VIRTUAL REALITY IN INDUSTRY

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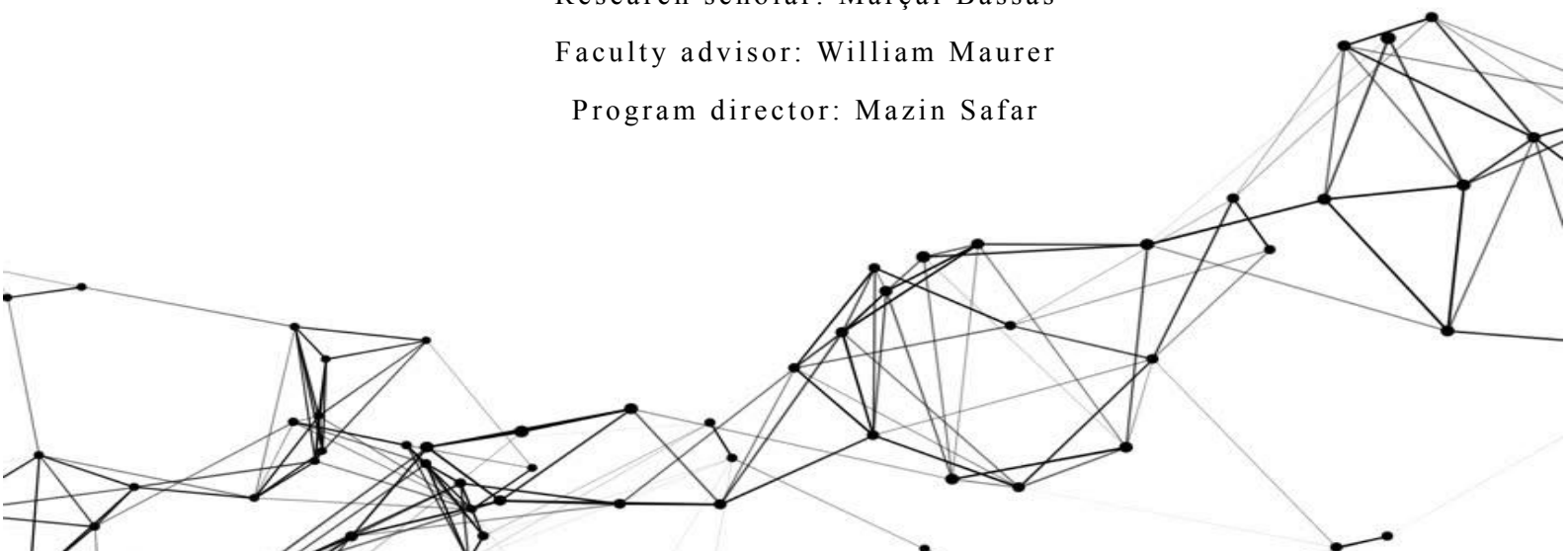


TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The industry is undergoing a digital transformation of automation and data exchange in manufacturing caused by the advance of information technologies and software. This transformation is called the 4th Industry and implies a generation of smart factories which represent a leap forward from the automation to a fully connected, flexible and optimized system.

Nowadays, every company is aware that a constant renewal and learning are essential to business success. And, among other advanced systems, Virtual Reality (VR) is a future digitization opportunity. Literally, VR makes possible to experience anything, anywhere, anytime. It is the most immersive type of computer-simulated technology and can convince the human brain that it is somewhere else. That is the reason why the largest enterprises in the world are currently investing huge amounts of money in VR companies and startups.

It is clear that the 4th Industry is bringing with itself elements such as innovation, entrepreneurship, sustainability and internationalization, requirements that every engineer should possess to be competitive in a market increasingly globalized.

As an Industrial Engineer, I decided to work on this research project because I am convinced that Virtual Reality will be a disruptive and innovative technology and part of our everyday lives in the coming years.

1.1 PURPOSE STATEMENT

Therefore, the goals of this paper are the following ones:

1. Present a general overview of this digital transition to the 4th industry, smart factories and virtual technologies.
2. Describe how VR works.
3. Figure out real and current applications in industry and justify the acquisition of this technology.
4. Explore what future steps for this technology will be and the issues still to overcome.

2. THE FOURTH INDUSTRY

Everything is changing. We are facing the 4th Industry revolution, also called Industry 4.0. Technology is advancing faster and in a near future, humans will find difficult to distinguish between what is natural from what is artificial. Not only this, technology will change the way we live, the way we work and the way we interact.

The First Industrial Revolution emerged in the 18th century in the UK and spread around Europe at the beginning. It was not only a technological revolution but social and economic as well, going from a rural economy based on agriculture to another one more urban and industrial. It was a transition going from hand production methods for self-consuming to new manufacturing processes powered by steam machines for commercial purposes. The textile industry was the first to use modern production methods and textiles were dominant in terms of employment, value output and capital invested. For instance, before the industrial revolution, just skilled women tailored hand-made cottage clothing items but then, industrial machines appeared and most of them were unnecessary. Some important technological developments were the steam machine used to move gears, the mechanical weaver and the steam locomotive.

The following revolution was born in the 19th century in the US, France and Japan. Due to population migration from the countryside to cities, the primary sector significantly decreased and the secondary, which is the manufacturing and industry sector, strengthened. It was used for electric power, replacing steam machines, to create mass production through production lines in factories. In addition, other important shifts took place in those years. For example, steel replaced iron in the construction sector because it was stronger and cheaper. So, it made possible to build rail lines at a competitive cost and spread transportation. Steel also facilitated the construction of ships, skyscrapers and longer bridges. The main discoveries were the first assembly line using conveyor belts, electricity and consequently electric machines, cars, planes and the radio transmitter.

The Third movement, born in the 20th century, used electronics, programmable machines to replace humans doing recurring tasks and information technology to automate production. It was characterized by the invention of computers and, soon after, PLC's (Programmable Logic Controllers). For instance, computers allowed manufacturers to find ways to reduce the amount

of time it takes to produce a product, how much materials are used to build it up and how to improve its quality without negatively impacting in production costs. The Industry 3.0 has gained traction in the 21st century along with high-speed Internet access, mobile connectivity, electric cars and renewable energy. This is the kind of industry that manufacturers are already leaving behind.

Now, due to the global competition, we are heading to the next generation of ideas that combine digital, physical and biological systems. (K.Schwab, 2016)

The convergence of a large sum of new materials, machines and software more powerful, important manufacturing processes and new digital services is changing the industry, as it is known. This new paradigm is sometimes called digitalization. This term could be understood as a massive adoption of digital and new technologies that are currently emerging. The ones presented below will be driven by the Industry 4.0:

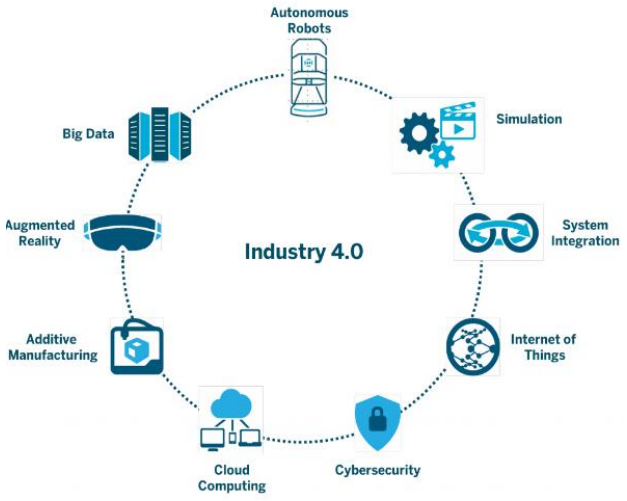


Figure 1: Digital technologies that are transforming the industrial production. Source: Robotics and Industry 4.0 - Aethon Blog. (2016, July 26)

Evolution goes straight up and one of the reasons is that all these technologies are coming together at the same time. Some general advantages that provide the adoption of digital technologies are: increasing productivity, reducing production and inventory costs, allowing to control and register the access, enhancing security and information preservation, being environmentally friendly, mitigating supply chain risks and improving quality, reliability,

maintenance and operational efficiency. Basically, they change everything about how products are designed, manufactured, sold, delivered and serviced.

Many of these technologies that form the foundation for Industry 4.0 are already used in manufacturing and they are also very interesting to study. However, this research paper focuses on virtual technologies which are currently in their infancy, but in a near future, enterprises will make much broader use of them because of their benefits.

2.1 DIGITAL TRANSITION

It is well known that people are resistant to changes. However, many companies are aware of the fact that the industry is living a digital transition from the automation of assembly lines to a fully connected, efficient and optimized system of manufacturing. This is possible by the integration of digital technology, such as the stated earlier, into all areas of a business, fundamentally changing how personnel operate and deliver value to customers.

Increasing volumes of available data, sophisticated analytics software and quickly decreasing technology costs are substantially changing businesses. According to PwC's 2016 Global Industry 4.0 Survey, it is expected that 35% of companies adopting Industry 4.0 await revenue gains over 20% over the next five years, thanks to data analytics and digital trust. Moreover, manufacturers expect to reduce operational costs by 3.6% while increasing efficiency by 4.1% annually through 2020 and 72% of them predict their use of data analytics will substantially improve customer relationships. (Appendix I, Figures 1 and 2)

According to the online magazine IndustryWeek, to compete in today's rapidly shifting industry, manufacturers need to package a potent array of new technologies and practices into a cohesive digital system designed to fundamentally transform their products, production and organization. Those companies not ready to embrace this global change and face the threats it brings will suffer the consequences of losing competitive advantage. So, in order to succeed and have the chance of leading the market, executives must elaborate long-term strategies such as investing in digital technologies and business models or training the workforce with new skills and digital culture.

Furthermore, society must work to adapt infrastructure and education and embrace the technologies of 4th Industry. The best way to get this is through a combined effort involving universities and research centers, government and companies.

All revolutions are disruptive and Industry 4.0 is not an exception. It is enabling a new era of manufacturing intelligent systems that will mark a before and an after at this start of the millennium and society should welcome it.

3. SMART FACTORIES

Smart factories, a fundamental pillar of the digital industrial revolution, are firmly underway. The use of digital technologies such as the Internet of Things[1], Big Data[2], Artificial Intelligence[3], Advanced Robotics, Virtual Technologies, 3D Printing and Cloud Computing[4] will transform the manufacturer. A manufacturing system that employs these technologies with the aim of keeping costs down while improving process efficiency, quality, reliability and safety, could be described as a smart factory.

According to a report of the consultancy Capgemini, manufacturers predict overall efficiency to grow annually at seven times the rate of growth since 1990 and 76% of them either have a smart factory initiative that is ongoing -56% of them investing $100 million or more- or are working on formulating it. In addition, they claim that smart factories could add $500 billion to $1.5 trillion in value to the global economy in five years. (Appendix I, Figures 3 and 4) (Capgemini consulting technology outsourcing, 2017)

Known as cyber factories, they are characterized by a constant and immediate intercommunication between different workstations of the assembly lines, supply chain, warehouse and offices. Also described as connected, flexible, optimized and agile factories, they are driven by the huge rise in data volumes, computational power and connectivity, advanced analytics and forecasting, new forms of human-machine interaction -such as tactile interfaces and virtual reality systems- and by improvements in the transfer of digital instructions to the physical world -such as in advanced robotics and 3-D printing-.

Nevertheless, all revolutions imply both positive and negative aspects. It should be noted that there is a clear concern around the interconnection of factories, production plants, machines... regarding the systems' security or cybersecurity.

[1] Interconnection through the Internet of computing devices integrated in everyday objects, enabling them to send and receive data.
[2] Strategy of analyzing large volumes of information, gathered from a wide variety of sources such as sensors, transaction records, videos, etc.
[3] Development of computer systems able to perform tasks that normally require human intelligence, such as visual perception, speech recognition or decision-making.
[4] The practice of using a network of remote servers hosted on the Internet to store, manage, and process data, rather than a local server or a personal computer.

Another preoccupation is about the massive recycling of workforce. Since everything is being automated, the number of workers with technical and specific profiles have been increased, however, it is predicted that many job positions will be replaced by machines or even algorithms. Then, no one knows what the employment landscape will look like in a few years, but predictions are not the best.

3.1 KEY BENEFITS

Digital technologies are disrupting the manufacturing value chain. Some of the impacts made by smart factories on manufacturing processes are presented below. In particular, it is shown how advanced technologies play a role in enabling more informed decisions and help organizations improve the production process.

Table 1: Improvements made by digital technologies in smart factories. Source: Deloitte University Press, 2017 and K. Lasse Lueth, 2015

AREA OF STUDY	EXPECTED IMPROVEMENTS
Manufacturing operations	• 3D printing to produce rapid prototypes through the construction of layers from a digital blueprint, reducing labor time and material cost and increasing customization. • Advanced planning and scheduling using real-time production and inventory data to minimize waste and cycle time. • Robotics to automatically perform series of tasks at minimum cost with high accuracy, traditionally done by humans and now in collaboration with them. • Virtual reality to simulate manufacturing steps and analyze them.
Warehouse operations	• Augmented reality to assist personnel with tasks. • Autonomous vehicles to carry and move materials and stock without a human being in control, either on the ground -intelligent transportation units- or in the air -drones-. They allow to increase transportation efficiency and reduce labor costs. • Intelligent sensors to track real-time movements and locations of raw materials, work-in-progress and finished products. • Data Analytics to optimize inventory and automatically send a signal for replenishment.
Quality	• Advanced process controls using optical analytics, detecting instantly if something goes wrong and making fast and right decisions. • Real-time equipment monitoring to predict potential quality issues. • Virtual reality to help product designers and engineers reduce the time, money and materials needed to create a series of physical products by using 3D virtual prototypes.
Maintenance, health and safety	• Sensors on equipment for predictive maintenance. • Augmented reality to assist maintenance team in repairing equipment. • Sensors to protect employees against dangerous equipment operating close to them or to monitor environmental conditions and other potential threats.

Strategy and data storage	• Predictive analysis and Big Data Analytics to extract information from data sets in order to determine patterns and trends of the market and, in this way, raise profits. • Digital performance-management system working with enablers and IT infrastructure to handle operations and processes to improve the business. • Cloud computing to host, store, manage and process information using a network architecture of secure cloud servers rather than locals. • Cybersecurity using encrypted data to protect machines against threats.
Workforce	• Virtual technologies to help workers process real-time information and make right decisions.

As may be seen from the previous table, the future of the manufacturing is in the hands of intelligent devices that will be able to exchange and respond to information independently directing processes of industrial production. In fact, society is facing a new paradigm in manufacturing where, among others, virtual technologies –Virtual Reality, Augmented Reality and Mixed Reality- play a big role.

4. COMPUTER-SIMULATED REALITIES

The annual Gartner Hype Cycle provides an illustration of many emerging technologies. It represents the maturity, adoption and viability of these technologies and trends according to a cross-industry perspective that business strategists, chief innovation officers, R&D[5] leaders and entrepreneurs consider.

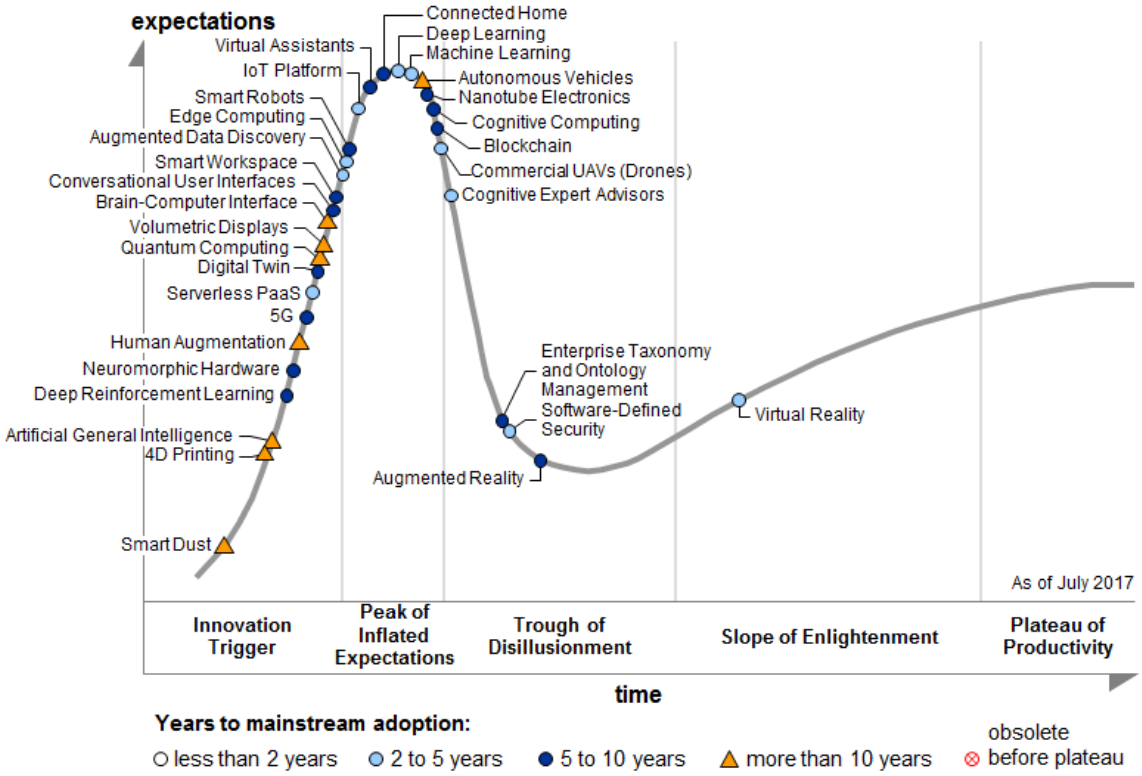


Figure 2: Gartner Hype Cycle for emerging technologies, 2017. Source: Gartner Inc. and its affiliates, 2017

The main idea behind this figure is that when a technology is born, the impact on the media is huge and generally generates unrealistic enthusiasm and expectations, a hype. In this peak of over expectations, most innovations die because of not meeting the expected standards. Only very few go through the slope of enlightenment where they are improved and profitable applications appear in the market. It is in a plateau of productivity where the benefits are widely demonstrated and accepted and the technology becomes more stable and evolves.

[5] Research and Development

According to this study, this is the case of computer-generated realities, consisting of Virtual Reality, Augmented Reality and Mixed Reality. These terms have been around for some time, but still many people remain unclear about what exactly do they mean.

Augmented reality (AR) connects people to the world. It is a technology that enhances real-life settings with digital layers onto a user's field of view. It merges the view of reality with a virtual environment and produces a composite view. The information, which is overlaid onto the physical world, typically informs at real-time by graphics and audio about objects and the environment where users are in.

This is very useful in the industry because it can provide workers with visual cues to help them perform difficult tasks such as maintenance, repair or assembly. Smart glasses can overlay instructions, maps, system information or real-time feedback over a worker's field of view. In retail, they can improve the way people shop by displaying or filtering information such as price, promotions, reviews, ratings. Moreover, they can allow increasing efficiencies in transportation supply chain by creating logistical solution such as displaying visuals to aid the warehouse picking process or real-time information about the route alerts. The advantages are countless.

Figure 3: AR used to assist a technical agent in performing his task. Source: Cisco - Augmented Reality: A New Reality for Utilities. April 13, 2017.

The concept of Virtual Reality (VR) refers to create a real-life simulation and immersive interactive experience for users. This environment can be a copy of the real world or pure

science fiction, but it replaces reality completely so that users can interact with virtual objects. It will be explained in detail in the following chapter.

Figure 4: VR used for a fully-immersed experience in a plant before construction. Source: Gray Engineering, Architecture, Construction. September 3, 2015.

On the other side, Mixed or Merged Reality (MR) is simply a mix of the last both technologies. It enables the merging of real and virtual worlds to produce new visualizations in which simulated digital objects, real objects and information can co-exist and interact with one another. Therefore, is less immersive than VR but more than AR.

For example, it can transport users to realistic training environments, which are either high-cost or high-risk, or enhance customer's experience by providing customized methods to interact with the company's services and products. The applications are also numerous.

Figure 5: MR used to visualize a mechanical hologram of a turbine. Source: Microsoft

In this way, the basic concept of these technologies involves simulation and computer-generated images to provide an enriching experience to users.

However, there are some important differences to consider. For instance, as indicated above, AR modifies one's current perception of a real-world environment with information or images to augment it, whereas VR replaces reality completely with a simulated environment. With AR, users continue being in touch with the real world while interacting with virtual objects around them, whilst with VR, the user is immersed in a completely fabricated world. The first one is partially immersive -like 25% virtual and 75% real- while the other one is fully immersive.

Besides that, AR is delivered to users through an app that can be installed on handheld devices -e.g smartphones and tablets-. It can be also supported by smart TV's, but the most life-like experience is given by wearable devices -smart glasses and helmets- because it becomes an integral part of users' entire field of view. As it does not require very specific hardware equipment, it becomes a less expensive technology.

Otherwise, VR, as it is a fully immersive technology, must be presented through a head-mounted display and a hand controller, which allows users to navigate and perform actions in the simulated world.

Despite their differences and similarities, it is clear that these technologies have a promising future ahead. In 2021, the AR and VR market is expected to reach a market size of $215 billion, mainly due to the integration capability of these technologies to most areas of an enterprise (Appendix I, Figure 5). In other words, their implementation could be applied in levels of management and organization, as well as manufacturing and operations and even in marketing and sales.

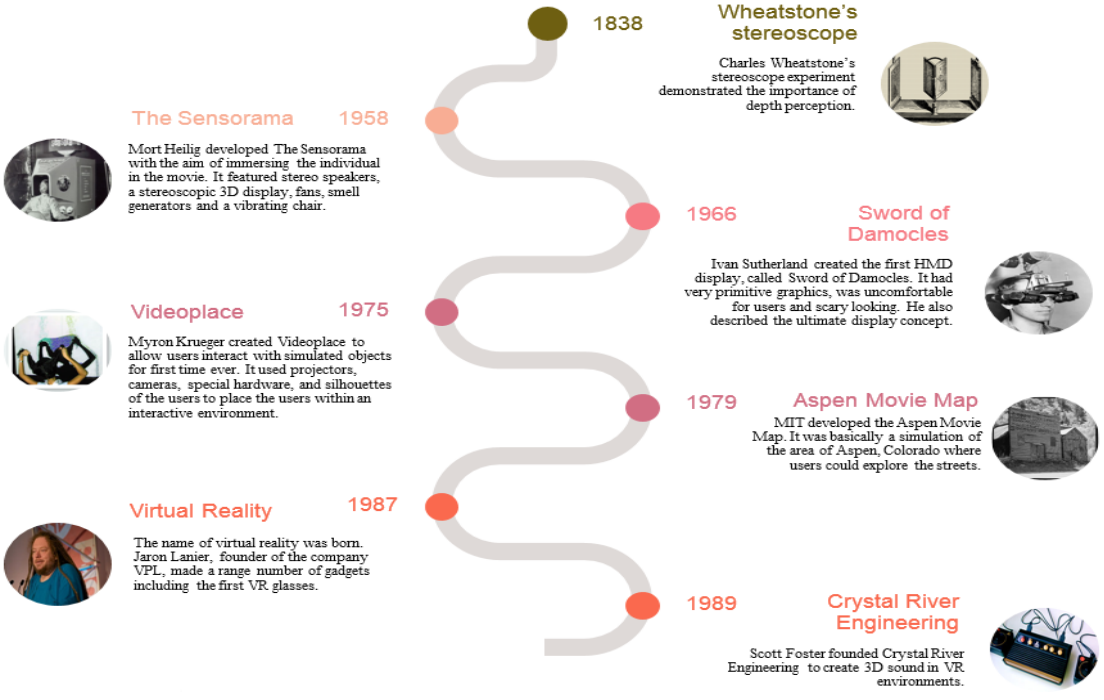
Virtual, augmented or mixed, these technologies are setting up a new relationship between the environment, people and information systems that can interact in real time overcoming time-space barriers and exchanging data as never before. (Deloitte University Press, 2017 and AYC Nee, 2013)

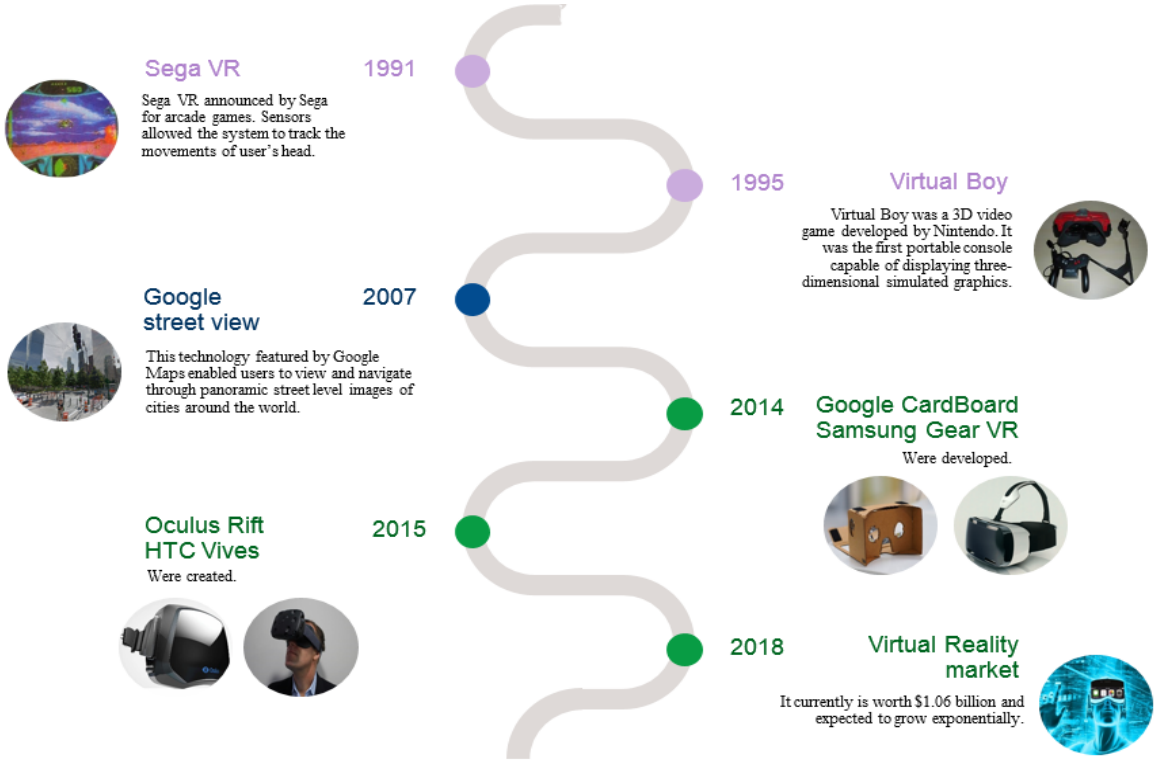
5. VIRTUAL REALITY

Virtual Reality is probably the most expecting trending and disruptive technology that will drive the Industry 4.0. Typically associated with computer gaming, this science-fiction technology may be in every workplace sooner than people think. Education, tourism, sport and rehabilitation, among others, join the group of market sectors where VR is already present -like architecture and flight simulations-. Although VR has some limitations in the enterprise environment, there are also plenty of benefits that include improved safety, faster prototyping, lower costs and better designing and training. Therefore, experts are expecting even more developments and new applications in the following years. This chapter aims at presenting the VR technology by outlining its history, understanding how it works and analyzing the role of psychology and the current state of art.

5.1 BACKGROUND

People think that VR is something that just started two or three years ago, but this technology has existed for few decades. It was a journey of secret labs, weird experiments and game consoles. Following is a brief summary of the most important discoveries and developments included in the timeline. (B.Crecente, 2016)





As can be seen from the last figure, 21st century has seen a significant advancement in the development of VR. Prices have dropped down, computer technologies have raised, overall boosted by the video game industry and the improvement of smartphone technologies.

In an industry defined by constant change and innovation, technology companies have added tremendous value creation. Many companies such as Google, Samsung, HTC, Sony and other tech titans are currently investing huge sums of money to develop, make new hardware and try to conquer this Blue Ocean[6].

However, nowadays, no virtual reality has yet been developed that is indistinguishable from reality. It is estimated that people will have to wait a decade or more to see it.

[6] Blue Ocean strategy generally refers to the creation by a company of a new, vast and unexplored market space that makes competitors irrelevant and that creates new consumer value and, with it, a lot of profit.

5.2 UNDERSTANDING VR

5.2.1 Concept

Terms for the forms of computer-mediated interfaces to interact with real and virtual worlds are frequently confused. Although the concepts of virtual, augmented and mixed reality have already been defined above, it is worth another review of what VR means.

The idea behind VR is replacing the current reality by another one better, by using a high-end user interface that involves real-time simulation and interaction. It allows users to experience virtual environments by making the brain think that they are somewhere else. In this way, users can explore and interact with virtual simulations, which could be real places or totally invented, combining high-level graphics, position tracking and motion sensors.

Finally, experts in the field claim that any experience must imply the following points, what makes the difference between VR and other digital media:

- ✓ *Dynamic control of the viewpoint*. Thanks to a built-in head tracking device covered by sensors, the system can update the images when users look around.
- ✓ *3D stereovision*. Users must be able to percept depth and three-dimensional structures like watching a 3D movie in a movie theatre.
- ✓ *A surrounding experience*. The idea is simple, the larger the screen is, the more immersive users feel. While in the movie theatre people can avoid looking at the screen and the images delivered, in VR this is impossible, even when users look around they cannot skip it.

5.2.2 Hardware

Hardware is needed to deliver a realistic, interactive and immersive VR application to users. They are systems that monitor the user in order to provide information necessary to give immersion in a space physical or simply intellectual. They provide an input for all sensorial mechanisms -visual, aural, tactile...- to enable users to interact with the virtual worlds and live an amazing experience. Experiences such as being part of a tale, playing basketball with the favorite team or even walking on the moon from the perspective of Neil Armstrong.

It is commonly believed that the concept of VR just means some computer-generated graphical representations of the real and fantasy world, but people actually view them on TV, movie theatres or smartphones. Recently, more people have started using this term of VR exclusively for the immersive experience consisted of the following three main aspects:

- ✓ *VR display*, supported by The CAVE or HMDs.
- ✓ *VR interaction*, which is possible due to controllers. The way users interact with a VR system greatly influences their experience. The modes of interaction affect how easy the system is to use, how mentally immersed users feel and the range of possible user actions.
- ✓ *VR content*, which refers to the images shown on displays that users can interact with.

The following lines explain these three key aspects in more detail.

VR outputs

Hardware and software systems are used to transform computer representations of the virtual world into signals sent to the display devices, so they can be perceived by human senses, and as each sense –visual, aural and haptic- has different displays and rendering requirements, they are usually created by different systems. The output signals, also named VR content, are primarily produced by personal computers, consoles or smartphones.

VR displays are the means by which users are physically immersed in a simulated world. A key component is how the user perceives the environment and it is based entirely on what the computer displays or presents the information. In terms of visual signals, these systems have to provide photographic quality, real-time and interactive 3D graphics. Then, it is required powerful processors with lots of memory.

Presently, the HMDs (Head Mounted Displays) are the most widely recognized forms of visual display for VR. Just as people use headphones to completely take over the sense of sound, these headsets mainly take over users' vision. Inside of a HMD is a series of sensors -magnetometers, accelerometers and gyroscopes-, stereoscopic eyepieces -normally tiny LCD[7] screens positioned over the eyes like glasses-, lenses -that make a moving 2D object look like real world 3D- and other components. Actually, these lenses create the magic. Humans have two eyes separated and

[7] Liquid Crystal Display

because of it, each of the eyes sees the world from a slightly different perspective. Humans' brain fuses those two views to create the sense of depth. Applying the same principle, the headset holds the image in the perfect distance and splits it into two, so that each eye focuses on the image through one of the lenses creating the 3D world. With only monoscopic images[8] and orientation tracking, HMDs enable many people to experience VR using standard commercial and home computing platforms.

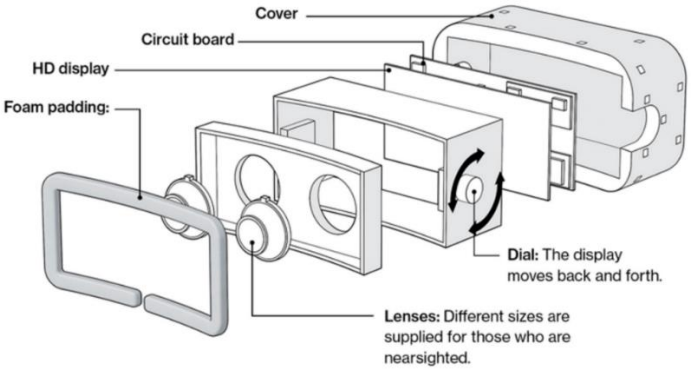


Figure 6: Head Mounted Display assembly view. Source: MedDigital. Mohamad, S.

An alternative is the use of large projection displays that surround the viewer. This method, called the CAVE (Cave Automatic Virtual Environment), has the advantage of limiting the number of gadgets the user has to be attached to. It consists in an empty room with four display walls, three around the user plus the floor, and projectors behind the walls to deliver high-resolution images. The user wears a couple of shutter glasses, with some sensors built-in synchronized to the displays.

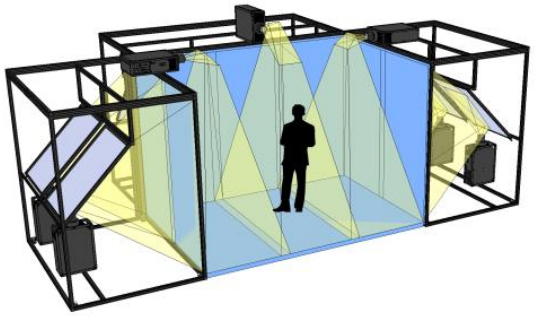


Figure 7: Cave Automatic Virtual Environment's computer-aided design. Source: Visbox Inc.

[8] Images viewed using only one eye at a time

Many factors go into deciding which type of visual display to use for an application. A research lab may already have a CAVE available to any of its scientists, for instance. However, as technology progresses toward displays that are as light-weight and easy to use as a pair of glasses, the usage of HMDs will increase.

In any case, it is worth to summarize the key benefits of HMDs and stationary displays like the CAVE. On one hand, HMDs cost much less, are more portable, take less physical space, have less concern for environmental factors such as room lighting and less computational power is needed. On the other hand, the CAVE has higher resolution, wider field of view, longer user endurance, fewer cables and give the chance of having applications with multiple users at the same time -each one carrying a device-.

Regarding the aural sense, it can be added to a VR system easily and inexpensively. Like visual displays, aural displays systems typically fall into one of the two categories discussed earlier: stationary displays – speakers – and head-based displays – headphones -. Neither the first one nor the other cost very much when compared with the cost of visual displays. Each one works better with the corresponding category of visual display.

Lastly, the haptic sense, the sense of touch, is quite powerful when it comes to believing that something is real. Sensory feedback is an ingredient essential to VR. The system provides direct sensory feedback to the users based on their physical position. Most tactile displays focus on presenting stimuli to the hands, particularly to the fingers, generated by the contact with emulated objects of the virtual world. This is because people usually use their hand and fingers when manipulating things. Compared to the other displays, the tactile ones are not very advanced. The most common actuators are simple vibrators so, in most cases, it is the visual sense that receives feedback because achieving immediate interactive force feedback requires high-speed computers. There are also expensive VR gloves that track fingers' movement, which may measure multiple joints of finger flexion or only contacts between fingertips. Even so, there are researchers trying to develop a haptic feedback suit, which would be more realistic than a glove for tracking and as a feedback device. It would be a wearable that works with haptic vibration pads which provide spot-on touch feedback. Also, sensor technology would allow the

suit to copy perfectly physical movements, leading to an exciting and enhanced interaction with the environment.

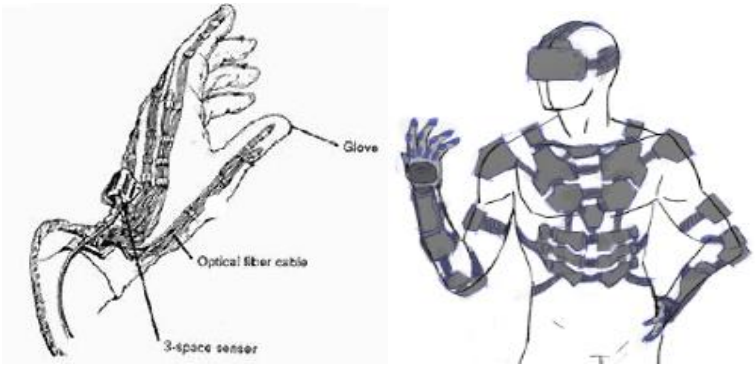


Figure 8: VR glove (left draw) and VR suit (right draw). Source: Pinterest and University of Rochester.

VR inputs

Tracking technology is used to update the displays according to the users' viewpoint, switching the images in milliseconds so that the human eye cannot notice the change. They precisely switch sixty times per second to produce the illusion of reality.[9]

It is wanted people to move, therefore it is necessary to track the user's body. For position and head tracking are used external optical tracking devices that are mounted in front of the headset in the HMDs. In the case of the CAVE, for position tracking there are several ceiling-mounted infrared cameras pointing at the user and some markers on the user's body and, for head tracking, there are small trackers on top of users' shutter glasses. Head tracking refers to the way in which the view in front of users will shift as they look up, down and side-to-side. In the current market, the most advanced system may have six degrees of freedom (6DoF) and measures user's head movements in all directions.

Any component of the body can be tracked in one or more degrees of freedom, assuming that a suitable tracking mechanism is available in an appropriate size and weight and attached to the system.

[9] This is the number of times the image on the screen is refreshed each second, also called frames per second (FPS). The human eye cannot notice that a video is a series of pictures after 24 fps.

The position sensor is the most important tracking device of any VR system because they report user's location and orientation to the computer. There are several types of position sensors, each with its own benefits and limitations -electromagnetic, mechanical, optical, video-metric, ultrasonic, inertial and neural position sensing devices-. Apart from the typology, the three most common sensors are magnetomers -acting as a compass, they indicate which direction on the surface of the Earth is the user facing-, accelerometers -to measure speed changes- and gyroscopes -to calculate orientation-. Giving an example, the gyroscopic sensor that comes in every smartphone could enable the reader to watch a VR video on Youtube and notice that the video moves with the motion of the mobile.

When the signal is interrupted, the tracking system cannot function properly. In other cases, users also lose position tracking when they move in a place where the sensor cannot see them. This means the graphics cannot longer be updated according to users viewing point. In addition, noise, low accuracy in the position sensor reports and lag time decrease the realism of the experience and can lead to nausea in some users.

Another option, which is commonly used to navigate around, is a wand composed of a touchpad or joystick, buttons and triggers as it is used in current video games. Walking around a 3D virtual scenario without moving the body allows users to explore a world bigger than the physical one where they are currently in. On one side, the use of these controllers are less natural for humans than position tracking, but on the other side, integrating position tracking and updating graphics in real-time consume a lot of computational power that must be considered.

Physical controls are the individual buttons, switches and valuators that also allow users to actively provide input directly into de VR system. All these controllers held by users in their hands are used to interact with virtual objects too -select them, picking them up, manipulate, moving or just gesturing-. Obviously, it requires rotation tracking of the wand. In addition, they can provide vibration to resonate with what users expect to feel in real life, for instance, putting a glass on a table or touching an object. So far, the best way to manipulate virtual objects is using gloves that track gestures, position and movement of the users' hand.

The main problem with most of hand-based inputs devices is that they do not provide force feedback. Therefore, users can watch the screen representation of their hand picking up an

object, but they will not feel the action. This limits the experience and creates problems with manipulation. Future versions of gloves may include some kind of force feedback, although it would be difficult to provide the kind of tactile feel required to be real.

With regard to the communication human-machine, a perfect immersive VR system would be one in which users communicate as naturally as they would do in a real world, thus it should incorporate a voice input and control device. As speech recognition systems become increasingly practical, they provide an excellent opportunity for natural communication with computers. The main goal of speech recognition software has been to create a system with unlimited vocabulary and complete independence, allowing continuous speech and offering very high accuracy in the translation. At present, the ultimate voice-sound recognition device has not been yet developed.

5.2.3 Software

Currently, the only way to create VR experiences is using 3D computer graphics, which means taking the representation of objects' height, width and depth and using them to create highly realistic 2D images. This process is called rendering and is handled by sophisticated development engines such as Unity 3D, Unreal Engine, CryEngine and Improbable. The simulation engines generate the signals that are displayed by the devices above described. How virtual worlds is perceived depends on how it is represented. Then, rendering must be done in real time, at a rate that the human brain perceives a continuous flow and not discrete images. These rendering systems have knowledge about the meaning of various inputs, the properties of objects in the simulated world and the ability to understand the consequences of any input action applied to them. The engines have to be fast and powerful to have a proper refresh rate where the simulation process has to be repeated -new input and new interactions have to be considered and the new result has to be generated-.

The process of rendering is also responsible for creating sound and, if the system includes them, smell, touch, temperature and taste. Nevertheless, the visual image is the most important aspect of any system and it can even cover some sound or touch failures. Conversely, a poor or slow visual image will destroy the effect even if the sound, touch and force feedback are perfect. Nowadays, the biggest problem is the speed of rendering because this technology works with voxels and being able to compute them generates enormous amounts of data. However, experts

have realized that human eye only focuses on about 5% of the field of view. The rest is out of focus and blurry. So once headsets have eye tracking, the computer will exactly know where the user is looking at and only render that 5% of view field in real-time and high quality, and let the other 95% blurry. Render in 360 degrees in full is ridiculous and technologically infeasible.

The first step for image creation is modeling the shapes that make virtual objects. The simplest screen images are 2D so many CAD packages create data as 2D views and then approximate them to 3D figures by using polylines and polygons. Most objects are made by simple geometric figures – like triangles, which are the most efficient to render – using Cartesian or Spherical coordinate systems to locate them into space and vectors to give them movement and animation. However, the most direct means of creating 3D representations of objects for VR applications is beginning with the real-world object and digitalize it. Once all the objects and figures are created, as well as their animation, as the filmmakers do, the project that contains them has to be imported into a VR software to be proceeded, or it can directly be created there. This software will transform the video project into a VR video splitting it into two images to be observed through a HMD. Once tested and corrected, it is ready to use the walk function.

Figure 9: Developer using a VR software to create an experience. Source: SpeedVR– Virtual Reality Media. 2017

There is another model of VR called 360 Video, or 360 VR, which is more restricted and therefore, less immersive. It is a technology based on pre-captured images from the real world. Consequently, users' viewpoint is limited to the position recorded by the camera so users cannot freely control movements through the simulation, just look around in 360 degrees. Another difference is that the video progresses on a timeline created by the filmmaker’s camera movement. Some good applications would include streaming live events and tourism.

5.3 THE PSYCHOLOGY OF VR

Something often used to describe and compare VR systems, in terms of quality experience, are the levels of immersion[10], shown in the following figure:

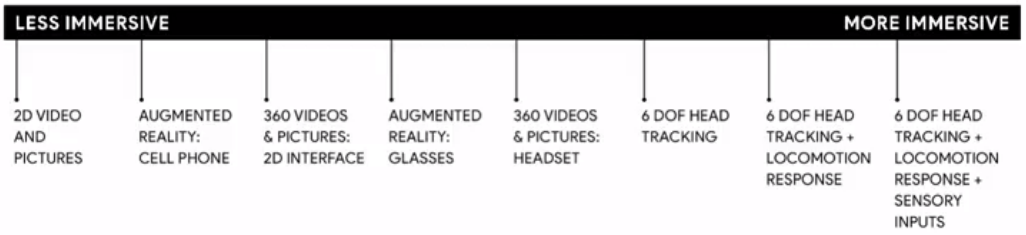


Figure 10: Immersiveness spectrum. Source: VIRT, Inc.

Immersion gives presence, which is the sense of being in the world described by the computer displays. The more immersive the experience is, the more users feel part of it. Observing the last figure, it is clear that looking at a 2D picture does not feel immersion in any way, on the other hand, 360 video is content that users feel surrounded by it and seems more realistic. In the end, the most immersive devices are those that have 6 degrees of freedom because it allows users to look around and change their position in the space as well. For instance, a HMD that tracks in six degrees is more immersive than one which does not track user's rotation so when the user moves nothing happens.

Researchers argue that the ideal system, a hundred percent immersive system, must simulate all five of human senses. Hence, it must provide virtual vision and sound -which are currently well-get with today's technology-, touch, taste and smell to reproduce the real world. These last three are more challenging but potential VR hardware could be developed in near future.

When the total immersion is not accomplished, the system is not accurate to reality, users can complain of eyestrain, headaches and even nausea or dizziness. This phenomenon is called simulation sickness and it commonly occurs by the discomfort between what users' brain expect from a real environment and what really perceives in the programmed world. Precisely, the general consensus is that the primary cause of this illness is that the body experiences a delay from the time it responds to a stimulus and the time the virtual world reacts, which is the latency period or lag time. For instance, if there is a delay between when users rotate their head and the

[10] Perception of being physically present in a non-physical world

corresponding image appears on the display. Further research on this will be necessary to ensure that VR does not become a hazard.

As already indicated, the state of being mentally immersed is often referred to having a sense of presence within an environment. Psychologists claim that three illusions must take part in VR systems to describe the feeling of being in a place:

- ✓ *Place illusion.* This means that when users look around and see the virtual world, their brains must agree that nothing strange is happening, nothing that does not follow physic laws for example.
- ✓ *Plausibility*. How much real do users take the events to be? Users must believe what is happening in this environment. It refers more to action than to place.
- ✓ *The body ownership*. If users look down to see their bodies, they must expect the shape and size of their real ones.

Knowing this, VR systems are classified into three different types regarding the immersiveness of the experience provided:

1- *Non-immersive systems:* in this kind of simulations, only a few users' senses are stimulated, primarily the visual and aural ones. Users enter into these virtual environments through a portal by using high-resolution monitors.

2- *Semi-immersive systems*: they closely resemble flight simulations. These simulations are powered by high-performance graphical computing systems, which are often displayed by large screen projector systems surrounding the user to properly stimulate the visual sense.

3- *Fully-immersive systems*: the third group provides the most immersive implementation of VR technology. Hardware such as HMDs and sensors are used to stimulate all of a user's senses. Fully immersive simulations can deliver very realistic user experiences by displaying a wide field of view, giving high resolutions and computing at increased update rates.

In conclusion, psychology plays an important role in this technology. It is important to take into account that there will be always a confrontation between the selling price and the quality and

quantity of technology used to develop a system, to give better presence and immersion and as a consequence more realism to the VR experience.

5.4 STATE OF ART

Leaving aside the CAVE systems, which could work perfectly in large labs, this chapter focuses on outlining the main types of VR headsets.

When it comes to choosing, the first question that people should ask themselves is how they want to deliver the VR application that they want to develop to reach their targeted users. They may prefer to upload the experience created on the Internet so that users can try it with their mobiles or they may want to use it privately inside the company to gain competitive advantage. As it is commented above, VR systems can run thanks to platforms such as mobile devices, PCs and consoles, so this first question will help to determine which kind of HMD is better to buy.

There are actually two kinds of HMD in VR: the first one is the accessory that users plug their smartphone into and becomes the screen, like Samsung gear VR or Google Cardboard. They are affordable and more portable, but these devices are not as powerful as the second category, the PC headsets or Standalone, like Oculus Rift or HTC Vive. The second type of HMDs are much more expensive because they do everything as they have the screen and sensors built-in, however, the main issue is that they are tied by cables connected to the computer or console.

Then, if it is wanted to develop an application cutting costs and trying to reach the mass market, a good idea would be starting with mobile headsets. On the other side, if it is something more private, for example in psychology treatments or company's products design, it would probably be better to own a dedicated area where having a full set-up supported by powerful computers and PC headsets or even a CAVE system.

Not both HMD categories will emerge as winners in the near future because although PC headsets are more immersive and offer better experiences, they are still too expensive for most consumers. Alternately, affordable headsets run by smartphones are more cost-friendly but can induce sickness because of lack of body track and computational power. (Appendix I, Figure 6)

As VR has gained name among businesses in the past years, some of them have taken risks and invested in this technology expanding their companies to new markets to capture more customers and revenues. The war to conquer the VR industry is already set. The next figure presents the most important technical features of each top companies' star product as a comparison between these two kinds of headsets.

Table 2: Major features comparison among top companies' star product. Source: Business Insider, 2016; New Atlas, 2016 and J.Mirt 2017

HMD model	Oculus Rift	HTC Vive	PlayStation VR	Samsung Gear VR	Google Daydream
Price ($)	$499	$799	$399	$100	$79
Company	facebook	htc	SONY	SAMSUNG	Google
Shipments 2016	355.000	420.000	745.000	2.317.000	261.000
Market ranking	4TH	3RD	2ND	1ST	5TH
Platform	PC	PC	Console	Mobile	Mobile
Equipment needed	PC/laptop, controller, HMD	PC/laptop, controller, HMD	Game console, controller, camera, HMD	smartphone, HMD	smartphone, HMD
Resolution (pixels per eye)	2160x1200	2160x1200	960x1080	1440x1280	1440x1280
Refresh rate (hz)	90	90	120	60	60
Field of view	110 degrees	110 degrees	100 degrees	96 degrees	100 degrees
Weight (lbs)	1.0	1.2	1.3	0.7	0.5
Positional tracking	✓	✓	✓	✗	✗
Wireless	✗	✗	✗	✓	✓
Focus adjustment	✗	✗	✗	✓	✗
Lens distance adjustment	✗	✓	✓	✗	✗
Built-in headphones	✓	✗	✗	✗	✗

6. ACTUAL BUSINESS IMPROVEMENTS

Virtual reality is no longer part of some distant future, and it is not just for gaming and entertainment anymore. According to Business Insider and Super Data Research, the VR market is projected to reach more than $30 billion by 2020 because the possibilities that it offers are endless. VR technology carries with itself extraordinary advantages that lead to a broad field of applications in many diverse professional sectors, and that is the reason why the largest companies in the world -such as Google, UPS, Walmart, Intel, Samsung, Sony, Facebook, HTC, among others- are investing heavily to incorporate it into their organizations. (S.Kumar, 2018)

Contrary to popular belief, VR can offer much more than just gaming, which has been a traditional consumer sector of the technology. VR has been proven so far to be beneficial in several areas and the most important ones -such as defense, healthcare, live events, education or training- are overviewed in this chapter. Furthermore, this section aims to justify why this technology can improve businesses by analyzing real company cases and identifying what VR have done for them.

6.1 VIRTUAL ENGINEERING

Caused by the current highly competitive business and manufacturing environment, the manufacturing industry is embracing this technology with the aim of implementing integrated VR systems that could enhance manufacturing processes, as well as product and process development, leading to shorter lead-time, reduced cost, increased flexibility and improved quality and safety.

In the area of product design, VR can change the way in which engineers develop products, by enabling companies to digitalize the product-design process in order to accelerate design workflow, generate ideas, embodying concepts, enhance quality and producing the information necessary for cost-effective manufacturing. Virtual prototyping technique has been studied and implemented in recent years in engineering design. In mechanical engineering, VR prototyping is going to replace physical mock-ups, as it is less expensive and more flexible.

Figure 11: BMW designers using VR into vehicle development . Source: BMW turns to HTC Vive and Unreal Engine to design cars in VR - SiliconANGLE. (2016, April 8)

Product design is probably the number one business application right now. VR is assisting in the development of products by enhancing computer-aided design (CAD) systems. The reason why this is so helpful is that it allows visualizing the product in the way humans normally do it, through images and not raw data.

The car manufacturer BMW Group is stepping up its innovating initiatives using VR to design and shape their vehicles, check out specifications or functions and test them. Engineers just need to wear a HMD and start drawing, modeling and assembling the new prototype in a more intuitive 3D space while previously, they needed to build full-scale models of their vehicles expending up to $6 billion, and spending a lot of time checking and manually going through the designs one by one. Now, this technology is mainly allowing them to cut costs and time involved in the research and development process. "The adoption of this computer system makes it possible to save a great deal of time, cost and effort, especially during the early stages of development", the company announced. This is translated to cheaper and faster output to the market. (BMW News, 2016)

Many others manufacturing companies are applying it, for instance, Chrysler and IBM reported working together on virtual cars that will speed up the design process and Boing is already using VR models to help in the design of tunnels and interiors of its airplanes. Basically, VR is enabling to see and manipulate detailed full-scale designs before production whilst conventional technologies are not.

Additionally, it is nowadays being used for factory planning – where to place machines, tools and operators-, to design production flows or to analyze workers and robots performing tasks, which are crucial factors for productivity. As engineering changes in existing manufacturing plants or a new ones need testing and trials, VR becomes very useful because enables instant alterations without increasing the cost.

Improving the ability to examine and explore 3D data is also being very practical. Not all VR systems are used to create a world that looks and feels like the real world people live in. Some systems make easier to visualize information by representing the data through images as it is made in finance, risk management insurance and all fields that require analysis of statistics and big data. For example, Metaphor Mixer is a computer program that uses the virtual world to let brokers visualize what is happening to the stock market and other data simultaneously. Instead of the data being represented in the traditional way as columns or numbers, it is shown through figures on a large surface. It even can give more visuals alerts than existing software when a specific stock rises or falls above or below a limit previously set.

As already appointed, the amount of data that a human brain can process on a bidimensional computer screen is limited. The two dimensions are also limiting graphics, charts and animations that could make easier to understand and analyze. VR visualization technologies are solving this problem in the oil field too, by enabling geologists to view fault block models of complex geologic settings to determine yield calculations. As the graphs become more interactive, the analytical work gets more intuitive.

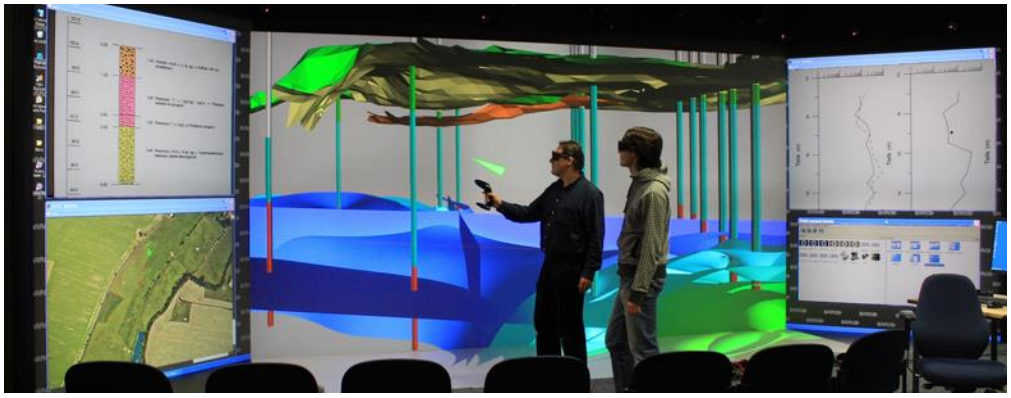


Figure 12: Researchers exploring geoscientific data in the oil and gas industry. Source: Dr.Björn Zehner. (n.d.). Mixing 2D/3D Vis. - Helmholtz-Centre for Environmental Research

Lastly, both the manufacturing and infrastructure sectors are governed by complicated and demanding security systems, which should be followed in order to avoid accidents. VR can help to eradicate them in the phase of designing a process of new facilities and factory layout, by allowing plant managers, maintenance technicians and engineers to walk-through of the proposed facility in the very early stage.

However, there may be still big risks in the development of the work related to these divisions due to the nature of the labor. That is why having a highly trained staff, capable of controlling any dangerous situation and reacting to the most serious work-related accidents is fundamental for these industries. VR is being used here to increase worker health and safety within these environments by recreating simulated emergency experiences like chemical spills, by developing simulations involving heavy machine usage or just by alerting emergencies with information into the operator's point of view. As it provides a realistic and riskless scenario, the number of injuries in the workplace can be reduced substantially. For example, there are cases of companies recreating VR environments such as quarries, oil refineries and facilities, electric power plants and other dangerous places in general, where operators work under risky situations and have to accomplish the established procedures. (L.Tommaso, 2017)

General Electric recreated its French nuclear power plant with VR to enable its engineers to familiarize with the equipment and learn how it operates. The designers used 3D models of generators, steam turbines, pipes, valves, etc. replicating even the smallest detail to give the fullest realism. Igor Ballaud, a GE manufacturing engineer, explained that maintenance engineers had to work with physical models to learn about specific parts of the power plant without the possibility of seeing them working, but now, thanks to this technology, they can observe all the machines interacting before stepping into the real plant. This, in effect, makes doing operations easy and improve workers safety. (M.Egan, 2017)

Figure 13: Operators or firefighters applying VR for training procedures. Source: TwoReality. (n.d). Formación y simulaciones en realidad virtual y aumentada

Recommended video: VR for Engineering from Virtalis, on Youtube

6.2 VR IN OTHER INDUSTRIES

6.2.1 Virtual healthcare

The benefits of VR technology have touched the medical world and is actually helping to save lives. From diagnostics to practicing difficult surgical procedures, healthcare institutions are incorporating this technology to enable doctors, trainees and healthcare professionals to decide the best location for incisions by analyzing 3D VR models and scientific data in a deeper way. There are extraordinarily complex and delicate organs, like the heart, that has to be well visualized and studied because ultimately people's lives depend on it. Before, the best doctors' resources were computer images, but now this technology is allowing to explore and practice medical operations through realistic simulations or even perform a complicated operation with the assistance of doctors located elsewhere, as the Royal London Hospital does.

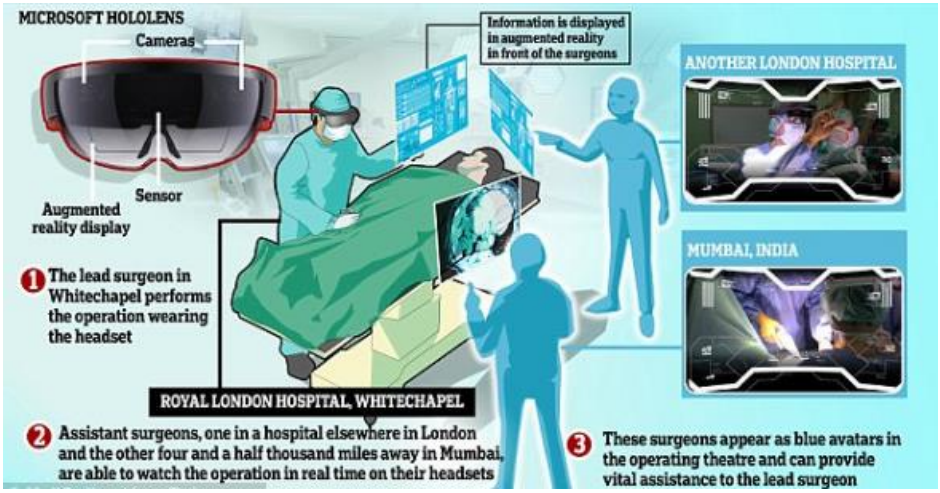


Figure 14: AR and VR applied in surgery. How it works. Source: DailyMail.com. Thompson, A - Health Reporter. (2017, October 24). Virtual reality headsets are set to revolutionise surgery

VR can also be used to synthesize diagnostic images of patient's body received from ultrasound, magnetic resonances and x-ray. This combined digital model provides much more complete diagnosis than any of the separate image techniques. For example, for patients with cancer, representations of the body can be used to allow a radiation therapist to travel around and inside a tumor and viewing it from every angle. This permits to target a tumor more easily and accurately.

A recent advancement is the application of VR in rehabilitation. Here, patients perform practice behaviors while interacting with the computer-simulation of an environment that imitates a physical presence in the real or imagined world. In this way, they can develop motor control, balance or strength by re-engaging connections in the brain.
After the patient becomes comfortable with catching or manipulating slow-motion objects, the action can be increased in speed gradually. As the patient progresses, the speed increases until the point close to real-world one. Finally, the patient is ready to practice the same skill in the real world. Some scientific studies results have proved that VR rehabilitation demonstrates being more effective than traditional rehabilitation methods, particularly in the area of post-traumatic stress disorder.

Probably one of the most practical and important application is concerning clinical psychology. Here, VR becomes an efficient instrument for the treatment of attention deficit disorders, mental health and managing pain. Professors at the University of Texas in Dallas have created a program that uses VR to help children with autism develop social skills, by putting them in social scenarios such as job interviews or blind dates with avatars. But, particularly, an interesting application is the cure for patients suffering from phobias and anxieties such as fear of heights or spiders.

The ideal way to accomplish this is gradually exposing users to the thing that frightens them and allowing them to practice on a slightly less threating situation than that which exists in the real world. As the person knows the experience is not real, the user may be able to practice relaxation exercises during the experience and just being involved emotionally, and not physically, so the user cannot be hurt in any way. After a few sessions, the person may be able to experience the situation in the real world. For example, Plextek Consulting has been researching use-cases of VR in mental health. Collette Johnson, medical business development manager at Plextek said

that VR would help in niche situations where traditional therapy is a struggle for particular patients. Other successful companies treating peoples' phobias such as fear of flying, animals, public speaking, agoraphobia and even traumas are Psious, Virtually Better and Bravemind.

None technology before could provide such an incredible benefit, and the advantage lies completely in the immersiveness of the experience and replication of a configurable reality. (M.C.Howard, 2017 and the Medical Futurist Institute, 2017)

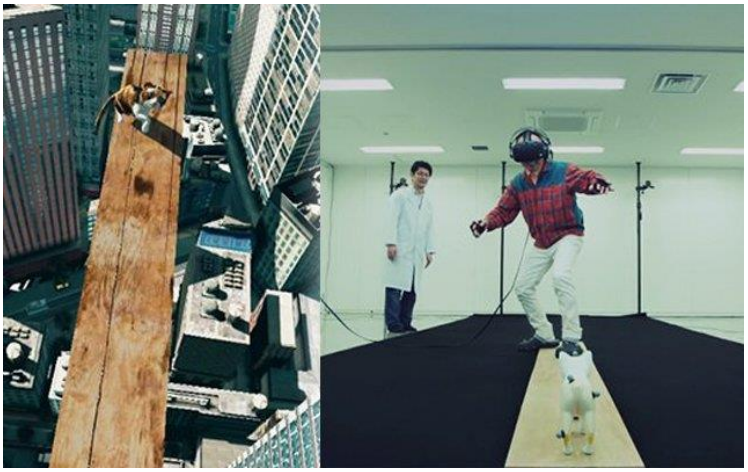


Figure 15: VR used to treat fear of heights. The user is trying to save the cat at the end of a wooden plank. Real world (right photo) and virtual world (left photo). Source: Grape. (2016, March 31). Japan Opens Up Its First Virtual Reality Store In Odaiba To Save Kitty From Falling - fear of heights show.

Recommended video: Overcome your fears in virtual reality, on Youtube

6.2.2 Virtual education and training

Another application area where VR is being very helpful is the information visualization, for educational and training purposes. VR brings the opportunity to interact with data, which is better than reading from descriptions of textbooks pictures, helping students to remember longer, learn faster and even decide better. Moreover, it lets people save money and time eliminating in-person education, real equipment or materials and is a better system for those without the opportunity to be where the educational class is taking place because VR would allow those to study online but virtually there.

The Physics Virtual Laboratory from Houston University is using it in order to help students to understand Newtonian quantum physic notions. Mendel Grammar School in the Czech Republic

is teaching students about the anatomy of the eye in biology classes with VR. The University of British Columbia in Vancouver is experimenting with virtual lecture halls. Trinity University in San Antonio, Regis University in Denver and Princeton in New Jersey, to name few more, are innovative universities currently using this technology to teach and engage prospective students. But, above all, this new trend is stepping into schools and high-schools where new generations are embracing innovative educational methods.

Figure 16: VR used in education and training programs. Source: Gajsek, D. (2017, October 25). VR Education - 4 Educational Fields in a Serious Need of VR - Viar360

Furthermore, VR can become a powerful tool in training as it can contribute to improving operators' skills, knowledge, competence, preparedness, awareness and safety behavior.

For instance, Walmart partnered with a VR startup called STRIVR, to use it at the training academies to help employees experience real-world scenarios, get that one-and-one expertise and make them ready to better serve customers among other tasks. As technology advances, Walmart academies advance and the result is more competent staff and satisfied customers, which means higher revenues.

The fast-food chain, Kentucky Fried Chicken, designed a virtual training room to teach its employees how to prepare and cook its famous food. According to a KFC spokesperson, the idea is to speed up the process and avoid the potential wasted product. However, it was made to supplement the company's hands-on cooking program, not replace it. Although the difference between both methods is that VR does not incur costs of food wasted for training purposes. (W.Fillon, 2017)

Similarly, the world's largest package delivery company, United Parcel Service Inc. or UPS, is training inexpert drivers with it. "VR offers a big technological leap in the realm of driver safety training", said Juan Perez, UPS chief information and engineering officer. The company's IT team created virtual content to improve safety by simulating on road hazards. This hyper-realistic technology is currently replacing the touchscreens devices that, previously, UPS used to teach lessons. (UPS Pressroom, 2017)

The good thing is that, in the training field, the risk is eliminated while simultaneously the realism of the training environment is enhanced. Overall, is much important in technic training, explained above, and medical training. In medicine, simulation of real operations helps students familiarize with medical procedures and the atmosphere where they are going to practice. Students could learn how to work under pressure and handle the emotional stress that could arise during an operation.

Western University, to give an example, is using it to teach anatomy to its medical students. In there, students can interact with objects in a 3D environment, learn about science and other subjects by being immersed in a virtual world or go on virtual field trips.

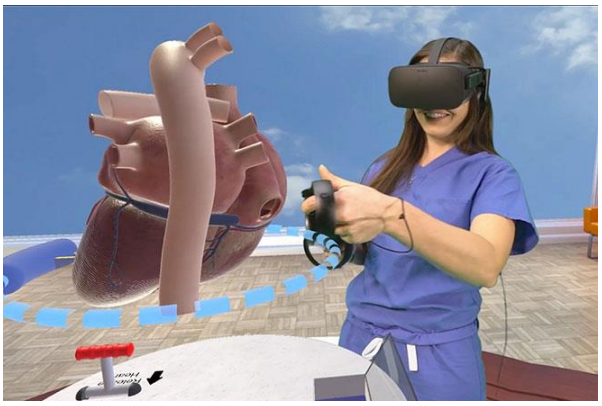


Figure 17: Trainee using VR to understand complex heart defects. Source: Stanford University School of Medicine – the Stanford virtual heart

Recommended video: This virtual lab will revolutionize science class | Michael Bodekaer, on Youtube

6.2.3 Virtual defense

Like many other technologies, one of the first areas where VR found practical applications was in military training and operations. It is very beneficial as a simulation of reality, extending the human senses through telepresence, enhancing military training by putting soldiers on the

battlefield without hazard exposure and allowing them to improve skills, test weapons and verify tactics.

Figure 18: Soldiers using VR to master their war skills. Source: Wearable – Tech for your connected self. (2015, December 31). 'How VR is training the perfect soldier

Telepresence, or virtual presence, also enables soldiers to operate equipment, often robots or weapons, from remote locations. By using VR technology to provide immersion, operators can better control machinery for precision tasks.

The US military has been using VR for training purposes -like flight, battle simulations and medical interventions- since 2012. It can provide a broad range of simulated and full-immersive scenarios for military practice, being more cost-effective than recreating the scenario in real life. (A.Stone, 2017)

Even the National Aeronautics and Space Administration, NASA, is using this technology to train astronauts for spacewalks and to connect their engineers with the devices sent to the space. The NASA's VR lab is actually helping a lot by giving the best solutions for their problems, because, basically, VR allows them to recreate the same experience astronauts may have in the Space in a way they could not do before. (A.Kauderer and B.Dunbar, 2011)

Recommended video: U.S. Soldiers Train Using Virtual Reality, on Youtube

6.2.4 Virtual cars, aircrafts and boats

The automotive industry has been among the first sectors using modern simulation and visualization techniques in the production cycle. VR technology in this field serves to evaluate, in a more naturalistic way, the product under development, mainly in terms of styling but also in visualizing post-processed results of simulations such as in technical analysis, scientific

visualization of fluid dynamics or crash analysis results. Moreover, this technology is being used as a driver-training tool for simulating real-life scenarios and teaching driving safely. Also, as a marketing and sales technique so that customers can live and test the driving experience of different cars.

Audi AG, member of the Volkswagen Group, recognized very early the potential of VR as a key future technology for digital retail formats and created the Audi VR experience, which gives customers the opportunity to configure any Audi model with the sales adviser and experience their dream car in a highly authentic way. Not much time ago, prospective buyers had to configure their car through a catalog and only could test the model that was in the showroom, but now, thanks to VR, customers can explore every detail by selecting instantly from several hundred possible models and equipment variants and then, feeling the excitement of driving it. The result is more pleased customers and more cars sold. (Ingolstadt, 2017)

A similar case is the partnership between Volvo and Microsoft on a demo that allows prospective car buyers to digitally configure and test cars at a dealership.

Figure 19: Lexus VR driving simulator. Source: Lexus. Retrieved from Hypergrid Business. (29, October 2015). 75% of top brands have VR projects

Regarding the aerospace field, VR produces a sensation similar to actually flying, where the pilot receives visual feedback both inside and outside the cabin. In the military, there is a simulator called SIMNET, which uses VR not only for training purposes but also to develop and test new combat strategies and tactics. Troops are being deployed with helmets capable of visualize very realistic flight simulations, which create advantages in the air on the battlefield.

In addition, VR is an incredible instrument for yachts manufacturers and sellers because of the possibilities it offers when it comes to projecting and visualizing the interior and exterior of these boats. Customers can explore the yacht in 360 degrees and interactively navigate through the spaces and environments, without having even to be there. They also can analyze possible design, material, finishing and decoration modifications, including the complete customization of details and characteristics. A real-time experience, innovative and surprising that allows users to visit any corner of the boat even under construction, observe the movement that waves and wind effect to the boat and choose the ideal place in which users want to locate it. This is achieved thanks to the use of identical scenarios to the boat that buyers have purchased, with an audio guide and with interactions that will turn this experience into something unique in its genre.

Recommended video: Ford is using Virtual Reality Technologies to design cars, on Youtube

6.2.5 Virtual retail

VR is truly going to revolutionize the e-commerce world, bringing the store of the future. Several companies and institutions around the world are nowadays using this technology to create virtual experiences that allow shoppers to buy online or also to promote their new products and services in commercial events.

IKEA is one of the first retailers to launch a very well done VR experience through a virtual store and incorporating e-commerce. ”Virtual reality is developing fast and in five to ten years it will be an integrated part of people’s lives. We see that it will play a major role in the future, for instance, it could be used to enable people to try out a variety of home furnishing solutions before buying them”, says Jesper Brodin, supply manager of IKEA. The company has known how to seize this technology by just letting customers do, instead of having to think up new room setups and show them through images in a catalog or build them in big stores, saving a lot of time and money in design, production and space. Apart from increasing sales by digitally displaying products designed by the customer, this experience is helping IKEA to receive a more precise feedback from its shoppers. (T.Akesson, 2016)

Mastercard Inc. allied with the crystal company Atelier Swarovski with the same purpose as IKEA, launch a virtual experience to immerse customers in a similar-to-reality store where they can browse, try and purchase items from home, with a Mastercard’s digital payment service. As

the reader can see, one of the advantages that VR provide is boosting e-commerce incredibly by bringing the experience of shopping in a store to the Internet. (K.Samuelson, 2017)

eBay partnered with Myer, the Australia largest marketplace, to create the first virtual department store in the world, changing absolutely the online shopping experience. The idea is simple and only requires user to have a VR headset and a smartphone to experience the concept through the app. Shoppers can browse, sort and purchase items and the department store learns from them, adapting itself and personalizing what it shows to be more comfortable, appealing and saving users more time of exploring. This concept is stepping forward, going from clicking on websites for purchasing items to actually buy as if users were in the store, which means going from e-commerce to virtual-commerce. (M.Dunn, 2016)

Finally, Walmart is joining the party by the acquisition of a startup called Spatialand. It is said that it is going to be the cornerstone of the long-term efforts that the company hopes will someday transform its different websites and stores in order to compete with Amazon. (R.Turcsick, 2018)

Another use is for stores set up. There are large brands and many retailers stuck in traditional methods, spending more than $20,000 per year in manipulating the shelves manually to appeal buyers. Currently, VR solutions are offering an innovative way to visualize new merchandising concepts and test different store layouts or shelving options in order to learn what will engage customers. (InContext Solutions, 2018)

Figure 20: User's point of view using VR to design a store shelf. Source: InContext Solutions. (n.d.). Mixed Reality Retail Optimization Platform

Recommended video: ShelfZone VR shopping experience – English version, on Youtube

6.2.6 Virtual videogames

Some of the advanced concepts and technologies that were created in research laboratories have found their way into the video game industry. Practically, VR was born in this market sector and now is changing completely the way gamers play. It is used to generate virtual environments, develop stunning games and allow users to interact with it. For example, playing tennis table is now possible using a VR controller as a ping-pong racket and an animated ball using physical simulation. (Appendix II).

Figure 21: User playing The Climb, a VR game. Source: Oculus Rift. (n.d). The Climb

Sony Corporation is a well-known leader of the videogame industry and it is actually making a fortune thanks to its spin-off company called Sony Playstation VR (Sony PSVR), which is bringing out VR games and selling consoles and virtual headsets on and on. "Working on game development, we always try to create a new kind of experience, and having VR technology is almost unfair" pronounced Shuhei Yoshia, president of Sony PS Studios, meaning that developers can quickly and easily prototype their ideas and create new experiences. Precisely, what VR have achieved that other tech could not is adding an extra dimension to gaming so that people can feel inside the game. (E.Makuch, 2014)

On the personal computer and workstation arena, Apple, IBM, Facebook, among other firms, are also investing in VR research and development. Actually, it is rumored that Apple has a secret research unit working on a futuristic and powerful VR and AR combined headset that, together with other accessories, is going to substitute PCs.

Recommended video: Introducing the games coming to Oculus!, on Youtube

6.2.7 Virtual social life

There are few video games using this technology as a tool to socialize with people around the globe such as VRchat or Sansar. Social VR is expected to be a very big thing. The experience would be like living a second life through avatars and wandering around virtual worlds. It would allow people to be who they want to be, live where they want to live or just do whatever they want without any risks, fears or embarrassing moments. Something unimaginable with other technologies.

Facebook, Inc. is one of the companies that has been investing heavily in this technology, for example with the acquisition of Oculus for $2 billion in March 2014. Its CEO, Mark Zuckenberg said once "VR is about imaging the world as it could be, creating opportunities for people everywhere, because we believe the future can be a lot better". With the aim of providing the best social platform ever, the company is planning to launch Facebook Spaces, which is a social VR app for Oculus Rift that allows users to meet friends -represented by digital avatars- anywhere as if it was in person, start a video chat or live broadcast and even capture a virtual selfies. (H.Kelly and S.Larson, 2017)

Recommended video: Facebook Spaces – Teaser Trailer on Youtube.

It can also be used for improving communication, enhancing collaboration and information sharing through face-to-face virtual conversations. It is allowing users in different cities or countries to sit and interact with each other in the same space virtually across vast distances. It will have an important role to play in office communication for holding meetings or for conference rooms, but will also be a great tool for contacting relatives and friends.

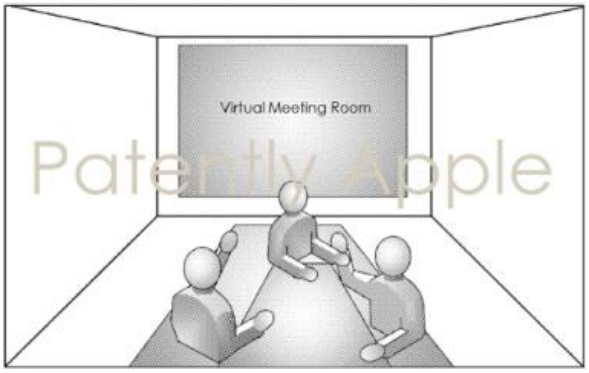


Figure 22: Patent of a virtual meeting room filed by Apple in 2017. Source: Google Patents

6.2.8 Virtual media an entertainment

This application has the aim for users to experience the news and documentary movies and be part of it. The immersion generated by VR really plays an important role and makes emotions raise, presenting something in a completely different way observed so far.

Cable News Network, better known as CNN, is bringing its VR new app to give the audience the opportunity to go there through interactive experiences, providing a deeper sense of connection with the news and taking the journalism to the next level. Jason Farkas, executive producer of CNNVR says in the commercial, "VR can absolutely change the way people understand stories". CNN broadcasted the first US democratic presidential debate in VR and it was watched across 120 countries. (CNN PressRoom, 2018)

National Geographic Society has launched a VR channel, which place viewers to the front lines of the action alongside the explorers, photographers and storytellers. In this way, users can live and feel the documentaries as if they were there, instead of watching the TV. (VRWorld, 2016)

VR is being embraced in cultural and ludic tourism too. One of the key selling points for this technology is its ability to put users in locations they are unlikely to visit in person because these are whether too expensive, too dangerous, out of bounds due to mobility issues or just because they do not like flying. Then, virtual tours of historic and art scenes, companies' facilities, hotels, or even parts of cities are becoming helpful to attract tourists because traveling in time and space to visit these sites in first person is a very attractive way to discover and better understand them. The experiences are made by recording with 360-degree cameras to recreate real places in three dimensions. In this case, VR is a powerful tool for companies in the travel industry because it allows customers to visit and interact with the different elements of their future trip.

Several airlines -such as Delta Airlines, Lufthansa, Singapore Airlines, Air France, XL Airways, etc.- are adapting VR to offer a service that once people do the online check-in, they have the chance of visualizing in advance the plane with which they are going to fly and the experience onboard that they are going to live. Some of them even showcase the most touristic place of users' destinations. In this way, curious customers get more satisfied with the services provided and more loyal to the company.

Another example is a boutique cruise line called Azamara Club which uses VR to demonstrate its onboard and destination offerings to prospective clients. Additionally, hotels like Hilton and Marriot Hotels and Resorts are doing the same successful strategy to appeal new guests. In particular, the British travel group Thomas Cook reported a 190% increase in tours booked to New York after offering a VR experience of the city in their stores.

Figure 23: Woman exploring her destination place through VR technology. Source: TwoReality. (n.d). Viaja por el mundo gracias a la realidad virtual

Furthermore, one of the best uses of this technology is the streaming of live events. Just imagine living a rock concert, appreciate an opera show form the front row without having to pay a premium ticket or watch and interact with players of the favorite sports team.

A company called NextVR is focusing on sport and entertainment and has already worked on the US Open tennis tournament and several boxing matches, as well as a live Coldplay gig. They enable the transmission of live and fully immersive content in broadcast quality and already have a total funding amount of $116 million. Another new trend lies in theme parks, where VR is used to offer movie rides. These rides show a visual image along with motion simulating the physical experience of a roller coaster or a cars race. Likewise, it is done in The Void theme park in Utah, where visitors become fighters in an alien war, run through a gigantic maze, experience VR rollercoasters and stay in VR-friendly hotels. This entertainment company is allowing family and friends to step beyond reality.

All of this it is now possible thanks to this technology. Although it is very realistic, the only problem is that there is lack of interactivity as it is done with 360 Video taken from a fixed position. Therefore, they are considered low immersive experiences.

Recommended video: Chicago in 360 Virtual Reality - GSC3 VR, on Youtube

6.2.9 Virtual real estate

Environment simulations enable customers and designers to explore an existing site and interiors of buildings via VR, giving them the opportunity to visualize how space can be modified or used effectively. In the past, scale models were built to ensure environment conditions such as lighting, heating, airflow and furniture layout were optimized. However, building models for design purposes are not only costly but also inflexible because any major change may require a new model to build. With VR, it is possible to update the representation of the building with new parameters so that professionals can improve the initial design.

In architecture is used to show clients a 3D walk-through experience of what a building will look like before constructions have begun, while in residential or commercial real estate is being used to recreate virtual tours letting buyers explore properties without traveling to the site as it was done before. When it comes to choosing, buyers value attractiveness, effect, functionality, viability, costs and benefits of decisions made through these interactive simulations. Clients seize this technology to enter in these virtual and participative environments in order to express their style preferences and interests. Firms such as Stambol Studios, HMC Architects, Archilogic and Holoplex are taking advantage of this. (C.Proffitt, 2017)

Figure 24: Client exploring a design solution on a real-world scale. Source: HMC Architects. (2017, November 8). Revolutionizing School Design with Virtual Reality (VR)

VR systems also step into homes. Virtual Reality, and Augmented Reality as well, are starting to streamline the way people run and furnish their houses due to the fact that today's home-owners expect easier and faster methods of doing improvements. (S.Dredge, 2016)

Recommended video:Virtual Reality is the new open house, on Youtube

7. FUTURE STEPS

Digital realities are getting closer, it is now possible to mix real environments with computer-based elements that provide additional information and build virtual realities to interact with. Then, looking ahead to the future, it is clear that people will be surrounded by computer-simulated realities and they do not have to be aware of that because, the truth is, these technologies are not here to take people's job but to help them to do their jobs better. Actually, experts forecast the industry reaching a value of $80 billion a year, 35 software and 45 hardware, by 2025 and, as manifested in the following figure, the potential of AR and VR technology being extremely diverse. (Appendix I, Figure 7)

Particularly, VR is booming the industry. New applications of this immersive technology have appeared and new businesses have been created during last years, so it is not a surprise that it is becoming less science-fiction and more science-fact and anyone who has tested a VR experience can attest to the quality and functionality.

As every disruptive innovation, it is predicted to gradually get into society while prices begin to come down. According to digital business platform INDVSTRVS, the VR market is projected to reach more than $28 billion in the next 2 years. However, most venture capitalists say that while VR has the potential of providing a very profitable return on investment, they are holding back before jumping in with both feet and are waiting to see if this takes off as many hope.

Although VR is in the very early stages of development and it is widely associated with gaming, it is believed to not only create new markets but also disrupt existing ones, because it is actually reshaping the current ways of doing things – such as watching a sports match, designing new products or teaching-.

Now, if VR is as easy as wearing a headset, the reader could wonder why are not people living in a virtual world today. Unfortunately, there are numerous issues still to overcome. This section presents the challenges that the VR industry has to overcome and what predictions of the future are going to be.

Table 3: Issues that VR technology has to face to keep growing. Source: UnfoldLabs, 2017 and M.Khoury, 2018

CONTENT
The big players in the videogame industry are not participating in developing VR technology. Top game developers like EA Games, Activision Blizzard and Ubisoft currently watch VR with a wait-and-see approach. This complicates the improvement of this technology because content producers do not have enough consumer market to justify investing in quality content and consumers do not have enough quality content to justify purchases of VR gadgets. An endless loop.
The good news is that even though VR is still at its infancy stage, strong merger and acquisitions are currently taking place in other markets apart from the videogame industry, which means a promising future for this technology.
A slow connection, which is not ideal for transferring large amounts of data, is negatively affecting the VR user experience.
Faster performance of wireless networks is also needed for VR to be widely adopted. Until 5G networks are in place, we probably will not see it being used by everyone.
Problems in creating good-looking 3D graphics and believable animations. If everything remains quiet, it would not feel so real. Users expect to see, e.g, leaves falling from a tree or cars moving on the road.
More computational power is required. At least, it has been discovered recently that in order to recreate a photorealistic environment, objects must interact properly with the light because unless this effect is rendered, things look flat and simple rather than 3D.
It does not exist any odor system working properly because once a smell is in a place, it does not go out of the way easily.
A Japanese startup called Vaqso has designed an odor emitting attachment for VR headsets. With the shape of a candy bar, the device has space for up to three different odors and comes with a fan that can change the intensity of the smell based on what is happening on the screen. Therefore, it seems this problem will be forgotten soon.
Most VR systems include audio. However, the production of realistic sound has not yet been perfected. In addition, limited optics, 3D graphics and interaction capabilities are offensive weapons of the skeptics against this technology.
This is the typical and very common early years growing pain. The technology is new and experimental, still under development. As time goes on and money is invested, new scientific discoveries will be made and new applications will be found out. Then, all these problems will be resolved quickly.
HARDWARE
There is not enough standardization for VR devices. Despite the efforts to standardize VR development tools through open source projects, there is a large number of different controllers, treadmills, hand sensors, gloves and other motion sensors available. This is a problem because the majority of consumers lack the time, money or physical dwelling space to support them. Plus, they create additional challenges for content creators as their content may be tied to a specific device configuration.

A healthy market development is needed and open source projects and collaborations should arise.
While companies are competing to bring VR to consumers, prices are still high and adoption is concentrated among enthusiasts and early adopters.
As always, the key to mass consumption is by making VR devices more affordable. As technology moves forward, new applications come to light and the demand increases, manufacturers will start to invest heavily and take advantage of economies of scale that will reduce unit prices.
Consumers can be unwilling to wear VR headsets in public due to bulky size.
Large size of processors and 3D displays may make it difficult to build headsets smaller and less uncomfortable at this moment.
Users are not free from the constraints of cables.
All the indicators point that, in the near future, there will be possible to have wireless HMDs powered by desktop machines, e.g through Bluetooth.
Virtual navigation, where users move forward and backward and turn right and left using joysticks or other controllers, is unrealistic and can cause nauseas. On the other hand, in physical navigation, which is the best way of moving, users are limited to space.
It is needed to discover other methods more naturals than importing a first person controller designed in 2D video games. Actually, researchers are working on omnidirectional treadmills to allow users to run in any direction while staying in place.

PSYCHOLOGY
One concern is that while this technology acquires higher quality and immersion, it becomes more attractive to those who wish to escape to a virtual life and avoid dealing with the real world. The idea of escapism is a common even in current addictive videogames.
This could be a clear side effect because as this technology improves and solves all its issues, this particular problem will grow. The only solution here is making people aware of it.
Simulation sickness is not fully resolved. Although latency rates are performing at a level needed to minimize dizziness, VR content often leaves users feeling nauseated due to differences in the brain's perceived visual field and the body's actual motion.
As VR systems become more precise and immersive, the experiences lived by people will start to be hyper-realistic and avoid any chance of getting sick. Moreover, it has been demonstrated that the more time users spend in a virtual world, the more they get used to it.
The sense of touch is difficult to reproduce. Experts use joysticks and touchpads to provide vibration, simulating the ability to interact with a virtual object in a naturalistic way. However, there is no haptic device that allows users to feel objects in different parts of the body nor the sensation of force feedback, e.g, if a virtual character pushes user's chest, he or she would not feel it.
This kind of tactile feedback remains unsolved so far, but it is believed that people will see soon VR gloves that will allow users to grab objects and feel them in any part of the hand, instead of only pointing at. Plus, rudimentary prototypes of full-body suits already exist, providing haptic feedback in any part.

Even though all these issues are still to be solved, the VR market is growing at a consistent rate because people believe in this technology and the levels of investment suggest that is heading

more towards practical applications than ever before. Improvements and enhancement will definitely push this technology further as it is integrated into people's lives. Actually, VR is bringing out to the market new applications almost daily, so it is not crazy to think of new uses for this technology where it has not been yet applied.

For example, a future application could be changing the environment to release stress and get relaxed, for instance, by simulating waterfalls or Polynesian rainforests in a yoga class or a workplace room.

Likewise, the most innovative restaurants could start to incorporate virtual experiences in order to bolster the business. VR simulations would help brands to stay ahead in the foodservice industry by evaluating the best setup for promotional products or showing customers the menu options in a life-like way to help them choose.

VR for sporting events is also a predictable arena where it eventually will be popular. This market sector moves a huge amount of money and organizations like the NBA, NFL or FIFA will surely broadcast VR multimedia soon. It would provide professional players more immersive experiences for their tactical sessions than sitting in a room watching the flat screen, but, above all, spectators would actually embrace VR because of the advantages it gives them. Fans would be able to watch the match from any view – aerial view, best seats of the stadium, even from the same playing field – while they are at their own comfortable homes. Overlay real-time statistics and commentaries would be also feasible.

Museums also could truly seize this technology for historical revival because as times goes by, history becomes more abstract and intangible. For instance, thanks to VR it would be possible to recreate the moon landing or the civil war from the user's point of view.

Another good implementation would involve watching content and practicing languages. Usually, when people are learning a new language they study writing, grammar and vocabulary. Nevertheless, it is often said that in order to improve quickly, it is needed to be more engaged and that is why travel to a foreign country is so useful. VR would allow these learners to really maximize their progress by practicing simulated conversations labeled by levels of difficulty so that they can directly train speaking and listening skills, which are the core of a language.

A final application that could come to mind would be as an instrument to recall places. This would be very used in retirement homes, hospitals or centers where disabled people stay. They would employ this technology to, for instance, walk around the city, enjoy outdoor activities like hiking or swim in the beach and, in this way, feel happy and fulfilled.

The possibilities are endless. From experimenting how is like having specific symptoms of an illness to being a celebrity for a while or from having virtual meetings with friends and family located in other countries to help students choose a career by watching a day-in-life of a professional in this job. (P.Kauffold, 2016)

To sum up, Virtual Reality is poised to be the biggest advancement in technology since the smartphone. It will likely revolutionize most of the industries by changing the way people view and interact with content and bringing experiences to life in a way that has never before been possible. The future of VR is just starting and the promise of having other worlds is getting close.

8. CONCLUSIONS

To conclude this project, the reader can confirm that all the goals shown in the introduction have been accomplished. It has been presented a general overview of this digital revolution called Fourth Industry, the concept of smart factories, the similarities and differences between the computer-simulated realities and a description of how virtual reality works. Writing from the general to the specific was a proper method to introduce the environment of virtual reality, which is the cornerstone of this project. Additionally, the most important current applications of this technology and actual business cases have been covered in the study, and future steps and uses have been predicted.

After doing deep bibliographic research, attending events, talking to experts in the field and VR software suppliers on the topic of virtual reality in the industry, I have reached the insights stated below:

- Due to a global competition and the vertiginous advance of technology, new manufacturing intelligent systems and digital services are rapidly shifting most of the industries and creating new profitable opportunities. Therefore, those companies not ready to embrace this digital change will suffer the consequences of losing competitive advantage.
- The use of innovative technologies such as Internet of Things, Big Data, Artificial Intelligence, Advanced Robotics, Virtual Technologies, 3D Printing and Cloud Computing is expected to drive a massive recycling of workforce for the next years.
- There is more than hardware and engineering behind VR. Software and psychology play a big role in order to make an experience truly realistic without causing any disorder.
- VR technology carries with itself extraordinary advantages that lead to a broad field of applications in many diverse professional sectors, and that is the reason why world's largest companies are investing to incorporate it into their organizations. The VR market is projected to reach more than $30 billion by 2020.
- Some say that VR is about escaping the real world but actually is about helping students to understand faster, improving videogames, enhancing manufacturing processes, assisting healthcare professionals, helping shoppers choose easier and, of course,

bringing us all closer together. There are many different ways that VR is manifesting itself in our everyday lives.

- As I attended an event held by VR startups based on Chicago, I could chat with some engineers and test for first time a virtual experience as well. It totally exceeded my expectations and I could analyze, personally, what were the weak points that did not make me feel pure realism. They were poor physical interaction graphics, any feedback force and lack of details.
- It is undeniable that VR has come to stay. Businesses and investors are heavily putting money in this technology and that is why new developments are coming to light almost every day. Moreover, based on the knowledge acquired, future applications have been presented in this project so this is a Blue Ocean open to new entrepreneurs.
- The limitations and capabilities of VR have been reviewed too. Lower hardware cost, improved software and a growing evidence of successful implementations will lead to a more accessible technology and a massive consumption. Thu I personally encourage business to get in early and exploit this opportunity, start making mistakes, learn from them and see what works and what does not because it is always better to be ahead of the game than behind.

Finally, I just want to add that I have been hearing from virtual reality for some time ago, however, by doing this research paper I could understand the current impact that this technology is actually doing in different market sectors. In addition, I could learn the basic principles behind the technology and, above all, I can attest to have the proper knowledge to identify in which business cases or applications it is worth to apply it.

Recalling the introduction, every company is nowadays aware that a constant renewal and learning are essential to business success and virtual reality is a future digitization opportunity. With this work, I personally feel more prepared to start a career in such a globalized, innovative and fast-paced labor market that we are all currently living in.

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