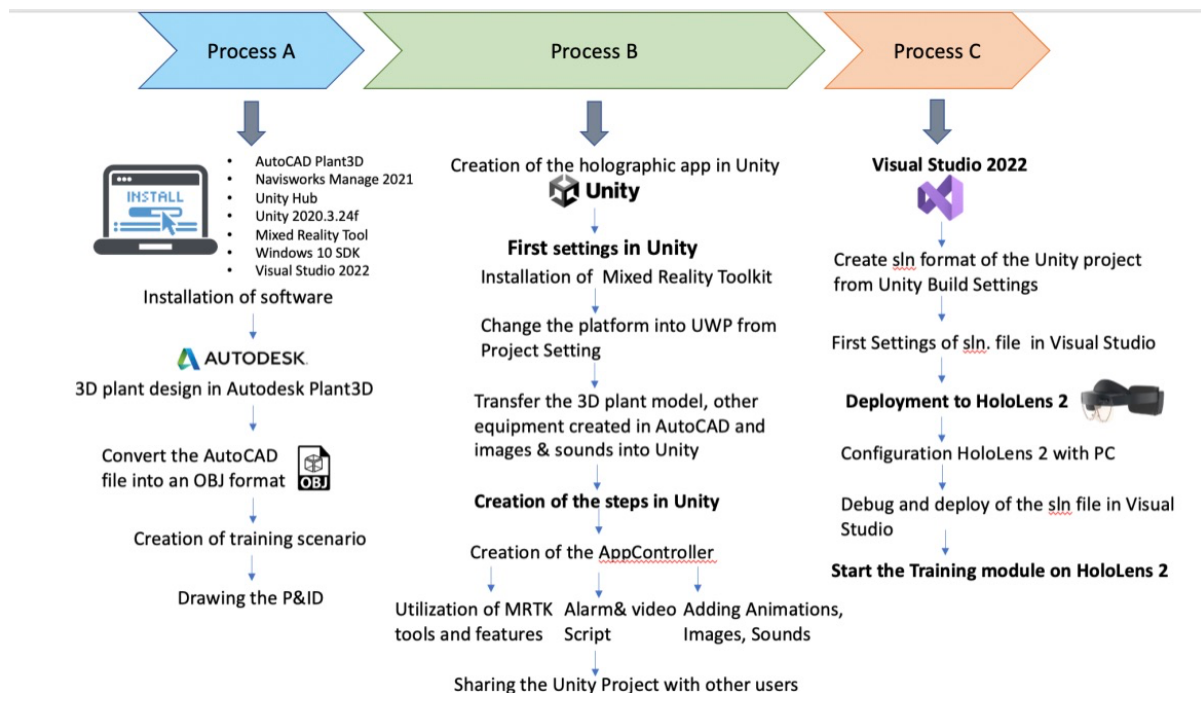


Figure 11. The Workflow of the Master Thesis

### 4.1. Installation of the Software and First Settings

All software required for creating the holographic app for the training module that can run on the HoloLens 2 is mentioned, the critical points during the installation and the settings made are described. The software versions and where they can be downloaded can be found in the Appendix A1.1 in tables with detailed descriptions.

#### 4.1.1. AutoCAD and Navisworks Manage 2021

The whole 3D plant model and the separate parts of the plant such as valves and tanks used in this master thesis have been drawn in AutoCAD. The installation is done by means of the own HAW account via the homepage of the company Autodesk. There all free available programs

are listed. It is possible to select the desired version and then download it via the respective installation path.

Since the 3D model used in this bachelor thesis is available in dwg format, AutoCAD is primarily used only to open and display the model. Further a conversion into a nwc format must take place. This is used as an intermediate step for the further conversion into a fbx format. Afterwards it is possible to open the file via Navisworks Manage which is used to convert AutoCAD file which is in fbx format to obj format which is a standard 3D image format and export it to Unity. An OBJ file contains a three-dimensional object with 3D coordinates, texture maps, polygon surfaces and other object information. This format is ultimately needed to be able to open the existing 3D model in Unity and edit it in such a way that it is possible to transfer the created app to the HoloLens 2.

The AutoCAD version 2021 and Navisworks Manage 2021 is used. The same version preferred in AutoCAD was chosen to be compatible with the other program. In the homepage of the company Autodesk, free installation is possible to be done by the own HAW account. There all free available programs are listed on that website. It is possible to select the desired version and then download it via the respective installation path.

#### 4.1.2. Unity

As it is known that Unity is a cross-platform for developing project which can be supported in desktop, console and virtual reality platforms. The 3D plant model and other components which are in obj format have been exported to the Unity for starting the development of the training module in accordance with the training scenario. By installing some toolkits, it is possible to design the model in a way that is suitable for Mixed Reality, so that it can be displayed as a virtual object in its own real environment.

#### 4.1.3. Unity Hub and Unity Editor

Unity Hub can be seen as the administration of one's own Unity account and the Unity projects located on the PC. Various editor versions of Unity can be added manually, and all created apps can be opened with it. Likewise, additional components such as platforms, documentation and language packages can be added to the editor and the new updates can be installed after the notification has been seen.

The first step is to download Unity Hub.exe from the Unity download portal. The version 2.4.5 is used for this master thesis, and then the Unity Setup is installed. For the first use of Unity Hub, an online registration on the Unity homepage is necessary. This involves several steps to create a Unity ID, which will later enable the use of Unity Hub. Registration requires the entry of personal data and the selection of the desired username. After confirming the e-mail link, the registration is complete and the selection of "Unity Personal" must be made for the free use of the Unity. Afterwards, entering the required information such as the country, the purpose of use and the role at Unity as well as which platforms (Windows, IOS, etc.) are to be used. Finally, the setup of Unity Hub is complete, and the created user is automatically logged in. On the other hand, the same Unity account can be used for all the Unity platforms like Unity Dashboard to share the project with other users and Unity asset store to install the required assets for the project.

After successful installation of Unity Hub, the desired editor must now be installed. The Unity download archive can be accessed under "Installs" and "Add" in the Unity Hub window. From there, the desired version of the Unity editor can be selected and installed. Here, the version 2020.3.4f1 is used, namely as LTS version. LTS stands for Long Term Support and uses the most stable and ideal version of Unity. Since the apps created in Unity will later be installed on the HoloLens 2, Android Build Support and Universal Windows Platform Build Support must be selected when choosing additional modules. Once the installation of the editor is complete, it is available in Unity Hub for creating apps. In addition, the user have options to change the version of the project from Unity Hub later although he/she has created the Unity project in another version at first. The target platform can also be changed afterward according to the targeted device where the Unity project will run.

#### 4.1.4. Unity Packages

The projects created in Unity must be suitable for the mixed reality technology in order to be able to view these holographic apps on the HoloLens 2. For this purpose, several packages are saved as exe files on PC in advance, which are imported into Unity during the creation of the apps.

##### 4.1.4.1. Mixed Reality Toolkit and First Setting for Unity Project

For the interaction of a Unity App with the HoloLens, it is the most important a cross-platform input system as well as basic components are required. This is provided by the MRTK as an open-source development kit.

The Mixed Reality Feature Tool is used to import all packages required for a project from the MRTK to Unity. After the download of Mixed Reality Feature Tool for Unity from the Microsoft Download Center, it is started with selecting the Unity project which the user would like to install the features into it in the start page on first launch. The Foundation package is the only mandatory package needed to use MRTK in created projects, as it contains the required core components. In this master thesis, the version MRTK v.2.7.3 has been downloaded. In addition, the Examples package and Mixed Reality Toolkit Tools are optional to the Foundation package and can be downloaded and used. The examples contained in it can initially be used very well for testing purposes. For MRTK Tools are used for the visualization of the training module steps with the virtual objects as an example of using progress bar with the animation of increased liquid level. Just like the Foundation package, they have been downloaded with the version MRTK v.2.7.3. Moreover, the "Mixed Reality OpenXR Plugin" with the version 1.2.1. must be selected in the platform support part. Then the steps are completed by confirming the boxes which are get features, import, approve and exit respectively at the right bottom. If the Unity project is open at this time, it is recommended to close and reopen the project.

A new Unity project can be created from the start page of Unity Hub by selecting 3D template, naming it and choosing the location where the project is going to be saved. In the created Unity project, from the "Build Setting" located under the section "File", the Universal Windows Platform section is opened to select the "HoloLens" option as the targeted device and "ARM64" for the architecture. After these selections, the platform is required to switch

by clicking the button called “Switch Platform” on the right bottom. Then, the file name is changed to UWP which can be shown on the top of the Unity. After installing the MRTK in Unity project, it is needed to activate the MRTK in Unity. It can be done by the instructions shown in the MRTK Project Configurator that comes automatically or manually inside of Unity settings. From the Mixed Reality tab on the top tab, click on "Project" and select the "Apply recommended project settings for HoloLens 2" command, and thus the project settings section opens on the screen. It is needed to care of the orange triangle which is indicated with orange arrow in the Figure 12.

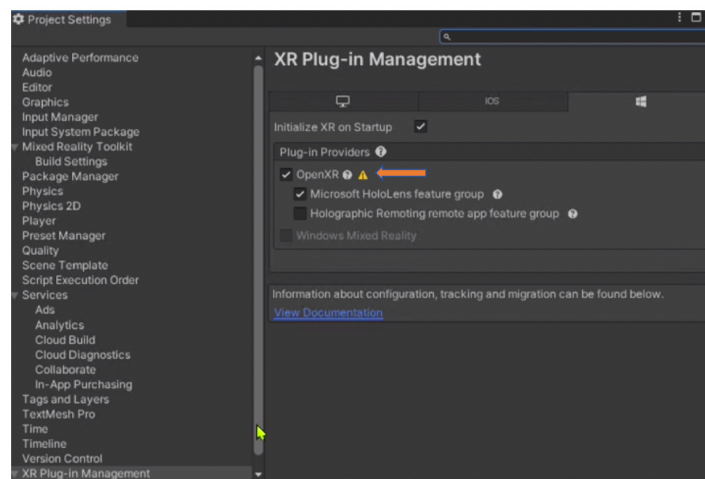


Figure 12. Project Setting after the Installation of MRTK in Unity

After clicking on the orange triangle, the errors are appear one after the other. They can be removed all by saying fixed all and the project settings is closed. The button “Apply Settings” are clicked on to make sure the settings are completed in the MRTK Project Configurator and it is gone with “Next” button and then “Apply” is selected to restart the Unity for the new project.

#### 4.1.5. Windows Software to use MRTK

Creating apps in Unity for HoloLens 2 requires, among other things, some software installations of Windows as well as changes in the settings of the PC. The Mixed Reality Feature Tool requires .NET 5.0 and Windows 10 to run on the PC.

##### 4.1.5.1. Windows 10 SDK

To create Universal Window Platform (UWP) apps, Unity requires Windows 10 SDK. It is necessary to use version 10.0.18362.0 or higher to develop apps for the HoloLens 2. In this case, version 10.0.18362.1 has been downloaded and installed.

##### 4.1.5.2. .NET Framework

.NET Framework serves as a programming interface and is required for creating Universal Apps. Since the HoloLens 2 uses an ARM64 processor for compilation to transfer apps via

Visual Studio, a .NET ARM64 file must also be available. This is the .NET Runtime 5.0 type with the version number 5.0.103, as Visual Studio 17.0.5 is used.

#### 4.1.6. Visual Studio 2022

Visual Studio is used to transfer apps created in Unity to HoloLens. Both the Community and Professional versions can be downloaded from the Microsoft Visual Studio homepage. In this work, version 17.0.5 of Visual Studio Professional 2022 is used here by again using the university account.

Additional workloads must be installed from Visual Studio installer to link Visual Studio and Unity. The “Development for the Universal Windows Platform” must selected under the “Desktop and Mobile Devices” section with the “Game development with Unity” from the “Gaming” section.

### 4.2. Creation of the Training Scenario

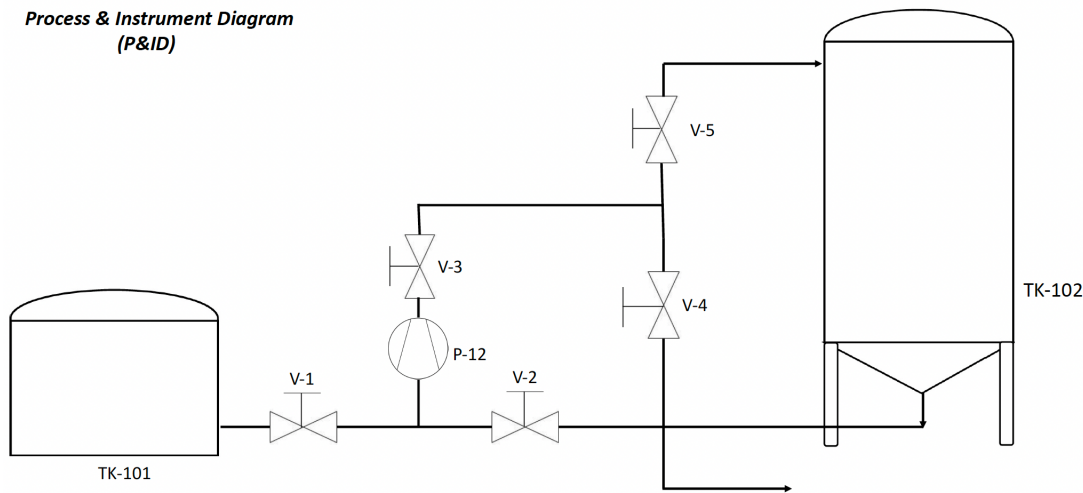
The preparation of the holographic app for the training module in Unity started based on the training scenario. Therefore, the purpose and content of the training scenario was clarified before creating the project in Unity. The general aim of the training scenario is to be didactic and understandable by the learner and the steps can be easily followed while using technical chemical engineering knowledge. The most crucial purpose is the preparation of the learner for an emergency situation that he/she may encounter in the factory in real life, and consequently the scenario consists of realistic steps. A process engineering student can do many internships during his/her education life, but it is unlikely that he/she will experience an emergency situation, and even if he/she is in such a situation, he/she will not be responsible for taking action most of the time. In addition to this, the correct drawing of the P&ID of the 3D plant model also plays an important role in the explanatory nature of this training module. Hence, the comprehensibility of the steps in the training scenario depends on it and the skills of the trainee. The trainee improves his/her chemical engineering knowledge while analyzing the P&ID.

With mixed reality, they will experience the scenario in the training module without losing contact with the real world. For example, if there is something he/she does not understand in the steps in the scenario during the training, he/she can ask questions to the trainer or another engineer next to him/her and this will not prevent him/her from continuing the training. Moreover, according to the content in this scenario, it was determined which features would be used, and research on that subject was intensified and knowledge was gained.

#### 4.2.1. Piping and Instrumentation Diagram (P&ID)

After the 3D factory design was decided, the P&ID of this model was drawn. P&ID is the fundamental to every chemical engineering project. In this master thesis, P&ID is the basis for determining the steps in the training scenario and their realization in the holographic app. Furthermore, analyzing P&ID is very important for the student both in this training module and in his/her future career in chemical engineering. The training scenario is designed for the trainee to understand and interpret P&ID correctly. Through the P&ID, solutions to the

problems encountered within the framework of the scenario will be generated and action will be requested in successive steps. The Figure 13 show the P&ID of the plant model which is used.



*Figure 13. The P&ID of the 3D plant model which is used in this master thesis*

In this P&ID, the abbreviation TK stands for tanks, V represents for valves and P refers for pumps.

#### 4.2.1. Steps of the Training Scenario

This scenario consists of three parts. The first part is aimed to remind the students of the safety rules and to ensure that they apply them as in real life. The steps include instructions which are shown in images and videos to clarify the demanded situation from the trainee. Before the actual event starts, the trainee is given the opportunity to get used to HoloLens 2 and its mixed reality features, as well as to familiarize himself with the equipment in the factory he sees. After completing the first part, the trainee is going to hear the alarm voice and the flashing alarm lights which seems in red color in whole plant area, and consequently the trainee can understand that second part of the training module has been started. It will also be supported by the text seen through the HoloLens 2 at the start of the second part. In the second part, the emergency must first be taken under control, and it is necessary to understand what the problem is that has caused this situation. Then, the trainee must keep going with the next steps for the solution and follow the commands. The main reason for the alarm is that the liquid level in the tank called TK-102 has risen above the limit value and this will be shown in the training module with effects. In that case, after acknowledging the alarm, it is expected from the trainee to take an action to prevent this increment in the liquid level of TK-102. As it is described in the following steps, it can be happened by finding the right valve based on P&ID because of causing backflow and turning the right valve into clockwise direction to close it. After that, by pressing the shutdown button, the pump is turned off and thus the pump sound that has been going on since the beginning of the training module is silenced. It is proved by the level indicators that the situation is under control and the next section is started. Third part focus on reducing the liquid level of TK-102. This can be possible by making the fluid turn back to the tank called TK-101. At this moment, the trainee has time to consider



about the method about how to accomplish it by examining the P&ID. The trainee must find out the way of providing backflow of the liquid to TK-101 by turning the correct valves in right direction to open it and decide whether to start the pump or not in further steps. All the operations will be shown and supported with animations and special effects in a way that the trainee will comprehend what he/she does with the little explanations in the training module.

On the other hand, the trainee can repeat the step again or restart the training module which is provided by the features of the MRTK in Unity project if needed. Therefore, the trainee follows the steps one by one on his/her own and consolidates his/her chemical engineering knowledge with the situation in the scenario. The steps used in the training module are written step by step in the appendix section.

### 4.3. Setting up the HoloLens 2

This chapter is about setting up HoloLens 2 for the first time and the settings required to use the application created in Unity.

#### 4.3.1. First Use of HoloLens 2

When using the HoloLens for the first time, the user works through a step-by-step guide. First of all, it is necessary to connect the HoloLens 2 to the internet for these steps. In general, the public has problems connecting to the Internet, so it is preferable to connect to a password-protected network. In the next steps, transferring data from the computer to HoloLens 2 via Wi-Fi will also be more reliable and with a faster performance. The user needs to follow the beginning steps like general information about the desired language and region is required to be filled in. Since the multiple user accounts can be created on the HoloLens, the private Microsoft account is opened for data protection and a successful registration can be done with a personal password on HoloLens 2. Then, for proceeding the next steps, the eye position is determined by calibrating the eyes in order to adapt the display of the holograms on the HoloLens to them. It is also possible to switch on the HoloLens via eye tracking. In addition, this step must be repeated each time the user changes because the eye tracking calibration changes for each HoloLens 2 user, which prevents comfortable use of the apps. After successful registration with a user password, the connection to Internet via WLAN should be checked to use the apps on HoloLens 2. Afterwards, test apps that have been already installed can be preferred to practice interaction with mixed reality, which includes invoking the start gesture, executing voice commands, using the hands to move, scale and rotate holograms, and selecting apps.

#### 4.3.2. Setting of HoloLens 2

The developer mode on the HoloLens 2 must be switched to deploy a created app via Visual Studio just like turning on the developer mode on the PC. For this step, the user clicks on the "Settings" option and then on the "Update and Security" item. The developer mode can be switched on under the selection "For developers" to enable Device Portal. These all can be done by either using hand or voice commands. As another alternative to transfer or deploy an app on HoloLens 2, USB cord can connect on PC for this purpose. The IP address of the HoloLens 2 must be found out. This can be found in the settings under the item "Network and

Internet" and then the selection "Hardware properties" or the IP address will be reached by giving the voice command, "What is my IP address?" in the language of the HoloLens 2 which is selected for use. After finding out the IP address, the user open web browser on PC and go to <https://> followed by the IP number.

#### 4.3.3. Configuration of HoloLens 2 with the Device

The Windows Device Portal (WDP) is used to manage device settings remotely over Wi-Fi or USB, install and uninstall apps and as an overview of running processes of the HoloLens 2. First of all, the developer mode of HoloLens 2 and the device must be activated to use the WDP. In HoloLens 2, the first settings are completed in the way as mentioned in the previous chapter. At this point, the device and the HoloLens 2 must be connected to same Wi-Fi to share the same IP address. To establish a connection, the browser window is opened, and the IP address of the HoloLens 2 is entered as the URL. In the PC, the web browser window is opened to enter the address "[http://<HOLOLENS\\_IP\\_ADDRESS>/devicepair.htm](http://<HOLOLENS_IP_ADDRESS>/devicepair.htm)" as URL.

For first-time use, the "Username" is the serial number of the HoloLens 2 and the "Password" is the previously selected password for unlocking the HoloLens. In the Set up menu, both the user name and the password must then be changed after requesting a PIN, which is then shown on the HoloLens display. After changing the username and password, only clicking on the button of request pin on the web browser and entering the displayed PIN on the HoloLens 2 will be sufficient to connect the HoloLens 2 to the device. In this website address, all the features of HoloLens 2 are displayed simultaneously and you can also see the basic features of HoloLens 2, such as charge percentage, while transferring data with the device, and you can also monitor the performance values while an application is running.

### 4.4. The Creation of the Holographic App in Unity

In this chapter, it is described that the methods and tools required for this Unity project, essential considerations while creating this training module, solutions for the possible problems encountered and the method of sharing the project with other Unity accounts.

#### 4.4.1. First Settings of Unity Project

As the first settings of Unity project after the first installation of Unity and MRTK are clarified in the Chapter 4.1.4.1. Mixed Reality Toolkit and First Setting for Unity Project. From the File in Unity, "New Scene" is created with selecting basic in Unity. Then, MRTK is added on the Hierarchy section and configure from the Mixed Reality tap on above and choosing the Toolkit where the option is available to add MRTK. After that, the file includes 3D plant model in OBJ. format has been imported into the Unity's project browser. All sound effects and images were transferred to Unity before starting the project. Dragging the demanded files into the Unity's project browser is sufficient for the importation. However, it is important that the sound effects are imported in MP3 format, otherwise other formats will not work in Unity. Filing of the GameObjects in Unity is useful method to avoid the confusion. For example, material patterns are collected under asset in a file called materials, while all factory equipment is collected in a folder called environment in the Hierarchy section located on the left side of Unity.

Since MRTK is added on the Hierarchy section, the main camera of the Unity scene replaces under the MixedRealityPlayspace. The main camera represents the player's point of view and therefore, after wearing the HoloLens 2, the main camera starts from wherever the user is. For this reason, the objects placed in the scene view should be placed according to the position of main camera so that the objects are not too far or too close when the app starts. In this master thesis, the 3D plant model is just located in front of the main camera which reduces the distance between the user and the 3D plant model after wearing the HoloLens 2. By pressing the "Game" button, it is necessary to preview where the objects displayed in the scene view will be displayed when the play button is pressed. Therefore, after dragging the imported 3D plant model to the scene view, its position is adjusted according to the main camera and the scale number is entered as 1 in the x, y, z coordinates in this project. Since the 3D plant model is designed based on the real dimensions of a chemical plant in AutoCAD, this scaling magnitude in Unity also corresponds with the dimensions of the real chemical plant.

During the creation of the training module, MRTK prefabs components are one of the essential components for the steps in the scenario. The installation of the MRTK Toolbox is done by clicking on the Mixed Reality Toolkit tab and selecting the Toolbox. The toolbox window is shown on the Inspector part to get MRTK out-of box prefabs in the current scene.

#### 4.4.2. Game View

Game View is a screen where objects added to Scene View in Unity can be seen how they are seen by the camera during the game. In this project, it gives a preview of how it will be seen on the screen after wearing HoloLens 2. When making changes on the Scene View, for example when positioning an object, it is necessary to look at how it looks from the Game Scene so that the object is not too far away or too close. In this master thesis, each change is displayed on the Game Scene to check if it fits well or not as it is shown in the Figure 14. In case of not seeing the Game tab already in the Unity project, it can be placed next to the Scene view tab by clicking on Window and selecting General and Game.

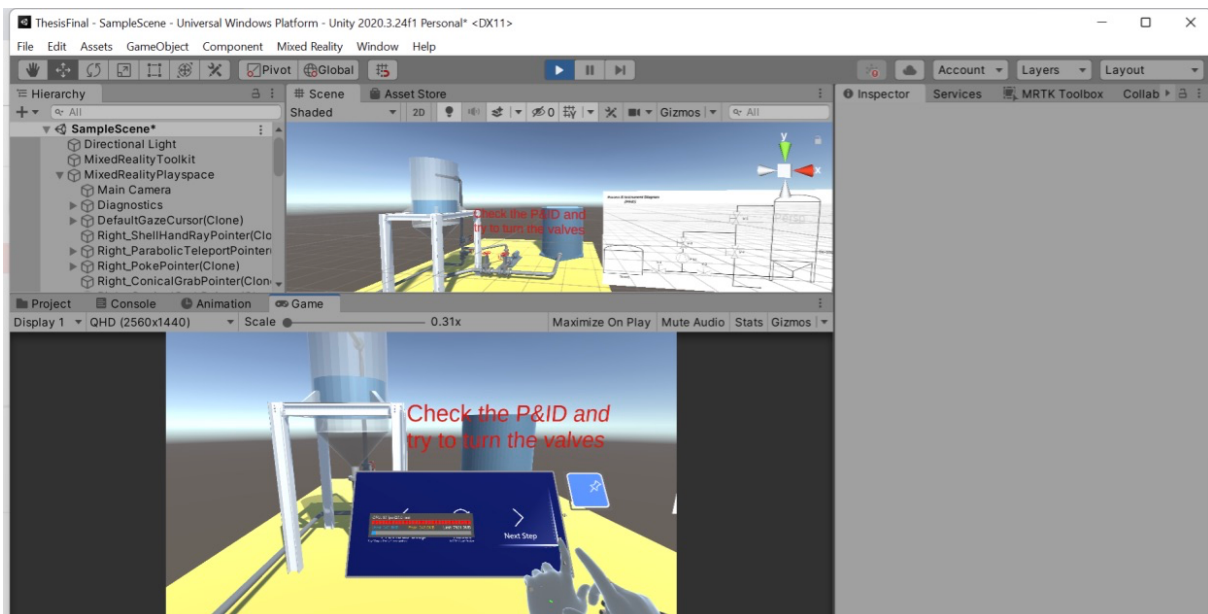


Figure 14. Game Scene in Unity from this Master Thesis Project

The Unity project is run like a game by pressing the play button in the blue surroundings above. In this Game Scene, it is possible to touch the button physically just like wearing the HoloLens 2 and trying to press them in the vision in front of the user. After running the Unity project in play mode, if the Spacebar on keyboard is pressed on the Game Scene, right hand simulation is appeared, and the button can be touched and pressed by clicking on with Spacebar and the mouse. Furthermore, if it is demanded to appear and see the left hand, it will be enough to press the Shift key.

#### 4.4.3. AppController

At the beginning of creating a training module, it is needed to establish a mechanism to ensure that the steps follow each other. To provide this mechanism, Near Menu 3x1 is selected from the MRTK Toolbox located in the Inspector side. This MRTK prefab is called UX components which means that includes already ready-to-use scripts such as the boundcontrol and object manipulator controls. These scripts provide the user to touch it by his/her finger to go further steps or return to the previous step and also change the position of the NearMenu 3x1 by grabbing it after wearing the HoloLens 2. In Figure 15, it is shown that how the preview of the MRTK prefab will look like from the HoloLens 2. Moreover, during the training module, it is aimed that the Near Menu 3x1 follows the user's head every time, and consequently it will not disappear or get stuck in somewhere. This can happen if we activate the "RadialView" selection in the NearMenu 3x1 by only putting a tick in the box. In case of demanding to stick the NearMenu 3x1 in somewhere, it will be enough to click on the pin where the user want to see it.

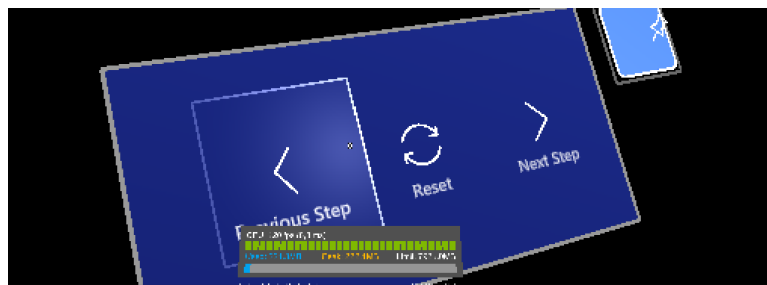


Figure 15. HoloLens 2 view of "Near Menu 3x1"

It is necessary to write code in Visual Studio to make this prefab go forwards and backwards every time the user presses it. Whenever you want to write a code, right click on the project browser and select "C# Script" by scrolling over the create option and wait for Visual Studio to open. The C# Script called FlowManage written for this prefab is shown in Appendix A1.3. The point to be considered when writing this code is to ensure that it does not show the remaining step every time when a new command is given just like pressing on the "Next Step". On the other hand, other MRTK prefabs from MRTK toolbox can also be selected for this mechanism instead of the prefab, "Near Menu 3x1", but more complicated MRTK prefabs can be useless according to the aim of the project and cause confusion while writing code for it.

After completing the script part, integration part of code and Near Menu 3x1 must be done. Two new empty GameObject named as "AppController" and "Steps" in this project is created

by clicking on the right side of the mouse and selecting the option “Create Empty” on the Hierarchy side. Then, the script is dragged and dropped into the “AppController” and the “Step” is also dragged and dropped next to the Step Holder text positioned under the Guide Steps.

The arrangements will be made in this MRTK prefab, Near Menu 3x1 and the final stage of integration will be completed. Under the Near Menu 3x1, there is Button Collection segment which the user can change every button in line with the target. First, the name of every button should be changed depends on their targeted functions under the part of “Main Label Text”. In this project, “ButtonOne” represent the previous step button. The “AppController” is dragged and dropped on the basic event section and select the “FlowManage.ChangeStep” for the function part. This action can also be repeated in the “ButtonThree” which represents the next step. However, there is one difference from the ButtonOne is put a tick in the checkbox near the script. For the function part of “Button Two” after drag and drop of “AppController”, the “FlowManage.ResetFlow” is chosen to reset the training and take it back to the beginning. The Figure 16 displays the difference between the buttons to hinder the confusion. The difference between the three buttons on the Near Menu 3x1 is indicated by marking in red.

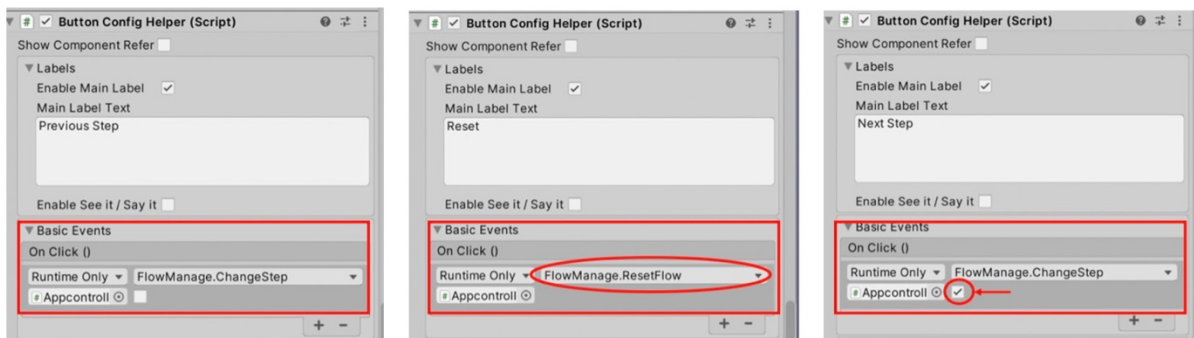


Figure 16. ButtonOne, ButtonTwo and ButtonThree respectively

#### 4.4.4. The Creation of Sub-Steps

In considerations of the number of steps, empty GameObjects will be created accordingly under the object “Steps” in the Hierarchy section. In this project, a total of 26 GameObjects were created for all of the steps in the training scenario. Under the main GameObject called “Steps”, 26 more sub-objects were created just clicking on the right side when the mouse is on “Steps” and selecting the command of “Create Empty”. These sub-objects are named according to the digit numbers and if there is something to be corrected later, it can be done by looking at the number of that digit from the training scenario. If we want these steps to work integrated with Near Menu 3x1, we need to click on the "Guide Steps" title in "AppController". Then, every completed step which are GameObject under the “Steps” must be dragged and dropped on the Element tab under the “Guide Steps”. Otherwise, the steps cannot be shown up although giving command to Near Menu 3x1 by physically touching on buttons.

In the next chapters, which effects, assets, MRTK tools and animations were used while creating the steps in Unity will be explained in detail. According to the content of the steps written in the training scenario, the steps are created by adding the features described. The same requirements can be demanded in different steps. As a shortcut, the created GameObject

can be copied by pressing Control+D on the keyboard and dragged and dropped on the desired step. Thus, you can repeat the same operations many times.

#### 4.4.4.1. Importation and Placement the Other Assets on the 3D Plant Model

All images, sounds and individual equipment to be used in this thesis, which are drawn in AutoCAD and converted into obj files, must first be imported into Unity. They can be all dragged and dropped on the Project Browser to import them in Unity. It is better to create files and store every imported issue separately under Assets in the Project Browser section of Unity provides more efficient and easier working space.

#### 4.4.4.2. To Provide Movement Feature to the Valves – MRTK BoundsControl

Regarding to the training scenario, the valves have to be turned by hand physically, and in some steps, when the correct valve is touched, the color change feature should be given to the user to show that the selection is correct. The imported 3D plant model does not include the valves as a separate asset inside of the file although other pipes, parts of pump and some tank parts existed as a separate asset which means that the user can move or replace them from the 3D plant model. Creating the whole 3D plant in AutoCAD can be more challenging, and consequently the parts which are needed to be used separately from the plant model are created drawn those parts one by one in AutoCAD and transferred them to Unity in OBJ. format. One valve was drawn in AutoCAD and transferred to Unity. Then, the imported file is replicated, and the replicated valves are placed on top of each valve in the 3D model plant in the same alignment. The valves are stable for all the steps.

BoundsControl component which is one of the MRTK components is added to the valves. When MRTK Tools is installed in Unity, these components are also installed automatically. Other subcomponents in this component will be modified according to the desired features and materials, and consequently the desired steps will be done more easily during the training module. These modifications are shown in Table 8.

Table 8. Visual Features of BoundsControl component on the Valves

Visuals	Features
Box Configuration	Box Material: BoundingBox Box Grabbed Material: BoundingBoxGrabbed
Scale Handles Configuration	Handle Material: BoundingBoxHandleWhite Handle Grabbed Material: BoundingBoxHandleBlueGrabbed Handle Prefab: MRTK_BoundingBox_ScaleHandle
Rotation Handles Configuration	Handle Material: BoundingBoxHandleWhite Handle Grabbed Material: BoundingBoxHandleBlueGrabbed Handle Prefab MRTK_BoundingBox_RotateHandle
Translation Handles Configuration	Handle Material: BoundingBoxHandleWhite Handle Grabbed Material: BoundingBoxHandleBlueGrabbed Handle Prefab: MRTK_BoundingBox_Translate
Links Configuration	Wireframe Material: MRTK_WireframeBlue
Proximity Configuration	Proximity Effect Activate: check the box

The materials which are shown in the Table 8 comes with the MRTK tool installation. Generally, they can be found out from the Packages following by Mixed Reality Toolkit Foundation, SDK, Features, UX and Materials respectively. After the modification of the visuals, the user will be able to comfortably grasp objects, hold them and follow the steps according to the instructions given without being unfamiliar with HoloLens 2 during wearing it.

#### 4.4.4.3. Creating the Pump Noise

In Unity, the sounds which are planned to use are in MP3 format since Unity only supports AIFF, WAV, MP3 and Ogg file formats. The audio files are imported as Audio Clips in Unity. In order to use these Audio Clips, they needed to be attached to a GameObject. The component, Audio Source is added to the GameObject, and then the sound which is needed to be used is dragged and dropped next to the AudioClip.

The same procedure is followed to create the pump noise. The GameObject is created and named as “PumpNoise” in the Hierarchy. However, the pump noise is only heard in some steps according to the training scenario. Therefore, the object, “PumpNoise” is replicated by the keys, Control+D and dragged to the steps where the trainee can hear it to control that the pump is working properly. Moreover, in some steps it is required to switch on and off the pump which can only be possible by putting a MRTK button to turn it on or off in line with the instructions. In the step which gives the command to turn the pump off, one of the suitable buttons of PressableButtons which is going to be named as “PumpButton” is selected from MRTK Toolbox for this purpose. In the Events, the GameObject, “PumpNoise” is dragged and dropped on it and “AudioSource.Pause” must be selected as a function of this button. On the other hand, in the step where the trainee must switch on the pump again, another button is selected from the MRTK PressableButtons. On the part of Basic Events in the button, the “PumpNoise” is dragged and dropped. For the function, the “AudioSource.PlayOneShot” is selected and the sound which corresponds with the pump noise is directly dragged and dropped in the space below the function.

#### 4.4.4.4. Materials of the Objects in the Project

The material of the objects is related to the graphics of the game which are also extremely important for the quality of the visions seen from the HoloLens 2. There are four criteria which are meshes, materials, shaders and textures. They are the base of the graphic and complementary features. Meshes are one of the main graphic principles and define the shape of an object. Material defines how a surface of the GameObject should be formed by adding color shades and more. There are various types. Shaders are shaders and perform mathematical operations to adjust the color of an object. Shader of the material is determined with the aim of the Unity project usage. The problems can be confronted if the template used with the shader is not compatible. Texture are textures, that is, they are used to determine the surface of the object to be covered.

In Unity, the equipment colors in the plant are kept as light and realistic as possible. The most important reason for this is to ensure that the image on HoloLens 2 must be clear and recognizable after deployment. The folder for the materials is created under the Assets in

Project Browser. In that folder, the material is selected from the create section by right clicking on the mouse and this process is repeated for each equipment separately. In the selection of the material type, it is considered the purpose for which the equipment will be used. Especially, the tank, TK-102 must appear transparent for the trainee to observe the change in the liquid level inside of it. In the following sections, how to create the water effect is explained. Thus, it will appear as if there is always liquid inside the TK-102. In the Inspector window of the material, standard is selected for the shader, and the feature of transparent is chosen for the rendering mode in the TK-120 material window. The standard for the shader and the opaque for the rendering mode is selected for the material of the other equipment. The color section near albedo is determined in line with the equipment and selected a propriate color. After the creation of the material, it is only needed to be dragged and dropped on the relevant object in the scene. On the other hand, the same color material in the valves added later is used as the valves in the main 3D plant model.

In Part 2 Step 5, the instruction is given to the trainee for shut down the pump. In order for the trainee to notice the pump and take action, the pump must be covered with another material to look like a hologram in that step. As a first step, we duplicate all of the pump equipment with the Control and D keys and locate them under the relevant step object. The new material is created in the asset folder and the shader of the material is changed into Mixed Reality Toolkit/Standard. The rendering mode is changed into the Additive and the black color is selected for the albedo. Then, the rim light button is activated to give the color of orange with increasing the power around 0.85. This material attracts the trainee attention on the pump and helps her/him for doing the requested task. This created material is also dropped on top of the replicated pump equipment on the step in the Hierarchy. Therefore, only in this step the pump will appear in a different material.

#### 4.4.4.5. Adding the Text on Scene View

In the training module, the trainee must be guided by the orders in writing and give them explanation about the reason of the demanded action from them. The text is added in every step according to what is written in the training scenario. It should be done by right click on the mouse while the mouse is on the new created empty GameObject under the “Steps” and select Text - TextMeshPro from the 3D Object section. Then, the Text Input can be changed depending on the sentences in the scenario. This text writing is repeated for every step in this project. As it is valid for every object, it can be adjusted on Scene view accordingly by looking at the Game Scene, as it will look the same in HoloLens as it looks in the Game Scene.

#### 4.4.4.6. Adding Images on the Scene

Images were used in some steps to help the trainee in the flow of the training scenario and to enable him/her to fulfil the desired task. After successful importation of the images in Unity, the texture type of the image to be used is changed into the Sprite (2D and UI) instead of Default. Without this feature, direct images cannot be imported into the Scene. Since Unity does not recognize it as a GameObject, it cannot be displayed in the Scene. In addition, this texture type gives the image the ability to look the same way from behind. This makes the image looks the same from everywhere when you go behind the image. Then, the image to be used is dragged and dropped onto the Scene at the relevant step.



The position and size of the image can be adjusted by looking at the Game View. Thus, in the training module, the picture appears to the trainee in the required position and at the normal size. If the same image with the same view is used more than one just like the P&ID, since the transferred image will appear as GameObject in the Hierarchy section, it is duplicated with Control and D keys and placed the copied image in the related steps.

#### 4.4.4.7. YouTube Link

The first part of the training module is to raise awareness about the Plant Safety and to show the trainee what to be attentive for when entering the factory. As a part of the context of the Plant Safety rules, MRTK button is used to activate the YouTube link which is a short video explains to the trainee what to be careful during the plant operation. Firstly, the C# Script is written in the Visual Studio 2022 to open the YouTube video from the web browser. This C# Script can be found in the Appendix A1.4. The empty object is created on Hierarchy and named as “YouTube Link”. The C# Script is dragged and dropped on the created object, “YouTube Link”. One of the suitable buttons of PressableButtons is selected from MRTK Toolbox, and consequently the trainee can reach this video with pressing the button. On the basic events section of the selected button, the object, the action, “OpenChannel” is chosen after “YouTube Link” is dragged and dropped. This final act integrates the button and the C# script to make the link work during the training module.

#### 4.4.4.8. Adding the Alarm on Scene View

When the Part 1 which includes instructions about the plant safety rules ends, the Part 2 starts, and the alarm scenario is activated. The first step in the Part 2 is about to acknowledge the alarm immediately and understand the reason of this urgent situation. If appropriate, an alarm sound in MP3 format is downloaded and imported into Unity. Two GameObject are created named “AlarmSound” and “AlarmLight” separately on the Hierarchy window. The “AlarmLight” is created for the integration with the Alarmbutton which is used to shut down the alarm in the training module. The API scripting, AudioSource is added as a component into the “AlarmSound” and the imported alarm sound is dragged and dropped next to the blank of AudioClip. Second of all, in order to make the red light flash first like a real alarm, and then turn completely green when a button is pressed, C # Script is needed that takes these actions. As explained in the previous sections, in this code, Visual Studio 2022 is opened by right click on the mouse on the project browser and clicking the C# Script section from the Create section and written there. The C# Script which is written in Visual Studio 2022 is found in the Appendix A1.5. The completed script is dragged and dropped on the created object called “AlarmLight”. Moreover, two point lights are created individually by the right click on mouse and selecting points light when the mouse is on the AlarmLight. The frequency, colour and intensity of the point lights called “Light PresenceLightGreen” and “Light PresenceLightRed” are configured as they would be in a real alarm situation. The parameter changes implemented and recommended in this thesis are shown in Figure 16.

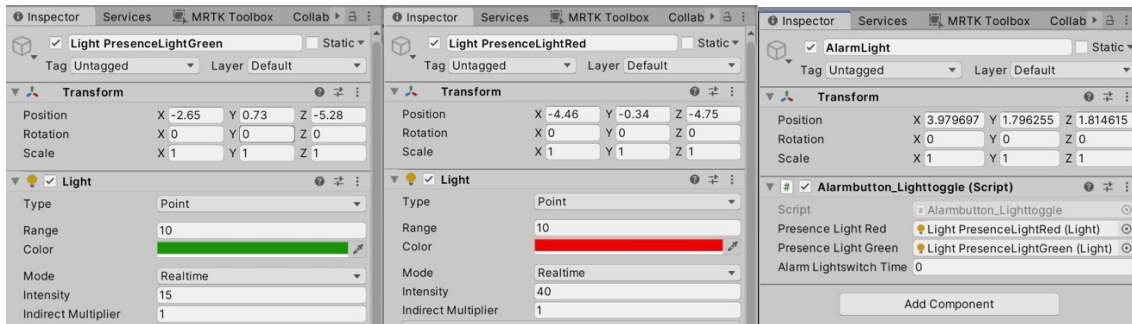


Figure 17. The Green and Red Point Light and "AlarmLights" with the added Components are shown respectively.

A button is required to switch this alarm on and off. Therefore, as mentioned in the Chapter 4.2.5 with Near Menu 3x1, one of the suitable buttons of PressableButtons is selected from MRTK Toolbox. It is named as "AlarmButton" by changing from the Text Input in TextMeshPro-Text on the button. The connection between this button and sound and light is provided by the modifications which are made in the Basic Events section of AlarmButton. Press the plus in the On Clicks section three times because three actions will be added. One to make the alarm go off when this step starts, one to change the color of the alarm from red to green when this button is pressed and the last event to silence the alarm sound when this button is pressed. For the first two events, drag the "AlarmLight" object and drop it on top of the events. While the function of Toggle Alarm () from the script for the first action is selected, the function, AlarmOff () is selected for the second task. In the last Event, the object, "AlarmSound" is dragged and dropped on it and the function, "Pause" is selected to complete the alarm part of this training module. All these GameObjects can be gathered under one main GameObject as an example called "Alarm" not to cause a confusion during Unity work. The AlarmButton should be placed in the Scene view where the user can see and reach it easily, so that no time is wasted during the training module searching for the button.

#### 4.4.4.9. Changing the Color of the Valve by Touching it - MRTK Interactable

In regard to the training scenario, the trainee must find out the right valve among five valves in 3D plant model. Therefore, the feature to be added to the correct valve should make the student comprehend whether the choice is right or wrong in the training module. The MRTK component called Interactable is useful for this purpose. This component will provide the ability to change color when the student touches the valve, in other words, the valve, which is normally red in color, will turn green when the student touches it.

Firstly, the valve to be found is copied by pressing Control and D keys while on the mouse and the copied valve is moved to the step in which it is desired to be found. The Interactable component is added on the correct valve in this step. In the C# Script of the Interactable component, the copied valve is dragged and dropped to the space next to the Target text. Then, the new theme is created and assigned by clicking on the relevant place under the text of "Theme". After naming the theme and clicking on it, the Theme window is opened to modify the properties. For the Theme Runtime, InteractableMaterialTheme has been selected to change the material in contact with the valve in the module. The Default material must be selected the same as the material used in all valves. The Focus and Pressed Material is selected as the color desired which is green for this project by the student when touched during the training module. The same theme can be used for other valves or GameObjects

where the same MRTK component, Interactable must be used. To select the same theme, it is possible to access and select the previously saved themes by clicking on the circle next to the Interactable component.

#### 4.4.4.10. Creation of Arrow Animation on the Valves

In some steps the student is asked to turn the valve clockwise or counterclockwise. This means opening and closing the valve in accordance with the desired situation. An arrow image with a blank back is found out from Internet and it is downloaded. This image is dragged and dropped into the Project browser of Unity. The image of arrow is clicked on it and the texture type is changed into the Sprite (2D and UI). Then, the arrow is dragged and dropped on the top of the 3D plant model which is needed to be rotate in a step. The scale tool is used to scale the arrow image down and with the move tool the image is placed on the top of the valve which is shown in the Figure 18.

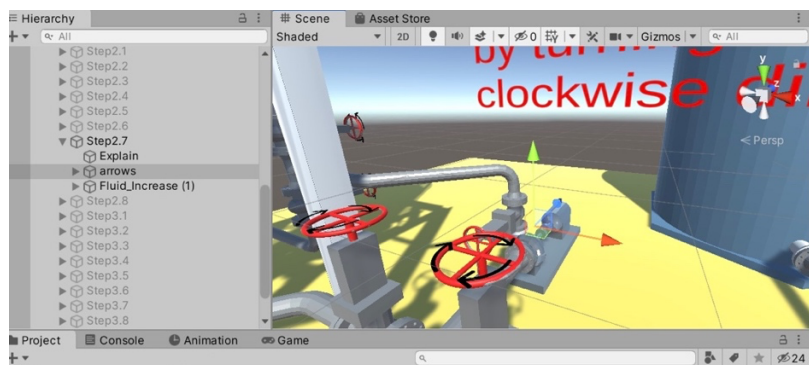


Figure 18. The Arrows on the top of the Valves

The animation is created for the arrow to give an indication that the trainee must know to rotate the valve in the right way. If the Animation window is not seen on the project browser, it can be brought from the Window by choosing Animation on the top of Scene view. Since the animator component must be attached to the arrow, select the arrow and press on the creation of animation in project browser. The animation creation is started with clicking on the record button, and the take the time slider to around two seconds. According to the place of the arrow, rotation tool is changed into the number 360 or -360 depending on the axis. This makes keyframes in timeline occur between zero to two seconds. In consideration of all of the steps, these arrows are desired to be reuse again. The creation of prefab is an option for this purpose. A prefab folder is created under the Assets file in project browser and the arrow is dragged and dropped into this from Hierarchy. When this arrow is needed in another step, it can be added only by drag and drop and the animation comes automatically on the scene. It should be careful about the aim of the step that in some situation the same animation may be requested in the opposite direction. Thus, the animation must be recreated from the beginning again.

#### 4.4.4.11. Adding Water Effect in the Tank

The water effect can be shown in Unity in many ways. In this training module, it is needed to simulate that the tanks are filled with liquid and make the liquid move in some steps according to the scenario. In order not to make the project too complicated, a 3D cylinder GameObject named “Water” of the same dimensions was placed inside the tank, TK-102.

This cylinder which is inserted inside of tank TK-102 was painted blue to represent the liquid and the material of tank TK-102 was made transparent. This transparency is achieved by changing the "Rendering mode" property on the material of tank TK-102 from opaque to transparent. It can be also set the transparency of the material in the Albedo parameter and set which part of the GameObject should look more or less transparent.

The increase or decrease of the liquid level is indicated by adding animation. As a result of this animation, the length of the 3D cylinder inserted into the tank will lengthen and shorten. But if animation is added to the 3D cylinder placed directly, the cylinder will be scaled in both direction which means that it will be lengthen and shortened from the exact center point of the object, which will not give the desired effect. Therefore, it has to be arranged to scale this 3D cylinder from one direction by changing the pivot point. First, an empty object is created named as "Fluid" on the hierarchy side and make this 3D cylinder a child of this empty object by dragging and dropping this cylinder into the empty object because it is demanded to change the pivot of this 3D cylinder. Then the position coordinates of the 3D cylinder are adjusted accordingly, as it is desired to move the arrows down to the left, as shown in the Figure 19. These values can be entered manually in the position coordinates or can be set manually as shown in the figure. It is needed to look at the arrows of the empty object "Fluid" until the desired alignment is reached.

After arranging the pivot of the GameObjects and providing them to scale them in one direction, the animation is created from the Animation window in Unity. The object, "Fluid" is clicked on it and the button is pressed for animation creation in project browser. After the Play button is pressed, the value of how much it is desired to increase in the x coordinate in the Scale section is entered and the timing section is marked in how many seconds it will increase. Determining how the animation will be depends on the current purpose of the step. For example, in the third section the tank level needs to decrease. In this case, the Scale x-coordinate of the "Water" object is set at the beginning to 0.8 and then create the animation to lower it to 0.3. This means that the animation showing that rising the liquid level is created with the same procedure, this time by writing a smaller number in the x coordinate. It is crucial to close the loop time in the animation, so there will be no repeating animation in the definite timeline.

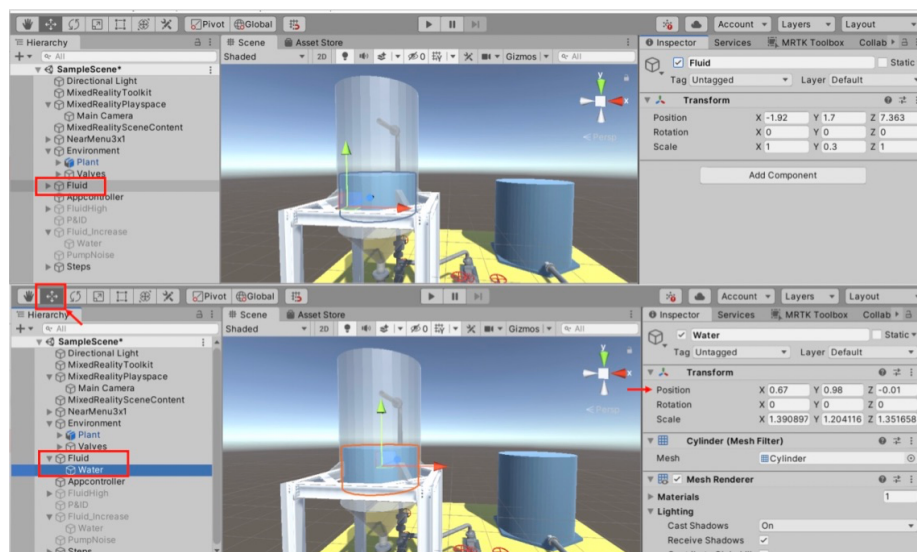


Figure 19. Changing the Pivot of the Object

The first image taken from Unity project of Figure 19 shows where the three arrows of the empty object should be, and the second image represents the 3D cylinder which corresponds with the liquid inside of TK-102. After completing the creation of this water effect, the object, “Fluid” is multiplied with the Control and D keys to be placed in each step in the training module. If it decreases or increases in regards with the content of the training scenario, animation is added accordingly.

#### 4.4.4.12. Adding Progress Bar on the Scene

The trainee can observe the liquid level of the tank, TK-102 and notice the rise or fall of the level from the liquid level inside of the TK-102, as well as the exact level value with the progress bar from MRTK tools during the training module. A loading bar is selected from the MRTK Toolbox as it is shown with number 1 in the Figure 20 and clicking on it only once will show it in the Hierarchy section. According to the instructions of the training scenario, the message text of the loading bar is rewritten into the “The level of TK-102” and the progress text is changed into the percentage at which level it should be written. The scale of “Bar” part is changed into the percentage which is written on the progress text to show the exact level in the step. The progress bar in which the "Bar" part remains fixed that means no animation is added, is duplicated with the Control and D keys to be placed in the appropriate steps.

If the animation is required to show the increment or decrement of the liquid level inside of TK-102, the animation is created and added on the “Bar” part of the progress bar as it is shown in the Figure 20. Two different animations can be created, one showing a rise and one showing a fall. These can be added to the "Bar" section of the progress bar according to the instruction in the step. One of the most important details here is to remove the tick on the loop time part of the animations to show them only once in the asset section later. For example, when creating a animation that indicates the fall of the liquid level of TK-102, the scale of the progress bar is set to the level it should first display. In the animation, the “Bar” part is manually reduced to the desired level just like 30% in the Figure 20.

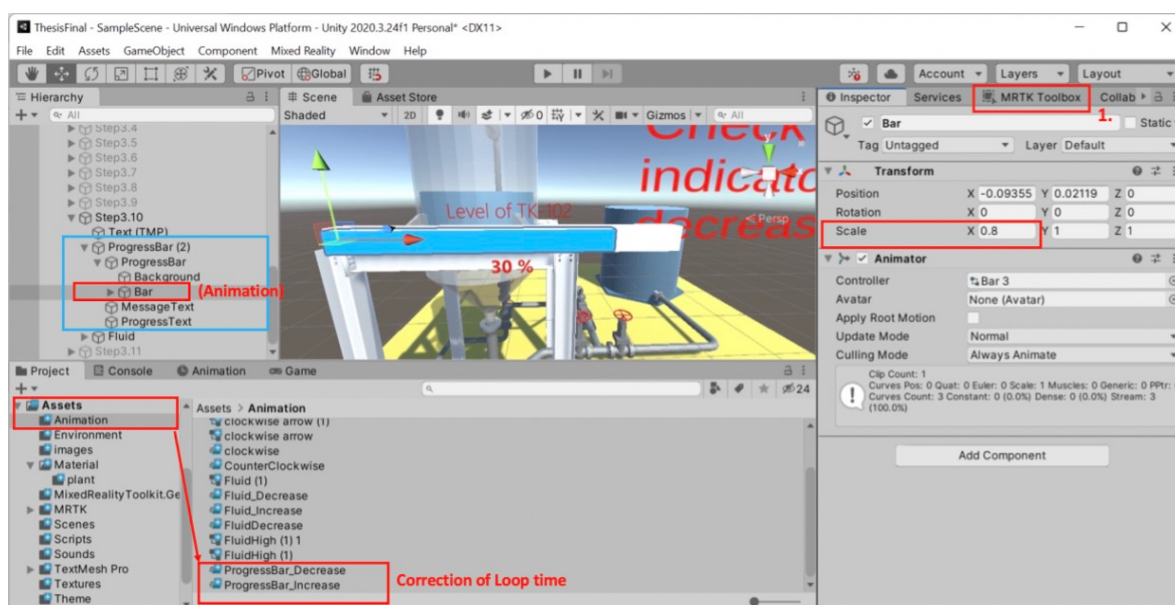


Figure 20. The Creation of the Progress Bar in Unity

#### 4.4.5. Sharing the Unity Project with Other Users

There are many options to share the Unity file you are working on with someone else. In this project, the method used called Collab allows someone else to make changes to the project while sharing the project simultaneously. This means that the training module can actually be prepared by more than one person, and consequently it is possible to make small changes to the training module according to the trainee and the decisions of other instructors. Next to the “Inspector” tab on the right side, there is a tab called “Collaborate” as shown in number 1 in the Figure 19. First of all, the project ID is set from there. The project setting is going to open on the screen that the user needs to select the organization name for it from the “Collaborate” located under the part “Services”. The username of the Unity account is selected and go further by clicking on the “Create project ID” button. After turning the collaborate segment into on, the project setting can be closed. In the Inspector part of Unity, the user can see “Collaborate” tab activated which allows the changes to publish on the Unity Dashboard. It will be enough to mark the changes you want to share shown by the number 2 and press the publish button that is seen as number 3 in the Figure 20.

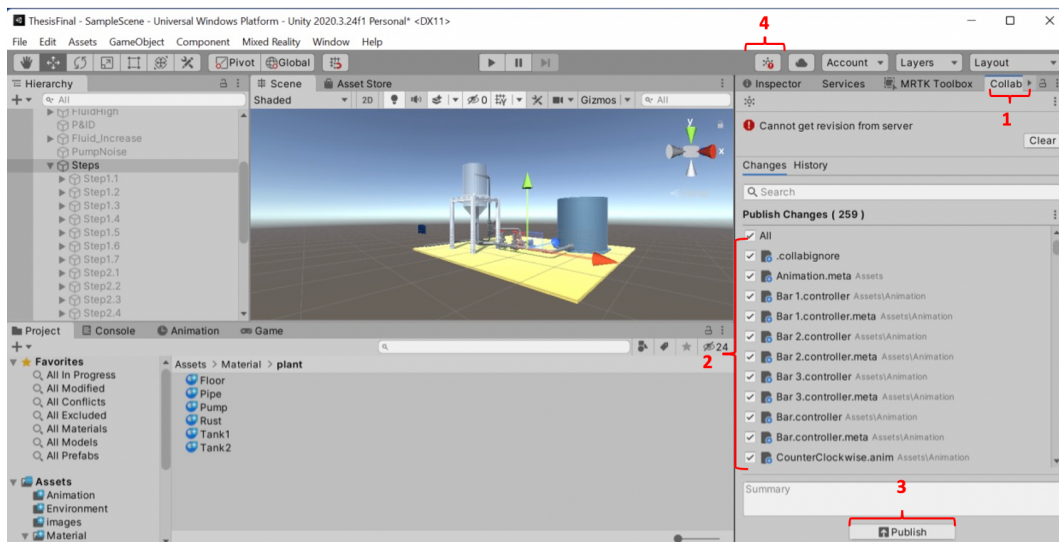


Figure 21. How to Share Unity Project with Other Users

After pressing the “Publish” command, the Unity Dashboard is entered on the browser by signing with the personal Unity account. In that page, the shared project can be visible in the “Projects” part and the project settings can be changed from there. The accounts the user want to share the project should be added in the organization members and the desired authorization should be selected. Then, the same member has to be added in the project members of the current project to confirm that the owner of the project gives the authority to make any changes on the Unity project. From the icon shown as number 4 in Figure 15, you can get information about the project by clicking there to check comments or changes.

## 4.5. Deployment of Unity Project on HoloLens 2

First of all, it is necessary to make sure that the initial adjustments on HoloLens 2 like activating the developer mode have been made as described in the chapter, 4.3. Setting up the HoloLens 2. The web browser page where IP address of the HoloLens entered such as `http://192.168.188.25/devicepair.htm` on PC in this master thesis. The connection between HoloLens 2 and PC is provided. In Unity, the Build Settings is opened to create a file which run on Visual Studio 2022 in the .sln. format. The targeted device is turned into any device and ARM64 is used for the architecture part. After clicking on the Build button, the saved file of Unity project on desktop is opened and a new file is created named “Builds” to save this .sln. format file inside of it. When you save the project in .sln format to run it in Visual Studio 2022, all the changes you have made so far in Unity are saved, but for later changes, it is necessary to save the project again in a new .sln file with the same followed steps.

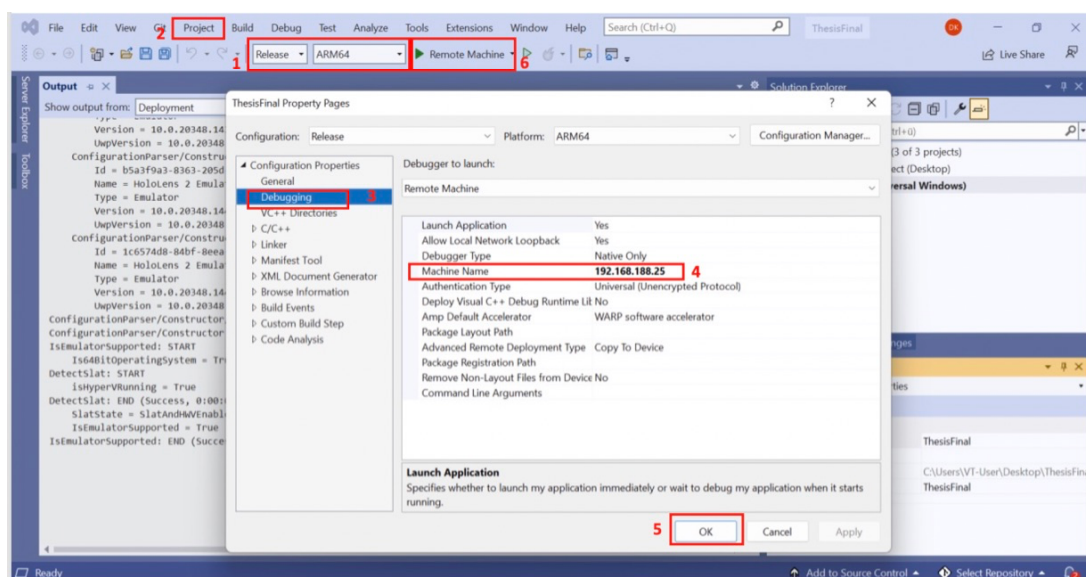


Figure 22. Sequential Steps to be followed for Deployment in Visual Studio 2022

As shown in Figure 21, when the .sln format file is opened after connecting the HoloLens 2 to the PC, which steps have to be followed in Visual Studio is shown in numbered order. The first thing is changing the compilation options by choosing Release and ARM64 which are represented by the number 1 in the Figure 21. The configuration option, Release means that all the optimizations are switched on and the profiler is enabled to utilize the performance of evaluate app. Also, it is recommended to use ARM64 for the Unity projects which has later version than 2019.3 as the build architecture in Visual Studio 2022 [60]. Since it is preferred to build and deploy the HoloLens 2 via Wi-Fi, the Remote Machine is selected as the targeted device among other debug properties. Then, the Project segment is clicked on like shown with number 2 in the figure and Properties is opened to configure other properties of the HoloLens 2. After choosing the Debugging section, the machine name is entered which is similar with the IP address that is exactly the same as the IP address used to establish the connection between the HoloLens 2 and the PC. This is one of the most important places to be filled or the project cannot be debugged. After pressing the OK button, click on Remote Machine as shown in number 6 and the debug process starts. At this process, it is required to wait to observe if there is an error in the Unity project for deployment or not.

In case of not confronting any error in the debugging, it is completed in approximately 4 minutes to deploy in the HoloLens 2. Meanwhile the user must wear the HoloLens 2 and it must be turned on for waiting the completion of debugging in Visual Studio 2022. In the error-free situation, a message saying “deployment completed” appears. Under this message, these two sentences must be displayed:

Build: 3 succeeded, 0 failed, 0 up-to-date, 0 skipped

Deploy: 1 succeeded, 0 failed, 0 skipped

If an error occurs, Visual Studio will say that it has found an error and that deployment is not possible. It will indicate this error either in the error list or directly as a small screen. Then, in Unity the error is tried to fix it according to the instructions in the error message. Once the error is found and corrected, the Unity project is built again as described at the beginning of the chapter. The newly created sln. format file is followed the same steps in Visual Studio again for deployment. The Figure 23 demonstrates the image of our 3D plant model as a result of a successful deployment.



*Figure 23. The View of 3D Plant Model from HoloLens 2*



## 5. Results

In this chapter, the evaluation of the methods mentioned in the previous chapter and the resulting training module are discussed. The gained results are mainly about the visualization of 3D plant model in the holographic app and the process of the deployment of the Unity project in HoloLens 2. In these two chapters which are about main development in Unity and postprocessor, the difficulties encountered are discussed and the reasons for these difficulties are analyzed.

### 5.1. Creation of the Holographic App

By carrying out the procedures described in the experimental part, the training module on the 3D model of a process plant is visualized on the HoloLens 2 with the mixed reality features which make up the instructions to guide the trainee. Except for the purchase of mixed reality glasses, all other programs and tools required for this process can be downloaded free of charge from the websites of the individual manufacturers.

The approach to creating such a holographic app is based on the use of Unity 2020.3.24f1 as an LTS version. Here, with regard to the individual applications and the import of packages, many articles and information materials can be found both in books and on the respective Unity websites. In the Unity Hub, it is allowed to change the version of the existed project, and consequently the project can be updated with the new Unity versions that can provide more features. This version can be downloaded via the "Installs" window in Unity Hub. There, further platforms, tools and language packages can be installed later via the "Add" button. Moreover, the user can download an example project from the "Learn" section and use it as a base for the major project.

All required components and packages of the Mixed Reality Toolkit are imported into Unity via the Mixed Reality Feature Tool. MRTK is the main component of turning the Unity project interactable and enabling the project to become a mixed reality feature in the usage of HoloLens 2. By using the toolkit and the Universal Windows Platform, all functional areas required for the use of an app that can run on the HoloLens 2 are covered, such as interaction through hand and eye tracking as well as gestures and voice control.

All other actions to be performed are done via the parts of Unity, Hierarchy, Inspector window, Project browser and the Build Settings. After using MRTK tools which are indicators, near menus, buttons to control the steps, equipment like switching the pump on/off and acknowledging the events, adding MRTK features which are BoundsControl and Interactable on the specific equipment and utilizing the necessary sounds and images, the Unity project is completed based on the training scenario. The transfer to the HoloLens 2 is done via Visual Studio 2022, making the sln file previously created in Unity available as an app on the HoloLens 2. The transfer of the app to the HoloLens 2 for the ARM-64 format can take place both via USB and via WLAN. The time required for this process is approximately 8 minutes which also depends on the size of the Unity file.

### 5.1.1. Important Aspects during the Creation the Holographic App

In Unity, it is worked by categorizing in Hierarchy and Project Browser in order to work regularly and provide organization. Thus, when an error is corrected or a change is required, it can be handled more easily. In this master thesis, it is planned to see the whole 3D plant model in a realistic dimension from the HoloLens 2 vision to resemble the training module just like in the real factory. A GameObject called “Environment” in the Hierarchy section is created to gather all the equipment of the 3D plant model. The “Environment” includes two main parts which are the whole 3D plant drawn and five valves. The position, rotation and scale are arranged according to the main camera which represents the eye of the user while wearing the HoloLens 2. It is very essential to locate the main object in front of the main camera because the holographic app starts from the position of the main camera. For instance, if the objects are too far away from the main camera, it is challenging to reach the major object and a larger space is needed to try out the holographic app. In the Table 9, the coordinates of 3D plant model is shown and all the values of Transform part of five valves are written in detail in the Appendix A1.6.

Table 9. The Coordinates of 3D Plant Model in Unity

Position:	X = 5.75	Y = -1.23	Z = 4.78
Rotation:	X = -90	Y = 90	Z = 0
Scale:	X = 1	Y = 1	Z = 1

As it is elaborated before in the Chapter 4, the valve drawing made in AutoCAD is transferred to Unity as a separate file in order to put the new ones on the main 3D plant model in Unity and the valves are gained the ability to move. Since all the equipment are located under the “Environment”, the position, rotation, and scale of all of them simultaneously can be changed directly in the Transform section of the “Environment”.

In addition, the user cannot be familiar with the usage of the HoloLens 2. In this situation, it can be a little bit difficult to turn the valves at the first time. Hence, it is asked to the trainee to try to turn the valves for trial in the Part 1. The component, MRTK BoundsControl provides the movement to the valves. However, it is testified that the component, Object Manipulator also comes with this component. This makes the valve relocate the place of it by using the hands of the trainee. As it is shown in the Figure 24, the valves turn from the point where is indicated by red arrow. Although it is not necessary in the training module, if the valve is to be enlarged or reduced, this operation is performed from the places indicated by blue arrows.

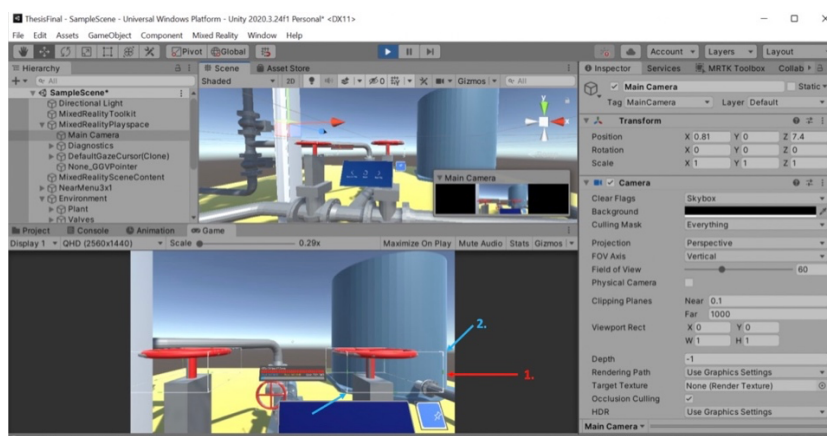


Figure 24. MRTK BoundsControl on the Valves

In the Chapter 4, the application of MRTK BoundsControl on the valves are explained in detail. The points required to rotate the valve at the edges and corners of the square around the valve are marked in green. The green colour is obtained by putting the green colored material in the space next to "Handle Material" and "Handle Grabbed" in the "Rotation Handles Configuration" section. Other color materials could have been used instead of the green color, but when the MRTK prefab is used, as in the others, the dots are not so obvious to lead the trainee to rotate the valves.

## 5.2. The Same 3D Plant Model in Different Unity Project

Considering the deployment performance of HoloLens 2 and the possibility of providing a more effective training environment, another Unity project was created using the same 3D plant model and based on the same training scenario. This project is named as Project B in order to prevent the confusion. The only difference from the other project is that the first part of the training scenario in the Appendix is placed on the objects around the 3D plant model and the training module is started directly from part 2. In this Unity project, the objects such as walls, television and other extra equipment which is not found in the main project is downloaded for free from the Unity Asset Store.



Figure 25. The Vision from the other Unity Project (Project B)

As it is shown in the Figure 25 , when the trainee enters the plant in the training module, he/she can see the instruction images about safety rules on the walls and the video is playing on the television. The video is the same video which is downloaded and transferred to Unity. The component, Video Player is attached on the object on the television and the video is dragged and dropped next to the video clip. Furthermore, the buttons next to “Play On Awake” and “Loop” are also get tick inside of them.

### 5.2.1. The Shader Error in MRTK tools

In the beginning, the Project B is configured to use the Universal Render Pipeline (URP) since the other assets which are installed free from the Unity Asset Store. Since the template is different from the main project’s template, UWP. The template URP is preferred to use the

first person template which can be installed freely from the Unity asset store in the project. Just like the same procedure in the main project, Mixed Reality Feature Tool is downloaded in the Project B. However, while adding MRTK tools in the Project B, they seem in the pink color completely. This error is completely caused by Shader incompatibility. The Shader of MRTK tools in the project must be upgraded for the URP. This can be done by clicking on the Mixed Reality on the top by opening “Utilities” from the “Toolkit” and selecting the “Upgrade MRTK Standard Shader for Universal Render Pipeline. The problem about the shaders can be solved this way. Furthermore, in order to hinder a problem that may arise again with the same issue, this can be achieved by clicking "Check for Shader Updates" this time from the same place. “Check for Shader Updates” allows on-demand shader updating.

### 5.3. Errors in Deployment of Unity Project in Visual Studio

In this master thesis, some problems were detected during the first deployment in Visual Studio 2022 by the message which tells that error is found in the build section as mentioned in Chapter 4.6 and then the causes of these problems were understood by looking at the Console section in Unity. If there is a problem in the build part, it means a problem with Unity project which should be figure out in Unity, but if there is an error in the deploy part, it indicates a problem with HoloLens 2 or configuration of HoloLens 2 with PC or Visual Studio 2022.

In first deployment, an error in build is detected and the reason of this error is about the component of the used GameObjects just like progress bar or 3D texts. In these objects, the component, Canvas Renderer must be removed from them to fix the error and the deployment is done successfully. It will only need to remove the component by clicking on the “Remove the Component” command by clicking on the three dots at the top right. However, it is crucial to remove all the components of canvas renderer from the objects which are detected in the console section of Unity.

### 5.4. HoloLens 2 Performance

After the deployment of Unity project in HoloLens 2, initial performance evaluation is not as desired. All the steps for the deployment process are done successfully in Visual Studio 2022 as it is explained in the Experimental Part and the user who wears the HoloLens 2 is able to see the 3D plant model from Unity app in front of him, but the image disappeared after about seven or eight seconds. At this point, the performance values of HoloLens 2 paired with the PC from the website, <http://192.168.188.25/devicepair.htm> are examined and get them in the Figure 26. When the pairing between PC and HoloLens 2 is completed, the Windows Device Portal opened on PC. From the Performance segment, the system performance is opened to examine.

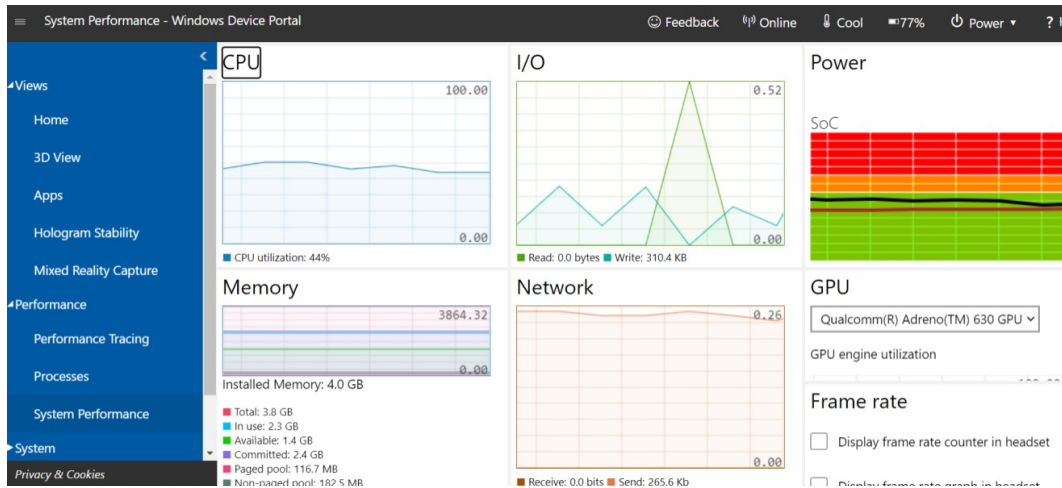


Figure 26. The Inaccurate System Performance of HoloLens 2 during deployment

The system performance in the figure shown above shows the instantaneous performance of HoloLens while running the app. If the whole performance is demanded to trace and record, from the section of performance tracing the trace is started and it can be stopped by selecting the stop link. It can be easily stated that among the graphs of system performance, there is a problem with the network graph. After the vision disappears on the HoloLens 2, this performance page elaborates the reason of this failure. In the network graph, the receive seems 0.0 bits and the send value is only 256.6 Kb which is really low for this Holographic app. This is due to the weakness of the internet strength between the PC and HoloLens 2. This problem is also evident from the I/O graph. I/O means the communication between different functional units or subsystems in a computing system or the sending of information signals directly to these interfaces. In this situation, the reader value is 0.0 bytes which implies that HoloLens 2 cannot get the information, so there is a fault in the reading process. As a result, the problem in the low performance of the HoloLens 2 is linked with internet connection. Therefore, it is recommended to make the internet connection more stable.

Furthermore, ambient light also causes the vision on HoloLens 2 to be fainter according to the observations during the deployment of the main project. While this can be solved by reducing the intensity of the surrounding lights, the material colors of the objects used in the Unity project have been selected so that they can be seen in the presence of intense light. Although this training module was tested indoors, it is difficult to see the image from HoloLens 2 when the light intensity increases at some points. When fully exposed to daylight, it becomes increasingly difficult to select objects in the vision of HoloLens 2. To sum up, as Microsoft recommends, applications should be tested in the environments in which they will be used to ensure that visibility and color are experienced as expected. This provides more certainty about the visibility quality of the training module.

### 5.3.1. Comparison of the deployment of two Unity project

Both of the Unity projects are deployed in Visual Studio 2022 under the same conditions (same daytime, Wi-Fi, environment etc.) in different times and observe the system performance from the Windows Device Portal. In order to resolve the internet problem discussed above, a router is used, and the internet power is enhanced. While the main project

is about 118 mb to build, the size of the Project B is about 228 mb to build according to the data after completion of deployment in Visual Studio 2022. The size of the Project B is almost double of the main project. First of all, the frame rates are examined during wearing the HoloLens 2. The framerate of the main project is almost 60 FPS just like the recommended value on the Microsoft website. However, when running the project B on HoloLens 2, it can only reach 29 FPS which is almost the half of the main project. In addition, the system performances can be compared during the debugging in HoloLens 2.

In the Figure 27, the system performances of the main project and Project B are taken from the Windows Device Portal. These performance graphs are recorded during the deployment of the projects on the same devices at different times. While keeping the external causes constant, only the effects of the different content of the Unity project can be compared.

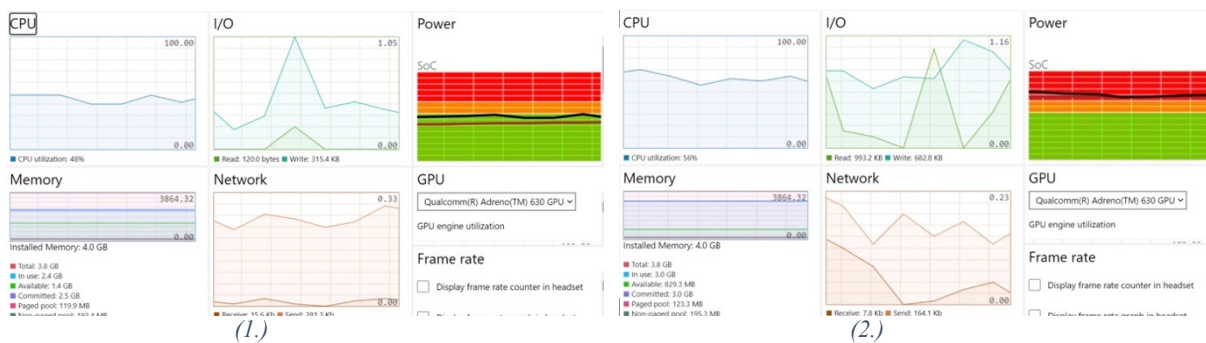


Figure 27. The Main Project System Performance (1.) and the Project B System Performance (2.)

The values in the graphs are also shown in the Table 10 for better reading and interpretation. Since CPU, I/O and Network values will be evaluated from these performance graphs, the values of these graphs are written in Table 10.

Table 10. Comparison of System Performances of the Main Project and the Project B

	Main Project System Performance	The Project B System Performance
CPU	48%	56%
I/O	Read: 120.0 bytes Write: 315.4 KB	Read: 993.2 KB Write: 682.8 KB
Network	Receive: 15.6 Kb Send: 281.3 Kb	Receive: 7.8 Kb Send: 164.1 Kb

The performance graphs of the main project seem at normal values that all the values can be readable and the lines in the graphs are mostly stable. This system performance evaluation is an ideal one for the main target of this master thesis. Especially as shown in Figure 26, there is no network problem this time. This proves that the network problem can be solved by a router to gain a stable vision during the whole training module. On the other hand, in the comparison of network graphs of both projects, it is noticed that the send value of the main which represents the interpretation of the message comes with receiver is higher than the Project B although the size of the Project B is bigger than the main project. This shows that due to the large size of Project B, data cannot be transferred from the PC to the HoloLens 2 as

fast as it should be when connected via the Internet. Additionally, the utilization of CPU values is close to each other, but the reason why the utilization CPU value of Project B is higher may be that more assets are used in the project. As the CPU value increases, the battery of the HoloLens 2 runs out faster. The program can overload the processor which can cause the device to heat up.

In aspect of evaluation the I/O graphs in both systems, Project B's graph is more disordered, and the writing rate is considerably lower than the reading rate. I/O represents that Input/Output operations per second which also corresponds with the standard unit of the measurement number of reads and writes to the storage locations. If the number of I/O per second increases, higher throughput is provided by memory. This value is also linked with the CPU. In comparison of the I/O graphs of both systems, the I/O of the Project B is quite higher than the main project. This indicates that using the memory in an extreme mode and it causes the holographic app freezing in Project B and the device starts to slow down. After a certain period of time after the deployment, about 2-3 minutes, the HoloLens 2 vision of the 3D plant model displays black polygons in certain places, preventing access to the full image which can be confronted like the Figure 27.

Within the scope of the SoC graphs, it can be commented on how much power the HoloLens 2 consumes or struggles when the two projects are running on HoloLens 2. SoC stands for System on the chip. In essence, SoC is a microchip that contains all the components necessary for a computer to work. In this evaluation, the working performance of the SoC of HoloLens 2 is analyzed. Qualcomm Snapdragon 850 Compute Platform which is a ARM based SoC for Windows devices is used in the HoloLens 2. As it is written above the graph, SoC actually represents the power of HoloLens 2, so this is actually related to how hard the battery is pushed and the discharge time. During the deployment of the main project, the lines in SoC graph are located in the green part and nearly goes parallel to each other. This indicates that the HoloLens 2's power will degrade over a normal period of time, while the battery is not forcing itself to display the project. On the other hand, if the SoC graph of the Project B is examined, it is clearly seen that two lines are in the red zone. This indicates that something is not going as it should. In this case, the battery runs out sooner and the device heats up more quickly. An increase in the temperature of the device can lead to undesirable situations such as damage to the SoC.

Although no severe problems were encountered in the use of the network compared to the previous trial, the receiver in the network graph of the main project is higher than the receiver in the network graph of the Project B. This reduces the holographic app transfer speed and vision quality in HoloLens 2, causes freezes during the training module and can even cause the image to disappear completely after a while by exhausting the processor.

## 6. Discussion

Based on the creating a training module for process operation with the integration of MR technology and its development process, this section generally evaluates the causes and effects of the errors that are confronted due to the method selection, deductions about the usage of MR technology in training and statements for the improvement in mixed reality training possibilities of the different training scenarios in the future and finally evaluates the solutions in technical discussion.

### 6.1. Method Determination

As it is aimed to create MR training module, the Microsoft HoloLens is preferred as MR glasses for interacting with MR via holographic projections that the user/operator can manipulate inside of the training. Since the definitions of MR, VR and AR in the literature are not unambiguous, but the interaction between the physical and the real world is given special significance in the context of this work, the definition from Microsoft's point of view is excerpted here from the previous chapters, and also used for mixed reality applications in the context of this work.

In comparison with the VR and AR technologies, MR technology is determined for the creation of this training scenario since the object interacts with the real environment which can have a positive impact of the comprehensibility of the trainer. There are several examples in the industry by the well-known companies that proves the benefits of MR technology in technical and manufacturing training. MR is a reliable training tool to support front-line technicians and service teams in aspect of efficiency, problem-resolution through remote and real-time assistance. While VR leads the learner into the virtual world which is completely different from the real world, trainers or operators can complete the complex tasks in real life with instantaneous support through overlaid images, videos and diagrams. Furthermore, for the training scenario, the object in the MR stands correctly on the ground and no longer floats in the air like the AR, so gravity is active in the MR just as in the physical world. In this master thesis, an example of how the training module can interact with the real world at the same time when realized with HoloLens 2 can be given as follows. In the first part of the training scenario, Safety Rules are explained, and the trainee is asked to apply them. In this context, the trainee can be asked to wear the safety clothes on the table in real life. This guidance provides the student with the opportunity to get acquainted with the materials in real life, while at the same time, the training module in the virtual world combined with real life provides an advantage, since instructions such as designing virtual clothing and putting it on the user can be difficult in MR technology with limited knowledge. In addition, it is requested to examine the pump in a step in the training module. In such cases, while inspecting the virtual equipment during the training module, the virtual world can also be placed outside the virtual world as a sample and the student can be asked to examine it. Therefore, this training module is determined to create with MR technology which is a combination of virtual world and real world in order to provide an interactive educational environment as close as possible to reality for the trainee.

At the beginning of the development process, a simple 3D model of chemical plant layout is drawn in AutoCAD and converted into the format of "obj" file to transfer it in Unity easily. After determination of the 3D model of chemical plant layout, the P&ID diagram is obtained to plan the context of the training module which is going to be developed by many features in



the chosen software. Although the choice of a simple factory design facilitates the creation of the training module, it may be insufficient as a preliminary impression of the events that may occur in a real factory. In future studies, training modules can be prepared on more complex factories to make it more realistic.

According to the P&ID diagram based on the 3D model of chemical plant layout, the training scenario is defined including three chapters which involve plant safety instructions, taking an action for the emergency situation and taking the situation under control. The steps in the training scenario are tried to be written as clear and comprehensible for each of learner who doesn't have many experiences in the plant operation or are not familiar with the MR technology either. The steps in the training process aim at specific objectives. It is aimed to be upskilling the learner efficiently and empowering her/him through real-time remote assistance which enable a reliable distant learning. Moreover, the steps in the training module are focused on reducing errors and mistakes on the operation and accelerate the complex assembly tasks. This training module must prevent waste of time from the point of the teacher and the learner, and consequently the learner can repeat the steps by her/his own. On the other hand, since this training module has not been tested with other students, it is not certain whether the scenario has enough qualification to fulfil the main purpose. It is currently unknown whether the training scenario is 100 per cent fit for purpose. If the training module is tested by a few process engineer students, the appropriateness of the steps in the scenario can be ensured or it can be reshaped according to its deficiencies. When a project similar to this is done, it can be better understood whether the project is in line with the objectives of the project and the performance of the project by getting feedback from the learners.

During the development process of the training module, a wide variety of software options which is compatible with the HoloLens 2 were investigated from the very beginning. Since it was already clear at the beginning of the work that the training module based on mixed reality would ultimately be implemented on the Unity, possibilities around this software were evaluated in particular. With the 3D development environment Unity, this digital image is expanded in the manner of a 3D computer game into a virtual world that can be viewed on the computer and entered and explored by a "player". At various points in this virtual world, it is programmed small scripts to fill it with "life", e.g. acknowledging the alarm, turning the valves in the direction of clockwise or the counter-clockwise, switching on and off the buttons according to the situation. Since these are usually very basic situations, the student cannot be expected to take action alone in a real-life factory when this training module is completed. Moreover, the HoloLens 2 takes the place of the PC and instead of a computer game character, the user of the HoloLens 2 simultaneously experiences the real environment in front of her/him on the display, enhanced by the additional information or applications stored in the virtual environment. Although it is advantageous that the real world and the virtual world are intertwined, it has been observed that the objects in the real world block the objects in the virtual world. For example, walls in the real world sometimes prevented access to an object in the virtual world. In order to prevent this, a feature that will change the size and location of the 3D plant model worked on in the training module according to the current environment can be added.

Mixed Reality Toolkit (MRTK) which provides a set of component and features designed accelerates MR application development in Unity is an important key software to correspond with the purpose of the master thesis is met. As MR is associating of real and virtual world to generate new visualizations and environments where physical and digital objects interact in the real time. MRTK is a bridge to add the features on the digital object for making it

interactable with the physical objects and the user. Within the scope of MRTK features, it provides physical properties to virtual objects in real life and at the same time provides communication between real objects and virtual objects. For example, it allows you to activate or deactivate the virtual buttons in the MRTK by applying force to them in real life, or it allows a virtual object to be enlarged or reduced by the user's hands. Furthermore, it is crucial to let the user trigger immediate actions in MR world. Thus, MRTK provides sufficient visual and audio feedback to enhance the user's interaction.

The Visual Studio is chosen to be used as IDE, an integrated development environment to work with Unity simultaneously during this master thesis. Its support for almost all existing programming languages provides great ease of use. Visual Studio, which allows both code generation and management, offers the user a great ease of use. Therefore, considering its use with Unity it was decided that Visual Studio is one of the best choice for C++ programming software for this project since the compatibility of the latest versions in the use of MRTK and Unity, the fact that the download and use of the program is free of charge for non-professionals, and the fact that we can easily access Microsoft's most up-to-date explanations on the use of HoloLens and Visual Studio and follow the changes in the new versions, indicate that Visual Studio 2022 is suitable for this project. Additionally, Visual Studio is the tool of choice for debugging and deploying of MR application that is created in Unity, in HoloLens 2 and it should be noticed that same IP address must be used by PC and HoloLens 2 to provide the connection. After running the project on Visual Studio, the Visual Studio builds a bridge to provide the visualization of the MR application in HoloLens. Some errors were encountered in the first runs of Deployment. In order to comprehend these errors, it is necessary to know the program well and make sure that no steps are missed. In addition, since the codes run in Unity were written in Visual Studio, when the codes did not work, if the creator is not familiar with the C++ programming, it can take quite lot time to understand the error and generally help is sought from an expert.

After the successful deployment to HoloLens 2, the performance evaluation of the vision is also important for the quality of the training module. The simplest way to streamline performance is through framerate, or how many times your application can render an image per second. It is essential to meet the target framerate as described by the platform that is being targeted. For the HoloLens 2, 60 FPS is the target framerate for stabilization the hologram, better world tracking, hand tracking etc. The optimization of the application performance at a frame-by-frame level depends on several analysis such as lightening analysis, polygon count analysis, shader analysis. Since the effect of lighting on the Unity project is an external factor, there is little that can be done to improve the project. In this master thesis, the targeted framerate of 60 FPS is not achieved during the first deployment. Then, it is figured out that the internet connection has an important role on reaching the target framerate on HoloLens 2. In this master thesis, a router has been used to solve the malfunction on Internet between PC and HoloLens 2. By the way, lightening of the environment where the HoloLens 2 is used affects the performance of the hardware, so the soft light such as a room light is preferred to experience the training module instead of the sunlight. As it is discussed in the Chapter 3.8.4. "The HoloLens Performance from a Technical Point of View", as this training module takes place in Germany since electricity frequency standard is 50 Hz in Europe, the frequency of the fluorescent lights may not be sufficient. The lights could be changed or modified in the environment as in the Chapter 3.8.4. mentioned. However, it is not always so easy to make these changes in the environment, because this master thesis is primarily applied in institutions such as universities, so it is more challenging to make changes in the lighting system than in the

personal living space. In the end, the 60 FPS in HoloLens 2 is almost reached out although the framerate cannot remain constant at 60 FPS during the whole training module.

By the end of the product development procedure, it can be said that these programs and methods, when working together, provided the desired result and the final product was as expected. In spite of the fact that there are many other alternatives in terms of software for MR technologies, since the methods used are easily accessible to everyone and the available resources also show how they are integrated and run simultaneously, the construction phase is made easier. However, other programs will be needed to create a more complicated training module. For example, to use a design program to add new objects, or to enable the view from the HoloLens to be viewed from another device.

## 6.2 App Creation and Usage

The procedure of creation of the training module is followed by a special focus on potentials for digital education and training in various educational contexts. The main purpose of creating this training module was to enable the student to access the information in the content in any environment regardless of space and time and to learn interactively. According to these purposes, the final product, the mixed reality training module based on the placement of virtual objects in the real world for the learner and the training scenario consists of three parts to imply on the crucial plant operation points. The trainees who wear the HoloLens 2 will be able to see the materials in real dimensions in their actual environment without going to a real factory, and they will be able to take actions according to the instructions written in the steps and see the results.

As mentioned before, the training module was designed in such a way that even a person who has not a good knowledge of MR technologies can easily use it. The MRTK Near Menu, which appears in front of you as soon as the training starts, guides the trainer about what to do. When the Next button is pressed, the steps are presented to the user one by one, and he/she is asked what to do. However, in the steps located in the training module, it is not only written what to do with the pure information only including direct instructions. In some steps, the trainer must use his/her chemical engineering knowledge and know how to read the P&ID in order to do the requested step. Otherwise, this training expects the student to follow the instructions directly without questioning the knowledge and this is contrary to the purpose of the training. Thus, the trainees need to be asked to apply the theoretical knowledge they have seen in their education life in practice and when they step into the industry after graduation, they will be familiar with the safety steps in factory operation, emergencies and how to take precautions. It is not possible to apply all the technical knowledge learnt in this training module, but it can be developed later by adding other sections with more steps to the same training module.

On the other hand, some difficulties were encountered in the implementation of this training module. As mentioned in the previous chapter, the performance of HoloLens 2 depends on some parameters. The training module will be better realized to the extent that these parameters are met. First of all, since MR places virtual objects in the real world, it is necessary to adjust the coordinates in the project taking this into account. In this master thesis, the objects in the factory such as tanks, pipes, valves, etc., were dimensioned to be the same as the actual dimensions because this training module was aimed to be the same as the training equipment in a real factory. For this reason, the size of area where the trainer

experience this MR training module should be correspond with the size of the virtual objects in the project. Otherwise, this would be a major obstacle to the realization of the training as it should be. In addition, the number of objects in the training environment should be as small as possible not to prevent the flexibility of the training module. When virtual objects and real objects overlap, the image seen from HoloLens 2 may be distorted, which may reduce the quality of the training. In this case, if changes cannot be made on the training environment, project can be changed in line with the circumstances. In future studies, An MRTK feature, such as a component such as Object Manipular, can be added to the HoloLens 2 to reconfigure the size of the 3D plant model according to the usage environment. The reason why this was not tried for this project is that firstly the content of the training module is important and the HoloLens 2 performance observation with the created holographic app is evaluated. Furthermore, as it is mentioned before that the lightening of the training environment in the real world has impact on the performance of HoloLens 2. The reason of this problem is caused by the sensitivity of cameras on the HoloLens 2. Therefore, it is not preferred to make the training module under direct the sunlight.

The main camera in Unity represents the player's point of view. In this master thesis, the main camera indicates to the coordinates at which the student starts the training after wearing HoloLens 2. Hence, the virtual object should be just located in front of the main camera in Unity, otherwise, if the objects are too far away, it will be necessary to walk to approach the objects in the training area. This is one of the important aspects to be considered at the beginning of the project, as it can be an indication that all objects will have to be relocated, which is a waste of time. As mentioned before, when the 3D plant model and other equipment in the project are all collected under a file (GameObject called "Environment"), the location and size can be changed with the user's hand movements by adding the MRTK component Object Manipulator. However, because of this feature, if the user is not used to using HoloLens 2, the whole 3D plant model may be accidentally moved during the training module.

In case of making any changes on the project in Unity, the project should be deployed in Visual Studio again after the change has been completed because HoloLens 2 reflects the last project run in Visual Studio to the user. The deployment time can be extended according to the changes made and this time may also vary depending on the debugging of errors. However, the time of deployment will be shorter in the subsequent deployment after the first deployment of the same project in Visual Studio. The initial deployment time can vary depending on the number and resolution of the images and virtual objects the Unity project contains and the initial deployment time is approximately 4-5 minutes for this master thesis. After each change in Unity project, the deployment time is halved in case of being error-free. On the other hand, the internet connectivity should be secure and stable during the deployment since the framerate of HoloLens 2 should be around 60 fps and it is detected that when HoloLens 2 connects with the public network, the deployment errors can occur. Since the PC and HoloLens 2 have to connect to the same source of network to share same IP address, connecting to the public network can cause deployment error which can be solved by using a router to create its own WLAN that all the devices used in the master thesis can connect. This solution is found out after the first experience in the deployment process. It is necessary that when PC and HoloLens 2 are connected to the same WLAN, the network connection must be powerful to stay constant during the training module. However, after experiencing that it didn't work with the public network, the router is used to provide private network for the PC and the HoloLens 2 for connecting to the created new network. Depending on the make and model of the router, you can find out how to create this network. After

connecting the router to your computer and connecting the main internet line from WLAN or LAN connections, you can create your new network and connect the PC and HoloLens 2 to it.

In aspect of the usage of Unity, MRTK can provide a great convenience for the creation of MR training module. In this thesis, MRTK is the most used set of components and features, but the usage of MRTK can influence the choices in Unity to complete the training module. As the template for the Unity project, URP (Universal Render Pipeline) and HDRP (High Definition Render Pipeline) can be considered to be selected in order to focus on performances and on quality rendering. In comparison with the template, UWP (Universal Window Platform), the quality of rendering, visions and performances seems more professional with the templates, URP and HDRP. However, UWP is advised for the combination with MRTK in Unity project. Switching the template can make MRTK features not working on the prefabs and also turn the all the prefabs into the pink which means that a shader is broken, missing or not compatible for whatever reason. This property limits the choice of template and feasibility of the creation of training module.

During the implementation of this master thesis, one of the challenging things is the insufficient literature sources to search for the method for Unity and HoloLens 2. This is due to the fact that technologies are constantly updated and new versions are released. It is not so immediate to see the application of new versions in a project with the same purpose as the project to be tried out and to find a written source of information about it. In addition, whether new versions are paid or not also reduces the interaction between users as it affects the number of users. For instance, Microsoft HoloToolkit was used instead of MRTK in Unity till the year, 2017. HoloToolkit was also defined as the collection of scripts and components that will make the creation of applications that aimed Windows Holographic easier. After 2017, HoloToolkit has been upgraded to MRTK with the new features for Unity. The rapid development in the software can complicate the user's life because there will not be enough written sources about new versions, only the information of the software companies located in their own website and the videos that the interested person has shoot about the software can be accessible on Internet. In case of encountering an error like coding error etc. in the software that you use, it can be difficult to find out the exact reason for the error and solution in the new version of the software. Technology blogs should be checked to see if anyone else has written about the same or similar error and inferences should be made for a solution. Generally, this way is preferred to handle the problem for the software since these blogs, software companies' website and videos can be more up-to-date with the new developments in the technology. Additionally, it is better to prefer the last version of the software to provide the compatibility between the different software while working on the project, as well as integrating new features into the old version due to gaps in the infrastructure can cause errors.

In the term of the transition from Industry 3.0 to Industry 4.0, this change in the role of humans requires new, modified human-machine interfaces. Mixed reality technologies, which represent a mixture of physical and digital reality, are particularly suitable for this purpose. Beside the changed role of humans in industrial production process, the education system took also its share. In the context of automated manufacturing and robotics, engineering students is required to adapt to this MR technology in their education life that makes them familiar with both processes and developments coming with Industry 4.0. The training with MR technology provides opportunity to comprehend the process operation just like in the real factory. Moreover, this type of training has more advantages in comparison with the old - fashioned training. It costs less than the old-fashioned training after having all the equipment like smart glasses, software and other hardware and saves time in the learning process. This is

because all of the applications used in the new model training module made with this MR technology are available free of charge. It is only necessary to buy the HoloLens device. After receiving the HoloLens, the trainee can apply the training module alone without an operator or instructor. Although the market value of HoloLens is a bit high, a training module with the same content can be created with its equivalents.

In the near future, it is expected to that university department about augmented reality technologies will be increased and become more specific. The departments to be opened will be aimed at preparing educational content with MR technologies, the factory to be built during the design of a factory will be built in the virtual world and possible error scenarios will be prevented. This training module can be used not only for school but also for training operators in the industry. In other words, in the training modules to be made with MR technologies, the student or operator will be prepared for this before experiencing an emergency situation in the factory. However, it is important that every detail in this training module, which will be applied by operators in factories, should be the same with the real factory. Otherwise, most of the things learnt in this training module will not be valid in real life. For example, if a valve or connection in the training module is different from the real factory, it will cause confusion in a real situation and lead to not taking the right action. In that scenario, the training module may cause a more catastrophic situation instead of helping the operator. Therefore, the plant design drawn in AutoCAD should be very detailed so that the training module is as realistic as possible and achieves its purpose.

In the context of Smart Factory and Industry 4.0, humans are often referred to as “augmented operators”. Beside the increment of the popularity in the engineering education, the smart factories where creases the degree of automation to such an extent that humans will no longer be a supporting component within the production processes will be based on this MR training method for their operators who are used for the work that cannot be done by automatically. Therefore, the demand for these trainings suitable for the factory will increase and job opportunities will arise in this field. Even today, large companies such as Bayern and Mercedes have started to train their operators with this technology [61].

### 6.3. Evaluation of the Finalized Training Tutorial

The creation of the training tutorial which is suitable for the process engineering students has been done by working organized with the free programs that are compatible with each other. In this master thesis, it is important for finding out the software which are most compatible with each other and free accessible for the steps, so everyone who examine this project can follow the steps to create their own training module in order. As a result of this project, even someone who does not master this technology can create this training without difficulty and develop himself in the subject he wants to specialize in.

This training module eliminates time and place limitations, allowing the student to make his/her own planning and prevents him/her from interrupting his/her education due to unavoidable reasons just like the pandemic situation or insufficient opportunities to test their knowledge in the real industry. For example, although the advantages of virtual training in the medical field and student feedbacks are more common, it cannot be ignored that virtual training in the COVID-19 pandemic also has advantages compared to on-site training. It is expected that there are more observations about virtual training in medicine than in the chemical sector during the pandemic, as the student in medicine should be more present with

people or in a hospital environment. According to the research, “Pre-graduation medical training including virtual reality during COVID-19 pandemic: a report on students’ perception” by R.Ponti, J. Marazzato and A. Maresca [62] while 90% of the 105 participating students had a positive approach to virtual reality education, 77% found the initial clinical assessment of the virtual reality education platform realistic for 77%, the diagnostic activity realistic for 94 per cent and the treatment options realistic for 81%. Only 28 % of the participants found online access technically difficult in virtual reality training [62]. In addition, according to another study in medical education in Egypt, virtual trainings achieved a high success rate during the pandemic instead of onsite trainings, despite fears of difficulties in implementation. It is rumored that these virtual trainings will continue after the pandemic. In addition, since the implementation of clinical courses is costly for a university, it is also aimed to reduce this financial burden with virtual education [63]. Likewise, since it is difficult for every chemical engineering student at the university to receive training in the factory and there will be limited quota, this virtual training can be very useful.

Visualization of the knowledge is always developing the long-term memory retention and increase the enthusiasm of the students to learn it. This training module is designed to be easily understood by anyone with knowledge of process engineering. The scenario in the training module is based on the most basic story that can happen to an operator in a chemical plant and the steps are declared clearly to overcome with this panic situation just like in the real life. Hence, process engineering student can review the theoretical knowledge that she/he has learnt during her/his academic life and apply it in practical way.

MR smart glasses can be better to modify the spatial awareness of 3D plant in the training module among the other options just like VR glasses. While VR glasses immerse the user in a virtual world and disconnect them from reality, MR technology preserves the user’s perception of reality while providing the possibility of external intervention during training. Moreover, the training module remains stored in the HoloLens 2 memory and the trainee can continue the learning process whenever he/she wants. This means that one deployment of each project in Visual Studio is enough to make it store on HoloLens 2.

After the deployment of the plant design in Unity to the HoloLens 2, it is realized that the magnitude of the entire plant may not overlap with the dimensions of the environment where the training tutorial will take place. In the Unity project, all the objects such as valves, tanks, pipes etc. are collected under the same file which makes it easier to change the sizes at the same time. In this training module, all of the plant equipment is located under the file called “Environment” and it is easy replace the whole equipment simultaneously. For instance, if there is any hurdle which can affect the vision of equipment in the training room, the place of the plant tools can be changed in the Unity. On the other hand, it is possible to change all of the plant dimension by changing all coordinates of the file, “Environment” from the “scale” on Unity. Then, all factory sections will be able to change without slippage and distortion. As it is mentioned before, after all change on Unity file, the deployment to HoloLens 2 should be renewed again to see the correct vision. Thus, there is a waste of time in every deployment process. This can be avoided by adding a new MRTK feature on the file, “Environment” in Unity. The feature called “Object Manipulator” gives the opportunity to change the sizes of objects, grab or move them by the user’s hands during wearing HoloLens 2. However, for someone who is not used to HoloLens 2, this feature would be quite challenging because of being not stable of the whole plant and very easy to move or change the equipment by mistake during the tutorial. Therefore, this can be a disadvantage of this training tutorial not to be flexible in arranging of sizes of the plant design.

However, I would recommend that in the beginning of the project the size of the whole plant equipment can be arranged according to the dimensions of the area where the tutorial takes place. This can be happened by the first deployment to HoloLens 2 after placing all the equipment in front of the main camera in Unity and observe which equipment does not fit with the training area or which ones should be removed or added in the project. Hence, the sizes of the plant and training environment can correspond from the beginning. After ensuring about the sizes, the user can work on the project in more flexible way.

Furthermore, this training tutorial include the baby-steps of the plant operation which means that it is enough to use simpler features to make this scenario happen. The project can be developed for the more comprehensive scenarios with more complex plant design. In actual factory, there are more equipment, buttons, or parameters to be considered in the emergency, and consequently more MRTK features could have been utilized in the training module. These improvements make the training module more professional and realistic indeed.

#### 6.4. Evaluation of this Method of Training

One of the crucial advantages of this incorporating immersive technologies like AR, VR and MR into education is improving learning efficiency and being more effective and attractive at teaching the learners in comparison with the other media such as books, videos or other online portals accessible from computers. This training tutorial is giving a chance to be accessible it independently from the place where the learner is and it has effect on increasing the learners motivation. In addition to removing spatial limitations, it increases physical work performance and collaboration by leading students to practice physically. It can be more effective method than only listening lectures or watching videos of the theoretical information. As we're living in the 21<sup>st</sup> of century, technology attracts the attention of the learners and increase their motivation in learning and practicing.

For the time being, it is not possible to change the entire education system into the training system which is occurred by MR technologies in aspect of economic reasons and deficiency of the knowledge about AR, VR and MR technologies. This is because currently, not all universities have the infrastructure and budget to provide this education. A HoloLens 2 costs \$3,500, it will be difficult for every student in every department to access this virtual education at the same time, and it will take a lot of time to create virtual education for all departments. However, the hybrid system can be offered where the old-fashioned teaching methods are integrated with this MR technologies in some points such as transferring 3D models into smart glasses to comprehend the feasibility in process engineering or architecture are or practicing in the plant operation without experiencing in real factory. In that way, the advantages of technology can be leveraged, and change can start in the education system. Since VR technologies start to replace manpower in some areas, the education system will continue to incorporate VR technologies over time and will continue to increase day by day.

Additionally, there are some global companies such as Airbus, Mercedes etc. [64, 65] who have started to invest MR training and aim to improve the safety, reduce the human error and accelerate completing the complex tasks. These companies are trying to adopt and perpetuate this kind of training. Thus, it will be beneficial for the process engineering students to get used to this MR technology during their education life. The benefits of the classical method are undeniable and cannot be easily removed from our lives, but the combination of classical education with VR and MR technologies is an inevitable phenomenon and the hybrid system



of training including these technologies can be developed more. In the near future, new departments will be opened in universities to specialize in these VR and MR technologies and virtual world architects will be trained for the various areas like mechanical engineering, process engineering, civil engineering and medical engineering etc.

## 6.5. Technical Discussion

The framework conditions of this master thesis defined related to the potentials of mixed reality training in process plant engineering. These are mainly determined by the programs supported by MR technologies were selected after Microsoft HoloLens 2 is chosen as MR smart glasses.

### 6.5.1. Review of the Application Used

As mentioned before in the Chapter 4, the following programs which are Unity, Visual Studio, Windows Mixed Reality Feature Tool are used to develop the targeted training unit in this master thesis. Since the HoloLens 2 is defined as the mixed reality headsets for this master thesis, the important decision in the selection of programs is supported platforms with HoloLens 2. Microsoft, the manufacturer, recommends Unity 2020.3. LTS version with the Mixed Reality OpenXR plugin for configuration compatible with HoloLens 2. Before starting the editing project in Unity, the 3D plant model has been created in AutoCAD and Navisworks Manage is used to convert the nwc file previously converted to AutoCAD into an obj format to make the file editable in Unity. In Unity, the training module is designed with the usage of MRTK with the template, UWP. In the template selection phase, it is also necessary to check which templates are supported by which versions. Otherwise, there may be compatibility problems when adding features during the project construction phase, which makes the features not work like animation and shader problems in used material, for example. After using Visual Studio to deploy and debug, it is needed to test the performance of the holographic app. Functionality, interoperability, performance, security, reliability can be considered as the factors which affect the performance, and a diverse set of environments also need to maintain performance and user comfort at all times.

In addition to these, it can be observed that there may be problems in the use of HoloLens 2 due to user error. The most basic example is that if the user does not calibrate his/her eyes after wearing HoloLens 2, he/she needs to focus his/her eyes on the cross sign as well as the voice command to close a window opened against his/her will during the training module. This also applies to the voice command of the buttons in the training module. Otherwise, the trainee has to go to the window himself/herself and close it by touching it, which may cause a waste of time. For this reason, the manufacturer of HoloLens 2 can reach the correct usage method from the explanations on Microsoft's own site.

In the training module, the objects which are found in the plant area such as cupboard, gas tubes or television etc. are downloaded from the Unity Asset store to make the training area more realistic for the learners. Although there are various assets available in the Unity Asset store, the free options are limited which can be suitable for the training are. Hence, this is one of the points that other program can be used for creating more professional training environment. For example, the 3D computer graphics software called Blender which is free can be preferred to create objects such as animations, interactive 3D applications, 3D models,

games, videos, montage (including sound). Therefore, the new steps can be added in the training module and make it more goal-oriented to teach the learner a specific subject according to the toolset which can be created by other programs.

On the other hand, there are several software which are also called SDK for development of AR application. SDK provides developers to apply typical and time-tested solutions and shortcut in the development instead of wasting time for the solution of all generic problems. Although there are many options for the development of AR world creation, several technologies for MR glasses were committed to is not as much as the AR glasses with the decision to select HoloLens as the target platform for the implementation of the prototype. Nevertheless, the AR and VR development platforms, Vuforia Engine and Unreal Engine can be other alternatives instead of using Unity for the design of the training module and get built-in HoloLens 2 developer support. When Unity, Vuforia Engine and Unreal Engine are compared, Unity is more preferred by developers. In this case, if a problem is encountered, it shows that it can be reached the solution more quickly on the internet, and it is also proof that the course of the project will be more fluent. Unity is preferred for making holographic apps in mixed reality due to the free accessibility of the Unity program and the fact that it is available on Microsoft's website in terms of ease and suitability for use with HoloLens and Mixed Reality technologies [66]. For example, the availability of MRTK tools in Unity provides great convenience in the creation of holographic apps. Therefore, more users share their resources online. This facilitates the solution of a problem that may be encountered during creation. Additionally, in line with the targeted project it, is better to prefer Unity 3D if it is planned to develop more complicated a bigger project.

### 6.5.2. Test of the Holographic App

It is one of the other vital technical issues to test the holographic app which means the training module for this project in aspect of spatial and audio impacts. There are too many factors that influences the quality of the holographic app. In this case, it would be technically very realistic for the user to complete the training by paying attention to so many factors. Stabilizing the factors that affect the quality of the holographic app may require more effort, time and cost than expected. Such as bringing the light Hz mentioned in the previous chapters to 60 Hz or bringing the internet to a consistency that is sufficient for all deviceless. However, when we stabilize these factors, it can actually be quite easy compared to normal training. Since MR technology allows MR glasses to interact with the real world and the virtual world, making it easy to be affected by disturbances in the environment, such as moving objects and makes the technical usage harder. As it is mentioned before, the performance of mixed reality app in HoloLens 2 depends on several factors to create a qualitative vision of the MR app.

Some problems are confronted while presenting the training module with HoloLens 2 in the final stage of this master thesis. HoloLens 2 has a number of limitations that massively affect the appearance of the displayed content. First of all, the display of black or dark colours is not possible due to the additive color mixing of the built-in LCD display. Black and dark colours should therefore not be used, as they create transparency in the model. Furthermore, there are many solution methods to prevent the detriment of the MR app which are linked with the Unity and outside effects after wearing HoloLens 2. In this thesis, the outside effects have been tried to eliminate such as low internet connection between PC and HoloLens 2, avoiding sunlight and getting rid of the objects in and around the training area etc. However, it was found that the Unity standard shader immediately lowers the frame rate noticeably. It is

possible to increase the GPU performance by Unity project settings as using Unity frame debugger which the user can control the sequence of draw calls and gives the information about their shader to render. In the further developments, performance recommendation about the Unity can be considered to enhance the entire performance quality.

Moreover, a frame rate of 60Fps is needed to reach during the deployment when creating applications on the HoloLens since at lower frame rates, it can happen that objects shift during runtime, or even blur, i.e. they move around the actual center of the object. In addition, HoloLens is a head-mounted mobile augmented reality device that is equipped with a variety of sensors, including four tracking cameras and a time-of-flight (ToF) range camera, so it can map its direct surroundings into triangular networks in real time and simultaneously position itself within these three-dimensional networks [67]. It should be noted that the HoloLens does not project an actual 3D model. It is only a two-dimensional image that has been calculated on the basis of several sensors and thus gives a three-dimensional impression [53]. In fact, aberrations in the HoloLens' perception of its surroundings do not have a major misleading effect on the resulting augmented reality vision. HoloLens is not an indoor mapping device, but rather a mobile augmented reality headset. As such, it has capabilities to capture the geometry of its surroundings are orientated towards the needs of an AR device where the user's direct surroundings, which would typically only be augmented with virtual content, must be continuously known [53]. Since the user only detects their current surroundings, which are captured consistently enough to allow the virtual content to realistically interact with the physical environment, large-scale drift in tracking and the resulting deviations in the captured meshes are not a problem for augmented reality [67].

In the Chapter 5, it is mentioned that Project B was created separately from the main project with the same model and training scenario and its differences from the main project. The biggest difference between them is that the Unity file size is larger in Project B because more auxiliary Assets are used to increase the visuality. This affects HoloLens 2 performance and renders it difficult to reach 60 FPS. Project B can be revised as a solution to this. The shaders of the auxiliary assets added later can be changed. Unlike the standard shader, unit or vertex lit (UI/Default) can be used. Moreover, the graphic quality can be set to the highest mode. This is done by clicking on the template in the Asset section and increasing the speed (4x or 8x) from “Anti Aliasing” in the quality section. On the other hand, the best solution is getting dead weight of Unity (gas tanks, televisions and video played continuously on them) to stabilize the frame rate and runs more faster. As these changes are made, HoloLens 2 can be deployed again, and performance can be evaluated and considered about improving.

After each change made in the Unity project, the project should be rebuilt from the project properties for Visual Studio and saved as a “.sln” file. In addition to being a waste of time in the project flow, the project must be deployed in Visual Studio 2022 every time the project is to be run on HoloLens 2. Therefore, it is necessary to find out how to save the projects in HoloLens 2. On the other hand, during the deployment of the holographic app on HoloLens via Visual Studio 2022, it is noticed that the deployment time increases due to the amount of the file size which depends on the number of objects and the utilization of material Shader. For instance, while the file with 228 mb to layout is deployed in 5.5 minutes, the file with 118 mb to layout is deployed in 3.8 minutes. Additionally, the use of Shaders incompatible with MRTK has also caused deployment errors. However, when all these are taken into account, a problem-free deployment is performed.

## 7. Conclusion

In regard to the task at the beginning of this master thesis, the aim was to develop a training module by visualizing the 3D model of a process engineering plant with several steps based on an emergency scenario on HoloLens 2 and make it utilizable for all of the learners in process engineering area. The suitability of this MR application related to the sub-steps of the 3D model design with the P&ID review, creating the Unity project in line with the training scenario by adding mixed reality features and deploy it on HoloLens 2 without any technical issue for the trainee.

Since the major aim is to develop and promote MR technology in the operational engineering education area, this thesis focuses on how MR applications can be implemented in the most feasible, practical and easy way. Some technical problems are confronted while working with the software, Unity where the 3D plant model is developed with mixed reality feature tools. One of the most common problems that can be encountered in the Unity project is that when using MRTK features and tools, as a result of the shader incompatibility between the other assets in the project, the pink color appears in the project and prevents the project from running. The solution to this is the correct Unity template selection, as well as the upgrade of the materials in Mixed Reality according to the project and the correct shader selection. Otherwise, the deployment errors can occur with increment in deployment process and the objects are not visible in the HoloLens 2 vision due to the Shader discrepancy of object material that comes with mixed reality feature tools.

After the training module was completed in Unity and deployed in Visual Studio, the quality of the image on HoloLens 2 was evaluated in relation to the performance of HoloLens 2. It should be noticed that HoloLens has a number of limitations that massively affect the appearance of the displayed content. This evaluation was done by analyzing at the performance graphs which are GPU, battery, I/O, network of the HoloLens 2 in WDP screen. The frame rate of HoloLens 2 is required at 60 FPS to ensure high and stable display quality during the training module. The frame rate of HoloLens 2 should be at 60 FPS to maintain high vision quality during the training module. In order to maintain this stability in frame rate, the internet connection between the PC and HoloLens 2 must be strong and stable during the deployment. Furthermore, the influences of the external factors such as ambient lighting should be eliminated as much as possible and the ideal environment for the training module should be provided. On the other hand, based on the example of Project B in Chapter 5 where the conclusion is discussed, the effect of extra Assets to be used in new projects on HoloLens performance should be deployed and checked while the project for the training module is under creation in Unity. Thus, the Unity project should be cleaned as much as possible from overloads as well as unnecessary assets.

As it is discussed in the Chapter 6, it is possible to develop a training concept that makes recognizable physical objects and visualize their associated digital information with the help of an MR application. After the creation of holographic app for the training module with 3D model of a process plant which is drawn in another program on PC, the application can run on the HoloLens 2 and then, the virtual objects it involves can be visualized for the user in the environment. All of the software required for this prototype must be compatible with each other in aspect of their version numbers and a precise procedure in the beginning must be followed to carry out the creation of this training module. Afterwards all the requirements about software are fulfilled, any training module can be created with MR feature tools according to the demanded scenario based on this master thesis.

This pattern of the training module was successfully implemented on the HoloLens 2 to identify the dynamic workpieces of the model factory. It is possible to improve in the context of this master thesis that the use of HoloLens 2 for the education of process engineering has many technical possibilities in aspect of MR technologies and the efficiency of learning process will increase according because of having possibility to use the technical knowledge in practical way. This is the reason that the proportion of universities and companies in industry that use augmented reality for their activities is constantly increasing. In the future, there will be more alternatives to design a training module by the development of the augmented reality which can help to improve skills, boost the performance and enhance collaborative working practices in the plant operation.

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# **APPENDIX A1**

## APPENDIX

The appendix includes, in addition to the following parts, a USB with further pictures and videos of the training module and the original installation of both main project and Project B, as well as a video created about the summary of the complete procedure for creating an app that can run on the HoloLens 2.

### APPENDIX A1.1. The Versions of the used Software

#### Unity Hub

Version	2.4.5
Link to download	<a href="https://unity.com/download">https://unity.com/download</a>

#### Unity (Installs in Unity Hub)

Version	2020.3.24f1
Link to download	<a href="https://unity3d.com/get-unity/download">https://unity3d.com/get-unity/download</a>

#### .NET 5.0 runtime

Version	5.0.103
Link to download	<a href="https://dotnet.microsoft.com/en-us/download/dotnet/5.0">https://dotnet.microsoft.com/en-us/download/dotnet/5.0</a>

#### Windows 10

Version	10.0.18362.1
Link to download	<a href="https://www.microsoft.com/de-de/software-download/windows10ISO">https://www.microsoft.com/de-de/software-download/windows10ISO</a>

#### Mixed Reality Feature Tool for Unity

Version	V1.0.2103.2 Beta
Link to download	<a href="https://www.microsoft.com/en-us/download/details.aspx?id=102778">https://www.microsoft.com/en-us/download/details.aspx?id=102778</a>

#### Getting the Features

Mixed Reality Toolkit (4 of 10)	Versions
Mixed Reality Toolkit Examples	2.7.3
Mixed Reality Toolkit Foundation	2.7.3
Mixed Reality Toolkit Standard Assets	2.7.3
Mixed Reality Toolkit Tools	2.7.3

Platform Support (1 of 4)	Version
Mixed Reality OpenXR Plugin	1.2.1

## Visual Studio 2022

Version	17.0.5
Link to download	<a href="https://visualstudio.microsoft.com/de/downloads/">https://visualstudio.microsoft.com/de/downloads/</a>

## APPENDIX A1.2. Steps of the Training Scenario

### Part 1

1. Be sure that you have all worn the personal safety equipment
2. Check the Safety Rule Board
3. In case of need, watch the YouTube video to get more informed by clicking on the YouTube button.
4. Check the P&ID and try to turn the valves
5. Try to turn the V-2 for a trial
6. Walk around and identify the equipment in the plant

### Part 2

1. Acknowledge the Alarm by pressing “Alarm button”
2. Check the value on the progress bar
3. Find out the Valve 3
4. Turn the Valve 3 into clockwise direction to close it
5. Stop the pump by clicking on the “Pump” button
6. Take the situation under control
7. Close all the valves by turning them into clockwise direction
8. Check the level indicator if it is stable or not

### Part 3

1. In this part, the fluid should return to TK-101 and lower the liquid level in TK-102
2. Think about how to make the fluid turn back to TK-101
3. Find out the V-2 from P&ID
4. Find out the valve V-2 to start the backflow by opening it
5. Open the V-2 by turning it in counterclockwise direction
6. Start the pump by clicking on the “Pump” button
7. Open the V-3 by turning it in the counterclockwise direction
8. Open the V-4 by turning it in the counterclockwise direction
9. Now, the fluid is provided to go outside from the pipes
10. Check the level indicator to observe the decrease
11. Report the situation in the plant & Finish the training module

### APPENDIX A1.3. The Script for the AppController

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class FlowManage : MonoBehaviour
{
    public GameObject[] GuideSteps;
    public Transform StepHolder;

    private int currentStep = 0;

    void Start()
    {
        ResetFlow();
    }

    public void ChangeStep(bool isNext)
    {
        if (isNext)
        {
            if (currentStep >= GuideSteps.Length - 1)
            {
                return;
            }

            currentStep++;
        }
        else
        {
            if (currentStep <= 0)
            {
                return;
            }

            currentStep--;
        }

        HideAllSteps();
        GuideSteps[currentStep].SetActive(true);
    }

    public void ResetFlow()
    {
        HideAllSteps();
        currentStep = 0;
        GuideSteps[0].SetActive(true);
    }

    void HideAllSteps()
    {
        foreach (Transform child in StepHolder)
        {
            child.gameObject.SetActive(false);
        }
    }
}
```

## APPENDIX A1.4. The Script for the YouTube Link

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class OpenLink : MonoBehaviour
{
    public void OpenChannel()
    {
        Application.OpenURL("https://www.youtube.com/watch?v=dWkNh7a0lqI");
    }
}
```

## APPENDIX A1.5. The Script for the Alarm

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class Alarmbutton_Lighttoggle : MonoBehaviour
{
    [SerializeField]
    private Light PresenceLightRed;
    [SerializeField]
    private Light PresenceLightGreen;

    [SerializeField]
    private float AlarmLightswitchTime;

    private float TimeRemaining;
    private bool AlarmEnabled = false;
    // Start is called before the first frame update
    void Start()
    {

    }

    // Update is called once per frame
    void Update()
    {
        if (AlarmEnabled == true)
        {
            if (TimeRemaining > 0)
            {
                TimeRemaining -= Time.deltaTime;
            }
            else
            {
                TimeRemaining = AlarmLightswitchTime;
                PresenceLightRed.GetComponent<Light>().enabled ^= true;
            }
        }
    }

    public void ToggleAlarm()
    {
        AlarmEnabled ^= true;
        PresenceLightGreen.GetComponent<Light>().enabled = false;
        PresenceLightRed.GetComponent<Light>().enabled = true;
    }
}
```

```

public void AlarmOff()
{
    AlarmEnabled = false;
    if (PresenceLightGreen.GetComponent<Light>().enabled ==
PresenceLightRed.GetComponent<Light>().enabled)
    {
        PresenceLightRed.GetComponent<Light>().enabled = true;
    }
    //PresenceLightGreen.GetComponent<Light>().enabled = false;
    //PresenceLightRed.GetComponent<Light>().enabled = true;
}
}

```

## APPENDIX A1.6. The Transform Values (position, rotation, scale) of the Main Objects

### Environment:

Position :	X = 0	Y = 0	Z = 0
Rotation :	X = 0	Y = 0	Z = 0
Scale :	X = 1	Y = 1	Z = 1

### Sub-objects of the “Environment”:

#### 3D Plant Model:

Position:	X = 5.75	Y = -1.23	Z = 4.78
Rotation:	X = -90	Y = 90	Z = 0
Scale:	X = 1	Y = 1	Z = 1

#### Valve 1:

Position:	X = 1.195	Y = -0.057	Z = 8.179
Rotation:	X = -90	Y = 0	Z = 0
Scale:	X = 0.00096	Y = 0.001016	Z = 0.001105

#### Valve 2:

Position:	X = 0.312	Y -0.057	Z = 8.179
Rotation:	X = -90	Y = 0	Z = 0
Scale:	X = 0.00096	Y = 0.001016	Z = 0.001105

#### Valve 3:

Position:	X = 0.609	Y = -0.497	Z = 8.879
Rotation:	X = -180	Y = 0	Z = 0
Scale:	X = 0.0007576	Y = 0.0007211	Z = 0.001105

#### Valve 4:

Position:	X = -1.261	Y = -0.322	Z = 9.217
-----------	------------	------------	-----------

Rotation:	X = -180	Y = 180	Z = -1.9459
Scale:	X = 0.0007721	Y = 0.0007030	Z = 0.001105

**Valve 5:**

Position:	X = -1.256	Y = -0.367	Z = 9.217
Rotation:	X = -180	Y = 180	Z = -1.9459
Scale:	X = 0.0007721	Y = 0.0007030	Z = 0.001105