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Master's Degree Thesis

Holomuseum: a prototype of interactive exhibition with Mixed Reality glasses HoloLens



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1. INTRODUCTION

In this thesis, I am going to talk about the results of the work I carried out, as Erasmus trainee, in the Universidad Politécnica de Valencia (UPV).

During my three months internship, I was under the supervision of a tutor, the professor Adolfo Muñoz García, lecturer in the Fine Arts and Computer Engineering faculties and researcher in the IDF, Instituto de Diseño y Fabricación, of the UPV.

Professor Muñoz lets me collaborate with him on Holomuseum, a mixed reality application for Microsoft HoloLens device, invented and designed by him, with these purposes:

- to change the experience of museums visitors, making it much more interactive and immersive, allowing them to download virtual objects from Internet with which they interact in the museum space;
- to give to the expo curator an instrument to easily manage and organize an AR (Augmented Reality) exhibit in the space;
- to create a flexible app that can be used in different kinds of exhibition.



Figure 1.1: Holomuseum logo, created by Professor Adolfo Muñoz García.

So, our final goal was to construct a prototype that could be used to demonstrate and explain the innovative ideas that were the basis of Holomuseum. In particular, we had to complete the application in time to take part in the exhibition "Fiera de los Inventos" (June 13 - July 25), that has the aim of showing the results of the research carried out in the university, every two years. We had to evaluate the following aspects:

- how to structure the object that will be the reference to the expo item;

- how to manage the download of the contents, taking into consideration their diversity (interactivity, file dimension, ...) and possible errors;
- from the curator point of view, what tools are necessary to prepare the exhibition for the spectators;
- the user experience design and the animations, both important to assure to the expo visitors an intuitive and satisfactory use of the application.

Therefore I will discuss all these subjects, analysing them accurately and considering, for each of them, the problems we had during the implementation and the relative solutions, the results we achieved, and what we can still improve.

2. STATE OF THE ART

Before starting with the description of Holomuseum, I think it is important to understand how the HoloLens work and to know their position in the current market. In this chapter, I am going to talk about the HoloLens device structure and the main applications developed in collaboration with Microsoft.

I will also refer briefly to the concept of Mixed Reality, making a brief comparison with the Augmented and the Virtual Reality, which are often confused.

2.1 Mixed Reality

Mixed reality is the product of the fusion of the physical world with the digital world. The term "mixed reality" was originally introduced in a 1994 paper by Paul Milgram and Fumio Kishino, "A Taxonomy of Mixed Reality Visual Displays"¹.

Milgram and Kishino theorized the concept of "virtuality continuum".

They placed on one extreme of the continuum the real world and on the other side a completely virtual world (Fig. 2.1). The space lying between the two extremes, all the technologies and applications, represents different flavours of Mixed Reality (MR), including AR (real environments augmented with virtual contents) and Augmented Virtuality (virtual environments augmented with real contents) (Brondi et al., 2016).



Figure 2.1: Virtuality Continuum (http://labs.dash.umn.edu/wp-content/uploads/2016/12/8.png)

Consequently the application of mixed reality is not limited to displays but involves environmental input, spatial sound and location as well¹.

The blending of computer processing, human input and environmental input, provides the possibility to generate true mixed reality experiences¹ (Fig. 2.2).

¹ https://developer.microsoft.com/en-us/windows/mixed-reality/mixed_reality

Whereas in the mixed reality real and digital world interact, and the second is influenced by the first, in the virtual reality nothing is real and everything is virtual: it is a completely separate and artificial world designed to change the user reality and immerse him in it. However, the augmented reality can be simply seen as a layer on top of the existing reality, not mixed into it; the AR elements cannot be interacted with as part of the larger environment, but only through a device screen.



Figure 2.2: Mixed Reality: combination of computer processing, human input and environmental input¹.

2.2 AR and MR for Virtual Heritage

The expression "Virtual Heritage" refers to interactive systems conceived through the application and integration of ICT technologies in the cultural heritage area.

This process supplies a visual representation of relics, artefacts, monuments, architecture, and in general anything that is inherited from the past and has to be preserved and protected for future generations.

Virtual heritage is useful for many scopes.

Firstly, to document and reconstruct objects or buildings of historical significance that no longer or only partially exist, due to weather agents or natural cataclysms, for instance (El-Hakim et al., 2004). In addition, to provide visual scenes from viewpoints impossible in the real world, due to size or accessibility issues, allowing interaction without danger of damage (El-Hakim et al., 2004). Finally, to create educational resources for students and researchers in various different fields (El-Hakim et al., 2004).

In many discussions about this subject, we can also find the more specific term "virtual museums", but it is important to point out that a virtual museum is not only, or necessarily, an online duplicate of a real museum, as the words could suggest. Citing the definition proposed by Hazan et al. in their V-MUST research (2014), a virtual museum is:

"a digital entity that draws on the characteristics of a museum, in order to complement, enhance, or augment the museum experience through personalization, interactivity, and richness of content. Virtual museums can perform as the digital footprint of a physical museum, or can act independently, while maintaining the authoritative status as bestowed by ICOM in its definition of a museum. In tandem with the ICOM mission of a physical museum, the virtual museum is also committed to public access to both the knowledge systems imbedded in the collections and the systematic, and coherent organization of their display, as well as to their long- term preservation."

Virtual heritage goes hand in hand with the significant changes museums have undergone in the twenty first century. In the current social, historical and technological context, museums cannot simply be limited to display objects or artworks, as well as their conservation and study. Sofia Pescarin (2014), in "Museums and Virtual Museums in Europe: Reaching Expectations", explains the reasons for this transformation.

She thinks we are witnessing to a shift in the view of the museum, both for curators and for the visitors, which can be described in two main directions.

The first cause could be the general crisis which in fact is not preventing people to visit museums, as we would expect, but is rather increasing the number of visitors (Pescarin, 2014). The speed of scientific and technological development, environmental changes, streamlined communication, cause people to perceive a sense of uncertainty that, especially with the awareness of the rate at which the world is changing, pushes them to find reference points that are stable and reflections of our past (Pescarin, 2014).

Therefore the first direction refers to the stability of content and communicated messages (Pescarin, 2014).

On the other side, there is an impulsion towards flexibility.

Sherry Turkle (2011), social scientist at MIT, perfectly observes the modern trend of communicating faster and faster, since "[...] *Technology sets expectations about speed*": because of this tendency, people need complex information divided into small or synthesised parts.

The idea of a museum, whose goal is just the preservation or study of its collection, is no longer feasible to attract visitors: there is the need to focus more on communication and fascination.

Summarizing, Pescarin (2014) affirms that "visiting a museum and, critically, re-visiting a museum, requires the museum to offer constantly new, attractive but serious exhibits, that might provide a combination of "stable", fast and flexible contents."

In 2014 V-MUST.NET conducted a preliminary survey in the Museum of Fori Imperiali in Rome, to understand better the meaning of "attractiveness" and the new emerging needs of twenty first century visitors. The poll showed that visitors see museums as "*places of social aggregation and of informal learning*" and "*want a museum that could tell them stories*" (Pescarin, 2014).

As confirmed by V-MUST studies, in this perspective virtual museums are a successful answer to these demands. Through the reconstruction of immersive environments users can learn and understand ancient cultures and new subjects, in a pleasant way, with the help of a narration that become a bridge between the visitors and the past epochs or the exhibit context (Noh et al., 2009).

V-MUST.NET survey studied also the main expectations people have about modern museums and virtual heritage. Results show that the majority thinks it is essential a simpler communication of the cultural information, thanks to a language close to the everyday one, and the presence of a narration: storytelling is in fact a real aid to understand the concepts the exhibit wants to transmit, both for adults and for children.

Furthermore, virtual museums should offer a greater number of details in comparison to a real museum and propose engaging and entertaining situations (especially the younger generation do not always consider visiting museums a pleasant and satisfying experience), and give possibilities of interaction (Pescarin, 2014).

These new visitors requirements have considerable repercussions on the curator side, since he has the task of managing the objects loans and their incorporation in his display, an operation frequently complicated because of preservation issues or costs that strongly limit the flexibility in the creation of the exhibition.

In this panorama, virtual heritage is consequently gaining an increasing consent and actually many AR and MR applications have been developed. They have been designed to meet the needs of visitors and curators in museums of different genres (sciences, natural history, archaeological, and so on).

Some examples of AR and MR applications are analysed below.

2.2.1 Archeoguide

Archeoguide is among the first AR applications developed in the cultural heritage field. It is installed at Greece's Olympia archaeological site for testing, demonstration, and user evaluation (Vlahakis et al., 2002).

It is a mobile system that works like a personalized electronic guide to outdoor archaeological sites, showing users, through a Head Mounted Display (HMD), the virtual reconstructions of the temples and other monuments directly overlaid on the real ruins (Vlahakis et al., 2002).

Archeoguide consists of a client-server architecture with three basic subsystems: the site information server (SIS), mobile units (laptop, pen-tablet and palmtop computers), and the network infrastructure (WLAN) (Vlahakis et al., 2002).

Users are treated as active pointing devices and, when they stop at the viewpoints, mobile units transmit a request to the SIS; the SIS extracts the corresponding audio-visual data from its database and transmits it back to the mobile unit; then the application matches the reconstruction model to the live video stream (Fig. 2.3) from the web camera mounted on top of the user helmet, transforms it accordingly, and renders it, synchronizing the audio narration to the visual presentation displayed via the HMD (Vlahakis et al., 2002).

An interesting aspect of Archeoguide is the personalization of the tour before the beginning of the visit: according to parameters like age, education, interests, archaeological knowledge, the system plans a specific tour for each user, who can modify it through his behaviour or gamepad inputs Vassil (Vlahakis et al., 2002).



Figure 2.3: Ruins of the temple of Hera in their present state and augmented temple with rendered model on top of live video (Vlahakis et al., 2002).

2.2.2 ARCube

ARCube system has the goal of increasing and enriching AR applications focused on archaeological objects. This low-cost and flexible system allows users to interact with digital

3D models just by handling a simple cube, the ARCube (Fig. 2.4 a)), rotate them through 360° and observe details in high resolution (Jiménez Fernández-Palacios et al., 2014).

Each face of the ARCube loads a different part of the 3D model, on a scale of 1:1 (Fig. 2.4 b)); thus each portion of the model has to be associated to a precise face of the cube to rightly display the object's geometry (Jiménez Fernández-Palacios et al., 2014).

Unlike other archaeological AR applications, that despite the use of expensive devices are often inadequate for visualizing complex artefacts, some executed tests proved ARCube reliability on a variety of objects characterized by different shapes and sizes (Jiménez Fernández-Palacios et al., 2014).



Figure 2.4: a) The ARCube device and b) a screenshot of the employed opensource BuildAR software for the visualization of archaeological artefacts (Jiménez Fernández-Palacios et al., 2014).

2.2.3 Who Do You Think You Really Are?

It is an AR system designed for the Natural History Museum in London to present evolutionary history to their visitors through an interactive film called "Who Do You Think You Really Are?", produced in conjunction with the BBC Natural History unit (Debenham et al., 2011).

The film projection takes place in the David Attenborough Studio lecture theatre and offers an innovative museum experience that makes use of a custom camera tracking technology with specially-designed handheld displays and rendering software (Debenham et al., 2011).

The need for a tracking system that gave perfect image stability between real and virtual components, led to the choice of a system using infra-red LEDs as markers. These could be placed around the Studio space in an unobtrusive manner, at positions that were precisely measured. Therefore LEDs were used, which were completely invisible to the naked eye but visible to the webcam (Debenham et al., 2011).

The handheld device contains a capacitive touch-screen display, a rear facing camera for the augmented reality system, and a forward facing camera to capture an image of the user for other

elements of the interactive film. It was developed by IVC Media Ltd and Melford for the Natural History Museum specifically for this application (Debenham et al., 2011).

The system combines animated 3D models of extinct creatures with live video from the webcam in the handheld display to create the impression that the creatures are wandering around the theatre in front of the spectators². The camera tracking technology allows the system to render a view of the creature that matches the handheld's camera view by exactly calculating the camera's position and orientation within the studio, giving the audience an opportunity to use their display to track the creature as it moves around them² (Fig. 2.5).



Figure 2.5: The application in use (Debenham et al., 2011).

2.2.3 Bitter&Sweet

Bitter & Sweet (the name refers to the location's bitter colonial history and the sweetness of the sugar imported from the colonies to Denmark) is a mixed reality prototype that combines AR software on iOS handheld devices, onsite media projection, performance, installations, in and around the Royal Cast collection of the Copenhagen National Gallery housed in the West India Warehouse³.

The developers used Argon, a framework that provides a set of abstractions and utilities in order to create an AR view to web application, in an independent way for platform and technology⁴.

³ http://livingarchives.mah.se/close-contact/,

² http://www.bbc.co.uk/rd/blog/2010-12-augmented-reality-film-launche

https://mw17.mwconf.org/paper/augmented-and-mixed-reality-design-for-contested-and-challenging-histories-postcolonial-approaches-to-site-specific-storytelling/

⁴ https://www.argonjs.io/

The prototype, shown at an event in February, 2016, uses image-recognition capabilities in AR to overlay digital material about postcolonial history in Denmark, such as old films, fragments of sound and images, onto surfaces and objects inside or close to the building (Fig. 2.6)³.



Figure 2.6: Participants gather close to the full body cast holding their devices up to the track image on her body³.

2.2.4 "Virtual Museum" at New York Armory Show

This is a purely artistic project that exploits the advanced holographic computing power of the HoloLens to allow visitors to freely move around the designed virtual projections and experience the art from any perspective⁵.

The Armory Show in New York, in its twenty third year, presented collections of some of the most important artworks from the last two centuries⁵. At the latest show, the online platform Artsy, aimed at exploring art from around the world, working together with Pace Gallery's Studio Drift, a design firm based in Amsterdam, created an art installation using an immersive mixed reality experience with Microsoft's MR headset⁵.

This project represents Microsoft's first official collaboration with a commercial art venture⁵.

Visitors begin the experience by entering a room marked with green lines that all interweave with one another; small broken pillars are apparently placed randomly across the installation⁵.

⁵ https://vrscout.com/news/art-exhibit-virtual-museum-hololens/, https://www.digitaltrends.com/virtual-reality/hololens-virtual-museum/, http://fortune.com/2017/03/02/microsoft-hololens-art-show/

(Fig. 2.7 a)). Thanks to the MR capabilities of the headset, virtual pillars extend from the physical structures spreading across the installation (Fig. 2.7 b))⁵.



Figure 2.7: a) The installation at 23^{rd} Armory Show in New York and **b**) a screen view of the relative developed HoloLens application⁵.

2.2.5 LBJ Presidential Library and Bullock Texas State History Museum

Cortina Productions, a media, design and production company specialized in location-based multimedia experiences, hosted two Mixed Reality demonstrations in conjunction with SXSW (South by Southwest Conference & Festivals)⁶.

Both of the AR applications generate 3D virtual overlays, affixed atop pre-existing exhibits, that users can visualize through the Microsoft HoloLens device.

The first display, at the Bullock Texas State History Museum, allows visitors to view the 300ton, 54-foot long shipwrecked La Belle in its full-scale wholeness, superimposed to the hull of the ship, the craft's only excavated remains⁷ (Fig. 2.8). The 3D model of the ship was enriched with detailed animations of the vessel at sea, such as flags waving in the wind or cannons firing at enemy ships⁷.



Figure 2.8: La Belle: the remains, at the left, and the 3D model of the whole craft, at the rigth⁷.

⁶ http://www.cortinaproductions.com/holograms-in-museums/

⁷ https://segd.org/experimenting-microsoft-mixed-reality-museums,

https://segd.org/cortina-productions-offers-ar-demo-lbj-presidential-library

In the second demonstration, at the Lyndon B. Johnson Presidential Library, with a similar app design, users view and interact with parts of the museum's vast historical collection⁷.

In the main gallery space there are several windows that look into the Library's archival collection; Cortina designed a solution to transform six of these openings into menu items (one for each day of the Six Day War of June 1967)⁷. When users select the windows, higher than most visitors' natural eye lines, a representation of archival images and documents falls in front of them (Fig. 2.9); visitors can walk up to these contents listening to some audio during the experience⁷.



Figure 2.9: Cortina demonstration at the Lyndon B. Johnson Presidential Library⁷.

2.3 Microsoft HoloLens

A brief description of the device used for the development of Holomuseum is presented below. I will summarise the main Microsoft HoloLens (Fig. 2.10) characteristics relative to hardware, optics, sensors and human input recognition.



Figure 2.10: Microsoft HoloLens (https://www.microsoft.com/en-us/hololens)

2.3.1 Optics

- See-through holographic lenses (waveguides)
- 2 HD 16:9 light engines
- Automatic pupillary distance calibration
- Holographic Resolution: 2.3M total light points
- Holographic Density: > 2.5k radians (light points per radian)

Microsoft HoloLens is a pass-through device: through the device's clear lenses, made up of three layers of glass (blue, green and red), we can see the real world around us and the holograms are projected in front of us, up to several meters away⁸.

The first element that defines the device optics, are the two HD 16:9 light engines, which are tiny liquid crystal on silicon displays, like those of a common projector; they are mounted on the bridge of the lenses, under the IMU (Inertial Measurement Unit)⁸.

The light engines produce images which must pass through a combiner that associates the projected images with the real world.

HoloLens uses total internal reflection (TIR)⁹ to create the final holograms. The TIR can bounce light internally or aim it at the user's eye, depending on the prism shape used to produce the reflections.

Microsoft had to face up to the problem that, taking advantage of TIR physics, a big volume was necessary to obtain a large FOV (field of view); the solution to maintain a large FOV, despite the small dimensions available in the device, was to use waveguides in the lenses, applying a surface coating on them⁸. As a result Microsoft was able to create a series of diffraction gratings⁸.

These diffraction gratings bend the light so that it reflects (in accordance with TIR laws) and hits a zone that causes it to turn about 90 degrees, in the direction of an "exit zone"¹⁰ (Fig. 2.11). This zone reduces the angle of the light that will no longer obey TIR and can exit towards the eye¹⁰.

Another function of the waveguides is to perform an "exit pupil expansion" so that the image can be viewed from a wider angle¹⁰.

⁸ http://www.tomshardware.com/news/microsoft-hololens-components-hpu-28nm,32546.html

⁹ Complete reflection of a ray of light within a medium (such as water or glass) from the surrounding surfaces back into the medium. Glass prisms can be shaped to produce total internal reflection and as such are employed in binoculars, periscopes, telescopes, and other optical instruments. (https://www.britannica.com/science/total-internal-reflection)

¹⁰ http://www.kguttag.com/2016/10/27/armr-combiners-part-2-hololens/



Figure 2.11: Diffraction gratings to bend light so that it obeys to TIR¹⁰.

It is crucial to get all of this right, otherwise the holograms will "swim" in user vision, potentially causing nausea⁸.

Using total internal reflection forced Microsoft to limit the exit angles to 35 degrees for each component, achieving a 70 degrees FOV at the very least for the current HoloLens¹¹.

2.3.2 Sensors

- 1 IMU
- 4 environment understanding cameras
- 1 depth camera
- 1 2MP photo / HD video camera
- Mixed reality capture
- 4 microphones
- 1 ambient light sensor

The sensors are the most important component, because they will determine the user experience.

The sensor bar on the HoloLens comprises: two "environment understanding cameras" on each side; a depth camera; an ambient light sensor; a 2MP photo/HD video camera¹² (Fig. 2.12). Some of these are standard parts, whereas Microsoft custom-built others¹².

The environmental sensing cameras allows the head tracking¹².

¹¹ https://mspoweruser.com/microsoft-found-way-double-hololens-field-view/

¹² http://www.tomshardware.com/news/microsoft-hololens-components-hpu-28nm,32546.html

The depth camera has two functions: it helps with hand tracking, and it also performs surface reconstruction, which is essential in the placement of holograms on physical objects¹².

These sensors work together with the optics module and the IMU, the Inertial Measurement Unit¹³, which is mounted on the holographic lenses, right above the bridge of the nose.

Environment cameras provide the user with a fixed location in space and posture, the IMU calculates linear acceleration and angular velocity, so that when the user moves his head around he can see through the displays the holograms according to the latest position information. The device needs less than 10ms to do all this: it is a reasonable gap to prevent image "swimming" and to ensure that holograms stay locked to their position in the real world space¹².

Finally there are four microphones that can benefit from noise compression and stereo speakers mounted on the headband, corresponding to the ears position.



*Figure 2.12: Microsoft HoloLens sensors (picture from https://www.tomshw.it/microsoft-hololens-abbiamo-provato-salto-futuro-87570, modified according to Microsoft information*¹²*).*

2.3.3 Human Understanding

- Spatial sound
- Gaze tracking
- Gesture input
- Voice support

The Microsoft HoloLens is the first AR device to use the HRTF¹⁴ (Head-Related Transfer Function) to configure audio to simulate the way people perceive and process sounds by ear, positioning them in the world thanks to the sound analysis of the brain.

¹³ Electronic device that measures and reports orientation, velocity, and gravitational forces through the use of accelerometers and gyroscopes and often magnetometers (https://www.spartonnavex.com/imu/).

¹⁴ https://www.onmsft.com/news/hololens-3d-spacial-sound-is-what-sets-microsofts-tech-apart

Matthew Lee Johnston, Microsoft's audio innovation director, explains in an interview: "Spatial sound roots holograms in your world. The more realistic we can make that hologram sound in your environment, the more your brain is going to interpret that hologram as being in your environment."¹⁴

In addition to perceiving the holograms projected in the real world, users can also interact with them.

First of all, the HoloLens glasses use the position and orientation of the user's head to determine the gaze vector: a ray that the applications intersect both with their holograms and with the spatial mapping mesh to establish at what virtual or real-world object the user is looking¹⁵. Generally apps should use a cursor to give the user confidence in with what they are about to interact.

The HoloLens device is able to recognize several hand gestures that permit the user to take action in mixed reality. There are two main inputs:

the "Bloom" gesture (Fig. 2.13), to go Home (similar to pressing the Windows key on a keyboard), performed holding out the hand, palm up, with the fingertips together, and then opening the hand¹⁶;



Figure 2.13: Bloom gesture (https://support.microsoft.com/en-us/help/12644/hololens-use-gestures).

the "Select" or "Air Tap" gesture (Fig. 2.14), the primary interaction to activate a hologram, consisting of a press followed by a release; it is performed positioning the hand with its back in front of the face, raising the index finger to the sky and then tap, by flexing the index finger down (the press) and then back up (the release)¹⁶.

¹⁵ https://developer.microsoft.com/en-us/windows/mixed-reality/gaze

¹⁶ https://developer.microsoft.com/pl-pl/windows/mixed-reality/gestures



Figure 2.14: Air Tap gesture (https://support.microsoft.com/enus/help/12644/hololens-use-gestures).

There are also complex gestures combining presses and releases with movements of the hand (for example the "drag and drop"), but it will not be discussed, because Holomuseum only supports the two fundamental inputs.

2.3.4 Processors and Memory

- Intel 32 bit architecture with TPM 2.0 support
- Custom-built Microsoft Holographic Processing Unit (HPU 1.0)
- 64GB Flash
- 2GB RAM

Microsoft Devices Group engineer Nick Baker explained they rejected using traditional components in favour of a personalized design that includes hardware acceleration and programmable elements¹⁷.

HoloLens had an Intel Cherry Trail chip and the Holographic Processing Unit (HPU)¹⁸.

The system is essentially mobile hardware with a 64 GB internal storage and 2GB of RAM (1GB for the SoC and the HPU); it is based on x86 architecture and runs Windows 10¹⁸.

The SoC carries out the majority of the work, since it handles the operating system, the applications and the shell¹⁸.

The HPU main purpose is processing the data originated from the sensors, such as the wearer's gestures, and sending it to the SoC¹⁸. The HPU's design allows Microsoft's engineers to assure latency and duty cycles during the elaboration¹⁷.

¹⁷ https://www.theregister.co.uk/2016/08/22/microsoft_hololens_hpu/

¹⁸ http://www.tomshardware.com/news/microsoft-hololens-components-hpu-28nm,32546.html

Microsoft revealed on July that it is working on a new artificial intelligence chip to enhance its second-generation HoloLens headset¹⁹. The system will implement deep neural networks (a machine learning procedure with a structure similar to that of the human brain) into the HoloLens' core processing unit¹⁹. Thanks to a dedicated A.I. chip, the complex data collected by the device depth camera and sensors will be interpreted and processed without latency¹⁹. Microsoft has not announced yet the updated glasses release date officially, but rumour has it arriving in 2019¹⁹.

2.4 Applications

The HoloLens glasses offer a huge number of possibilities of usage, much more than the several VR glasses present in the market we are accustomed to see, almost exclusively deployed in the videogames sector.

The HoloLens Agency Readiness Partners program, focused on facilitating and supporting digital companies and solution providers who are dedicated to develop mixed reality solutions for their clients, is a clear proof of its adaptability.

The request for the HoloLens has quickly grown, and Microsoft has soon begun shipping the glasses to many developers and commercial customers around the globe, including those in Australia, Ireland, France, Germany, New Zealand, the United Kingdom, China and Japan²⁰.

In March 2017 the Agency Readiness Partners Program accepted six more Europe-focused partners, from U.K., France and Germany, expanding from the original 10 agency partners serving the U.S. and Canada²⁰.

On July 10, in a Windows Blog post Jeff Hansen for Microsoft HoloLens Product Marketing, declared that more than 30 HoloLens Agency Readiness Partners were producing tangible results such as proof-of-concepts (POC), pilots and deployments of world class mixed reality solutions, leading the digital transformation for customers like Boeing, Cirque du Soleil, Cleveland Cavaliers, Cylance, Lowe's, Jabil, Paccar, PGA Tour, Real Madrid, and Stryker²¹. In addition, he announces:

"Today, we are excited to announce that due to growing demand from partners and customers, we have created the Mixed Reality Partner Program, which expands the agency readiness

¹⁹ http://time.com/4871245/microsoft-hololens-workplace/

²⁰ https://blogs.windows.com/devices/2017/03/13/microsoft-hololens-agency-readiness-partner-programexpands-europe/

²¹ https://blogs.windows.com/devices/2017/07/10/were-expanding-the-mixed-reality-partner-program/

program to welcome systems integrators (SIs) and digital agencies around the world. All existing HoloLens Agency Readiness Partners will be grandfathered into the Mixed Reality Partner Program."²¹

Many companies have seen in HoloLens and in mixed reality a powerful means to enhance their production systems, in many different areas: design, architecture, engineering construction, manufacturing, retail, healthcare, education, utilities, etc.

Some examples of companies that are transforming their business thanks to this new technology are described below.

These precedents will be useful to understand better the setting in which Holomuseum was born, its goals and its innovative side.

2.4.1 Autodesk

Microsoft HoloLens and Autodesk Fusion 360 are enhancing cooperation across the entire product development process, supporting the real-time interaction between engineers and designers.

They explored methods to project holograms on office flat surfaces, such as walls and open areas, and studied how users could discuss various aspects of a product design while looking at the holographic model and walking around it²².

They also considered the possibilities of creating and editing an artefact through the direct management of a holographic model (Fig. 2.15), as well as pitching a final design to an executive team or a client²².



Figure 2.15: A frame from the video "Microsoft HoloLens: Partner Spotlight with Autodesk Fusion 360" (https://www.youtube.com/watch?v=Hx6biWE2VsM)

²²https://www.autodesk.com/products/fusion-360/blog/future-of-design-with-microsoft-hololens-and-fusion-360/

2.4.2 Trimble

In a collaboration with Microsoft HoloLens, Trimble and the University of Cambridge are bringing mixed reality to the AECO (Architecture, Engineering Construction and Operations) industry with two trials on using the holographic device in inspections of buildings and bridges²³.

The first is "Automated Progress Monitoring", that changes notably the laborious and error prone process of remote structures inspection by presenting all physical and digital information through HoloLens; the application permits inspectors to control, cross-reference, report on inspections very fast, and collaborate with site representatives²³.

The second is "Automated Bridge Damage Detection". It allows reducing costs and improving efficiency, limiting the number of inspections of structural engineers, who can receive high-resolution images of the bridges by local teams²³. The pictures are automatically mapped onto 3D models of the respective bridge and the engineers can then review the structural integrity of a building in mixed reality using HoloLens, and order repairs or other preventative measures²³.

2.4.3 Case Western Reserve University (CWRU)

Educators are investigating how holographic visualization could help students to reach deeper knowledge, increasing participation and joy of learning. The Case Western Reserve and the Cleveland Clinic, for example, have decided to work with Microsoft HoloLens to develop a holographic anatomy programme for medical students to use when they begin classes at the HEC (Health Education Campus, a 485,000-square-foot building now under construction, scheduled to open in the summer of 2019)²⁴. Using holograms during the classes, "give students the opportunity to see different organs both separately and in the context of the body, as well as virtually dissect to see interiors without compromising the outside of the organ"²⁴. In addition, the holograms could be programmed to show particular diseases, and even to move to demonstrate a function (as with a beating heart)²⁴.

²³https://blogs.windows.com/devices/2017/01/25/trimble-university-cambridge-build-future-constructionhololens/

²⁴ http://engineering.case.edu/HoloLens-World-Economic-Forum

2.4.4 NASA's Jet Propulsion Laboratory (JPL)

NASA's Jet Propulsion Laboratory collaborated with Microsoft to create a piece of software called OnSight (Fig. 2.16). As detailed by Jeff Norris, the OnSight project lead, they use HoloLens to connect scientists and engineers with the environment of the Curiosity Mars Rover²⁵. Since NASA cannot put its scientists physically on Mars, this technology allows them to investigate what is possible, making them "virtually present": the Mars Rover images of the mapped surface of Mars are transformed into holograms, and scientists are able to work as if they could walk on the planet surface²⁵.



Figure 2.16: A screen view from OnSight²⁵. Image credit: NASA/JPL-Caltech

2.4.5 Lowe's

Lowe's Innovation Labs partnered with Microsoft to introduce the Lowe's Hologram Experience in five pilot stores. In these shops, a HoloLens specialist helps clients to plan their kitchen renovation in an interactive, mixed reality environment, increasing their likelihood of purchase²⁶.

Customers can visualize holograms overlapped with physical objects while standing in a showroom kitchen²⁶ (Fig. 2.17). Clients can interact with their environment with easy gestures and choice from an assortment of design alternatives and Lowe's products²⁶.

²⁵https://www.jpl.nasa.gov/news/news.php?feature=4451

²⁶http://www.lowesinnovationlabs.com/hololens/

An important improvement of the experience is the possibility for users to select appliances or material samples saved on their Pinterest accounts, which then appear in the user's field of view as holograms and are paired to similar Lowe's goods²⁷.



Figure 2.17: An example of model of a kitchen that customers can visualize in a Lowe's store, thanks to the mixed reality application²⁶.

2.4.6 Stryker

Each surgical discipline needs completely different operating room configuration and setup²⁸. To design operating rooms that fit several medical disciplines, an analytical assembly must take place²⁸. This is a problematical and inefficient process: the heads of each surgical area, along with their staff, and a complex variety of technology and equipment are shuffled around to determine what arrangement can accommodate all the necessities²⁸.

Stryker has found a way to design a shared operating room in a far more efficient manner: thanks to the 3D design software By Design (Fig. 2.18), multiple hospital stakeholders are now able to modify, configure and build different operating room scenarios with holograms and mixed reality²⁸.

²⁷https://www.usatoday.com/story/tech/news/2016/09/26/microsoft-expands-lowes-hololens-design-scope/91115600/

²⁸https://blogs.windows.com/devices/2017/02/21/stryker-chooses-microsoft-hololens-bring-operating-roomdesign-future-3d/



Figure 2.18: Example of use of By Design²⁸.

2.4.7 Thyssenkrupp

Thyssenkrupp, with Microsoft HoloLens and Azure, has found a solution to enhance the design of custom-built stair lift home solutions.

Every stairlift must be adapted to each separate staircase, so measuring, manufacturing, and installation is time-consuming²⁹. Using the HoloLens can make this process four times faster than before: the device executes digital data capturing by measuring the steps of the staircase, stores a record of this data and uploads it to the Microsoft cloud in real time; this way the manufacturing site can consult this data and the production on the stairlift can start immediately²⁹.

A future option for customers will be the visualization of a preview of the stairlift through an animation provided by the HoloLens²⁹.

2.4.8 Volvo

Volvo, thanks to HoloLens technology, allows clients to visualise features, such as colour and material, as 3D holograms rather than 2D computer images³⁰. The company can also demonstrate to customers how sensors and other safety devices work³⁰.

In addition, Volvo is planning to use the Microsoft HoloLens with the final goal of helping the car company decrease the development time of a new car model from 30 months to 20 months³¹.

²⁹ https://hololens.reality.news/news/thyssenkrupp-claims-up-4x-faster-workflow-with-hololens-0177209/

³⁰ http://www.wired.co.uk/article/industries-using-microsoft-hololens

³¹ https://www.onmsft.com/news/volvo-is-testing-hololens-to-speed-up-car-development



Figure 2.19: A demonstration of Volvo safety devices (https://mspoweruser.com/canadianautomotive-component-oem-magna-to-demonstrate-car-of-the-future-at-ces-using-hololens/).

2.4.9 Scopis

On May 5, 2017, Scopis launched its newest project, the Holographic Navigation Platform, to offer an increase in accuracy and speed to surgeons, and better results to patients subjected to open and minimally-invasive spinal procedures³².

For instance, integrating Microsoft HoloLens into the Scopis' technology, lets surgeons plan the positioning and alignment of pedicle screws during multiple vertebrae fixation surgeries³² (Fig. 2.20). Wearing the HoloLens, the surgeon can see the planned positioning of the pedicle screws projected onto its field of view and overlaid exactly onto the patient; the precision of hologram location is improved through additional 3D position tracking³².



Figure 2.20: Example of use of Scopis³².

³² https://navigation.scopis.com/news/holopressreleaseone

In Bartosz Kosmecki's opinion, CEO and Founder of Scopis,

"Scopis' Holographic Navigation Platform is a universal solution that offers specific advantages for spinal surgeries and can also be applied in the many other areas where the highest levels of precision and speed are critical. In neurosurgery, for example, brain tumours could be located faster and with higher accuracy"³².

2.5 Why Holomuseum is innovative

These are only few examples of the mixed reality products developed with Microsoft HoloLens, but they are enough to realize the field of application of this new technology is really vast and diversified.

In this large panorama, we can affirm that Holomuseum is rather innovatory for many aspects. First of all, Holomuseum it is not designed to improve a specific industrial process, or to make it easier for people to collaborate with each other on different tasks in the same project (which are the goals of almost all the HoloLens applications mentioned until now).

Our prototype is designed to extend the visitor experience in an exhibition, to make it better, more complete and interactive by providing the expo curator with a wide range of possibilities of usage.

Holomuseum also offers the curator "double access", one of the most important characteristic that we have to underline: it is the possibility to easily organize the exhibition layout, preparing it for visitors, through the "Edition Mode", that allows a simple and user-friendly management of the exhibition objects. In this way, the curator can choose how to arrange the reference boxes and decide where the contents required by the user will appear.

In addition, the arrangement in the space is permanent, that is to say the application stores the information about the expo objects location in the room, and it is able to place them in the same position over different sessions.

From a more artistic point of view, we can say Holomuseum generates a new way to communicate because, thanks to the HoloLens technology that creates a connection between the real and the virtual world, making them look like a unique reality, the curator has the potential to transmit new emotions and sensations to the spectators through the AR exhibition. Furthermore, comparing Holomuseum with the AR and MR applications cited before, which were created for a specific exhibit, we can affirm that our prototype is truly versatile and can be adapted to many kinds of expo and museums. For instance, we could imaging using it in a

science or technology museum, to observe the inside of a spaceship, thanks to a hologram that is perfectly overlaid on a real model, or to visit a 3D reconstructed room of a famous royal palace in an history museum. Alternatively, we could simply use it to learn new interesting details about a work in an art gallery, through interactive texts, images and videos, or to help make a complex subject easier and engaging for children and schoolchildren, with some minigames.

Since the application does not have a unique and precise purpose, the Holomuseum target is significantly huge as well, and includes children as much as young and adult people.

It is evident that young people are more used to trying new technologies. However it is not always immediate for the older public to learn the HoloLens gestures. To resolve this problem it is possible to supply the applications with a vocal command option for each task that the user has to complete.

We can affirm that Holomuseum is a concrete answer to new museums needs, since it provides "technological innovativeness as referred to visitor attraction and understanding (interaction, visualisation, immersivity, usability), technological integration and technological accessibility and usability" (Pescarin, 2014).

3. METHOD AND IMPLEMENTATION

The main characteristic of Holomuseum is the double interaction between real and virtual world, users and holograms, represented by the couple Poster/Content: when a visitor launches the application, he sees six cubic boxes of 15 cm edge, each one of them containing a smaller cube and positioned in front of a poster stuck on a wall. These cubes are references to assets stored in a web page and work like buttons: when the user click on them (select them with a vocal command or an air tap), a content is demanded and uploaded from Internet, appearing in the exhibition.

The posters report the title and some information of the contents that will appear when the boxes open.



Figure 3.1: Photo of users trying Holomuseum during the exhibition "Fiera de los Inventos" (June 13 - July 25, 2017)

Generally, the downloaded items can be the expo objects themselves (as in Holomuseum), for instance 3D art models, real applications that demand users participation, or complementary elements that widen the real world exhibition, such as texts or videos.

3.1 An Overview of AR Interface Design

Each AR/MR system can include various kind of input methods to allow users to interact with the virtual contents. In particular, we can identify five AR interface types, developed since 1960's (Billinghurst et al., 2015):

1) Information Browsers

These interfaces, for showing AR information on the real world, require the most basic interaction tasks: visualize the AR scene through a display and browse the information provided, as in Figure 3.2 (Billinghurst et al., 2015).

Users can simply use their natural intuition to move through the physical environment. For instance, when using HMD they simply have to turn their head to change their view, with handheld AR displays, they have to hold and move the device, pointing at the direction to view (Billinghurst et al., 2015).

Some examples of other common interactions are the choice of information to view, the change of visualization style, the navigation into details; most of these interactions can be accomplished using traditional 2D graphical user interfaces (GUI) and screen input (Billinghurst et al., 2015). On the one hand this interaction method is simple and easy to learn, but on the other hand it has limitations in supplying direct interaction with virtual objects (Billinghurst et al., 2015).



Figure 3.2: An example of AR Information Browser, the NaviCam AR browser (Rekimoto et al., 1995)

2) 3D User Interfaces

3D UI use 3D interaction techniques to manipulate virtual object in space through various types of devices, used in virtual reality too, such as a 3D mouse or a wand type pointing devices, 6 DOF joysticks, and 3D motion tracking sensors, which are one of the most widely used technologies (Billinghurst et al., 2015):.

It is possible to identify three main classes of 3D interactions, used to achieve the most common and universal tasks: navigation, selection and manipulation (Bowman et al., 2004).

As Schmalstieg explains, 3D navigation techniques might not be directly applicable to AR applications, because navigation in AR environments is naturally accomplished by the users

moving their body, but selection and manipulation interaction techniques can be easily adopted (Schmalstieg et al., 2000). For example,

"The use of windows as abstraction and interaction metaphor is a long-time convention in 2D GUIs. Its extension to three dimensions seems logical and can be achieved in a straightforward manner: using a box instead of a rectangle seems to be the easiest way of preserving the well-known properties of desktop windows when migrating into a virtual environment." (Schmalstieg et al., 2000).

We can find this type of interface in Kiyokawa's VLEGO II application (Fig. 3.3), originally developed for single-user and later for two users.

VLEGO II is a collaborative immersive modelling system in which users' hands are tracked in 3D space; they can pick up virtual blocks in the AR interface and cooperate to construct compounded 3D virtual objects, simply assembling, scaling and colouring basic primitives with several different two-handed manipulations (Kiyokawa et al., 1998).



Figure 3.3: A shared augmented workspace of VLEGO II (Kiyokawa et al., 1998).

3) Tangible User Interfaces

Ullmer (Ullmer et al., 2000) explains that "tangible interfaces give physical form to digital information, employing physical artefacts both as representations and controls for computational media."

Combining Tangible UI, the intuitive manipulation and interaction of physical objects, with the improved display potential of AR, we obtain Tangible AR interfaces (examples in Figures 3.4

and 3.5), that support continuous interaction between the real and virtual worlds, and provide a range of natural interactions that are difficult to find in other AR interfaces (Billinghurst et al., 2008).



Figure 3.4: The user interacts with 3D virtual objects by manipulating a tangible object, such as a simple paper card (Billinghurst et al., 2008).

Since in Tangible AR interfaces each computer-generated object is registered to a physical object and the user interacts with virtual objects by handling the corresponding tangible objects (Billinghurst et al., 2008), an accurate tracking of the objects is required.

Input devices can be classified as space-multiplexed or time-multiplexed: in a spacemultiplexed interface, generally more intuitive, each function has a single physical device occupying its own space, while in a time-multiplexed design a single tool controls different functions, depending on the status and context (Billinghurst et al., 2008).



Figure 3.5: Tangible AR interface with a physical book with virtual object overlaid on it (Billinghurst et al., 2015).

4) Natural User Interfaces

This type of interface enables users to interact with gestures and body motion; previously the user had to wear some device that tracked his motion and hand gestures, now, thanks to the

development of computer vision technology, AR applications became capable of recognizing user actions in real time without the use of any wearable sensors (Billinghurst et al., 2015).

In particular, the use of depth cameras, has become in these last years largely accessible in AR systems and allows the tracking of able and more complex hand motions for corporal interaction with virtual objects using bare hands (Billinghurst et al., 2015).

For instance, Microsoft HoloDesk (Fug. 3.6) is an interactive system combining an optical see through display and Kinect camera to create the illusion that users are directly interacting with 3D graphics³³.

Virtual objects are shown on an optical see-through AR workbench, aligned with the real-world for the viewer³³. Users can easily stretch out their hands into an interactive space displaying the virtual image, and interact with it, without the need for any particular head-worn hardware or input device³³.



Figure 3.6: Microsoft HoloDesk³³.

5) Multimodal Interfaces

This last interface can probably be considered the most complete, as it offers to application users a mix of different input methods, generally gestures combined with speech.

Although the rich interactivity this interface provides, many researchers have used speech and gesture inputs in VR systems, but the usage and research in augmented reality field is still relatively small (Billinghurst et al., 2014).

One of the first examples is SenseShapes (Fig. 3.7), a set of statistical geometric tools designed to identify the objects being manipulated through speech and gesture in a multimodal AR application, helping to solve a common problem of systems that support multimodal interaction (Olwal et al., 2003).

These volumetric regions of interest can be attached to the user, providing valuable statistical data about the user's interaction with objects in the environment; SenseShapes determines,

³³https://www.microsoft.com/en-us/research/project/holodesk-direct-3d-interactions-with-a-situated-see-throughdisplay/

through the statistical information, to which objects a user is referring and which are irrelevant and have probably fallen into the user's gaze and pointing direction (Olwal et al., 2003).



Figure 3.7: An AR user interacting through gesture, speech and SenseShapes. The tracked glove and three possible gestures are shown at the right (Olwal et al., 2003).

In 2006 Irawati enhanced, adding speech input, an application for the arrangement of virtual furniture named VOMAR (Fig. 3.8), that already had an intuitive tangible AR interface for moving virtual objects using paddle gestures (Irawati et al., 2006). The study demonstrates how combining speech and paddle gestures improved performance: using multimodal input, users could place the objects more accurately in the target position, and completed an assigned task a third faster than using paddle gestures on its own (Irawati et al., 2006).



Figure 3.8: A participant using VOMAR and an example of a virtual menu that contains a set of virtual furniture (Irawati et al., 2006).

3.2 Design

Aesthetically Holomuseum shows a linear and clear design centred on cubes. This artistic simplicity, due to factors that we are going to comment on later, hides a considerably elaborate system structure design.

Actually, the boxes that faced the users are only apparently simple cubes, since they mask a rather complex composition due to the application.

First of all, the main function of these elements is to reference different kinds of resources which will be uploaded from a web page according to visitors' desires. This implies user interaction with the boxes, which must then be animated objects that respond to inputs and provide acknowledgments during the content loading process.

Moreover, the structure of each single box reflects the need to run the application in two modes. This depends on the purpose of the user: if the user is the exhibit curator, this involves preparing and organizing the exposition in a certain space; if the person is wearing the viewer is a spectator, this means simply entering in Holomuseum world and interacting with it.

Consequently, the single object, named Exhibit, is divided into three macro-children:

- Item Group is the reference to the exhibition item (Fig. 3.9);



Figure 3.9: Screen view from Holomuseum (Fiera de los Inventos). Examples of Item Group.

- Item Group Editor is the game object used to decide and change the Item Group position in the exhibition room;
- Mark is used to define the position in which the content referenced by the respective Item Group will appear when user will require it.

In Figures 3.10 and 3.11 we can see which objects are respectively visible in the edition mode and in the visitor mode.



Figure 3.10: Structural hierarchy of the Exhibit object - Edition Mode.



Figure 3.11: Structural hierarchy of the Exhibit object - Visitor Mode.

The Mark's form (Fig. 3.12) is not really important, since it will not be visible to the exhibition viewers and it is only a reference point. In our case it is composed of a cube (Mark Editor), with a texture that makes it appear as it was shaped by a grid, and a smaller sphere (Sphere) positioned in the cube centre; both the elements are made by the same bright light blue material, in order to be easily seen.


Figure 3.12: Mark.

When the user hits a Mark with its gaze, a white and bright frame (Frame) appears around the cube (Mark Editor), to inform user that he can select it (with an air tap).

Similarly, the shape of the Item Group Editor (Fig. 3.13) is not relevant as well.

It is made up by a cube with transparent faces (Cube), a frame (Frame) equal to that of Mark but rotated 90°, and a Canvas; the Canvas contains a picture and the name of the asset referenced by the corresponding Exhibit object. The asset image is positioned inside the cube.



Figure 3.13: Item Group Editor.

A lit multicolour line connects the Mark and the Item Editor so that it is simple to see which Mark belongs to each Item; the line is drawn by means of a Line Renderer component added to the Exhibit.

Item Group is clearly the most significant of the three elements, being part of the expo and the object with which users will interact. It constitutes the boxes the users can see when the application starts: six cubes with see-through faces which contain a smaller cube.

Item Group is the parent of an Empty object, called Item, which has none other children: Moving Cube, Inner Cube, Face1, Face2, Face3, Face4, Face5, Canvas Close and Canvas Error. The bigger cube's transparent faces have white edges. Each face is composed of a different Empty GameObject, FaceX, where X is a number between 1 and 6 (the Face6 element is the child of Face4 element for animation matters). Each Empty object is the parent of a Quad game object that defines the four sides of a cube face. The Quads are characterized by a bright material characterized with a shader we created using the Unity node-based editor "Shader Forge"³⁴.

Inner Cube (Fig. 3.14) is an Empty object together with its child Scaling Cube, which is a Cube game object; they make up the smaller cube that users can see inside the bigger one.

Scaling Cube has six Canvas children, each one parent of a Raw Image with a texture that represents the asset referenced by the root Exhibit.



Figure 3.14: Structural hierarchy of Inner Cube

The function of all these objects will be examined alongside, in the animations description. Anyway this relatively complex hierarchy is hidden from Holomuseum users and the visual result is a simple and linear design centred on the cube shape.

The choice of a cube as main element of the UX (user experience) design is more than an aesthetic preference, as it was a choice based on the hardware as well as the user's needs.

First of all, a cube suggests the idea of a box that can be opened. This implicit hint is emphasized through the presence of another smaller cube in the first one, which has transparent faces to making the inside visible. The little cube's faces are covered by an image which represents the exhibit object, so that users are pushed to interact with the box to open it and let the content exit.

The second reason of this choice was the need to maintain a basic and clear design so that the logic of the system was prioritised. Holomuseum is still a prototype and both the primary and main goal was to create a working and user-friendly application, with the sufficient flexibility to be used in exhibitions of different shapes and sizes.

³⁴ https://www.assetstore.unity3d.com/en/#!/content/14147

Time was also an important factor that influenced our work on the prototype, leading us to choose a design that fitted the purposes of the system well, agreeable and at the same time did not complicate the development of the application.

The simplicity was also essential from the hardware point of view. In fact, since a reference item (a box) corresponds to each exhibition object, in a big expo the device has to show a great number of items: the glasses do not have the computational features needed to display many high poly meshes simultaneously, then a cube is a proper option to ensure the amount of vertices to be rendered is low.

If supported, more complex polygons could create large waiting times or could be rendered wrongly.

Another notable aspect was the need of a model with a shape that could be easily positioned. The curator can decide to rest the boxes on the ground, on a pillar or on any structure available in the exhibit room, or hang up them on a wall.

In Holomuseum, for instance, when the app is launched, all the boxes are placed on a wall in front of the visitors; as was commented before, each one of the reference cubes is virtually affixed on a poster (Figures 3.15 and 3.16) with a brief description of the corresponding content uploaded when that specific cube is selected, and other information. The posters act as frames: in their centre they have a white 15 cm edge square that outlines the box position.

Through this project we created a coherent integration of holograms in the real environment. On the contrary, using compounded meshes, makes the placement of the objects more problematic, and consequently the complete and natural incorporation with the exhibition room becomes difficult.



Figure 3.15: Example of poster used for the arrangement of Holomuseum boxes.



Figure 3.16: Poster details. 1) Asset description, 2) credits, 3) possible interactions.

The material's choice was also important, because of intrinsic features of the device optics. The HoloLens make use of additive displays, that is to say the light employed to render the holograms is overlaid on the light from the real environment.

According to Microsoft³⁵, this means that:

- first of all, holograms colours can be influenced by the real-world surfaces on which they are rendered;
- since the HoloLens display cannot remove light from a setting, true blacks do not exist, dark colours appear transparent;
- by contrast, white appears very brilliant and RGB values greater than 235 should not be used.

As a result, for the scene objects we used light colours (mainly white and light blue) and we applied in most cases the shaders offered by HoloToolkit, which were optimized to work alongside the HoloLens device.

We had to create only one custom shader, using the node-based editor Shader Forge.

³⁵ https://developer.microsoft.com/en-us/windows/mixed-reality/color_design

We put in the editor some sliders to control the material colour, opacity and blurriness. Through the sliders we could alter these parameters, setting and changing them in the Animation window.

Returning to Billinghurst's classification, Holomuseum presents a multimodal interface, as it recognize many types of inputs: position and orientation of user's head (gaze), hand gestures (air tap) and speech commands.

Voice commands are helpful when users are not familiar with mixed reality technologies, since hand gestures, although basic, require a minimum level of precision in the execution (with regard to hand position). They can be also a valid alternative of interaction for people with a motor disability.

Vocal orders are allowed by the HoloToolkit "Keyword Manager" script; it permitted us to choice the keywords for speech commands simply setting them in the Unity Inspector.

3.3 Animations

We accurately studied the boxes animations to guide users during the whole experience. The animations are essential to notify that the executed action has produced an effect, and to entertain visitors during the necessary waiting time to upload the contents.

Since the HoloLens device offers a good sound spatialization (processes audio using HRTF), an appropriate sound matches each visitor action. In fact, receiving an auditory feedback helps users to complete their tasks and to immerse in the experience.

Therefore we added in the Unity Scene an AudioSource component to all the elements that have to produce a sound when their animation is triggered.

All the animations, except one defined in the code, are managed in a single animator (visible in the Fig. 3.17) attached to the Item object. The AnimationClips are enabled through trigger or boolean parameters.

We created nine animations, listed below, that reflect different steps of the user interaction and the corresponding states of the box.



Figure 3.17: Screenshot of the Animator window in Unity (Item Animator).

Idle

It is the default state: the outside cube has completely transparent faces and white edges (Face1,..., Face6), the cube inside (Scaling Cube) is small (Fig. 3.18).



Figure 3.18: Screenshot from Holomuseum in the Unity Editor. Idle animation.

Focus

It is enabled when the user's gaze hits the cube: the edges shine, the faces become transparent blue.

The twinkling effect of the edges (Face1,..., Face6) is obtained through the animation of the parameters that define the shader we created.

Then the box appears highlighted and the user understands that he can interact with it (Fig. 3.19).

It is an animation aimed at informing the user that he can select that object, equivalent to those we are used to seeing on web sites when we pass over a link with the mouse.



Figure 3.19: Screen view from Holomuseum. Focus animation.

Uploading asset

Visitor performs an air tap gesture or says the verbal order "Open box", maintaining the head oriented towards the focused cube.

Selecting the highlighted box, the user requires the uploading of an asset (saved in a web page as AssetBundle) and launches a new animation: the edges shine faster, their colour changes lightly, the inner cube (Scaling Cube) starts to grow (Fig. 3.20).

We wanted the inner cube to stop growing when the requested asset was ready to appear in the display. Therefore we had to map the small cube growth on the time interval needed to upload the content.



Figure 3.20: Screenshot from Holomuseum in the Unity Editor. Scaling cube growing.

To this purpose, we created a Blend Tree, a special type of state in the Unity's animation state machine (Fig. 3.21).

As we can read in Unity online manual, "Blend Trees are used for allowing multiple animations to be blended smoothly by incorporating parts of them all to varying degrees. The amount that each of the motions contributes to the final effect is controlled using a blending parameter, which is just one of the numeric animation parameters associated with the Animator Controller."³⁶



Figure 3.21: Screenshot of the Animator window in Unity (Blend Tree).

Our blend tree is really simple, since it manages only two animations (1D Blend Type). We only have one blending parameter ("scale&alpha", Fig. 3.22), a float variable varying between 0 and 1 (the chosen thresholds) according to the download progress of the requested content.

 Inspector 	Services	Collab Histo	ory			≧ -≡
Blend Tr	ee					🛛 🕼 🌣,
👅 Blend Ty	pe 1D					+
Parameter scale&alph			а			*
0						1
Motion				Threshold		€.
= 🖪 Scaling(Cube_0		0	0	1	
= ScalingCube_1			0	1	1	
						+, -

Figure 3.22: Screenshot of the Inspector Window in Unity (Blend Tree parameter).

The value is continuously updated in the code, through a Coroutine.

```
private float progress;
private IEnumerator InnerCubeAnimation(WWW www)
{
    while (!www.isDone && www.progress < 1f)
    {
        progress = www.progress;
        animatorMovingCube.SetFloat("scale&alpha", progress);
        ...
    }
}
```

³⁶ https://docs.unity3d.com/Manual/class-BlendTree.html

}

Box opening

When the asset is completely uploaded, and the inside cube has reached the exterior cube size, the box opens: one face (Face1) moves forward, separating off from the cube, and the opposite face (Face4) keeps still; the other four faces rotate 90°, using the sides of the motionless face as rotation axis (Fig. 3.23).



Figure 3.23: Screen view from Holomuseum. Box opening animation.

Cube moving

As soon as the box opens, the cube that has grown (Scaling Cube) disappears and makes place for another cube (Moving Cube, until now invisible) which, spinning round, falls towards the position where the AssetBundle content will appear (Fig. 3.24).

This animation is necessary to show users the uploaded asset position, previously decided by the curator (we are going to discuss it in the "Edition mode" paragraph).

For users, following the falling object with their gaze, was not really intuitive, so we created a "trail": a Particle System component emitting cubic light blue coloured shape particles was added to the moving cube; the particles are produced until the moving cube has reached its destination.

The arrival point, the angular and the linear velocity of the cube are set through the code (this is the only animation not present in the Animator).



Figure 3.24: Screen view from Holomuseum. Cube moving animation.

Box opened

The uploading process has been completed and the rotating cube (Moving Cube) has arrived at its destination. It disappears making room for the asset required, that can finally come out following an animation defined in its own animator.

The cube (Face1,..., Face6) remains open and a button (Canvas Close) with the "Close" writing appears, so that at any time users can close the box, hiding the corresponding exhibition object (Fig. 3.25).



Figure 3.25: Screenshot from Holomuseum in the Unity Editor. Canvas Close.

Users can observe the asset from several points of view and, if the content is an interactive application, can interact with it.

Holomuseum is a prototype, and we tried to show its versatility using different contents for the six boxes:

- three of them are artworks created by UPV Fine Arts students (Figures 3.26, 3.27, 3.28); two of the works offer users an interaction based on their movement in the room;
- one is an interactive model of a robot ("Agilus", Fig. 3.29) created in the IDF (Instituto de Diseño y Fabricación) of the UPV for a research that aims at integrating the Microsoft HoloLens usage in the robotics sector;





Figure 3.26: Daphne.

Figure 3.27: Morph.



Figure 3.28: Garrote Vengativo.



Figure 3.29: Agilus.

- one is an interactive model of a tunnel for the detection of imperfections in car bodies (Fig. 3.30) which use technologies developed by the IDF;



Figure 3.30: Tunnel for the detection of imperfections in car bodies.

- the last one is a 3D animated scene that explains how Holomuseum works (Fig. 3.31).



Figure 3.31: Holomuseum system explication.

Box closing

The visitor clicks on the "Close" button (Canvas Close) with an air tap or saying "Close box": the asset uploaded in the room disappears, the reference cube closes and returns to its initial state with a reverse animation. All the boxes are in the idle state again.

Inactive

When a box is open, all the remaining cubes have to stay closed; consequently, when a box is selected, the others are disabled and users cannot interact with them.

This animation is launched each time a visitor selects a box. All the reference cubes, excluding the selected one, will not appear in the exhibition.

Error

We also had to consider the possibility that something would go wrong during the content upload process.

If an error occurs, after the little cube (Scaling Cube) reached the maximum size, the exterior cube (Face1,..., Face6) does not open, its edges become red (the typical colour we are used to see associated with errors) and a canvas (Canvas Error) with a red error icon appears (Fig. 3.32). Therefore the event is notified to the visitor.



Figure 3.32: Screenshot from Holomuseum in the Unity Editor. Error notification during the asset upload.

In the Figure 3.33 a block diagram summarizes the animation flow of a box according to user inputs.

Focus Enter Event (HoloToolkit script) is fired if the user's gaze is hitting the considered cube; by contrast, Focus Lost Event is launched if the user's gaze is not hitting the considered cube. Pointer Click Event (Event Trigger component) detects the box selection; if the considered cube is selected, the Pointer Click Event launches the content upload;



Figure 3.33: Animation flow.



3.4 AssetBundles and Content Uploading

An important notion that must be introduced is that of AssetBundle.

As we can read in Unity Manual, an AssetBundle is an archive file, created in the Unity editor during edit-time, containing platform specific resources that can be demanded and loaded at runtime, from a local or remote location; they can include any kind of asset type recognized by Unity, as models, textures, prefabs, audio clips, and even entire scenes, except the scripts, that are not allowed³⁷.

AssetBundles can express dependencies between each other; for example, a material in AssetBundle A can reference a texture in AssetBundle B^{37} .

The resources can be stored remotely and accessed as needed, increasing the adaptability of the project, reducing the initial application size and the runtime memory pressure³⁷.

In our prototype AssetBundles were absolutely fundamental, to guarantee curators the flexibility they need to structure their exhibitions, and assure users an entertaining experience with a good management of the waiting time. In fact, thanks to this system that enables easy content loading and unloading, Holomuseum lets curators to design displays with a large variety of objects, and all of them can be applications themselves.

To organize and setup bundles in the editor, the assets need to be assigned to an AssetBundle. We have to select them and use the AssetBundle Name drop down menu, located in the lower part of the Inspector, to create a new AssetBundle name or choose an existing one (Fig. 3.34).



Figure 3.34: AssetBundle setup in Unity Editor³⁷.

³⁷ https://docs.unity3d.com/Manual/AssetBundlesIntro.html,

https://unity3d.com/learn/tutorials/topics/scripting/assetbundles-and-assetbundle-manager

Until now we have analysed only the "exterior" side of what happens when a user selects a box. In parallel to animations, the system performs a process that is at heart of the application working: the asset uploading from Internet.

All the exhibition objects which will be demanded by visitors, are packaged in AssetBundles (3D models, textures, animations, etc.), saved as "unity3d" files and uploaded on a web page. We created an XML file that lists these contents. For each of the contents we defined five attributes: name, title and description, that characterise univocally the asset that will appear in the exposition; AssetBundle URL and picture URL, that define the position of the AssetBundle in which the asset is contained and the position of an image representative of the content (this picture will be visible in the Exhibition List when the app runs in edit mode, as explained in the next section).

We can see below an example of XML code that shows the structure of the XML list we created and saved in a web page.

```
<?xml version="1.0" encoding="Windows-1252"?>
<Exhibition>
  <Objects>
  <Object name="tunelIDFv2" title="Tunel de inspección"
    urlBundle="http://example.es/wp-content/uploads/bundletunel2.unity3d"
    description="Tunel reconocimiento de defectos en pintura de carrocerias"
    urlPicture="http://example.es/wp-content/uploads/logotunel2.png" />
    ...
    </Objects>
<//Exhibition>
```

Each one of the listed assets in the XML file is associated to a cube. When a user selects a box, the upload process of the correlated content begins.

3.5 Edition mode

One of the most significant and original aspects of Holomuseum is the possibility to start the application in two different modes, the "Visitor Mode" for exhibition visitors and the "Edition Mode" for curators.

The visitor mode is the default running way of the application, whereas the edition mode (Fig. 3.35) is set up to create and organize the display in the room.



Figure 3.35: Screenshot from Holomuseum in the Unity Editor. Edition Mode enabled.

This double possibility wants to be a concrete answer to the needs of the curators, based on the wishes of visitors of the museums: since the public demand for innovation caused the spreading of augmented reality displays, the easy management of virtual objects has become an important prerequisite for a successful exhibition as well.

Thanks to edit mode curators can therefore determine the exhibition layout changing the position of the individual virtual objects with a simple and quick interaction.

To enable the edition mode the user has to pronounce the words "Show settings" that make a settings menu appear. It is the only operation that cannot be completed in two ways, but only with the voice command, to avoid unauthorized users opening the menu accidentally during the gesture interactions with the system.

The Settings Menu (Fig. 3.36) has two toggles and a button to close the menu itself. One toggle enables and disables the edit mode. The other, when visitors require contents, if selected,



Figure 3.36: Screenshot from Holomuseum in the Unity Editor. Settings Menu.

permits the usage of the AssetBundles previously stored in the cache (if already saved); if not, the app will download the AssetBundle requested another time.

When the Edit Mode is enabled, the Exhibition List appears.

The Exhibition List (in Figure 3.37) is a panel that allows the visualization of the display item list.

The panel has four buttons and each one of them, if clicked, calls a function. Events and methods fired through these buttons are described below.



Figure 3.37: Screenshot from Holomuseum in the Unity Editor. Exhibition List.

Button 1: Download XML exhibition list

When a curator wants to arrange the exhibits in the space for the first time, he needs to download from the Internet the XML exhibition list. As I explained in the previous section, it is a file which contains the list of the exhibition contents that will be uploaded when users require them, and the information relative to their location.

The web address at which the XML list is stored is specified in the application code.

Button 2: Load XML exhibition list

Now the curator can visualize all the exhibits in the Exhibition List GameObject in form of records. As is possible to see in Figure 3.35, each record (Item Panel) occupies a little Panel and it is defined through a name, a title, a description and a picture.

Button 3: Save XML exhibition list

The curator can store the XML exhibition list in his device, in a persistent data directory³⁸. This way he will not need to download the list in case of modifications of the exhibition lay-out. A new download will be necessary after some change in the XML file (for example the inclusion or the deletion of an exhibition item).

Button 4: Create Exhibition

Clicking on this button, the six boxes are instantiated and their necessary attributes, such as the name of the asset they reference and the URL at which the asset is saved, are set. The curator can finally create his display for visitors.

Each reference cube, as previously explained, is formed by three part: Item Group, Item Group Editor and Mark. In the Edition mode only the last two are visible.

The exhibition curator can organize the exhibits in the space selecting the Item Group Editor and the Mark and moving them in a new position. The selection task is the same as the visitor one: the user has to move his gaze towards the chosen object and, when it is highlighted, do an air tap.

Changing the head orientation, the selected item will follow the gaze; when the curator has chosen the new location, he executes another air tap to release the object in the point to which he is watching.

The new positions are stored in the device, so that holograms will appear in specific real world locations across several instances of the application.

In Windows Holographic systems, an element position in the physical world is represented by a World Anchor: a connection between a precise point in the real space and the parent GameObject of the world anchor³⁹.

³⁸ In Windows Store Apps this directory points to:

[&]quot;%userprofile%\AppData\Local\Packages\<productname>\LocalState",

⁽https://docs.unity3d.com/ScriptReference/Application-persistentDataPath.html)

³⁹ https://docs.unity3d.com/Manual/windowsholographic-anchors.html

The holograms persistence is guaranteed by the WorldAnchorStore, the class responsible for storing and loading the world anchors across sessions⁴⁰.

As a result, curators can easily establish his exhibits arrangement in one or more rooms permanently, maintaining at the same time a truly versatile system that lets him have the possibility to make changes, as many times as he needs.

In each mode, edit and visit, Holomuseum appears in a fixed state, which certain elements visible and other invisible, functions enabled and others disabled. So, from a code point of view, we had to find a way to manage the two application different states systematically, while preserving the coherence between the modes.

The solution was make use of static variables, events and delegates.

Normally, those variables are declared as static when they have the same value throughout all instances of the object: in our case, the variables that, when a user input causes their change, have the purpose of activate one of the two possible application modes, determining which game objects and methods are activated and which are not.

We saved these static variables, in the shape of key-value pairs, in PlayerPrefs⁴¹ (player preferences) Unity class, so that we could store and access them between app sessions.

The whole process is managed through four scripts, whose main roles are summarized in the Figure 3.38: *"Holomuseum Manager"*, *"Settings Menu"*, *"statics"*, *"Holomuseum States"*.

The Figure 3.39 shows a scheme which represents curator actions associated with the scripts functions called in answer to inputs. When the curator demands the settings menu because he wants to change something in his exhibit, the menu opening causes the subscription of a method to an event: it means that hardware converts external user actions into specific event code.

When the curator selects or deselects the edit mode toggle, the Set property of a boolean static variable is called; this variable notifies if the application is running in edit or in visitor mode and, according to its value, the system calls a method that triggers the appropriate event.

If the edit mode toggle is selected, the event relative to the edition mode activation is fired: only the objects (and the relative scripts) the curator needs are enabled, and he can finally make the necessary modifications.

The same process happens when the curator, after he has finished changing the exhibition arrangement, deselects the edit mode toggle and closes the settings menu.

⁴⁰ https://developer.microsoft.com/en-us/windows/mixed-reality/persistence_in_unity

⁴¹ https://docs.unity3d.com/ScriptReference/PlayerPrefs.html

	Settings Menu	statics	Holomuseum States
Holomuseum Manager - defines events and delegates relative to the Settings menu opening and closing - defines methods to call the events	 sets Settings menu Toggles values calls properties defined in statics script add key-static variable pairs in Player Preferences, if not already stored 	 defines static variables properties (get/set) fires events to spread them through delegates updates Player Preferences according to static variables changes 	 function subscription: adds a delegate instance to event when the settings menu is enabled function unsubscription: removes a delegate instance from event when the settings menu is disabled





Figure 3.39: Scheme that summarizes the user actions associated to script functions.

3.6 Other Scene GameObjects

In this section we will examine briefly the remaining GameObjects that compose the Unity Scene in which users will immerse running Holomuseum: Camera, Cursor and Manager. We will discuss their composition, their purpose and how they work.

An image is inserted in each GameObject description to show its hierarchical structure.

3.6.1 Camera

The only camera present in the project is that through which users will see the exhibit. To adjust the camera for an experience improvement, we had to apply the Scene Settings in Unity

- to move camera to the scene origin (0, 0, 0), so that the user head is the world centre;
- to make the background black rendered by the camera, to allow the user to see the real world wherever there are no holograms (colour black is transparent in HoloLens);
- to update the near clipping plane of the main camera to the recommended setting, to reduce eye fatigue;
- to update the main camera Field of View so that Unity Editor more closely reflects what will be seen on the device at runtime.

As we see in Figure 3.41, the Camera has two children:

- the Initial Tutorial (Fig. 3.40), a group of 2D animated Sprites that shows users how Holomuseum works and how interact in it through a brief and simple tutorial.



Figure 3.40: Screen view from Holomuseum. Initial tutorial.

The animation starts when the application is launched, but it is possible skip it pronouncing the speech command "Skip tutorial".

- Gaze Controls (parent of ten Empty objects with the "Axis Controller" HoloToolkit script attached), which allows the usage of keyboard, mouse, or joystick during the application testing in the Unity Editor;



Figure 3.41: Camera hierarchical structure.

3.6.2 Manager

This Manager GameObject (Fig. 3.42) has two children: Input Manager and Event System.

Event System has attached the Event System component responsible for processing and handling events in the Unity scene⁴².

Input Manager is parent of three Empty objects whose function in the application is determined by the attached HoloToolkit scripts.

Gestures Input and Raw Interaction Sources Input have respectively the purpose of:

- give access to system-supported gestures;
- give details about current source state and position, and allow users to access the source up/down and detected/lost events, which are not communicated as part of standard Windows gestures.

⁴² https://docs.unity3d.com/ScriptReference/EventSystems.EventSystem.html



Figure 3.42: Manager hierarchical structure

The third element, Editor Hands Input, permits to manually control the "hands" when the applications is running in Unity Editor, thanks to the HoloToolkit "Manual Hands Control" script. Hand gestures in Unity Editor are in fact simulated through two little hands (two plane meshes with a texture) that are controlled by means of the keyboard and the mouse (Fig. 3.43).



Figure 3.43: Screenshots from Holomuseum in the Unity Editor. Simulation of hand gestures.

Editor Hands Input is parent of another Empty Object named Hands Control, which has two children, Right Hand and Left Hand. These last two elements (each one of them is parent of other five objects, not represented in Fig. 3.42) supply the components that "Manual Hands Control" script needs to simulate actual HoloLens behaviour.

3.6.3 Basic Cursor

This is simply the little blue circle that marks which point in the space the user's gaze is pointing to.

It is the default cursor provided by HoloToolkit and it is constituted by a 3D model similar to a torus.

3.7 Software used

To develop our application, we used the two main tools offered to create holographic experiences: Unity 3D, version 5.6.0f3, and Visual Studio 2015, with the Universal Windows Platform (UWP) development option. We programmed in C#.

We also used HoloToolkit-Unity⁴³, a collection of scripts and components intended to accelerate development of applications targeting Microsoft HoloLens. It is a really useful resource, because makes available all the code needed in a mixed reality app with many examples of usage. To use this tool, we had only to import the whole HoloToolkit folder in the Unity project.

After doing that, it was necessary to change some settings in the Unity project clicking on the new voice, "HoloToolkit", appeared in the main menu. Then we had to go on "Configure" and click on:

- "Apply HoloLens Scene Settings", and tick all the four options to optimize the Camera settings to improve the holographic experience;
- "Apply HoloLens Project Settings", to enable some recommended or required features to get an application that meets the requirements necessary to be an UWP, Windows Store and HoloLens device application;
- "Apply HoloLens Capability Settings", to enable the microphone for the speech commands, the webcam, the access to the world mapping capabilities and the access to Internet.

⁴³Available at: https://github.com/Microsoft/MixedRealityToolkit-Unity; recently the tool has been updated and it can be used for the development of applications targeting Microsoft HoloLens and Windows Mixed Reality headsets as well.

4. RESULTS

We can affirm to be satisfied about the achieved results with Holomuseum.

We have reached the aims we have initially established: we obtained a flexible application that is easy to use, for the expo curator as well as the visitor, and which surely has a great impact on the public.

Of course the application presents also some defects we could not correct because we had to complete the project in time for the exhibition in the UPV campus.

For instance, it is possible some parts of the code would have to be simplified or cleaned for a better efficiency.

There are also some aspects impossible to improve because of depending on factors we could not control, such as the intrinsic characteristics of the device or the display surrounding environment.

For example, during the "Fiera de los Inventos" some users needed more attempts to succeed to complete the little tasks required in Holomuseum:

- users who were not used to such technologies, trying the HoloLens glasses for the first time, not always found the right hand position in which device could recognize their gestures;
- there was noise in the exhibition room then, when visitors tried to interact with the voice commands, the device was not able to distinguish the speech from the surrounding;

Another aspect that can result annoying is the limited device field of view: occasionally, if the 3D contents displayed are truly large or attempt to reconstruct a 360° environment, holograms can be entirely visualized only changing the head orientation.

A possible, but not sure, FOV enhancement has been hypothesized thanks to new optical technics based on the patents that were filed in April with the World Intellectual Property Organization: *"Through proper design, embodiments described herein can be used to provide even larger FOVs of up to about 90 degrees*"⁴⁴.

Unfortunately, my traineeship period finished a few days after the beginning of the UPV exhibition and I could not start a preliminary survey with the visitors who tried our application.

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https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2017180403&recNum=15&maxRec=86060&office=&prevFilter=&sortOption=&queryString=ALLNAMES%3A%28Microsoft%29&tab=PCTDescription

Anyway Holomuseum is still an application under development and it will be submitted to a testing phase with users in future.

A conceivable improvement involves the exhibit arrangement method.

Recently Vuforia software has been incorporated to Unity (version 2017.2). Vuforia is a SDK that enables the creation of Augmented Reality applications for mobile devices and digital eyewear⁴⁵. One of the tools it offers is the recognition of images, 3D objects and English words (from a standard database)⁴⁶.

This feature could radically transform Holomuseum: a symbol or a photo on each poster would be sufficient to set the exhibition lay-out without the need to organize the exhibition objects one by one manually.

⁴⁵ https://developer.vuforia.com/downloads/sdk

⁴⁶ https://www.vuforia.com/features.html

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