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**Augmented reality for maintenance and marketing purpose
inside EthosEnergy**



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Abstract

In this work of thesis will be deepened the augmented reality and mixed reality technologies, the history of the systems starting from the origins, the use cases with the different applications applied to different field (medicine, military, educational, marketing); will be defined the development methods and tools, especially will be covered the advantages that an augmented reality and mixed reality system can give inside an industrial context, like inside EthosEnergy, specialized field service company that work in the field of electrical production through gas and vapor turbine.

The possible advantages in this context are a higher security and productivity, reduction in human errors and in costs, this is analyzed thanks to the development of two HoloLens2 applications.

The second part of the paper is devoted to the development of the two augmented reality and mixed reality applications, this is done through different software and tools, like Unity, Vuforia, and Microsoft Reality Tool Kit, these will be deepened in order to evaluate characteristic and efficiency for the defined context and for the project requests.

For what concern the developed applications will be exposed the technical details and the choices made in order to solve the problems found during the development.

The first application, called “EthosEnergy Tutorial”, is an augmented reality tutorial that will assist the employee during the mounting phases of the blades inside of the turbine disk, the software will track the environment and will search for a target, the target, posed over the disk, will be used to anchor the starting point of the procedure, this permit a good interaction between the real and the virtual environment; will be analyzed the efficiency and the usability of the system and of the user interface.

The second application developed, called “EthosEnergy VirtualShow”, gives to the client the possibility to see in details the machines inside of the factory, this is done through a video call and it works thanks to a mixed reality system that track the environment and search for a marker, associated with a machine, when this is found it shows through holograms the info, the 3D models of the raw and worked pieces, and also the video simulation of the machine in function. Also, for this application will be checked the efficiency and the usability of the system.

The evaluation of the efficiency, the usability and of the physical discomfort of the two developed software is done through the administration of specific questionnaires to a cluster of users, this will be done after the usage of the two applications, in this way is possible to make a statistic analysis of the results.

At the end will be deepened the future development possibilities for the augmented reality and mixed reality systems, this will be done in general and for the specific case of the EthosEnergy context.

1. Introduction

The purpose of this paper is to tackle the possible uses of the mixed and augmented reality inside of an industrial context. Will be analyzed the technologies and the instruments utilized to develop the environment and to improve the experience of the users during the use of the AR applications.

The augmented reality, also with the virtual and the mixed, is changing the approach inside various areas of interest, it is used in industrial, military, and medical field but at the same time it is also growing in the uses of everyday life.

The increasing power of the processors and sensors gives the opportunity to everyone to use an AR application with a smartphone, without the need to possess a specific viewer for that purpose. In the last four years the mixed reality and the augmented reality had a big expansion in the consumer world, for various cases, an example of AR application is the application 'IKEA Place' introduced by Ikea in 2017 where is possible to measure the environment and to put furniture inside the real room, another example of AR that is highly used and downloaded all around the world is the game Pokémon Go, it was made available in 2016 from Niantic and it enjoyed a big success.

Even the social networks had a big raise in applications that uses Mixed and Augmented reality, the most relevant examples are the filters used by Instagram and Snapchat.

The AR has a lot of advantages depending on the application site, the one that is deepened on this work of thesis is the industrial one.

Inside an industrial environment the use of AR gives a lot of benefits:

- *Security*: it increases the security because it can be integrated with IoT, and it leaves both hands free to move.
- *Productivity*: it gives a faster way to communicate, and the fact that both hands are free to move helps in the case there are some instructions to follow.
- *Reduce human errors*: an operator can be helped by the AR environment that could signal some error during the operations thanks to the sensors.
- *Remote assist*: Facilitate long distance maintenance and assistance.

The design and development part of the thesis is focused on the development of AR an MR applications for HoloLens 2, one is a live tutorial that helps the user assembling the parts of a gas turbine, especially the blade of the rotor, the other application has a marketing purpose, in fact is used to explain better to the clients the behavior of some machines inside the factory during a video conference.

To understand exactly the function of the developed applications an introduction about the company and about the turbine is done in the following paragraphs.

The final goal of the thesis is to demonstrate if the AR technology inside the EthosEnergy business will give some benefits, will increase the productivity and will be easy to use for new users; the type of users will change if referring to the first or to the second application.

1.1 EthosEnergy presentation

EthosEnergy is a company specialized in the Power Generation and industrial field, is defined as a solution provider, inside of it an engineering team provides services to the customers, inside the factory the turbine implant is developed and mounted to be delivered to the clients.

Every step to create and calibrate the turbine is done inside of the factory, also the control systems are done inside of it.

The factory was founded by the Fiat group in Turin in 1952, the first production was dedicated to produce the gas turbine for Westinghouse, it became a consolidated agency in the world devoted to electric production centrals with more than 350 Gas Turbines installed in more than 40 countries.

In the first years of 2000 it entered in the Siemens group, changing its name to “Gas Turbine Technologies” and after in “Turbo Care”.

In 2014 the name changed in the actual “EthosEnergy Group”, this time thanks to the joint venture between Wood Group and Siemens, this was done to create an independent solution provider in every area of the rotating equipment service market.

The Turin facility, EthosEnergy Italia S.p.A., works on different type of heavy duty turbine, it deals with machine design, control systems, verification of the plant, repair and maintenance, onsite and remote assist for the customers.

1.2 How AR could improve the company business

AR technology could bring many benefits in an industrial context, especially thanks to the HoloLens2 device. Speaking about the EthosEnergy context there are prevalently two type of applications that could help the business, those two are the applications developed in this thesis.

The first application is a type of application devoted to instructing someone about an industrial process, in this special case is a tutorial that will help the operative field in following many steps to mount a blade inside a disk of the turbine ‘Frame 5’.

The second application, called “EthosEnergy Virtual Show”, is an HoloLens2 application that will increase the efficiency of the conference call with the clients, it will help to describe and show the working processes of the various machines inside the workshop, it will permit to show a 3D model of the pre and post elaborated material, a real life video, a 3D simulation of every machine and also a description of the material that every machinery can elaborate, this is a good way to show the company working phase and to elevate the advertise part.

Those two applications have the purpose to increase the productivity and to give to the client a clear idea of the machine working.

The result obtained and the real increase in productivity will be evaluated at the end of the paper, this will be done through questionnaire dispensed to the final user of the applications.

1.3 Preparatory introduction to the composition and operations of a gas turbine

A gas turbine “Figure 1” is a type of continuous and internal combustion engine, it is used for electrical production.

A gas turbine is composed, as visible in the image, by three principal components, the compressor, the combustion chamber, and the turbine.

The air enters from the compressor (left side in the image), this increase the pressure of the air and drive it in the combustion chamber, then inside the combustion chamber is injected the fuel through the injectors, after the burn of the fuel the turbine starts rotating thanks to the energy produced by the combustion, the turbine permit to rotate all the rotor including the compressor.

The most interesting part of the machine, in this paper, is the turbine part, it is composed by different stages, in this case there are two stages, each stage is referred to a different disk, each wheel has mounted in it blades of different measures depending on the stage.

The blades are the parts that will be mounted in the disk thanks to the help of the live tutorial developed for HoloLens 2 in mixed reality.

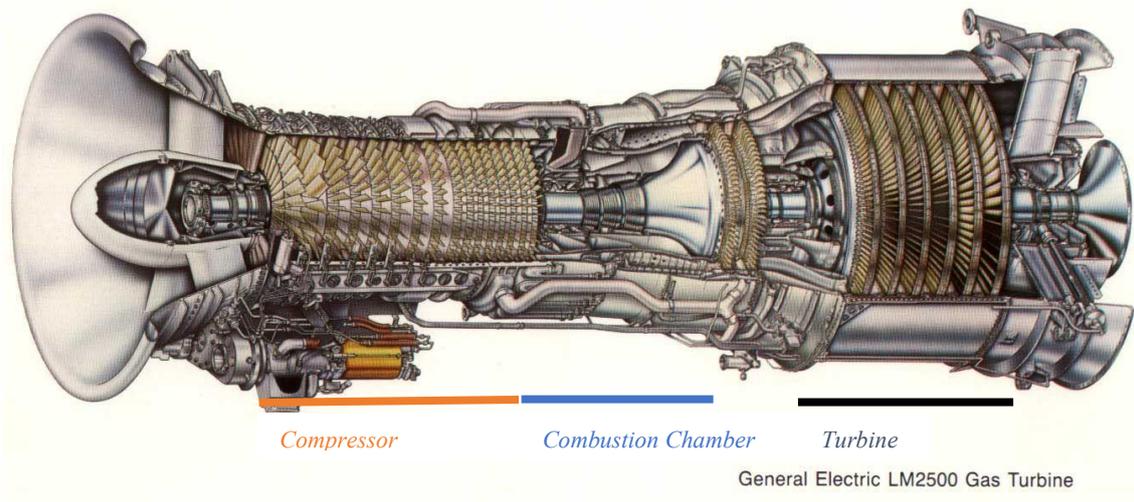


Figure 1: Turbine schema

1.4 AR and MR applications and use cases

The fields that can benefit from use of AR and MR are many, each one use this technologies for different purpose. Here are shown some examples of subjects that are enjoying the advantages of these technologies:

Medical field: speaking about XR in the healthcare system is possible to see many advantages and applications for the future, actually is possible to see that in some technologically advanced hospitals are using the AR technology for example to reduce the number of machine and displays inside of the surgical room.

An example of use case is the surgeon wearing a HoloLens to see the biological data of the patient in real time, or also to analyze the pathologies of a patient through advance 3D models “Figure 2”.

The advantages are not only inside the operation room, the XR systems are also used in education and training for the medicine students, this eliminate the risk to damage the patients. These are only few of all the possible applications inside the medical field.



Figure 2. Medical AR example

Military: In military sector is possible to see many advantages in the use of XR technologies, it gives many strategic tools that help the soldier in the battlefield “Figure 3”, with the interaction with databases and IoT is also possible use the AR as a substitute for remote controlling any equipment.

Many examples are present to explain how useful the XR for military purposes could be, one of the most important could be the possibility to create a virtual battlefield and train soldiers as in a realistic war. XR is useful so that during the communications and the data check the soldier has the hands free; the most advanced technology could be obtained mixing the AR with the remote control, this could be an advantages also to command and see the position of a military robot or of a drone.



Figure 3. AR in a battlefield planning session

Educational: AR and MR could be used also for advanced teaching methods in every grade of school, from primary to university. The students that use the XR can interact directly with what they are learning, school's subjects are more efficiently taught if the students see the explained thing in real time, depending on the argument there are different examples on how the AR could be useful in this field, but the principal scope for every field is to increase the interaction between the students and the argument.

The examples of subjects that could be taught interacting with an augmented reality are different for each grade of instruction, in primary and secondary school for examples the subject could be history, chemistry, astronomy "Figure 4" and many others, in university there could be many other examples depending on the type of university, mechanics, electronics, informatics and medicine are the most important.



Figure 4. Astronomy lesson in AR

Car manufacturers: Car manufacturers are using AR to substitute the displays and so to reduce the space occupied inside of the vehicle, but this is not the only usage that could be done with XR, for example the after sales of some company is made thanks to XR, substituting the catalog or also the mechanics in some example, also the navigation and maps are changing their shape adopting the augmented reality technology “Figure 5”.



Figure 5. experimental windshield for AR

Also, safety is increased by the use of augmented systems, the displays and the windows could signal some advertise to inform the driver about some nearby obstacle.

Travel: For travel purpose the use cases can differ on the type of travel, this technology could be found inside a museum to show information about a statue or there are also possible usages in traveling around a city, the system could show augmented information about point of interest and also guide the user to a specific place.

TV show: AR use cases exist also inside TV shows, especially in the news and in sport, an example is to show on screen some information about a match or to show an interactive view of the shoots of a team “Figure 6”.

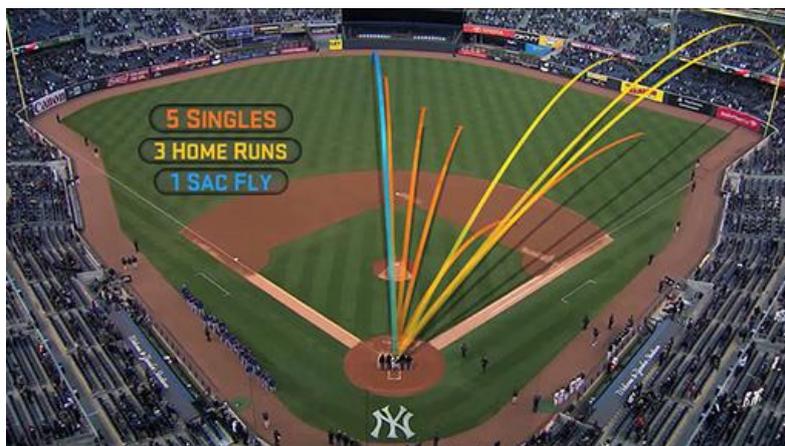


Figure 6. Baseball AR shoots in a match

Industrial: The advent of the industry 4.0, thanks to the growing technologies, like IoT, robotics, networking and XR, increased exponentially the efficiency, the security, and the profits inside the industrial context, this also permitted to develop new systems to advantage the workers in doing their manually jobs. This is especially the case of the just analyzed AR, technology that had a big expansion in the last years that tries to bridge the real world with the virtual one.

Speaking about IAR (Industrial augmented reality) there are many use cases and advantages inside a factory, depending on the context and especially on the type of operations that are done inside of it.

Navigation

Augmenting the physical environment with computer generated information leads to many possible advantages inside a factory, as described in [1] and [2], a possible use of AR is for navigation “Figure 7” inside a factory to repair a selected machine, it could be indoor or outdoor, using the triangulation of the wireless connection, the GPS and sensing the position of the device, for the indoor case it will use LBS (Local based Sensor) and a context aware system.



Figure 7. Indoor Navigation

In the IAR this is a possible use case that permit to locate a machine or to navigate inside a factory, the system will guide the user displaying holographic indications in AR, the purpose could be to guide the user to a machine that must be repaired, in the interface the selected machine will have a ‘Pin’ or a ‘Sticky Note’ to identify it in a large space like a factory and to describe the maintenance or repair requests.

Logistic

For many industries the Logistic department is the most important one, and the AR can help and increase the productivity for this important process, especially in industries that have big factory and that work with the big distribution, an example of this application is the control of the warehouse, packaging, handling and storage; as explained in [3], it is possible to reduce the human errors in the logistic processes thanks to the AR, Amazon is an example of company that is using AR in their factory to reduce errors in the distribution processes.

The type of application for this purpose guide the user to the sector where the package or the items is stocked, in great factories this reduce the searching time and increase the precision “Figure 8”.



Figure 8. Logistic use case

Intercommunication and remote collaboration

Many industries provide aftermarket services to the client, on many occasions it is possible that the client facility is in a remote place, a war place, or in the case of 2020 it's impossible to reach it because of the pandemic; the AR gives big advantages helping the provider to collaborate remotely with the client and support him in various processes. This could be done also to communicate between different facilities of the same society, for example to coordinate a work that is split in different factories. The principal processes during the remote communication are maintaining, repair, mounting and configuration instructions, an example of AR remote communication software could be seen with the software developed by Microsoft, Dynamic365 and now also Microsoft Mesh.

Display info from database (substitute paper)

As seen in [4] another AR advantages is to access documentation, 3D models and instruction while performing an operation in a machine or during a productive process, this gives the opportunity to the users to have the hands free and to avoid using paper and physical documents. Microsoft provide the Azure cloud service to store different files so that are available every time.

Tutorial/Training

In [5] is explained how an AR system could help in a tutoring process, teaching to someone, new to the factory processes, how to proceed and how to work on a defined process.

For the same purpose, in [6] is introduced an augmented reality tutorial on how to execute a welding process. This use case allows the user to be completely autonomous doing some task that is not common or that is different from the normal. It gives the opportunity to

reduce the workforce on a single task and also to teach to a new employ a procedure that only a few other employees know.

Advertise/Marketing

Thanks to the increasing power in processors now the AR is available also for the normal customers, this is possible because of the smartphones and because of the really powerful portable devices, this leded many companies to produce advertise in AR, so that the customer could interact with the 3D model of the sold products, this is an innovation that many companies are using, like BMW and also Ikea as possible to see in the [7], [8] and [9].

The AR is used, as explained for Audi in [10], for the after sales, in this case the customer downloads an application and is supported by an AR system that track the product, check the problems, and gives repair or configuration advice.

So, the AR in the marketing sector is used in different occasions like advertise and after sales support, the example of actual AR marketing application will be seen in the state of the art.

Maintenance and repair

Speaking about MRO is possible to split, as analyzed in [11], in different categories depending on the physical asset and on the final scope, the four type are: Corrective Maintenance, Preventive Maintenance, Risked-based Maintenance, and Condition-based Maintenance.

There are different ways to provide a maintenance process in AR, the principal subdivision is between on demand (online) and offline MRO, the first one is used especially when a compliace happens and is not possible to apply standard operations, the offline category is especially used when there are defined passages that are almost standard, and when there aren't any possible complications during the MRO.



Figure 9. BMW maintenance AR system

The topics relevant with this paper are especially the maintenance and repair operations (MRO) and the commercial/marketing purpose.

2. XR (AR, MR, VR)

To understand better the purpose of the thesis a brief introduction to the systems dedicated to the virtualization of the reality is compulsory.

Those systems could be grouped in a unique cluster called XR, this one is the general terminology that include all the other types, it stands for “extended reality”.

In this chapter are explained the origins with the history of the XR and the differences between AR, MR and VR, systems that are changing the working and playing methods, and also how a person engages with the world around; secondly, will be deepened the use cases and advantages in an industrial context and, at the end, will be shown the state of the art with the possible drawbacks and advantages of using an AR system and the related solutions to the various problems.

2.1 Differences between VR, AR, and MR

As already seen in the previous paragraph the XR environment “Figure 10” encompasses three main technologies that are VR (Virtual Reality), AR (Augmented Reality) and MR (Mixed Reality). Is possible to analyze separately the three categories enlightening the advantages and the drawbacks of each one respect to the others:

- *Virtual reality (VR)*: VR is the most famous one, the user is inside a completely virtual environment, the devices that are mostly used for this technology are head mounted visors (HMD) with joypads to control the digital world, the development of this system requires a very high number of 3D elements because everything in it is digital, also the background. It is mostly used for video games purpose. Oculus Rift, HTC Vive and Google cardboard are the most used devices for VR experience.
- *Augmented Reality (AR)*: this is the category that places virtual objects inside a real environment thanks to cameras and sensors build in on the device. AR technology overlaps the digital objects to the real world.

“An AR image is any representation which involves the augmentation of a Real Environment with some kind of computer generated object.”. [12]

To interact with the virtual objects there are many ways, depending on the device that is running the application, it could be by touching the screen of a smartphone or through some joypads connected to the device. An example of this category is the game ‘Pokémon Go’ developed by Niantic in 2016, this permit to place the monsters inside the real world and to catch them throw a swipe in the smartphone display. The AR technology is growing so much in those last years, it is used in many environments, especially in industrial, educational and architecture.

- *Mixed Reality (MR)*: the Mixed Reality concept is the most difficult but also complete and useful.

MR is a technology that combines both the AR and the VR experiences, it uses the most advanced sensors and cameras to track the environment, to interact with it and to anchor the digital objects inside the real world, this interaction with the real world and the anchoring operation is what differs MR from the AR, those two technique permit to give the illusion of reality to the user, that can interact with the object like it is physically present in the environment. MR has a high computational load because the camera and sensors must track the world around the user to place the objects in a good manner.

Some MR devices permit to interact directly with the digital objects projected in the real space without the need to touch a display or use a joypad, it uses visual computer technologies to recognize gestures accomplished by the user. MR technology is just now starting to take off with Microsoft’s HoloLens, one of the most notable MR devices. The application fields are a lot, industrial, educational, construction, military, medical and many others.

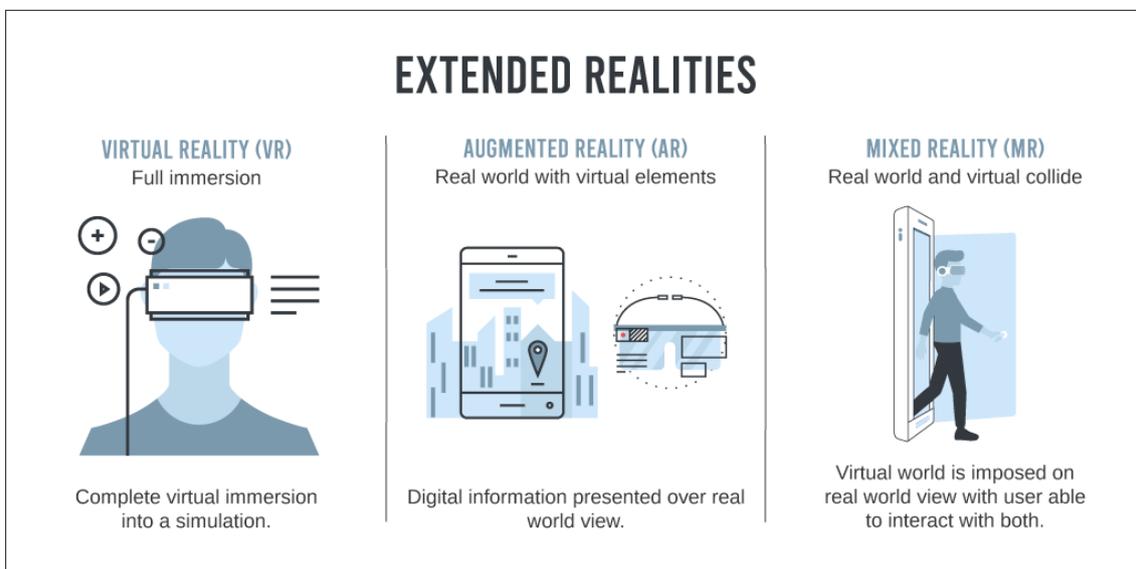


Figure 10. Extended Reality (XR) comparison

2.2 History and evolution of XR systems

Speaking about XR it’s easy to think that is a completely new technology, this belief is incredibly wrong. The first examples of extended reality, or simply called 3D reality, could be found in the 18th century when the scientist Charles Wheatstone outlined the concept of ‘stereopsis’ or also called ‘binocular vision’, this is the ability of the brain to combine two images (one for each eye) and to create a tridimensional image merging them, in this way giving the illusion of depth. This discovery permitted to invent the first stereoscope, an instrument that takes two images and form a tridimensional one. The concept discovered by Wheatstone is still applied today in the XR systems to simulate the depth in digital images and give the feeling of immersion to the user.

This was only a primordial example of the foundation on which is based the modern technology for the extended reality systems; a first practical application of this concept in an immersive environment dates back to 1960, when the machine ‘Sensorama’ ‘Figure 11’ was invented, this machine was used for cinematographic purpose, and it was provided with a 3D display and a surround audio system.



Figure 11: Sensorama

The first ever head mounted system was developed for military purpose in 1961, it was called ‘Headsight’, it was developed to view dangerous situations remotely during military inspection.

In 1980 ‘Eye tap’ ‘Figure 12’ was developed, this was the first ever AR system, was composed by a wearable computer and by a head mounted viewer, this system showed that extended reality wasn’t necessarily bulky and unnatural for the user.



Figure 12. Eye Tap

The interaction between the user and the system was introduced only in the late 80s, when RB2 was developed as a virtual controller, this was also the first time an XR system was dedicated to commercial purpose.

In early 90s is possible to see a boom in XR systems, in this period SEGA presented the first video ludic viewer ‘SEGA VR’ during CES, but this was criticized because too realistic; in 96’ was introduced the AR inside TV programs, especially in sports programs.

Till 2010 was a quiet time for XR technologies, after this year is possible to underline an increasing interest and development in extended reality systems thanks also to the exponential increase of power in processors and to the fact that many technologies (advanced sensors, cameras, HD displays) are now available also for the average customer.

By 2010 many companies developed software and hardware that permit to use the XR environment in everyday life especially in the sectors of manufacturing, education, healthcare, construction, and many others.

The most relevant examples of systems developed in the last decade are:

- *Google Street view* [13](2007): a VR system that permit to the user to visit all the world only using a computer or a smartphone
- *Oculus Rift VR* (2010)
- *Google Glass* (2014)
- *HoloLens*-Microsoft (2016) the most advanced AR/MR headset
- *Pokémon Go* (2016) “Figure 13” an AR game produced by Niantic; it is now the most popular AR application in consumer sector
- *Ikea Place* (2017) application that permit to place furniture inside the environment
- *Instagram and Snapchat filters* (2017) MR filters that change the face of the user with different masks thanks to the face tracking



Figure 13. Pokémon Go

In 2020 the pandemic forced the companies to adopt remote systems to permit the workers to work better and in security, many new XR applications have been developed like Microsoft Mesh “Figure 14”, a HoloLens application that gives the opportunity to collaborate at distance on the same project thanks to shared holograms.



Figure 14. Microsoft Mesh for HoloLens2

2.3 State of the art (Assembly, Maintenance, Repair and Marketing)

Starting from 1990 were developed many systems that are related to the principal topic of this thesis, the most relevant studies and the last developed AR applications regarding the assembly, maintenance, repair, and marketing solutions will be analyzed in this paragraph.

The advantages for the AR in the assembly and maintenance process are many, starting by the fact that the beginner user doesn't need a second person leading him to the success of the task, this decreases the time spent in the task, the money spent to teach a new employ a precise operation and at the same time this increases the productivity.

Some issues present inside an industrial context sometimes can be easily solved thanks to a precise AR application, for example a common issue is the aging and decreasing number of experts in a certain maintenance area, this is exactly the case described in [14], where is analyzed the development of two AR applications that helps the younger workers on doing some maintenance task.

In [11] is explained the advantages and the methodologies to substitute the in presence support and maintenance with most technologically advanced AR support, in it there is explained the creation of a suitable framework and Cloud based connection channel between the technicians and the expert engineers, in order to facilitate the online maintenance. The described application connects the shop-floor, where the malfunction is happening, with the technical expert, as soon as the engineer understand the problem they generate an AR models, through a Graphical User Interface, in order to explain the solution. A similar approach with Cloud oriented system is described in [15].

Inside a factory there are maintaining information that are needed every time the machine is started, especially in plants where there are many operations to do for each machine, the AR could help displaying information about the routine of the machine, this is the case explained in [1], in this case the AR system works like a virtual map of the facility, and for each machine there is a sticky note in it that resume the passages that the worker should accomplish to maintain the machine, the notes are of three type: static, recurring, dynamic. The type of note depends on the type of task and on the type of machine.

AR is useful not only in case an already constructed machine needs some repair operations but also to assembly from zero a working piece, this is the case explained in [16] where is explained how a GUI in AR should work.

When maintenance of electronic components is treated, the only AR technology is helpful but not enough, the temperature measure is necessary sometimes, this could be done through IR sensors; the complex task to integrate the AR technology with thermal sensors is accomplished in [17] where an AR system called MANTRA is developed.

In IAR a common problem could be the low speed of the internet connection inside of the factory, and also the low computational power and small memory of the devices that lead to high latency, this could be solved through different ways, for example Microsoft tries to reduce this problem providing cloud rendering and cloud storage through the Azure services, in [18] is proposed an advanced architecture that could reduce the problem of intercommunication, it utilize an Edge computing method with more computer distributed in the factory as gateway in order to provide the service and the intercommunication between the industrial sensors and the IAR devices.

The second use case that is developed in this thesis, is the software called “EthosEnergy VirtualShow” and it has a marketing purpose, it will help explaining to the customers how the machine inside of the factory works.

The AR marketing sector is growing big in this last years, there are many references about this, especially in car makers, in furniture and in retail companies.

The advantages of the AR in marketing sector are the ‘WOW’ effect that a new technology gives to the users and the facility to access it.

In [19] is highlighted how the XR brings benefits to the customer marketing, considering all the important factors that improve the user experience, the same article summarize all the possible application of this technology in the actual marketing sector.

The use of XR for marketing application is an innovative field that is trying to emerge, thanks to the empowering in processor it is starting to have a great success.

The most relevant example of application that is aimed to solve practical problems in the furniture field is IKEA Place, in [20] is analyzed how this application helps the user during the shopping process, in this way they test if the furniture fits in their home.

2.4 Drawbacks and advantages

The drawbacks of an AR systems depends not only on the purpose of the application, on the site of application, but also on the platform in which is deployed, each device has its limitations and sensors efficiency, depending on the environment each device will be less or more functional.

The first thing to consider is the fact that this technology is still an immature one, the possibility will grow in time, but the actual fact is that is still an experimental one.

The prevalent problems are the loss of tracking, it happens when the movements of the device are too fast or if the place where the technology is utilized is not illuminated or it is too big.

The low FOV is another problem that is not solved yet, the HMD have a high FOV but not high as the human view, this will impact on the visual effect and on the general experience for the user.

The most dramatical problem is the low autonomy of untethered devices, the high power request and the complexity of the architecture bring the system to require an high capacity for the battery.

Taking in example HoloLens2 the only problems that could be identified are the short battery duration and the limited FOV, but until now it is the best AR device in commerce.

The advantages of an XR system were already listed in the use case and application section, but shortly the main advantages are dependent on the site of use and also as just explained on the field of usage, resuming some of the main benefits common for every type of application:

- *Higher Security*
- *Speed increase*
- *Reducing effort*
- *Facilitate jobs*
- *Higher learning rate*

3. Hardware and Software technologies for XR

As already seen in the previous chapter the definition of MR is based on the AR experience, the only difference is that in MR the digital objects are completely integrated in the real world as they be real objects and not only superimposed with the reality as in AR technology, so the user interacts directly with the displayed objects.

Depending on the type of experience, AR or MR, different technologies and different devices are adopted, some of them could be used for both the experience.

In this paragraph will be analyzed the devices, the technologies and development kit utilized to create the two types of experience, dwelling especially on the technologies used on MR, for the fact that MR is a most complete technology respect to AR, it also needs more complex and expensive devices.

3.1 Hardware and devices

The devices used for experience AR and MR are divided in different categories, depending on the site of use and the needs that it should achieve.

- *Heads up display (HUD)* “Figure 15”: HUD are displays that show information in AR overlaying the real world with digital elements, not always the elements displayed are 3D, they are prevalently AR devices, but they can also be converted in MR systems in future.



Figure 15. HUD inside a car (Texas Instruments) and HUD in aircraft

These devices were firstly implemented in military airplanes to show a target and information about altitude and aircraft status; in the last years the principal cars producer introduced the same systems inside their top model cars, in this case the display shows the state of the car, the velocity, the direction and other relevant information for the driver.

- *Holographic display*: are displays used for every XR technology, those system are used for different purpose depending on if they are AR, MR or VR.

These types of displays are mostly used for brand advertise in store, showing the model of the object in 3D with all the characteristics and details.

An example of this display is the ‘Dreamoc’ “Figure 16” produced by Realfiction, it uses four glasses with the prismatic method to give the illusion of tridimensionality, the customer could turn around the system to see the projected object in all the angulation.



Figure 16. Dreamoc by Realfiction

The second type of display is a new product like the previous one, the only difference is that is equipped with a MR technology, it interact with the world around and the people interact directly with the holograms, an example of this device is produced by Realfiction and is called ‘Deepframe’ an example of use is inside the museum, the display positioned in front of a sculpture animates it, the same can be done with a skeleton of dinosaur “Figure 17”.



Figure 17. Deepframe by Realfiction

- *Handheld*: are the cheapest and customer available devices, with many applications available, these are mobile devices that can be used in motion. An example of this devices is the smartphone with an AR or MR application installed in it, using the sensor

and the camera inside the phone to work. In the last years the XR had a big raise thanks to the increasing power in mobile processors.

Many AR applications were developed for smartphone in the last four years. The principal user of this device is not specifically defined, it depends on the scope and on the site of use, the way to interact with the AR and MR world is through touching the screen. The problem with this type of device is that one or both hands are occupied to hold the device, this problem is solved in the next type of device.

- *Smartglasses* (Optical see-through HMD): Smartglasses or head mounted display (HMD) “Figure 18” are the main devices when speaking about the XR experience, in the last years there were many producers that developed their own head mounted machine, every device with different characteristics depending on the scope and the use case.

Depending on the site of application and especially on the XR reality wanted (VR, AR, or MR) there are many different devices, each one with different specifications, hardware structure and cost. As seen in “Figure 18” the system generates a graphic image and project it in a transparent mirror (Optical combiner) that mix the real world with the generated image, giving the illusion of reality to the user.

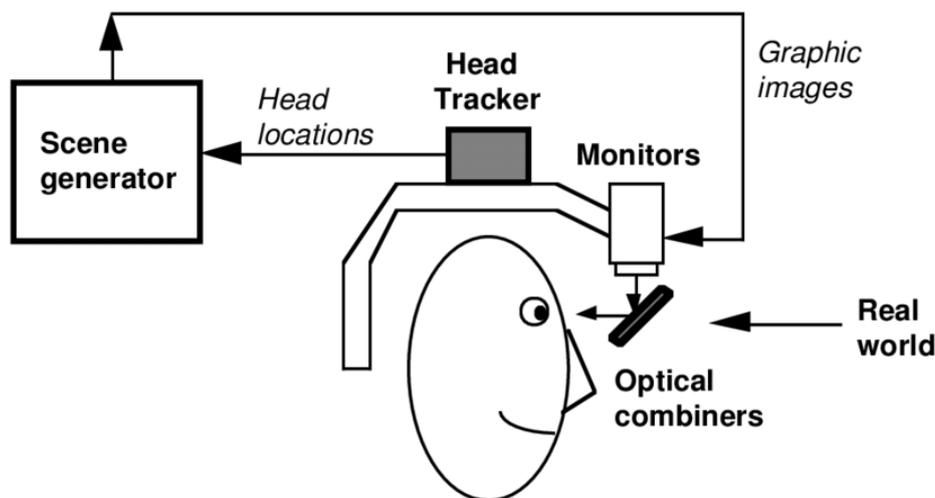


Figure 18. HMD System composition

The following devices are the main for each category.

- *HTC Vive Cosmos* “Figure 19”: This is natively a VR viewer, but it can also be used as an AR device thanks to the six cameras mounted in it, it is composed by a display, 3D audio, six cameras that permit to track the environment, and two joysticks needed to interact with the system, it is based on windows 10 and is equipped with an i5 processor and a GTX 970 graphic card.



Figure 19. HTC Vive Cosmos

- *Google Glass*: The first Google glasses “Figure 20”, produced in 2013 were a big failure, in 2019 Google produced a new model dedicated only to the enterprise world, this model is a light type of glasses with built in camera, sensors, and a touchpad to interact with the system. This is an AR device that permit the user to have both hands free when he works on something.



Figure 20. Google Glass

- *HoloLens2*: Produced by Microsoft, HoloLens “Figure 21” is the most advanced MR device, it has different sensors and cameras that permit a perfect interaction with the gesture of the user and the tracking of the world around, this device is the one used inside the development part of this thesis, so it will be described in detail in the next chapters.



Figure 21. HoloLens 2

3.2 Technologies used in AR and MR

In this paragraph will be analyzed the technologies that characterize AR and MR.

As already seen, the MR is considered as an advanced AR, so it uses all the technologies and sensors of this last one, sometimes in different ways, this obviously will have aftereffects on the processors efficiency, on power consumption, on the computational request, and also on the cost of the device, otherwise this is necessary because the user should interact easily with the digital world superimposed to the real one, the holograms should be stable, good incorporated with the real environment and they also should seem real to the user.

To do this the device should analyze the world around the user and scan all the objects inside the room to display the holograms in a good way, this process is called Environment tracking and is followed by a comprehension of the environment, this is done thanks to various systems incorporated in the device, like sensor and cameras. The environment comprehension is done through different sensor, depending on which machine is running the application, the sensors devoted to this work are the IR sensors and the cameras, this technology will be deepened in the HoloLens2 paragraph.

Another important feature that is useful for advanced AR an MR systems is the identification of the device and user position respect to the environment, this is done through two different methodologies:

- *Outside-In:* The device and the accessories are tracked by an external device; the cameras are placed in the environment and calculate the coordinate of the headset in relation to it.
- *Inside-Out:* In this scenario, the camera is placed on the device that must be tracked and looks out to determine how its position is changing in relation to the external environment. As the headset moves, the sensor re-coordinates its place in the room. Inside-out tracking can be done with or without markers around the environment. This is the case of HoloLens.

“Figure 22” show the difference between the two methods.

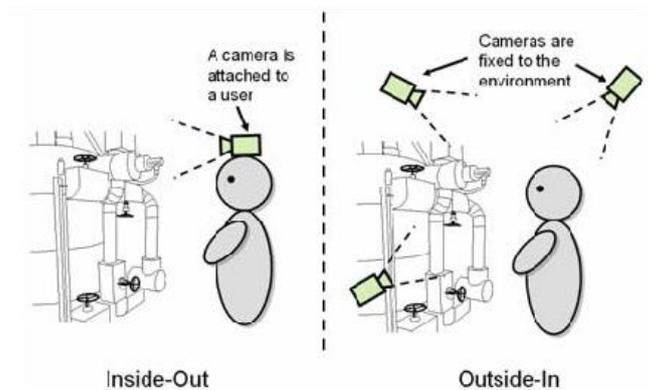


Figure 22. Inside-Out VS Outside-In

The process that are used to obtain the coordinate of the device respect to the environment are: SLAM, VISLAM, PTAM.

The holograms need to be stable and to be positioned in a certain space and position permanently, till someone decide to move it, to do this is possible to position ‘Anchors’ inside the tracked environment to save the position, about this method will be treated in detail in the next chapters, speaking about the cloud anchor service.

A task executed in both AR and MR is the projection of the digital objects inside the real world, there are different ways to do this depending on the chosen device, if the device uses a display the objects will be created inside the display through the pixels, in the other case, if the system uses a transparent viewer the objects will be projected through a light beam inside the prism of the glass.

To interact with the AR and the MR there are different methods, through the joysticks included with the viewer, or the best way to do this is to track the movement of the hands and use these with various gestures to manipulate the digital objects and the menus, this was introduced by Microsoft with HoloLens, in the chapter where is analyzed the HoloLens there will be explained in detail how these technologies works through the various sensors and camera, especially for this device.

3.3 SDK

To develop the various applications dedicated to the XR world there exist many engines and many other tools that help the developer to create and modify the virtual world, each of this tools or software developer kit (SDK) has different functions and approach to the developing of the application depending also on the type of reality and on the type of experience requested.

Such kits allow to speed up and simplify the process of developing any program with elements of AR and MR.

Each of these tools is chosen depending on the request of the application and on the platform that should be used.

The most popular cross platform engines in the market are Unity [21], Unreal engine [22], Godot, Cocos2D, Marmalade and others, depending on the project request, on the platform and on the developer’s preferences can be chosen one or another engine.

The SDK prevalently depends on the destination device, and is added inside the chosen engine, the principal are ARKit (Apple) [23], ARCore (Android) [24], MRTK(Windows) [25].

These are all high-level development environment and are complemented by different tools (called also these one SDK) depending, also in this case, on the preferences of the developer; the different tools are integrated and compatible in the engine.

The SDK are differentiated for integration inside the engine and for the technologies adopted in the tracking operation, some of the most used tools are:

- *Kudan* [26]: Tool that use recognition of simple images and 3D objects, it provides easy to use database to implement in Unity.
- *Wikitude* [27]: SDK that uses SLAM and GEO recognition as 3D tracking technology.
- *Vuforia* [28]: this is considered one of the best platforms to develop an AR system, it uses VISLAM (Visual Inertial SLAM), is prevalently used in Industrial, Robotics and Autonomous vehicle field, it can recognize different type of objects, VuMark, text and environment, the unity plug in is very powerful. The platform has many applications that help the user to create tracker and to test them in the environment. This SDK is the one utilized in the development of the industrial application, and it will be deepened in the following chapters.
- *AR foundation* [29]: is one of the most powerful cross platform tools after Vuforia, it has a more complicated structure and is more difficult to use.
- *VisionLib* [30]: like the Vuforia SDK with some differences, it doesn't need an external application to create a tracker and it doesn't need to train the model.

In the other way is possible to find some disadvantages, the device should be calibrated, it doesn't provide a 360° mode.

In the chapter dedicated to the development of the industrial application will be deepened the tools and the engine utilized in this case.

3.4 HoloLens2: Hardware specifications and features

HoloLens2 is the device protagonist of this work of thesis, it is an AR HMD produced by Microsoft, it is the heir of the first version (HoloLens) and it has many new and improved features respect to his predecessor, so it gives a more comfortable and immersive experience.

HoloLens2 is a Mixed Reality device, it tracks the environment to display the holograms inside the space around the user, the eye tracking with the slightly bigger FOV than the one of the first model permit to increase the immersive experience.

It runs on the Windows Holographic OS based on Windows 10, so that it provides a robust and easy system to the developer and to the users.

The viewer is visibly composed by:

- *Visor*: Contains the HoloLens sensors and displays. You can rotate the visor up while wearing the HoloLens.
- *Headband*: To put on the HoloLens, use the adjustment wheel to expand the headband. With the HoloLens in place, tighten the adjustment wheel by turning to the right, until the headband is comfortable.
- *Brightness buttons*: When wearing the HoloLens, the brightness buttons are on the left side of the visor near your temple.

- *Volume buttons:* When wearing the HoloLens, the volume buttons are on the right side of the visor near your temple.
- *Power button:* When wearing the HoloLens, the power button is located on the right side of the rear outer cover.
- *USB-C port:* When wearing the HoloLens, the USB-C port is located on the right side of the rear outer cover below the Power button.

The internal components, as shown in “Figure 23”, are many and subdivided in different categories.

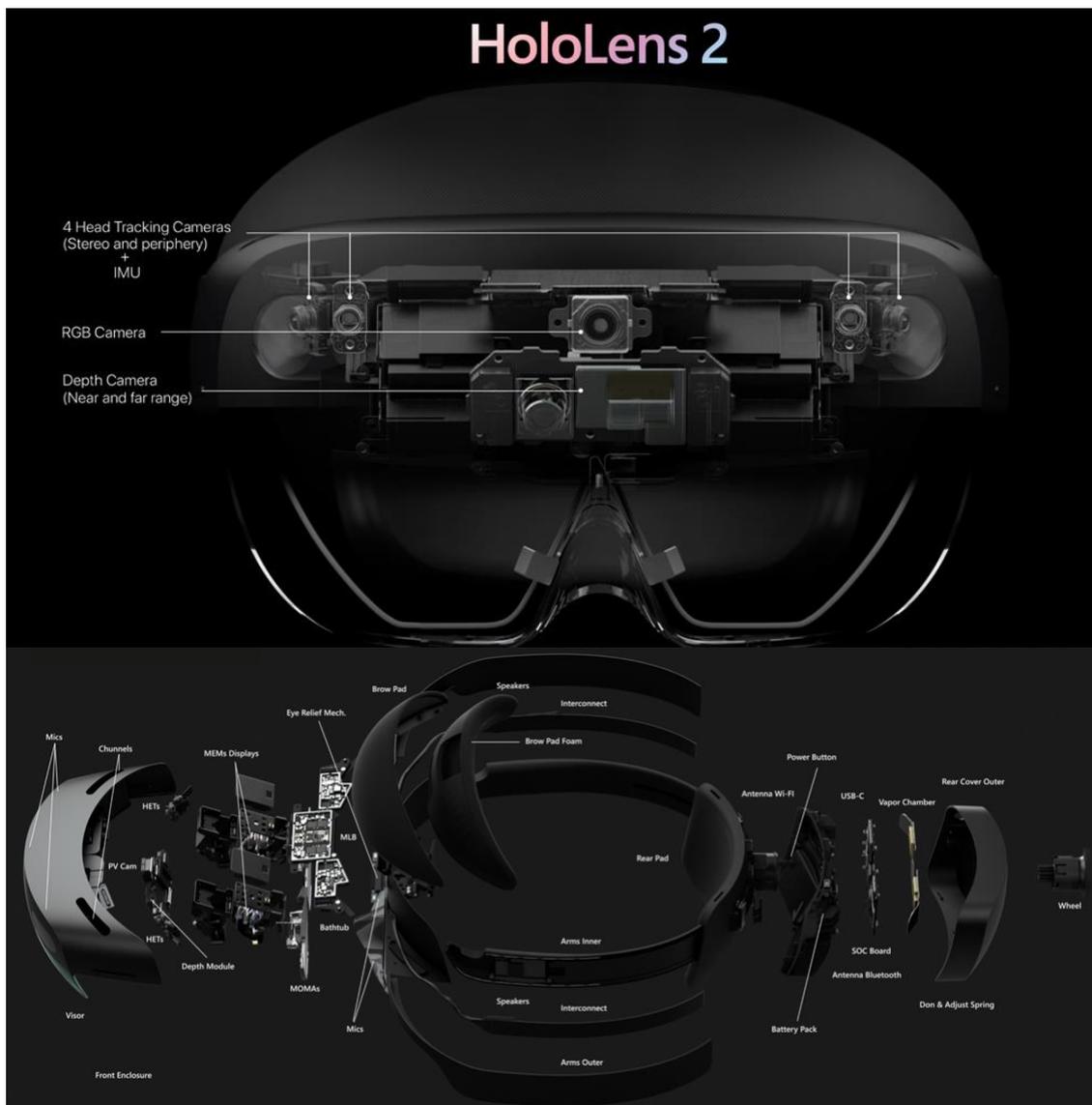


Figure 23. HoloLens2 decomposition

The components also give the technical specifications:

Display:

- Optics: See-through holographic lenses

- Holographic resolution: 2k 3:2 light engines
- Holographic density: 2.5k radiants(light points per radian)
- FOV: 52°
- Eye-based rendering: Display optimization for 3D eye position

Sensors:

- Head tracking: 4 visible light cameras
- Eye tracking: 2 infrared (IR) cameras
- Depth: 1MP time of flight depth sensor
- IMU sensors: Accelerometer, gyroscope, magnetometer
- Camera: 8MP, 1080p 30fps

Audio and speech:

- Microphone array: 5 channels
- Speakers: Built-in spatial sound

Compute and connectivity:

- System on chip: qualcomm Snapdragon850 Compute Platform
- Holographic processing unit: Second-generation custom-built holographic processing unit
- Memory: 4 GB LPDDR4x
- Storage: 64GB
- Wi-Fi 802.11ac 2x2
- Bluetooth 5.0
- Usb Type C

Power:

- Lithium battery
- Battery life: 2-3 hours of active use
- Cooling type: passively cooled

Weight: 566 grams

Device Capabilities:

Human understanding:

- Hand tracking: Two-handed fully articulated model, direct manipulation
- Eye tracking: Real-time tracking
- Voice: Command and control on device; Cortana with internet connection

These three functions permit to the system to understand exactly how the user tries to interact with the interface.

Environment understanding:

- 6DoF tracking: World-scale positional tracking
- Spatial mapping: Real time environment mesh
- Mixed reality capture: Mixed hologram and physical environment photos and videos

Environment understanding or also called Scene understanding use the AI to give a physical interpretation to the mesh created during the spatial mapping, giving so a high-level environment representation. This leads to Spatial Awareness concept; this is the definition that is given to a system that understands the world around the user, defining what is a wall, a platform, or the floor inside the generated mesh.

This concept is necessary to place the holograms inside of the environment and to let them interact with the real objects and planes positioned inside of it.

HoloLens2 is prevalently a mixed reality device, thanks to the tracking, mesh creation, human and environment understanding has many good, structured functions, it tracks exactly the position and the movements of the user respect to the environment, this permits a stable system and stable holograms.

Considering the device capabilities, listed before in the specifications, is possible to summarize it prevalently in four characteristic functions that make HL2 such a futuristic device: Hand tracking, Eye tracking, 6DoF tracking and Spatial mapping.

Hand Tracking: Hands are your principal input device, this is what makes HoloLens an innovative device, as seen in “Figure 24” the hands of the user, when in the FOV of the



Figure 24. Hand Tracking

device, are tracked and a mesh is generated, depending on the position of the fingers a function is activated, this characterizes the gestures of the system, the various gesture are resumed in “Figure 25” is also shown how to open the principal menu with a gesture,

watching the thumb the Windows logo appears and the menu could be opened touching it with the finger of the other hand or also closing the thumb with the index.



Figure 25. Hand Gesture

Head and Eye Tracking: These two innovative features introduced in HoloLens2 gives so many advantages during the device usage. They work thanks to a camera pointed to the eyes that tracks the movement, when the HoloLens is turned on the device is calibrated on the eyes of the actual user and tracks the head position respect to the environment, giving it the starting position of (x:0, y:0, z:0).

Eye tracking is used also for the authentication procedure, it recognizes the eye of the user and if the user is registered in the system, so it logs in.

Eye tracking together with head tracking is used also as input methods, the system recognizes which object the user is watching and if the function is activated it interact with it, these functions are named Eye Gaze and Head Gaze, those are useful when the user can't use hands or voice. The eye calibration also permits to give to the user a better quality view and so a better experience.

6DoF Tracking: 6DoF (Degrees of Freedom) tracking is a tracking system that gives to the system the exact orientation and position of the device respect to the environment, this permit to the device to know the rotation and translation movement of the user respect to the real world.

Spatial mapping: Spatial mapping “Figure 26” provides a detailed representation of real-world surfaces in the environment around the HoloLens, this permit to place holograms on real surfaces, by merging the real world with the virtual world, an application can make holograms seem real. Applications can also more naturally align with user expectations by providing familiar real-world behaviors and interactions.

Generally, the real environment is not static, sometimes there are objects in movement or people walking in the room, this leads to two different spatial mapping methods, depending on the necessities, these are called Cached or mapping Continuous, the first one is done once and stored in system cache, this will permit to have less CPU usage. The continuous mapping, instead, is done continuously so that the application will have an updated mesh every time to work in the best way, this leads to a high usage in CPU.

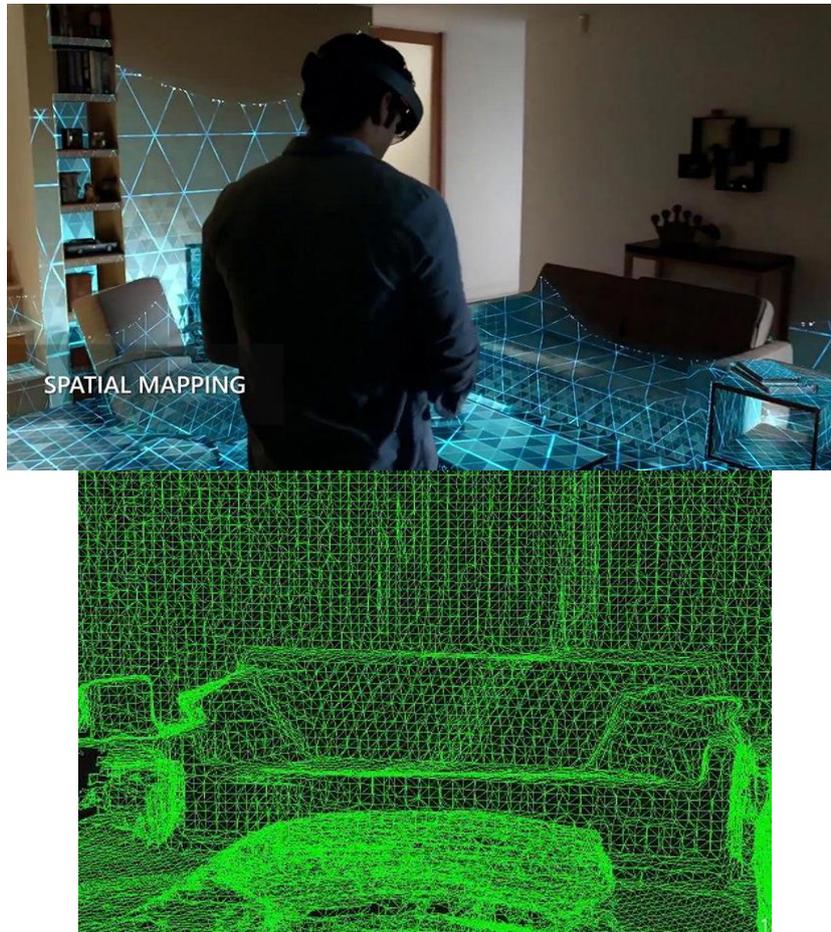


Figure 26. Spatial Mapping and mesh generation

There are various functionalities and interactions between the holograms and the real world obtained through the spatial mapping:

- *Placement*: this is the possibility to place virtual objects inside of the real environment. This is an important functionality and is the best way to give to the user the illusion that a virtual object is real. A simple example could be a book placed over a table, in the real world it will never be half inside of the table and half visible.
- *Occlusion*: occlusion is the best functionality that permit to the system to give the illusion of reality, this give to the user a feedback about where the hologram is placed.

The mesh interacts actively with the holograms thanks to this function when a hologram is positioned behind a wall or behind a surface it disappears as it is really there.

This behavior has a huge impact on the user experience, he can leave some holograms in a room, go in another room and the holograms will be hidden by the room's wall till he will go back to the room where the digital elements were placed.

- *Physics*: physics simulation is another way to reinforce the presence of holograms inside of the real world. A simple example could be a ball that bounces on the floor or over the table, in reality the ball will never pass through the table or will not bounce in the air.

This simulation depends on how the application is set.

- *Navigation*: this functionality gives the ability to avatars and digital elements to navigate inside of the environment. The most useful usage of this functionality is the possibility to give to the user a navigation map in order to reach a defined position in the real world, an example could be the tour inside of a factory, the system will indicate to the user the direction to take.
- *Visualization*: visualization is the possibility to show the digital mesh superimposed to the real world.

3.4.1 Trimble XR10

HoloLens2 is sold in different versions, depending on the purpose, the industrial model is called Trimble XR10 "Figure 27", respect to the normal version it has functions and certifications that are needed inside a factory context, the hardware specifications are almost the same respect to the normal version, the differences are:

- Weight:
- Dust and water resistant: IP50
- Hardhat: Compatible with MSA V-Gard (Cap Style and Full Brim) with Fas-Trac III Suspension
- Speakers: Mobilus mobiWAN_TR bone-conductive Bluetooth headset



Figure 27. Trimble XR10 with HoloLens

3.5 Software and services for HoloLens2

Microsoft gives many opportunities and solutions to work greatly with HoloLens2, it provides not only many and good integrated AR software to the final users, but also it gives to the developers a lot of services that can help on developing applications with a great user experience and also really good integrated with the Windows platform.

The available software are still not so many, but the ones that Microsoft integrate with the system are really good especially for remote assist or to cooperate with different HoloLens in different places.

In this paragraph will be listed and analyzed the software and services that Microsoft makes available with HoloLens2.

3.5.1 Microsoft Mesh

The first software in the list is the one that Microsoft released as the last one in 2021, Microsoft Mesh is a collaborative remote software that gives the opportunity to collaborate on the same model or in the same project even if in different places.

This is the future of the virtual meeting room, the future of Microsoft Teams, an AR and MR video call that gives the opportunity to interact remotely with other collaborators, this system create an avatar of the user and project it in the HoloLens or in the device of

the other participants of the call. It is like being in the same room thanks to the avatar projected.

Microsoft Mesh it's an entire platform built on top of Azure, it gives the opportunity to work remotely on 3D models that is difficult to model remotely, it is an advantage for engineers, architects and other professional that works with CAD, BIM, and other type of 3D formats.

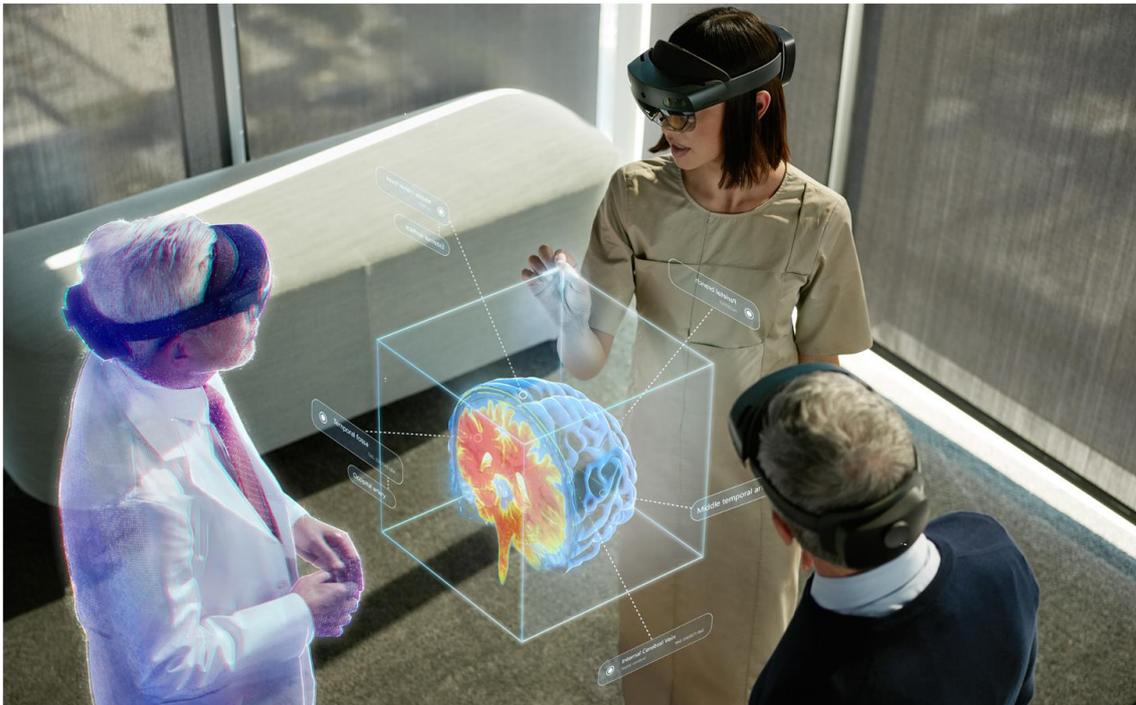


Figure 28. Microsoft Mesh

3.5.2 Dynamic 365

As said in (Wikipedia: Dynamic 365), Microsoft Dynamic 365 is a product line of enterprise resource planning (ERP) and customer relationship management (CRM) applications produced by Microsoft, it was developed to increase the Business Agility (the capacity of a company to follow the technological changes and to apply them to the internal processes) it is completely integrated in the Azure cloud. The applications compatible with the AR and HoloLens2 are two:

- *Dynamic 365 Remote Assist*

Remote Assist is an application that gives the opportunity to follow a process in remote, to help the operative field resolving a problem. Share the real-time view with experts remotely to get the needed help and stay hands-free on HoloLens or Dynamics 365 Remote Assist mobile.

- *Dynamic 365 Guides*

Guides is an application that gives the opportunity to create custom tutorial based on a selected process, the user will follow the AR indications to finish the job. It can be customized inside the Azure cloud.

3.6 Development environment (HoloLens2)

The SDK that gives the opportunity to develop high quality applications for HoloLens2 is partially customizable, this means that the developer could choose between different engine and tools in order to create a good end user software, the only constant are the OS that is Windows 10 and the integrated development environment (IDE) that is Visual Studio.

In this paragraph will be analyzed the software and tools utilized to develop the two case study applications done in this work of thesis, specifying the versions utilized, the alternative to this tools will be only mentioned.

3.6.1 Preparatory steps: Windows 10 and Visual Studio

What is necessary to start developing for HoloLens2 is a computer with the latest version of Windows 10 installed in it and with the ‘Developer mode’ enabled, to enable it go to Settings→Update&Security→For Developers, the same thing should be done on the target device, in this case the HoloLens2.

The second step necessary to deploy to HoloLens is the IDE (Integrated Development Environment), the software used to write code, debug, test, deploy, in this case is Visual Studio, the version utilized in this paper is Visual Studio 2019 version 16.10.4, the installation is done through the ‘Visual Studio Installer’ application, during the installation procedure the following workloads must be added to make the computer and HoloLens2 interact in the best manner:

- Desktop development with C++
- Universal Windows Platform (UWP) development
- Game development with Unity (if planning to use Unity)

They are also shown in “Figure 29” inside of UWP workload be sure to enable tools:

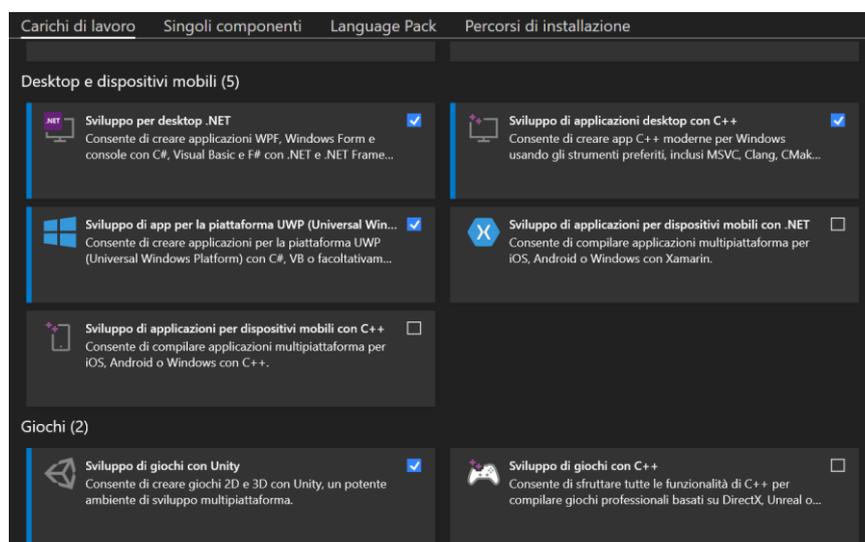


Figure 29. Visual studio Workloads

- Windows 10 SDK version 10.0.19041.0 or 10.0.18362.0
- USB Device Connectivity (required to deploy/debug to HoloLens over USB)
- C++ (v142) Universal Windows Platform tools (required when using Unity)

Also shown in “Figure 30”

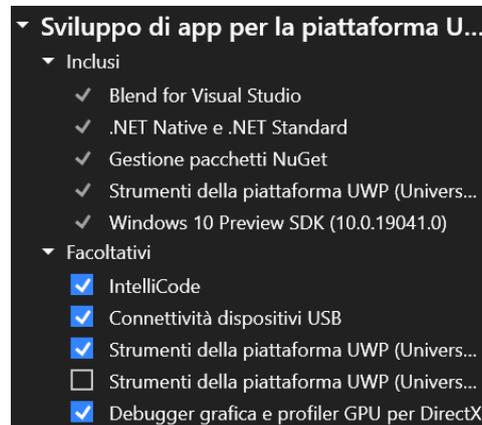


Figure 30. Visual Studio tools

To test the applications is also possible to install a HoloLens emulator, this optional emulator lets run applications on a HoloLens virtual machine image without a physical HoloLens, otherwise it needs that the PC runs Hyper-V, a virtualization software available on the Enterprise edition of Windows 10.

After this compulsory steps is necessary to choose the engine and the optional tools.

3.6.2 Unity

After OS and IDE configuration there are many paths that can be followed speaking about the development environment, the first choice that should be made by the developer is the one relative to which engine to utilize, there are prevalently four possibilities: Unity, Unreal Engine, JavaScript (WebDeveloper) and Custom, each one has different features.

The engine utilized in this work of thesis is Unity, that is the best one if speaking about feature and tool integration for development of AR applications.

The version utilized in this paper is Unity 2019.4.10f1(LTS) with Legacy Built-in XR. The installation is performed through the Unity Hub, during the installation be sure to install the tools:

- Universal Windows Platform Build Support
- Windows Build Support (IL2CPP)

After the installation, the project, with the Windows Mixed reality (WMR) platform, and scene settings must be set in order to be ready to develop mixed reality applications and to deploy it to HoloLens2.

Start configuring the project settings, go to File→Build Settings “Figure 31” .

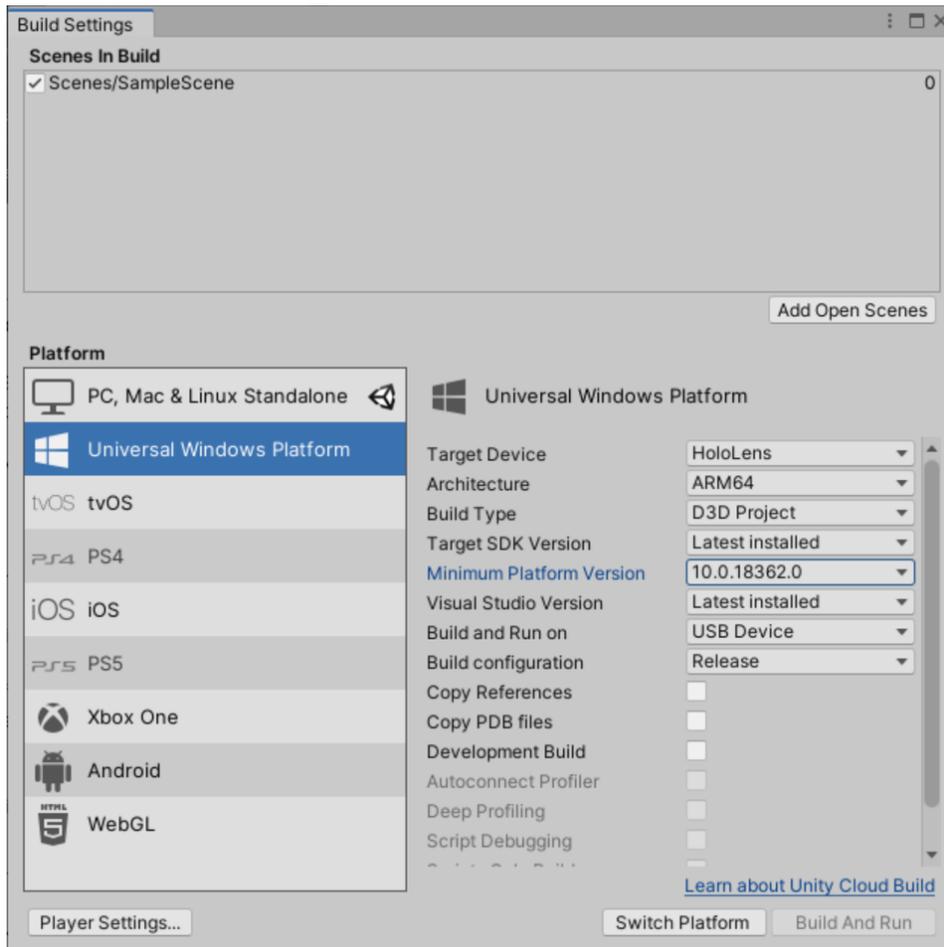


Figure 31. Build settings in Unity

The next step is to configure an immersive view, the holographic render and the spatial input, in Unity 2019 the built-in LegacyXR help configuring the XRSDK, in this case opening the ‘Player Settings’ is possible to set the parameters for the Windows Mixed Reality, it is possible to see the complete settings in “Figure 32”

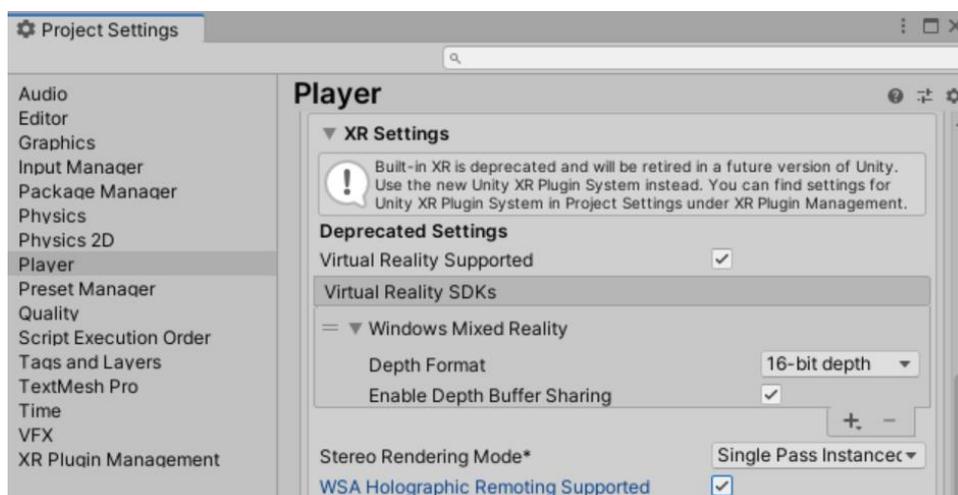


Figure 32. Project settings in Unity

The last step is to ask permission to the device to access determinate functionalities, in this case the needed features are Microphone, Webcam, Spatial perception, Internet client. These are set going to Player Settings → Setting for Universal Windows Platform → Publishing Settings → Capabilities.

It is also possible to configure the WMR automatically by importing the Mixed Reality Toolkit (MRTK) that will be analyzed in the next paragraph.

3.6.3 MRTK (Mixed Reality Toolkit)

MRTK for Unity is an open-source, cross-platform development kit designed to make it easy to build amazing mixed reality applications.

MRTK provides a cross-platform input system, foundational components, and common building blocks for spatial interactions. With MRTK version 2, is possible to speed up the application development for Microsoft HoloLens, Windows Mixed Reality immersive (VR) headsets, and many other VR/AR devices. The project is aimed at reducing barriers to entry, enabling everyone to build mixed reality applications and contribute back to the community as we all grow.

The version utilized is MRTK 2.6.1.

3.6.4 Blender

Blender [31] is a free and open-source 3D computer graphics software toolset, in the XR and HoloLens context it helps on simplifying a 3D model in order to reduce the rendering computational load, it also helps creating animation to be imported in the developed applications. The version adopted is Blender 2.93

3.6.5 Vuforia

As seen in paragraph 3.3 there are many possible choices that can be done between the various SDK, each one has different functionalities and different destination platform, for this work of thesis the choice fell on the Vuforia engine, version 9.8.8.

Vuforia [28] is an extended reality SDK that uses computer vision technology to recognize and track planar images and 3D objects in real time, it makes available many useful tools in order to help the developers to have a good interaction between the system and the real environment.

To work with Vuforia is necessary to have a license, the basic license is free and provides all the tools and functionalities of an advanced license, the only difference is the limited quantity of targets that can be created and uploaded in the database. The database contains all the models that are generated and that are tracked by the engine.

The first step that should be done to use the engine is to generate a model or marker that will be tracked, this depends on the necessity of the developers and on the purpose of the

application. Vuforia, according to the needs, provides many tools to generate and upload an effective model or marker. Here will be analyzed the different features and the correlated tools.

The features that characterize the Vuforia Engine gives the opportunity to track different types of targets, these are split in different categories:

Tracking Images: In this case the engine tracks 2D images, the fantasy of an object, multiple images or VuMark (marker with singular encoding, like QR code), this tracking operation is done comparing the acquisition of the camera with all the files uploaded inside of the database, after the recognition of the target the system will use it as an anchor for the correlated elements.

To upload a target is necessary the image or the marker file, the supported formats are .jpg and .png, the file must be smaller than 2.25 MB.

An image target is defined as a good target if it has a complex pattern, this is evaluated during the upload in the database, after the analysis the system will give to the target a score from one to five stars. In “Figure 33” is shown an example of image inside the database, in this case the image has a grade of five stars, the maximum possible, here are also shown the tracking points that characterize the image.



Figure 33. Marker AR

Tracking Objects: This type of tracking gives the opportunity to track a defined object, or a model with a defined form, in this case the quality and the precision of the tracking is given by the complexity of the shape of the object, the evaluation is done in the same way as the Image Tracking score.

In order to create and upload a good and precise model in the database, there are some tools that help the developers, the type of tools needed depends on the dimension of the object and also if the 3D model is present and already digitalized.

In case the 3D model already exist is possible to obtain a Model Target through the desktop application *Model Target Generator* “Figure 34”, this application support the following formats: .obj, .fbx, .pvz, .stl, .igs, .dae, .stp, and .vrmf.

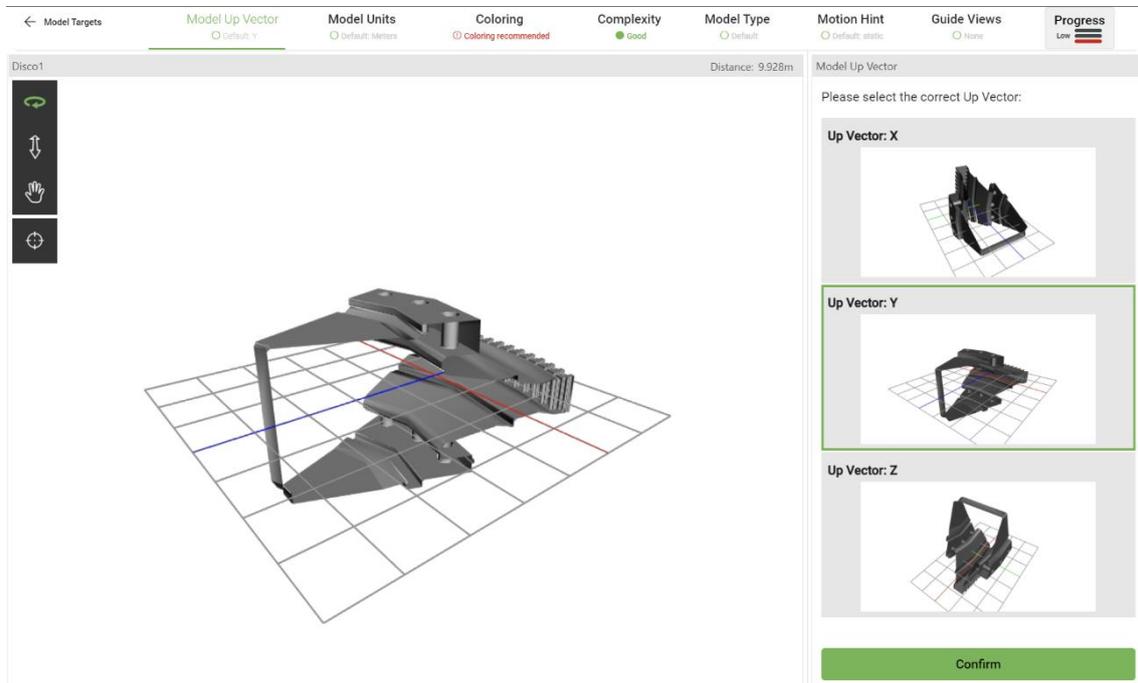


Figure 34. Model target generator

In the opposite case, if the 3D model doesn't exist and the object is small Vuforia provides an Android application (APK) tool called *Vuforia Object Scanner*, allows the developer to scan a small object positioned inside of the A4 dimension image available in the site “Figure 35”.

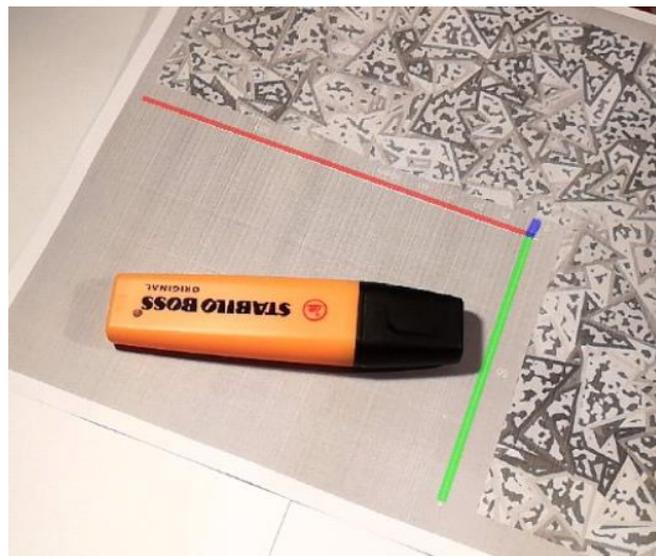


Figure 35. Example of A4 scanning paper

This will generate an object in format .od that can be easily uploaded in the database.

After that the model is created is possible to test the effectiveness with another APK application *Model Target Test App*, this will evaluate the model just created.

In the chapter where is explained the development of the first application will be also analyzed the differences with advantages and drawbacks of the two tracking methods just presented.

Tracking Environment: the environment recognition is a useful feature in the Vuforia universe, it permits to analyze and recognize the world around the user; as the Object tracking, Vuforia provides almost the same type of tools to create a model and upload it on the database.

If already exist a 3D model of the environment the tool that should be utilized is the *Area Target Generator*, similar to the Model Target Generator in the object case; if, instead, the model doesn't exist the needed application ins *Vuforia Area Target Creator*, this needs a camera with built in LiDAR sensors.

In this case the testing app is *Area Target Test App*.

In order to use the marker just analyzed is necessary to setup Unity with Vuforia importing the Assets, download the database and upload it into Unity, the process of download will create an Unity package "Figure 36" that is easily uploaded to the Unity project and utilized, this will be done after that the license key is inserted inside the Vuforia configuration.



Figure 36. Unity package file

After that all the passages are completed is possible to create an Object "Model Target" inside Unity through the Vuforia assets.

3.6.6 Deploy

After that the applications are developed is necessary to build and deploy them inside HoloLens, this is done through the Visual Studio interface. This procedure is done connecting the device with the USB or directly with the Wi-Fi.

The build inside Unity will create an ".sln" file that can be opened inside Visual studio.

The output must be set in order to be compatible with the device, in this case the output architecture should be ARM64, the deploy type should be set to "Release" and the device should be chosen in the available list "Figure 37".

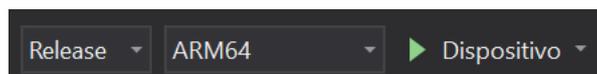


Figure 37. Deploy settings

Inside of Visual Studio, during the deploy, is also possible to define many stylistic parameters inside of the “Package manifest”, for example change the name displayed in the device, choose the icon that must characterize the application, the description, and the version of the software.

To finish the deploy is necessary to associate the HoloLens2 and start the deploy without the debug operations.

4. Development of XR solutions in industrial context

In this chapter will be exposed the two applications developed during the work of thesis, will be analyzed what is the role and the functions of the single application, and for the technical part will be deepened the development choices and the functions articulated inside of the single software.

4.1 Case1: EthosEnergy Tutorial (AR)

The first application that is presented is a maintenance tutorial software, it is aimed to instruct the employees of the operative field on how to perform the mounting phases of the blades inside of the turbine disk Frame 5 (Frame is a type of turbine produced by EthosEnergy, the number 5 indicates the dimension).

The advantages on using this application are prevalently the reduced time in maintenance and assembly procedure, the fact that the employee doesn't need an instructor to learn the job, the fact that he has all the needed information with a hands free system, and especially that he can see exactly the position of each piece at the end of the mounting steps.

In the next paragraph will be analyzed the technical choices, the problems found during the developing part and the solutions adopted.

4.1.1 Project requests

The project request for this application is to display in AR a step by step tutorial in order to instruct a user on how to execute a mounting procedure, for this reason the system should be highly intuitive and easily comprehensible, the software should execute the mounting steps directly inside of the real disk displaying the holograms inside of the industrial context.

The user can't interact with the 3D objects and the animations, he can only play again the animation to see the procedure.

The system should guide the user step by step in a set of defined passages.

The application should recognize the starting point in the disk and mount in AR precisely the pieces inside of it.

Every step should be described by a text and should also be followed by an intuitive photo that shows the mounted piece.

4.1.2 Technical requests

The device that will be used is HoloLens2, the technical aspects that must be respected by the application are based on the capacity of the device, for this reason is requested a

good stability, a precision higher than 1 cm, a fast response and a good interactivity between the user and the interface.

It is possible to utilize a marker in order to track the starting point, this will be seen in the following section how is useful.

Internet connection is not needed, the system should be utilized anywhere.

4.1.3 UI

The User Interface is easy, it is composed by three starting menus that introduce the tutorial and gives the preparatory information.

After the third menu a loading screen appears and wait that the marker is tracked, when the tutorial begins, there is an info panel that explain every single step, the user could interact with three buttons positioned near the animation “Figure 38”, for every step there are the same buttons: Play(Replay), Back, Next.



Figure 38. Button Interface

The steps that compose the tutorial are eleven, each one has its animation and its info panel. The user could go back and forth by clicking the Back and Next button, the animation can be played anytime and how many times the user wants.

After that the tutorial is ended it restart from zero.



Figure 39. UI EthosEnergy Tutorial

4.1.4 Technical details and choices (Marker VS 3D)

Speaking about the technical choices the first problem was to recognize the disk and track the starting point.

In a first moment was utilized the Vuforia 3D model recognition, the advantage in this case is that is not needed an external marker, but the drawback are too many and difficult to balance, the first problem is the fact that the disk is mounted in an industrial context, an open space full of objects, this decrease the tracking precision and influence the stability of the animations making impossible to use the application; the second problem is that the mounting phases should start from a precise point because every blade has a different weight, with the 3D tracking is not possible to understand or to tell the system which is the right starting point, because every part of the disk is equal to the other.

These problems are solved creating a marker with the entrance form of the disk, the user will put the marker on the starting point “Figure 40”, the system will track it and will pose the animation precisely there with the buttons in the proximity, this permit to have a good precision and stability and also to define which is the starting point.



Figure 40. Marker position

Another technical aspect that was necessary to analyze was the complexity of the objects inside of the scene, in order to reduce the computational complexity, the objects were reduced in dimension and in number of polygons. This was necessary because the CAD files in an industrial context are very complex before the reduction.

The other aspects that were analyzed are the lights and colors of the 3D models inside of the scene, this is an important aspect inside an extended reality system, because some colors can't be reproduced in the holograms, for this reason was chosen a light color, the

chosen one is the most similar to the color of the real piece, this is done in order to give the illusion of reality to the user.

For the same reason, the illusion of reality is given also by the fact that the holograms are set with an occlusion method, so they are covered if a real object is in the middle of the view “Figure 41”.



Figure 41. Occlusion method

4.1.5 Objects and animations

Speaking about the object, as already said in the previous section, the complexity of the original CAD model should be reduced by decreasing the polygon number, this is done through Blender.

In the case of the “EthosEnergy Tutorial” the objects utilized are the elements that must be positioned in order to have a clear idea of the procedure, the original model was complete of all the parts of the turbine, so, in order to produce an efficient and coherent animation, this is cut in order to obtain a slice of the disk with the elements necessary for the animation “Figure 42”.

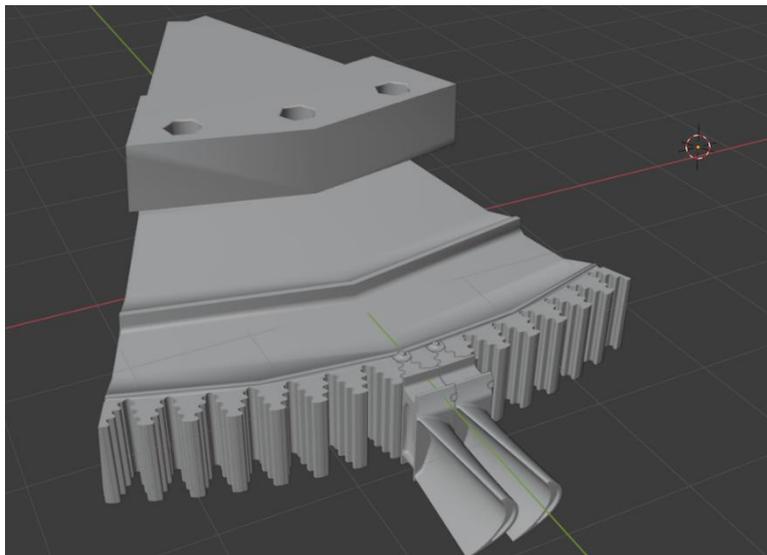


Figure 42. 3D model of the disk

The principal objects that are animated during the procedure are:

Twistlock: the first element inserted, it locks the blade in position. “Figure 43”

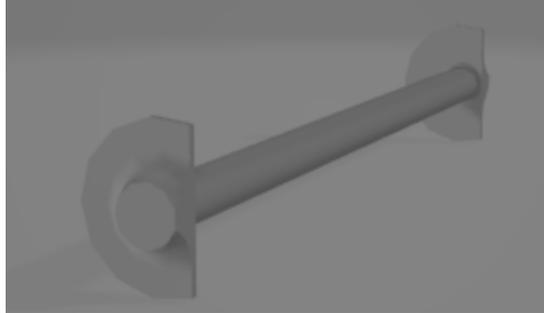


Figure 43. 3D model of the twistlock

Blade: The blade is the second element inserted. “Figure 44Figure 44”

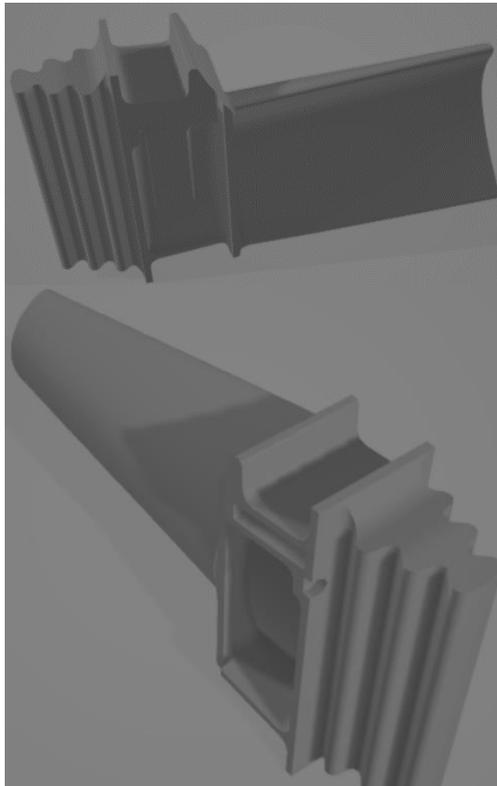


Figure 44.3D model of the blades

Seal and Radia Pin: the seal and radial pin are the pin that insulate the stages inside of the turbine and are mounted in the third and fourth steps.

Hammer and needle: The hammer and needle models are utilized to show to the employee how to fix the Twistlock at the end of the procedure.

The principal part of the disk is removed during the Unity procedure, it is utilized only to align the animations with the final marker and to have the good scale in the real environment.

Starting from the complete model all the single parts are animated, also this step is done in Blender and then imported into Unity, during the use of the application the animations are triggered through the button ‘Play’.

The animation is then split in eleven different animations that will be reproduced step by step through the user interface.

The animations are organized in Unity thanks to the Animator window “Figure 45”, it gives the opportunity to set the state of the single animation after that it is assigned to a defined object.

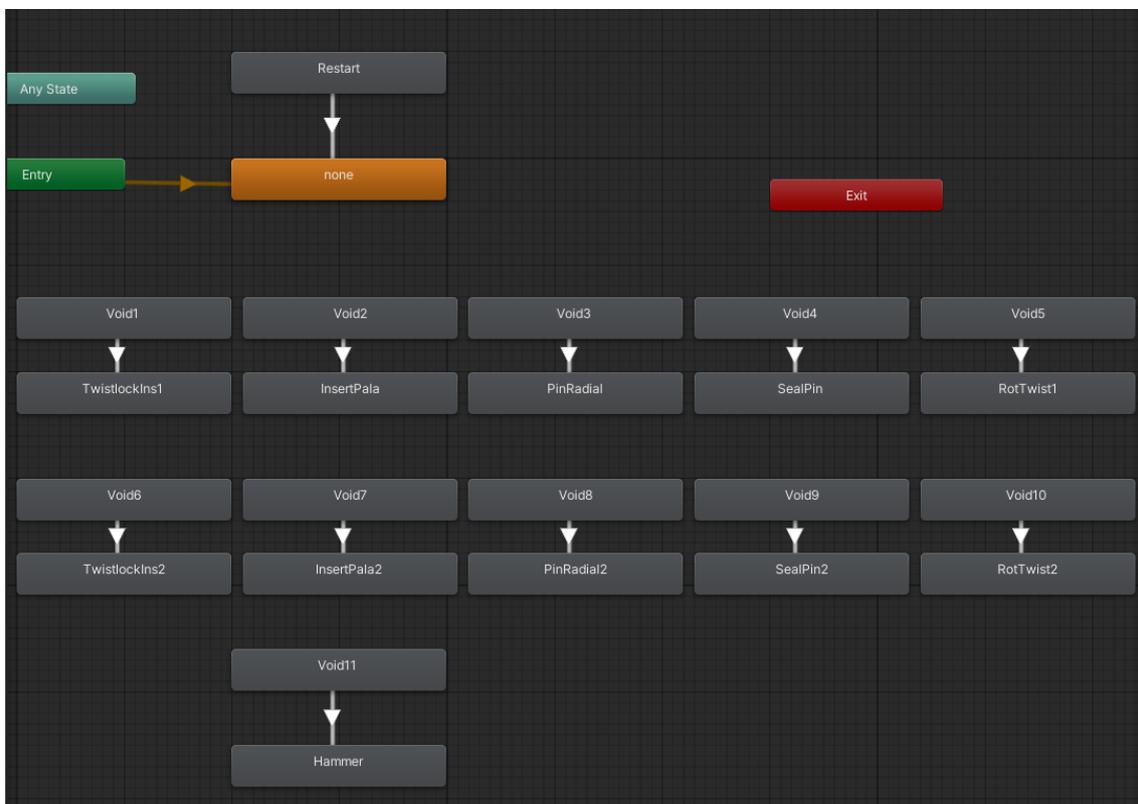


Figure 45. Unity Animator

The animations are then triggered by the dedicated button, each button is assigned to a different animation thanks to the script ‘Animazioni’, the order of the animation is precompiled so the user can’t jump from the first to the last animation but is possible to do the opposite.

4.1.6 Scripts

In this section are described the principal scripts utilized to develop the “EthosEnergy Tutorial” application:

Game Manager: game manager is the script that manage the 3D objects inside of the scene, the principal parameters are:

- Show: activate the object that was invisible before
- Unshow: disable the active object

NearInteractionGrabbable: The NearInteractionGrabbable gives the opportunity to the user to interact with the menu and move it in the space, this is done to organize in the best way the user interface. This function is assigned to the first menu and also to the info panel. This also gives the possibility to dimension the designed screen.

MinMaxScaleConstraint: Assigned to the menu and also to the info panels set a threshold that can't be passed in order to dimension the screen, so the user can't size the object too big or too small.

Animazioni: the parameters inside of 'Animazioni' script are functions that trigger the animations through the animator. There are two type of animation functions: the first one activate the animation that is still not activated; the second function reset the state of the animation in order to reproduce it another time.

Follow: this function is assigned to the menus and to the info panel, it track the movement of the head in order to move the chosen display in the right position, this allows to pin a screen every time in the FOV of the user. The parameters that could be modified are:

- Min Distance: set the minimum distance of the menu from the user
- Max Distance: set the maximum distance of the menu from the user
- Default Distance: set the starting distance of the object
- Max View Horizontal: set the horizontal distance in which the menu should stay
- Max View Vertical: set the vertical distance in which the menu should stay

Face User Constraint: The face user function, assigned to menus and info panels, rotate the object following the movement of the head, in order to be every time face to the user.

Button Configuration: button configuration is the assignment panel for the functions that a button should activate. Inside of it is possible to assign an object and activate the different functions that are assigned to the defined object.

Default trackable event handler: Script assigned to the image target, it decide which is the function activated when the target is found and when is lost.

Image Target Behavior: is the script that interact with the Unity package file in order to choose which is the image inside of the marker.

4.1.7 Life cycle and results

To understand easily how the application works, the functions and the user interface this paragraph analyze the life cycle starting from the first menu till the end of the experience,

deepening all the functions activated by the buttons, the experience is repetitive in order to be easier and more understandable for the user. At the end will be explained the results and the possible problems that appear during the experience.

The application starts with three menus.

The first menu “Figure 46” present the tutorial and is an introduction to the type of machine on which will be mounted the blade.



Figure 46. First menu

The second menu “Figure 47” is an overview on the components and on the user interface, here are shown the 3D models of the object that must be mounted in the process and are also shown the buttons that appear during the experience.



Figure 47. Second Menu

The third menu “Figure 48” is a check list of the needed objects, on the right is also shown the image of the marker in order to be sure that the marker is the right one.



Figure 48. Third Menu

After the three menus the system start searching for the target, a loading screen appears, the loading scene will disappear only after that the marker is tracked. As already seen the target indicate the anchor in the space in which the animations should be assigned.

After that the target is found the tutorial starts, in front of the user are displayed the info of the first step with the real photo of the piece mounted in the disk, the user could play the animation by clicking the button ‘Play’, so the animation start reproducing and in the first stage is possible to see the insertion of the twistlock in the disk, now the button displayed are two, the first is ‘Repeat’ it reproduce again the animation, the other is ‘Next’ it close the info of the current step and go to the next one in order to play the new animation.

The experience is almost the same for every step, reproduce the animation, see the info, and go to the next step, the new introduced button is ‘Back’ that opens the previous info panel and show the animation of the previous step.

The end of the eleven steps finish with the hammer and needle procedure, the last button is 'Exit', this will start again the procedure from the first menu.



Figure 49. Final Step of the tutorial application

The problems that could be found in this application is the loss of tracking, this happens when the HoloLens has low battery or when there are too many applications opened in background. In order to solve the tracking to be repeated every time and to position again the interface the marker could be taken away or covered with a white paper after the first tracking.

The precision of the system is really high, it is over 0.5 cm. the other drawbacks is during image acquisition, the video will never show the application as seen by the real user, it will be unstable and not precise, this is evident also in the photos inserted in this work of thesis.

4.2 Case2: EthosEnergy VirtualShow (MR)

The second application is a mixed reality software designed to facilitate the interaction between the commercial section of the company and the client, so it has a marketing purpose.

This application is aimed to show to the client the various machines inside of the factory through a mixed reality experience guided by the employee; the system will track various marker, each one associated with a different machine, when the target will be found the system will show over it a set of buttons. Each button activates a different function, this is done in order to show to the customers different elements during a video call done through the Microsoft system Teams.

Each button is associated with a different element that explain a different aspect of the machine, these are resumed in: Info, 3D models, simulations, real video. Each one of this elements will be deepened inside of this section.

The advantages on using this application are prevalently the fact that is the easiest way to explain the work done by the machines inside of the factory, often, during the video call with the clients, the machine are turned off, this makes the explaining process really difficult.

In the next paragraphs will be analyzed the technical choices, the problems found during the developing part and the solutions adopted.

4.2.1 Project requests

For this application the principal requests were to display all the info of the machine tracked, to interact with them and to have an intuitive system that can be used during a video call inside of the workshop or during a video conference with the clients inside of conference room.

In this case the user should interact with the holograms that appears during the experience, this is necessary in order to have a fluent interaction between the information told by the user and the elements that characterize this type of experience.

The system should be used inside of a factory or inside of a congress room, so the marker could be horizontal or vertical, the system should adapt on the occasion.

The marker should be portable and easy to recognize.

4.2.2 Technical requests

As already explained and seen in the other paragraphs the device that will be used is HoloLens2, the technical aspects that must be respected by the application are influenced by the characteristics and capacity of the chosen device, for this reason is requested a good stability during a video call, in this case the precision is not an important factor, a low but obviously not terrible precision will not impact on the general application usability, a fast response and a good interactivity between the user and the interface is needed.

It is possible to utilize a marker in order to track the starting point and is also needed a fast internet connection during the use of the application, this is necessary in order to give to the client a fluent experience.

4.2.3 UI

The user interface of this mixed reality application is studied to be easy and standard for every machine. It is composed by a push-button panel “Figure 50” this will appear

anchored to the marker; the panel is composed by four or five elements depending on the type of machine selected.



Figure 50. Buttons Interface

The buttons on the left will activate the chosen function displaying the chosen element, the elements that are present inside of the application are shown in “Figure 51”:

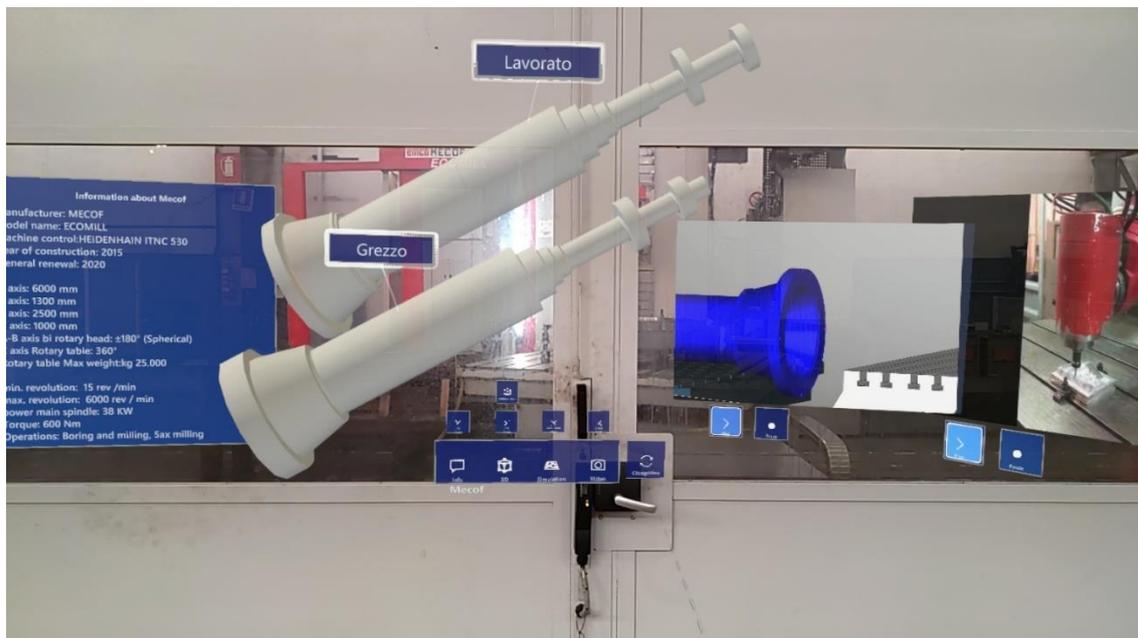


Figure 51. All Open Options

- Info: a panel where are shown the information about the selected machine, the producer info, and the technical data.
- 3D models: the 3D models show the raw pieces that enter in the chosen machine and the worked pieces that exit from it. Those have a label that indicates which model is the raw one and which is the worked.
- Simulation: this is a 3D simulation of the machine in action, in every case shows how the raw 3D model is worked inside of the machine
- Video: this is present in five out of nine machines; it displays how the machine works in real life.

The single button on the right side, called ‘Change View’, change the angulation of the user interface.

4.2.4 Technical details and choices

In order to choose the machines to be inserted inside of the application a check on the available documentation was done, so were chosen only the machines with available the 3D models and the 3D simulation.

The chosen machines are nine, for each one a characteristic marker was generated, the marker has the logo of the company, written the name of the characteristic machine and a binary color code in order to be distinguishable by the system respect to the others. The marker is displayed in an A6 sheet so that it can be easily visible and tracked by the system “Figure 52”.

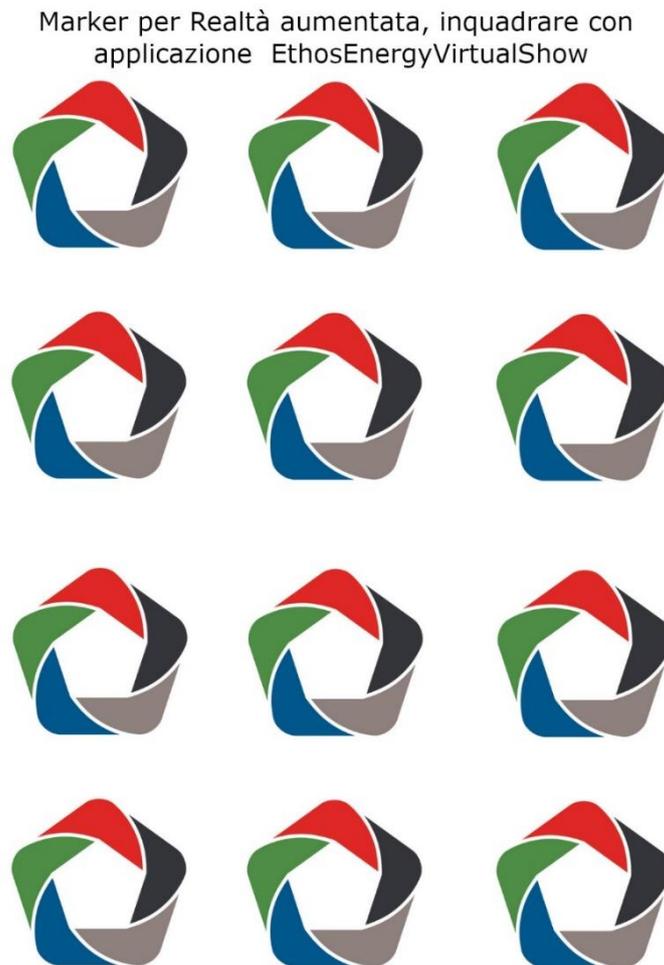


Figure 52. Marker EthosEnergy VirtualShow

Every pop-up is movable and resizable, this is done in order to maintain a good order during the presentation and to explain nimbly the chosen machine.

This characteristic, present especially in the 3D models, is what make the application a mixed reality software.

The user could turn around the holograms so two additional light were necessary added into the scene, this is done in order to make the 3D models and the videos visible from every angulation.

As for the other application the colors were chosen based on the capacity of the system to reproduce them.

A problem that appears during the use of the software is that the system continuously tracks the environment searching for a marker, this will cause instability of the pop-up button panel, in order to solve this problem, the choice made is to cover the marker after that is tracked for the first time. This will avoid instability.

The 3D models are simplified in order to have a low computational load, those models have only the part that is worked inside of the chosen machine.

For each 3D model is attached a label that tell if the piece is 'Raw' or 'Worked', in a first moment the precompiled label produced by Microsoft inside MRTK were used, but, when a bug appeared, it was necessary to delete it and substitute with a new type of label, in image are shown the old vs the new label "Figure 53".



Figure 53. Labels on 3D models

Considering the loss of tracking is possible to add a secondary marker that helps in the anchoring process when the interface is not set in the right way; this solution can substitute the method used to cover the marker.

As already said the application should work in case the marker is vertical or horizontal, for this reason was introduced a button that change the view of the interface, the starting position is vertical, because the main use is inside the workshop where the marker is attached to the machine “Figure 54”.



Figure 54. Different UI positions

4.2.5 Objects and multimedia

The objects, as seen before, are simplified through Blender, in order to have a less complex model so that is displayed easier. The shown objects have different size and are different for each type of machine .

The multimedia elements, in this case the simulation and the real video are played inside of a starting transparent panel, the video are set to be 1920x1080 and are reproduced on the panel where is positioned the chosen texture.

Sometimes the models can be superimposed to the real machine so that it's easier to explain the mounting procedure “Figure 55”.



Figure 55. 3D model inserted in a real machine

4.2.6 Scripts

ChangeView: this script is the script associated with all the elements inside of the application, it is necessary in order to change the angulation of the buttons and of the panel when the marker change the position from horizontal to vertical or in the other case.

It works taking the chosen position and rotation “Figure 56”.

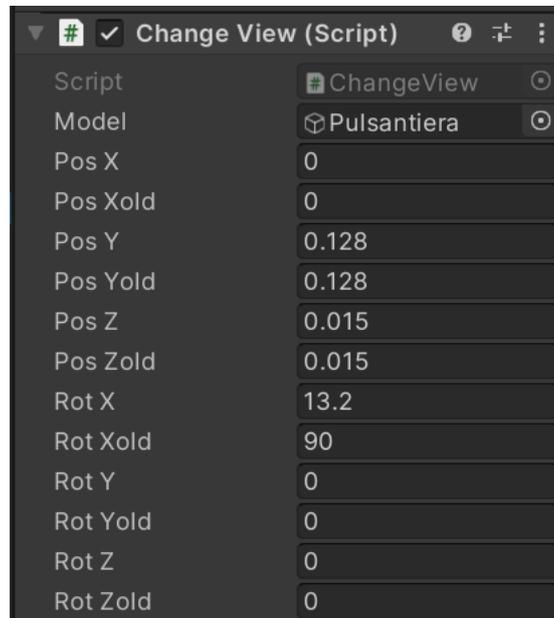


Figure 56. Change View settings

Button Configuration: button configuration is the assignment panel for the functions that a button should activate. Inside of it is possible to assign an object and activate the different functions that are assigned to the defined object.

Game Manager: game manager is the script that manage the 3D objects inside of the scene, the principal parameters are:

- Show: activate the object that was invisible before
- Unshow: disable the active object

Dimension: the ‘Dimension’ script, associated with the 3D models, is the script that bring to the original dimension the object after that are manipulated

NearInteractionGrabbable: this is a grab interaction script that uses the collider and mesh associated to the object to manipulate it, the object to be moved must be near the user.

ObjectManipulator: this script gives the opportunity to move the chosen object around the scene, change the dimension and rotate it.

VideoPlayer: the VideoPlayer script displays the selected video in every panel configured with a certain texture, in this case the texture is set inside a RawImage.

The VideoPlayer also set the working functions of the buttons that control the reproduction of the video.

4.2.7 Life cycle and results

The life cycle of this application is easy and linear, the user watch the marker associated with the near machine, now the system tracks the image and displays the pop-up button panel, the user now can interact with the system and choose what to show.

After that a panel is opened will appear a button in order to close the elements, this is done to maintain a good organization in the space.

When the 3D models are changed in dimension a button appears, this will bring the models to the original dimension.

When the user opens a video or a simulation it will not be played automatically, there are the buttons 'Play' and 'Pause' under the panel, this permit to start and stop the video when wanted.

After that the user will see a new marker, the system will track it, close the previous pop-up buttons with all the information and displays the new one over the last seen marker.

Otherwise, the test done during the video call presented an incompatibility between the Vuforia tracking and the application Dynamic 365 Remote Assist, this drawbacks doesn't allow to use the application during a video call, but it doesn't affect the general usage, the application can be recorded and showed to the customer.

5. Test and Results

In order to evaluate the usability, the effectiveness of the developed applications and also the fatigue that the systems gives to the user, three type of questionnaire are given to a cluster of users inside of the company.

In this chapter will be also analyzed the advantages that the applications brings inside the EthosEnergy business and also the problems that are found inside of the industrial context.

5.1 Pros and cons in EthosEnergy business

After the testing inside of the workshop is possible to speak about the advantages and drawbacks inside of the EthosEnergy context.

Speaking about the first application, the AR tutorial, is possible to see many advantages, the user will be able to operate with the hands free, this increase the security and the fastness in finishing the task, he communicate directly with a remote assistant that will assist him. The drawbacks of this first application are dependent on the site where the marker is applied, an industrial environment, open space and full of objects could confuse the HoloLens and this bring to a loss of tracking, in order to solve the retracing of the anchoring position, the marker is taken away or covered during the tutorial, this leads to a stable experience.

The second application, the Virtual Tour, is characterized by the same drawbacks of the first one, also in this case the problem is solved covering the marker with another sheet or taking it away. The advantages of this application are prevalently the fact that the user will explain in a better way the functioning method of the machine inside of the factory, he is supported by the information, by the video and by the 3D models.

The principal problem, that appeared during the test, is the incompatibility between the tracking system and the contemporary use of the application Dynamic 365 Remote Assist. In the last chapter will be evaluated a solution.

This application is a high scalable application, this gives the opportunity to enlarge the set of machines inside of it, change the UI as the user wants and is also very portable, it can be used everywhere.

5.2 User satisfaction and fatigue tests

In this paragraph will be shown the results of the tests, deepening each questionnaire and the scope.

These are only preliminary investigations and statistical analysis, the group of people that did the interview was composed by twelve candidates, equally subdivided for age, gender, academic background and experience with the system, in order to have results that can be

equally analyzed and that are not influenced by external factors, so that the cluster is homogeneous.

In details the group of people was composed mainly by people that were not familiar with the device, three out twelve were women, the majority had a STEM background, also considering the age:

Two out of twelve were between 20 and 30.

Two were between 30 and 40.

Four were between 40 and 50.

The other four where between 50 and 60.

In order to have better results the cluster should be composed by a greater number of people, this was not possible during the realization of this work of thesis, but the preliminary results obtained are good enough to speak about the general satisfaction in the experience.

5.2.1 SSQ

The Simulator Sickness Questionnaire(SSQ) is used to evaluate the fatigue that the system brings to the user, in this case it is arranged so that is useful to the AR system, some questions were irrelevant for the study, so were taken only the ones that investigate the oculomotor disturbance in detail:

-General discomfort

-Fatigue

-Headache

-Eyestrain

-Difficulty focusing

-Difficulty concentrating

-Blurred vision

The scale of points is:

- 0: no perception of the symptom
- 1: light perception
- 2: perception
- 3: severe perception

In order to obtain a good result, the test is done twice, before to use the system and the second time after the experience, this permit to extrapolate the real discomfort that the system gives to the user.

Now are analyzed the results:

-Pre Test:

PreTest	Difficulty Focusing	Difficulty concentrating	Blurred Vision
Partecipante 1	0	0	0
Partecipante 2	0	0	0
Partecipante 3	0	0	0
Partecipante 4	0	0	0
Partecipante 5	0	0	0
Partecipante 6	0	0	0
Partecipante 7	0	0	0
Partecipante 8	0	0	0
Partecipante 9	0	0	0
Partecipante 10	0	0	0
Partecipante 11	0	0	0
Partecipante 12	0	0	0
Media	0	0	0

Table 1.PreTest1

PreTest	General Discomfort	Fatigue	Headache	Eyestrain
Partecipante 1	0	0	0	0
Partecipante 2	0	0	0	0
Partecipante 3	0	0	0	0
Partecipante 4	0	0	0	0
Partecipante 5	0	0	0	0
Partecipante 6	0	0	0	0
Partecipante 7	0	0	0	0
Partecipante 8	0	0	0	0
Partecipante 9	0	0	0	0
Partecipante 10	0	0	0	0
Partecipante 11	0	0	0	1
Partecipante 12	0	0	0	0
Media	0	0	0	0,090909091

Table 2.PreTest2

How is evident from “Table 2”, only one person had eyestrain before to start the experience with the HoloLens.

The users were in good shape before to start the questionnaire.

-After Test:

AfterTest	Difficulty Focusing	Difficulty concentrating	Blurred Vision
Partecipante 1	0	0	0
Partecipante 2	0	0	0
Partecipante 3	0	0	0
Partecipante 4	0	0	0
Partecipante 5	0	0	0
Partecipante 6	0	0	0
Partecipante 7	0	0	0
Partecipante 8	0	0	0
Partecipante 9	0	0	0
Partecipante 10	0	0	0
Partecipante 11	0	0	0
Partecipante 12	0	0	0
Media			

Table 3. AfterTest1

AfterTest	General Discomfort	Fatigue	Headache	Eyestrain
Partecipante 1	0	0	0	2
Partecipante 2	0	0	0	0
Partecipante 3	0	0	0	0
Partecipante 4	0	0	0	0
Partecipante 5	0	0	0	0
Partecipante 6	0	0	0	0
Partecipante 7	0	0	0	0
Partecipante 8	0	0	0	0
Partecipante 9	0	0	0	0
Partecipante 10	0	0	0	0
Partecipante 11	0	0	0	1
Partecipante 12	0	0	0	2
Media				0.41

Table 4. After Test 2

During the after test three users experienced symptoms, all associated to Eyestrain, how evident in “Table 4”.

The average symptoms values are very low, so the system doesn’t affect the health of the user, is necessary to say that the experience were not longer than forty minutes, so the tests are not associable for a longer usage of the system.

5.2.2 SUS

The second questionnaire submitted to the users is a test that evaluate the system usability, the System Usability Scale (SUS), this is done in order to evaluate how the AR is seen from a professional point of view and to understand if the system could be useful inside of the EthosEnergy business.

The SUS is articulated in ten questions:

1. I think I would like to usually use the system.
2. I think the device is unnecessarily complex.
3. I found the system simple to use.
4. I think I need a person that support me during the experience.
5. I found the functionality good integrated in the system.
6. I found that the functionality were incoherent with the system.
7. I think the majority of the people can learn easily how to use the system.
8. I found the device really difficult to use.
9. I felt comfortable using the device.
10. I needed to learn a lot of processes before being able to make the best use of the device.

For each question is possible to give a score from 1 to 5:

- 1: Completely disagree
- 2: Disagree
- 3: Not agree neither disagree
- 4: Agree
- 5: Completely agree

The evaluation of the final score is done through a specific calculus, the 1,3,5,7,9 questions give a score of 'p-1', the other questions give a score of '5-p', at the end the score obtained is equal or less than 40, so to obtain a value in a scale of one hundred it is multiplied by 2,5.

If the final score is higher than 68 the system is considered acceptable, during the experience the use of the applications were alternated, if one person used the tutorial application as first the next user should use the Virtual Tour as first, this was done in order to have a better statistical dataset, not influenced by the first experience.

In "Table 5" are shown the values for each question, the average and standard deviation.

USER CODE:	1	2	3	4	5	6	7	8	9	10	11	12	Avg	Score	StdDev
I think I would like to usually use the system.	5	5	5	4	5	5	5	5	5	3	4	5	4,63	3,63	0,65
I think the device is unnecessarily complex.	1	1	1	1	1	1	1	1	1	2	1	1	1,09	3,90	0,28
I found the system simple to use.	5	5	5	4	4	4	5	5	5	4	4	4	4,54	3,54	0,52
I think I need a person that support me during the experience.	2	1	1	3	3	4	1	1	1	5	1	1	2,09	2,90	1,41
I found the functionality good integrated in the system	5	3	5	5	5	5	4	5	5	4	5	5	4,63	3,63	0,65
I found that the functionality were incoherent with the system.	1	1	1	1	1	1	1	1	1	1	1	1	1	4	0
I think the majority of the people can learn easily how to use the system	5	5	5	3	4	5	5	5	5	5	5	5	4,72	3,72	0,62
I found the device really difficult to use.	1	1	1	2	1	1	1	1	1	1	1	1	1,09	3,90	0,28
I felt comfortable using the device.	5	5	5	3	5	2	3	5	5	4	4	4	4,18	3,18	1,02
I needed to learn a lot of processes before being able to make the best use of the device.	1	1	1	1	1	1	1	1	1	2	1	1	1,09	3,90	0,28

Tot Score 90,9

Table 5. SUS Questionnaire

As evident the total score obtained is 90,9 and is way higher than the requested score of 68, this tell us that the usability of the system is considered really good by the user that tested it.

The questions that need to be mostly considered and analyzed are prevalently:

-I found the system simple to use



Table 6. I found the system simple to use

The mean value “Table 6” for this question is 4,5 it has a low standard deviation, and it tells us that almost every user felt that the system is simple to use.

For this question is needed a score near to 5 to have a good result.

-I think I need a person that support me during the experience:

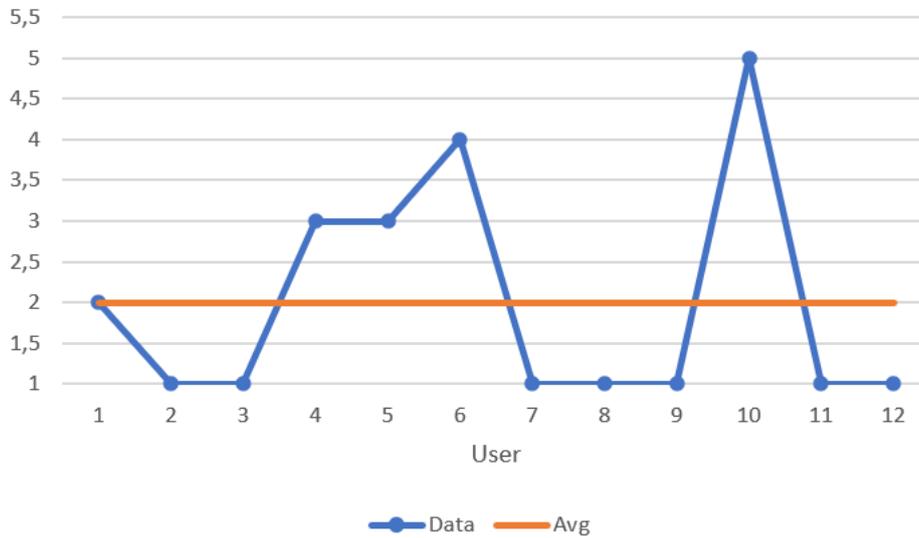


Table 7. I think I need a person that support me during the experience

In this case “Table 7” the results are better if they are near 1 but as evident in the table there is a variation in the response, in two cases the score of five or four leads to an evident insecurity of the user during the usage. This is also evident in the calculus of the standard deviation; the scores are way different respect to the other questions.

-I felt comfortable using the device:

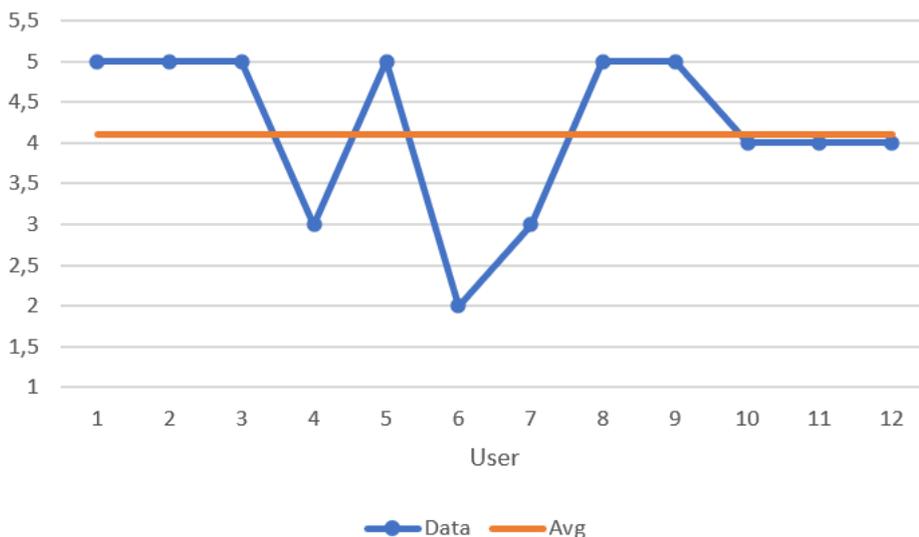


Table 8. I felt comfortable using the device:

As seen in the graph not everyone felt comfortable with the system, this can be associated with many issues declared during the test, those issues are all referred to the HoloLens system and not on the applications.

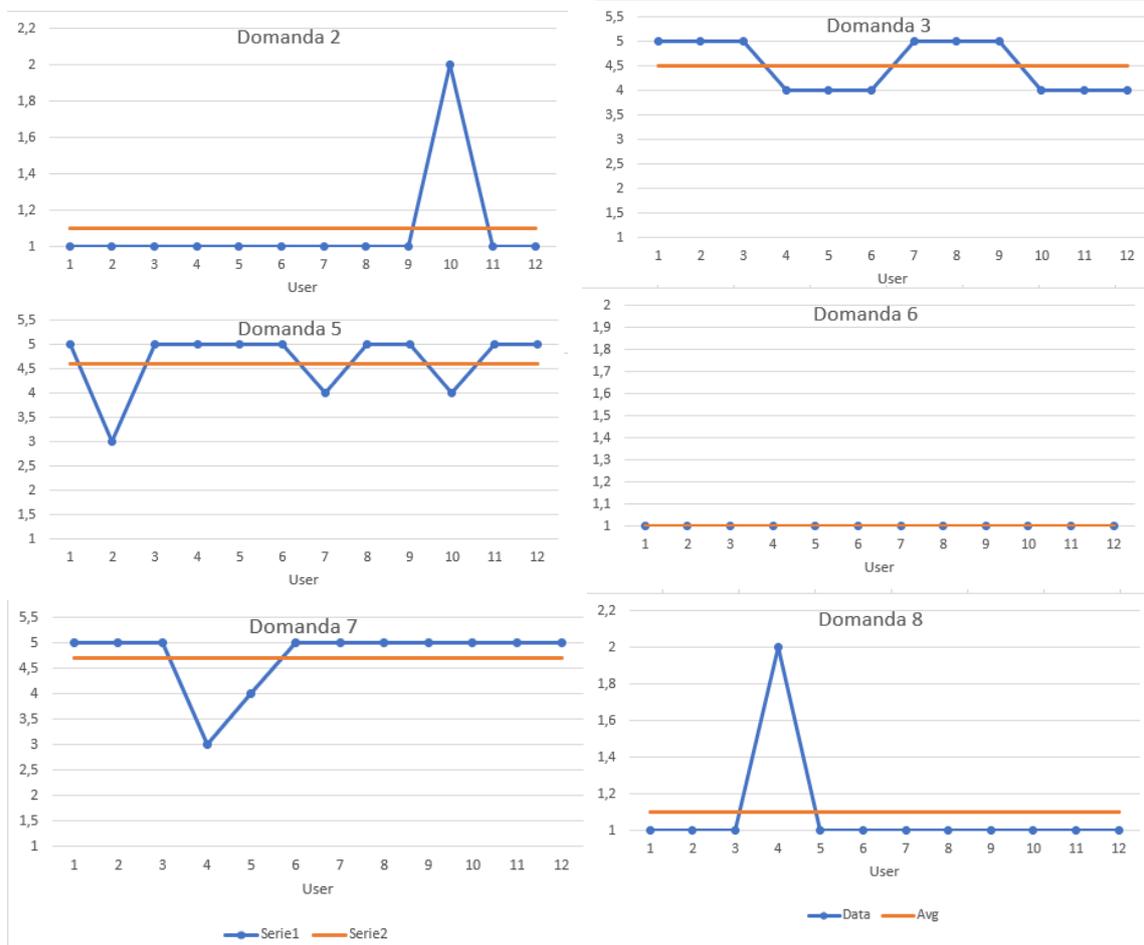
The limited FOV, the tracking of the marker and the quality of the displayed holograms were the main problems reported.

In the questions just set forth is possible to note that the average score goes from 0,5 to 1 below the maximum value, it could seem a negligible value but in a scale that is composed by 5 values this is relevant in statistical terms.

The other questions had a less impressive score, and the high final score of 90 is a really good result.

The next graphs “Table 9” represent the scores of the other questions, the X axis shows the number of the participant, the Y axis displays the possible score, in blue is plotted the grades given by each user, the orange line shows the Average value.

The values obtained are experimental, in order to have a most accurate result is necessary to have a greater cluster of users, as already explained in the beginning of the chapter.



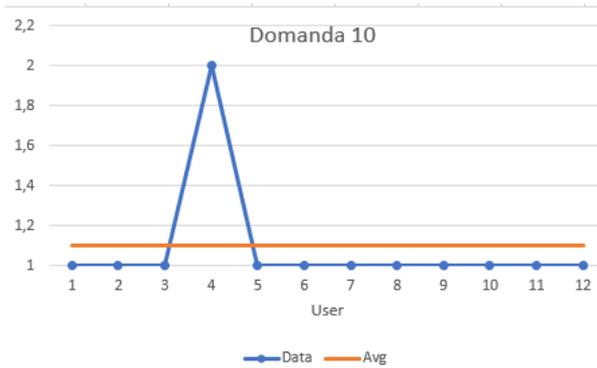


Table 9. Graphs of the questions

5.2.3 VRUSE

After the evaluation of the usability of the system, it is necessary to consider the usability of the single application developed, for this scope is utilized the questionnaire Usability Evaluation of Synthetic Environment Systems (VRUSE).

This type of questionnaire is subdivided in ten typologies of evaluation and one hundred questions, for our purpose there are two typologies that are relevant, the User Input and the Functionality, each one with five specific questions.

The score is equal to the one just explained in the SUS questionnaire, the points goes from one to five and the final score is computed multiplying the final value for 5.

For each application were submitted two type of questionnaire.

The first test evaluates the User Input, and the questions are:

1. The system response to user input was acceptable.
2. I kept making mistakes while interacting with the system.
3. I kept making mistakes while interacting with the system.
4. It was easy to select and move objects in the virtual environment.
5. The input device was too complicated to use effectively.

The questions 1,3,4 give a score of 'p-1', the other questions a score of '5-p'.

The last question asks about the general satisfaction and is evaluated with five scores:

- VS: Very Satisfactory
- S: Satisfactory
- N: Neutral
- U: Unsatisfactory
- VU: Very Unsatisfactory

In “Table 10” are shown the result for the EthosEnergy Tutorial.

User Input														
USER CODE	1	2	3	4	5	6	7	8	9	10	11	12	Avg	
The system response to user input was acceptable	5	5	5	3	5	4	5	5	5	3	5	4	4,5	
I kept making mistakes while interacting with the system	1	1	1	2	1	2	1	1	1	4	1	1	1,5	
I had the right level of control over what I wanted to do	4	5	4	3	3	4	4	5	5	3	5	4	4	
It was easy to select and move objects in the virtual environment	5	5	5	4	5	3	4	4	4	3	5	5	4,2	
The input device was too complicated to use effectively	1	1	1	2	1	1	1	1	1	1	1	1	1,1	
Overall, I would rate the user input as: very satisfactory, satisfactory, neutral, unsatisfactory or very unsatisfactory.	VS	VS	VS	VS	VS	VS	S	VS	VS	VS	VS	VS		

Tot Score 85,5

Table 10. User Input Case 1

As already explained the base score that must be reached to have a satisfactory result is 68, in this case the User Input of the application ‘EthosEnergy Tutorial’ is 85,5, is a really good score, so the UI experience was satisfactory for the user that tested it.

The two questions that needs to be analyzed because of the lower score respect the general flow are:

-I had the right level of control over what I wanted to do:

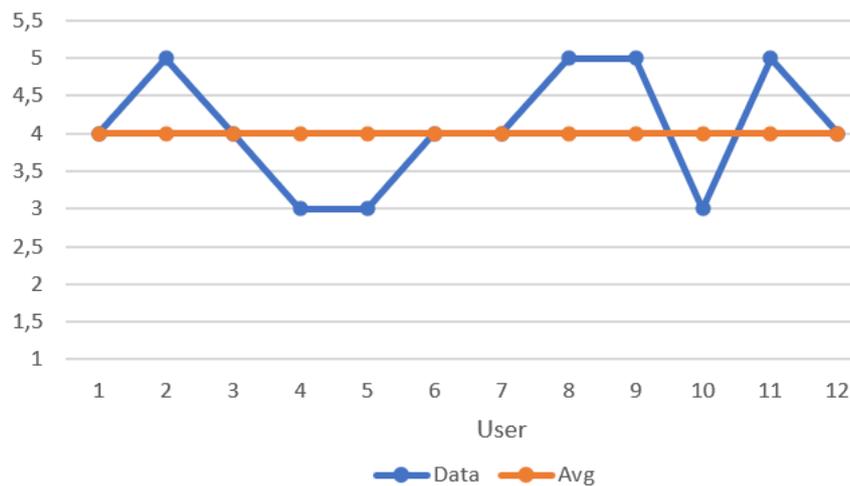


Table 11. I had the right level of control over what I wanted to do:

As evident in the table, some user was not so satisfied speaking about the level of control they had during the use of the ‘EthosEnergy Tutorial’.

This can lead to errors, loss of time and concentration, but the avg score of 4 is not so low to be worried about this possible compliance.

-It was easy to select and move objects in the environment:

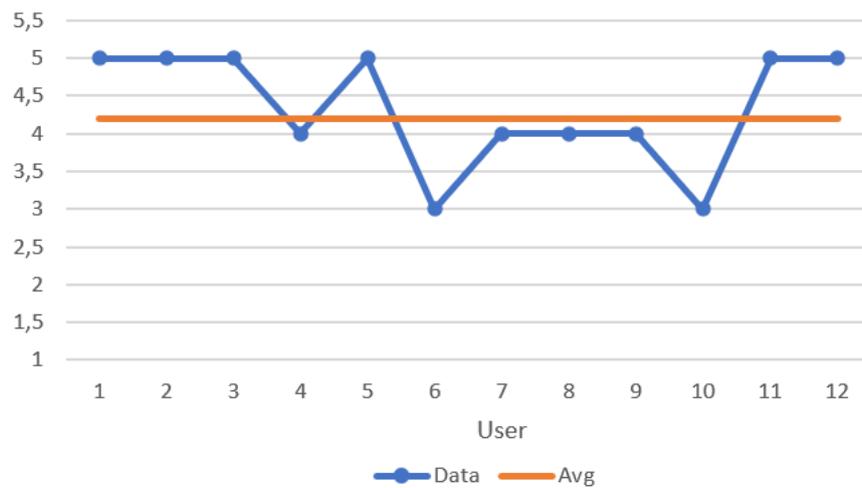


Table 12. It was easy to select and move objects in the environment:

The tutorial application is an AR application so the interaction between the user and the virtual environment are restricted to the menus and the virtual buttons, it is not possible to move the 3D model; is necessary to explain this to understand better the graph and the results.

Someone was not so happy with the interaction fluency, but the average points of 4,2 is satisfactory for our purpose.

The other questions had a general satisfactory value.

Considering the User Input questionnaire done for the ‘EthosEnergy Virtual Show’ application “Table 13”, is evident, from the next table, how it was way better compared to the satisfactory first case.

User Input														
USER CODE	1	2	3	4	5	6	7	8	9	10	11	12	Avg	
The system response to user input was acceptable	5	5	5	3	5	4	5	5	5	5	5	4	4,6	
I kept making mistakes while interacting with the system	1	1	1	1	1	1	1	1	1	1	1	1	1	
I had the right level of control over what I wanted to do	5	4	4	2	3	4	5	5	5	4	5	4	4,1	
It was easy to select and move objects in the virtual environment	4	5	5	4	4	4	5	5	5	3	5	5	4,5	
The input device was too complicated to use effectively	1	1	1	2	1	1	1	1	1	1	1	1	1	
Overall I would rate the user input as: very satisfactory, satisfactory, neutral, unsatisfactory or very unsatisfactory.	VS	VS	VS	VS	VS	VS	S	S	S	VS	VS	VS		

Tot Score 90,5

Table 13. User Input Case 2

As evident from the total score, the second application had a really satisfactory result, speaking about User Input.

Only one question should be analyzed and interpreted with his grade, because of a lower average point respect the others:

-I had the right level of control over what I wanted to do:

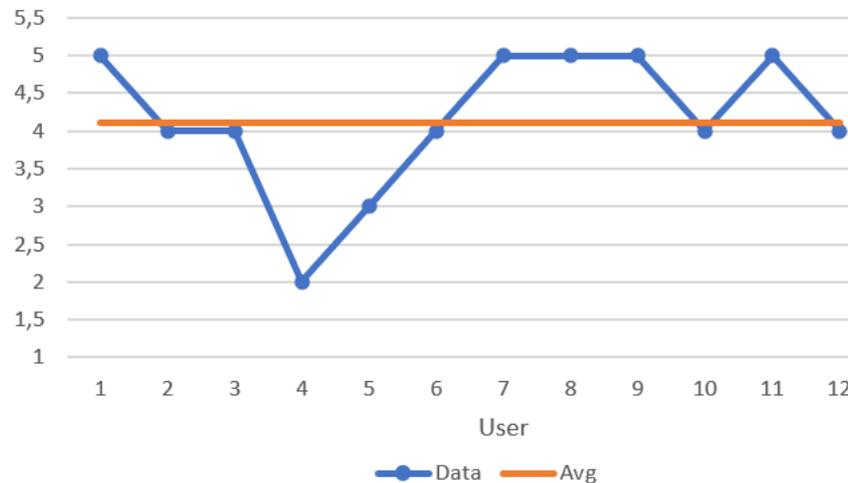


Table 14. I had the right level of control over what I wanted to do:

Is evident that the bad experience of one person reduced a lot the average grade, but is possible to consider the average value obtained still satisfactory.

After the discussion on the results obtained for the User Input is now necessary to underline the statistical analysis done speaking about the second type of VRUSE questionnaire, the Functionality.

In this second part, dedicated to the evaluation of the Functionality, the questions are still five, this time are referred to the general functionality and the coherence with the two applications.

These questions investigate if the functionality provided by the applications are coherent with the task and with the scope of the software.

The questions are:

1. I found it easy to access all the functionality (control) of the system.
2. I understood the meaning of the control interface.
3. The level of functionality (control) provided by the system was appropriate for the task.
4. The functionality provided by the AR system was ambiguous.
5. I did not need to use all the functions provided.

The last question, in the same way of the previous part, evaluate the general satisfaction on the functionality.

As already done before, the analysis starts considering the score obtained for the ‘EthosEnergy Tutorial’ application “Table 15”, in the second part will be analyzed the other application.

Functionality														
USER CODE	1	2	3	4	5	6	7	8	9	10	11	12	Avg	
I found it easy to access all the functionality (control) of the system	4	5	5	4	4	5	5	5	5	5	5	5	4,7	
I understood the meaning of the control interface	5	5	5	3	5	5	5	5	5	5	5	5	4,8	
The level of functionality (control) provided by the system was appropriate for the task	4	5	5	3	5	5	4	5	5	4	5	4	4,5	
The functionality provided by the AR system was ambiguous	1	1	1	1	1	1	1	1	1	1	1	2	1	
I did not need to use all the functions provided	1	1	1	1	1	1	3	1	1	3	3	2	1,4	
Overall I would rate the VR system in terms of functionality as: very satisfactory, satisfactory, neutral, unsatisfactory or very unsatisfactory.	VS	VS	VS	VS	VS	S	S	VS	VS	VS	S	VS		

Tot Score 93

Table 15. Functionality Case 1

The total score obtained is 93, is evident how in general the functionality of this application is appreciated by the users, for this reason the questions that give a critical score in input is not present.

The important question that gives an idea of the easiness of the experience is:

-I understood the meaning of the control interface:

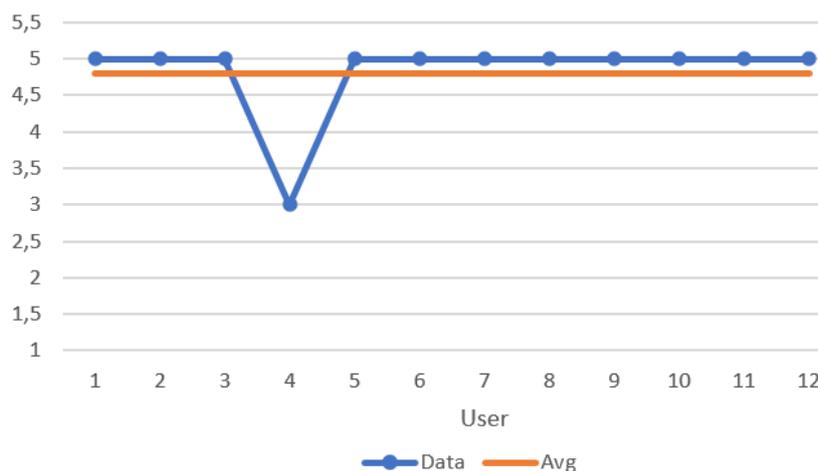


Table 16. I understood the meaning of the control interface:

It’s evident from the graph “Table 16”, with an average value of 4,8, that for almost every user the functionality of the system were easy to understand and interact with.

Considering the Functionality questionnaire for the ‘EthosEnergy VirtualShow’ “Table 17” the values are similar compared to the ones obtained in the previous just analyzed.

Functionality														
USER CODE	1	2	3	4	5	6	7	8	9	10	11	12	Av g	
I found it easy to access all the functionality (control) of the system	4	5	5	4	4	5	5	5	5	5	5	5	4,7	
I understood the meaning of the control interface	4	5	5	4	5	5	5	5	5	5	5	5	4,8	
The level of functionality (control) provided by the system was appropriate for the task	5	5	5	4	5	5	5	5	5	5	5	5	4,9	
The functionality provided by the AR system was ambiguous	2	1	1	1	1	1	1	1	1	1	2	1	1,2	
I did not need to use all the functions provided	1	1	1	1	1	1	3	1	3	3	3	2	1,7	
Overall I would rate the VR system in terms of functionality as: very satisfactory, satisfactory, neutral, unsatisfactory or very unsatisfactory.	V S	V S	V S	V S	V S	S S	S S	V S	S S	V S	V S	V S		

Tot Score 93

Table 17. Functionality Case 2

The final total score is equal for both applications when Functionality is treated.

The question that gives us the most considerable value it's the same of before:

-I understood the meaning of the control interface:

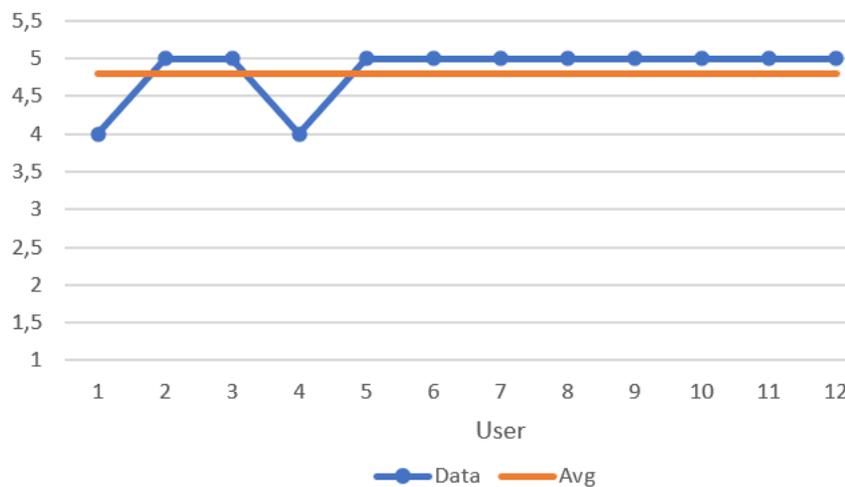


Table 18. I understood the meaning of the control interface:

With an average score of 4,8 the consideration are the same just done for the Tutorial application.

The final consideration that can be done speaking about the general user satisfaction are that the applications are good constructed in order to respect the requests of the task, the questionnaire evaluation tells that in general the twelve user are satisfied by both the applications.

The system is simple to use, even if sometimes the structure of the HoloLens doesn't help and complicate, or also ruins the experience, this happens when the tracking is lost, and it tries to anchor the previous animation and UI.

As already said the solution for this problem is to tell the user to cover the marker after that the interface is anchored.

5.3 User advice on how to improve the experiences

At the end of the test, some additional questions were asked to the participant:

- What have they liked about the applications?
- What would they change inside of the applications?

Almost everyone liked the two applications, especially the User Interface and the animations of the Tutorial software.

Speaking about what they would change, someone thought that the UI of the 'EthosEnergy Tutorial' could be better if customizable by the single user, so that the position of the buttons fits the necessity of the user.

For the second application no one told anything on how it could be modified to have a better experience.

6. Conclusions and future development

In this last chapter will be deepened how the AR, the MR and especially the two developed applications impact on the EthosEnergy business, will be also analyzed the possible future development of the applications, and use cases of the XR inside an industrial environment.

This work of thesis tried to answer to the question that ask if an augmented reality system could be used and be useful inside of an industrial environment, especially in the EthosEnergy business.

The questionnaire analyzed in the chapter 5 showed a positive general result for both the applications, this was confirmed by the test done inside of the workshop; the best thing to do, to understand the usefulness and the results, is to speak separately of the two applications.

The application “EthosEnergy Tutorial” resulted to be a useful application for the maintenance and repair purpose, it was tested by the field service and inside of the workshop; the application could also be a nice solution to instruct an operative field employee on how to mount the stages of the turbine, especially in a remote site. This application is scalable and customizable, it can be easily modified to insert different type of tutorials. This type of application, as seen in the state of the art paragraph, is greatly used inside of the industrial context, this avoid mismatch and errors during the procedure, it increases the security and also the time efficiency.

Speaking about the future development of this application, it could be a good idea to insert a list of possible languages of the tutorial, insert video of the mounting phase and also increase the number of mounting procedures executable through the tutorial.

In general, thanks to the results obtained during the development of the application, it is considered a helpful application inside of the EthosEnergy business.

The second application “EthosEnergy VirtualShow” is a really worthwhile application that will be considered an upgrade for the normal remote calls done with the customers for marketing purpose; the problems found testing the application in a video call will not compromise the general result, the application could be recorded and showed to the customers, is evident how this application will help the EthosEnergy marketing sector during the site view.

This application is a nice solution when the machines inside of the workshop are turned off, it gives all the important information and has a really intuitive set of input, the user is supported by this application to explain in the best way the working phases done inside of the EthosEnergy workshop.

The scalability and the easy to use characteristic are helpful speaking about a future grow up of this application, inside of it is possible to easily insert many other machines, and a good function could be to insert an interactive 3D simulation visible by every angulation and manipulated by the user.

Considering the problem found during the contemporary use of the application and the video conference software Dynamic 365 Remote Assist, a solution can be found avoiding using the marker and replacing it with a menu, it will contain all the machines and will be set in order to follow the user, avoiding using a stable and standard anchor.

The “EthosEnergy VirtualShow” is a useful application, this will help the marketing with the customers, and take the business one step inside of the industry 4.0; is now possible to say that the objectives set in the starting part of this thesis are achieved.

After that, a good thing to do is to analyze the future development of the XR inside of the EthosEnergy business and inside of a general industrial context; this type of technology can become really useful if inserted inside of an industry 4.0 context, in which many other new technologies are utilized, for example the IoT and the 5G; these three technologies, together, could be used in order to interact with the machines through the XR experience, the IoT is useful to connect the applications with the machines and check remotely the state, the 5G is useful to reduce the latency (one of the most important specifics inside of an industrial context), and the AR or MR will replace the physical commands machines, this system increase the usability and the security, and will also reduce the space used in the work shop and the time of machinery.

In general, the XR systems has many benefits and many future development inside of an industrial context, especially if the system is configured for all the new technologies that characterize the industry 4.0.

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Index of Acronyms

AR Augmented Reality

APK Android Application Package

CAD Computer Aided Design

CES Consumer Electronics Show

FOV Field of View

GUI Graphical User Interface

HMD Head Mounted Display

HUD Heads Up Display

IAR Industrial Augmented Reality

IDE Integrated Development Environment

IR Infrared

LBS Local Based Sensors

LTS Long Term Support

MR Mixed Reality

MRTK Mixed Reality ToolKit

OS Operative System

PTAM Parallel Tracking and Mapping

SDK Software Developer Kit

SLAM Simultaneous Localization and Mapping

SSQ Simulator Sickness Questionnaire

STEM Science, technology, engineering, and mathematics

SUS System Usability Scale

UI User Interface

VISLAM Visual Inertial SLAM

VR Virtual Reality

VRUSE Virtual Reality Usability System Environment

WMR Windows Mixed Reality

XR eXtended Reality

6DoF 6 Degrees of Freedom