UNIVERSITAT POLITÈCNICA DE VALÈNCIA

Conception and realization of an augmented reality application for the use in the educational context

Bachelor Thesis

presented by:

Domenec Miralles Sanchis

tutor
Stefan Kim

cotutor
Juan Jesus Izquierdo Domenech

Abstract:

Augmented reality is a relatively new technology. It’s mainly based on the superimposition of digital information to a real environment, offering numerous benefits to the user.
Augmented reality systems are increasingly being used in areas such as training, marketing, entertainment and especially in education. The purpose of this work is to investigate the possibility of augmented reality applications in this field using devices and applications in the current market.

I believe that using this kind of technology in classrooms can improve the experience significantly for the teacher and the student. For the student having an interactable application, makes him more immersed and engaged with the content. And for the teacher, sometimes trying to explain some topics without a visual representation, may be challenging, that's why I believe this technology can be of a lot of help.

If implemented successfully, AR not only improves learning but also reduces costs and trains different skills like spatial abilities and mechanical skills into growing children.

Lastly it can also improve accessibility to people with difficulties, giving them an easier time when learning some topics.

Abstrakt (German Abstrakt)

Augmented Reality ist eine relativ neue Technologie. Es basiert hauptsächlich auf der Überlagerung digitaler Informationen mit einer realen Umgebung und bietet dem Benutzer zahlreiche Vorteile.
Augmented-Reality-Systeme werden zunehmend in Bereichen wie Training, Marketing, Entertainment und insbesondere in der Bildung eingesetzt. Der Zweck dieser Arbeit ist es, die Möglichkeiten von Augmented-Reality-Anwendungen in diesem Bereich unter Verwendung von Geräten und Anwendungen auf dem aktuellen Markt zu untersuchen.

Ich glaube, dass die Verwendung dieser Art von Technologie in Klassenzimmern die Erfahrung für Lehrer und Schüler erheblich verbessern kann. Für den Schüler, der eine interaktive Anwendung hat, taucht er tiefer in den Inhalt ein und beschäftigt sich mit ihm. Und für den Lehrer kann es manchmal eine Herausforderung sein, einige Themen ohne visuelle Darstellung zu erklären, deshalb glaube ich, dass diese Technologie sehr hilfreich sein kann.

Bei erfolgreicher Implementierung verbessert AR nicht nur das Lernen, sondern reduziert auch die Kosten und trainiert verschiedene Fähigkeiten wie räumliche Fähigkeiten und mechanische Fähigkeiten in heranwachsende Kinder.

Schließlich kann es auch die Zugänglichkeit für Menschen mit Schwierigkeiten verbessern, indem es ihnen das Erlernen einiger Themen erleichtert.

Thanks:

Thanks to my mother for giving me support, my classmates for giving me advice when I was lost and to all the youtube tutorials I have followed that taught me more than my university teachers.

Índex

Introduction:

In certain occasions, the new technologies are necessary for progress and innovation in a society in which phone devices are present in the daily lives of the users. The technological development and improved device performance have propitiated that the new technologies as for example the augmented reality is introduced in all areas of today's society.
It should be said that the entertainment sector has been the one that has promoted the concept of augmented reality again, which has caused other sectors to see multiple benefits in its use.
The education sector is not considered an exception, as it has already experienced a technological evolution and incorporated new ways of teaching kids.
The incorporation of augmented reality in this process can allow better communication between professors and students, as well a greater interaction between the student and the teaching subject.

Motivation:

The main motivation of this work is the different people I have met and subjects I've had in my bachelor studies.
I took a lecture called "game developing" which introduced me to the Unity game engine. My teacher of the course taught me that Unity is a very versatile engine and can be used not only for making games but also educational applications, to help people with difficulties etc.

My interest in the Augmented Reality(AR) field arose when in another subject I read that in a study made by the Boston Consulting group they mentioned augmented reality is one of the pillars of technological advance of the 4.0 Industry.

After developing some AR games using Unity in the posterior year in one of the conferences my university hosted, a father showcased an application he made for his son to play using AR technologies. That gave me the idea to make an application that could be used to teach kids about things.
Since a lot of my family members are teachers, I asked them which aspects they had trouble teaching and if this could be viable. Their main concerns were that some kids have a hard time trying to understand what the teacher is trying to communicate, for example emotional intelligence or some hard topics that are hard to visualize. At the moment I thought that using Augmented Reality to illustrate some of those topics would help kids understand them better.

Objectives:

The objectives of this work are:

Understand what augmented reality is.
Research current technologies related to Augmented Reality.

Develop an application in the educational context using Augmented Reality technologies.

Thesis Structure:

We will divide the thesis in 3 parts.
First the state of art in which we will talk about the current state of Augmented reality and in which fields are being used.
Secondly, we will do research on technologies related to augmented reality applications.

And lastly the discussion about the application, which includes compares traditional education to AR education methods and showcases the application.

State of the Art

Before starting showcasing the Augmented Reality application is it necessary to talk about defining what this technology is and put it in context. For that we'll talk about the concept of Augmented reality, as well as the current situation of AR and in which context it is being used nowadays.

Augmented reality.

Augmented reality (AR) is a technology used to enhance the physical world with virtual elements such a digital visual or sounds giving the user a real scenery augmented with virtual information.
Refers to the technology capable of complementing the perception and interaction with the real world, offering the user a real scenario enhanced with virtual information.[1]
Augmented Reality aims at simplifying the user's life by bringing virtual information. Through this technology Text, images, audio, videos, 3D models and other elements can be incorporated into the user's real world perception. This enhanced reality can help the user comprehend better what's happening in his environment and bring him more knowledge.
A good way to visualize this is through Paul Migram and Fumio Kishino definition of the Milgram-Virtuality Continuum in 1994 as a line from the real environment to the Virtual Environment. The space between these is what's called Mixed reality.

[1] C. Orozco, P. Esteban and H. Trefftz, 2006

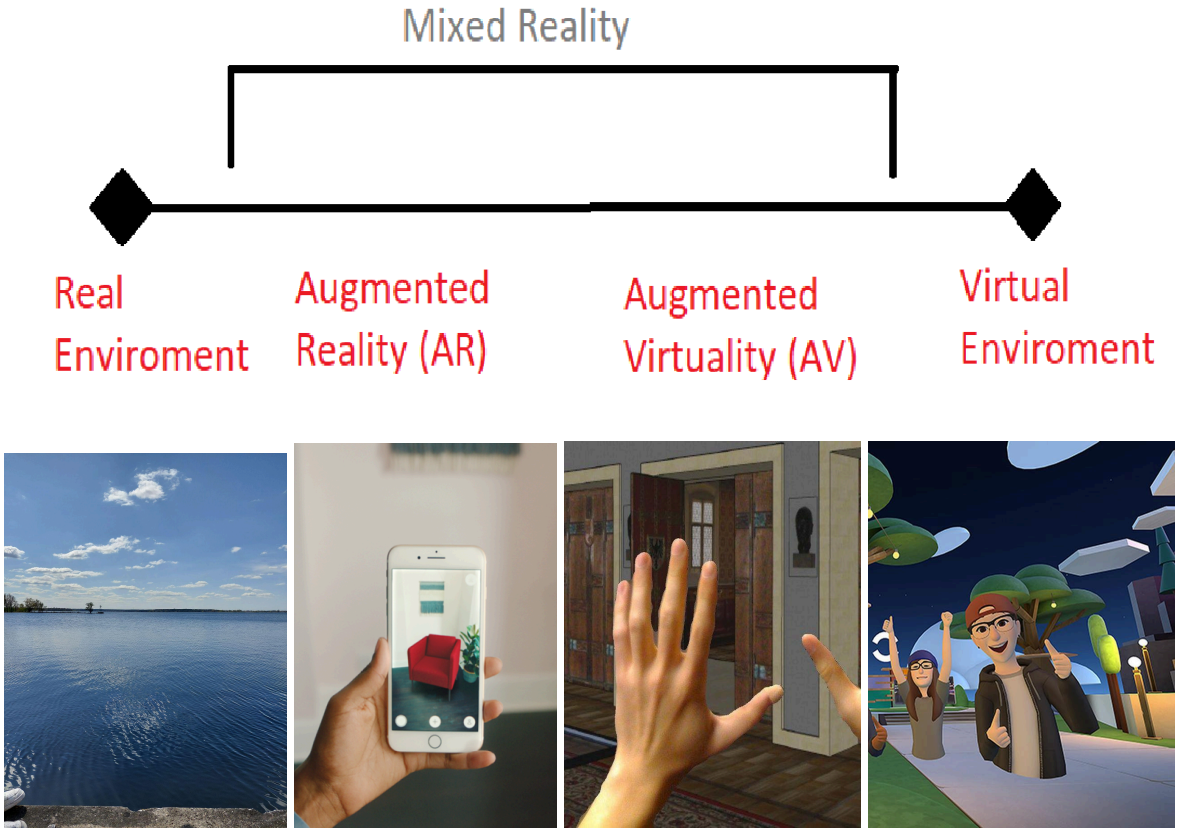


Illustration 1: Milgram's Reality-Virtuality Continuum
Source: Paul, M. y Fumio, K. (1994) IEICE Transactions on Information Systems.

As you can see in the Illustration each edge represents a reality. The anchor on one end consists of real objects and the other with a purely virtual environment. The space between both anchors is considered to be a Mixed reality (MR). When the environment is augmented with virtual content is called augmented reality (AR), and those where most of the content is virtual but there's some inclusion of the real world objects it's called Augmented Virtuality. They consider any environment which consists of a blending of real and virtual objects to be mixed.

Azuma's definition of AR:

In order to explain the behavior of some devices, it is also necessary to talk about Azuma's definition of AR.

According to Azuma AR allows the user to see the real world with virtual objects, superimposed or composited with the real world. Therefore, AR supplements reality, rather than completely replacing it.

Azuma's definition states that AR systems have the following three characteristics:

- Combines real and virtual
- Interactive in real time
- Registered in three dimensions (3-D)

Registration, the third characteristic, is about seamlessly aligning virtual objects into 3-D space in the real world. Without an accurate registration, the illusion of virtual objects existing in the physical world are compromised; the believability is broken.[2]

[2] Jordi Linares, Introduction to XR course.

How AR works:

There are three augmented reality technologies and applications that allow AR to work. These are simultaneous location and mapping (SLAM), depth tracking, and image processing and projection. When put together, they make AR a reality.

SLAM (simultaneous localization and mapping) is a piece of technology that lets you build a map and localize your device in that map at the same time. It is aided by localizing sensors to take a full sense of a physical setting. Depth tracking, on the other hand, measures the range of an object or a surface from the AR device's camera. Lastly, the AR application or software processes the images to get the dimensions and the location correctly.

When these applications work simultaneously, they project a digitally produced object into the real space.[3]

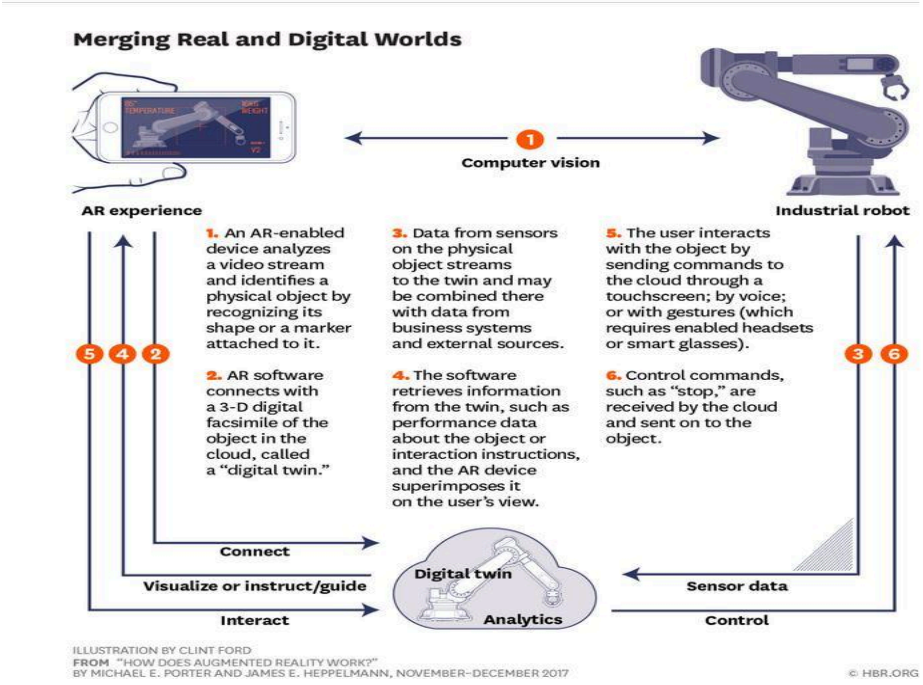


Illustration 2: How does augmented reality work?

Source: Harvard Business Review

Capturing element.

The function of this element is mainly to capture the information of the physical environment to pass it on to the software in order to process it.

It is required to meet some basic technical requirements, such as are that ir records correctly, being evident that the greater resolution the camera has, the higher quality the real image will have and therefore the final result will be more optimal.

[3] Gilbert, Nestor. "Augmented Reality Technologies Today: 2022 AR Research

The camera can be independent of the display device of the augmented reality signal or integrate into it.
The common examples are web cameras connected into computers or cameras integrated in phone devices.

Positioning element.

One of the fundamental pieces in an augmented reality system is that source of information, also called “activator of augmented reality” which allows the virtual layer to be positioned within the reality, this function can be fulfilled by three classified groups of the following way:

- Markers
- GPS, compass, accelerometers.
- Object recognition.

These are location elements such as GPS that currently are integrated into smartphones and tables, as well as gyroscopes and accelerometers that allow to identify the position and orientation of said devices. As well as labels or markers of the type RFID o bidimentional codes, or in general any other element capable of supplying information equivalent to that would provide what the user sees, such as sensors.

Processing element:

In order to interpret real-world information that the user receives, generating virtual information and combining it appropriately it is necessary to have a process unit and specialized software.
The requirements of his process unit will depend on the system used, needing more power in recognition systems by images. For the same reason in the case of overlapping 3D models, more graphic powers are needed.
Lastly it also requires specialized software capable of managing the different devices and analyzing and adding virtual information to images.
This element can be installed and used on devices, such as computers, game consoles, tables and smartphones.

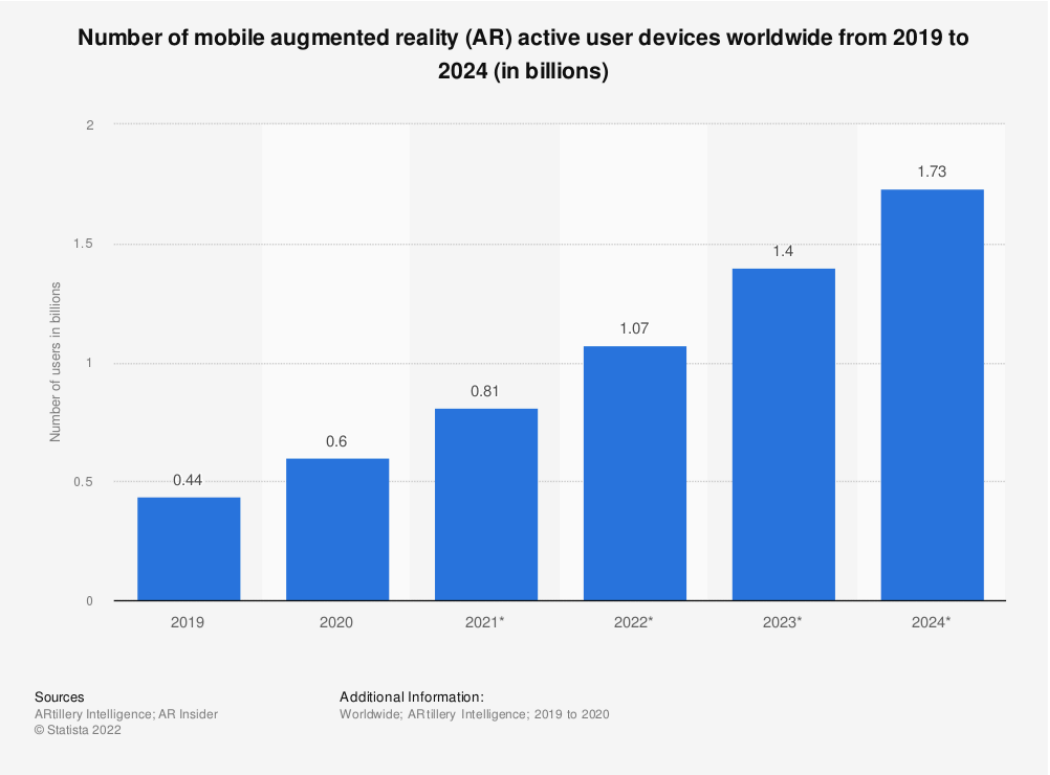
Projecting element:

At last it is necessary to have an element or device on which to project the content with the mixture of real and virtual information, leading to augmented reality. To do this, they can act as such a screen or monitor of a computer, television, smartphone, tablet, game consoles or even some special glasses, which can even have a built-in camera. The larger the screen size the better the sense of immersion in augmented reality it also allows the user to be able to join the two layers (real and virtual) more effectively.

Interest in Augmented Reality:

Augmented reality technology has proven to be one of the top innovations opening up new growth points for businesses around the world.With a large market to tap into, providing AR experiences can be a competitive edge in many industries.

For the past years AR active users have been growing considerably and it is predicted that these numbers will grow further. It is expected that slowly but surely AR will be part of our domestic and professional lives.



Graph 1: Number of mobile augmented reality active user devices worldwide. Source: Global mobile augmented reality (AR) user devices 2019-2024

Augmented reality is in my opinion the base for being the next big technology that serves as a bridge to the virtual world , improving our daily lives, helping workers develop their work , aiding disabled people or even helping persons get to their destination. There are a lot of contexts in which AR can be useful.

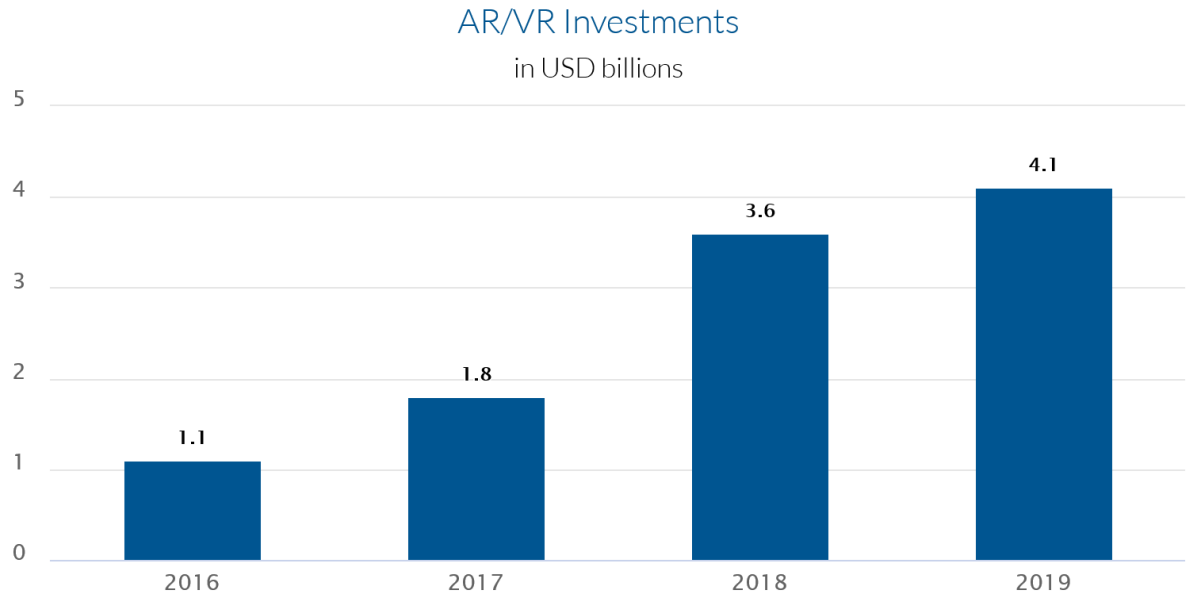
Furthermore for the last decade there has been large investments into VR/AR technology which expanded the horizon of this technology. Some of the reasons of this investment are:

The Covid19 pandemic has amplified the advantages offered by AR. With shops shuttered worldwide and consumers prevented from physical interaction with products, being able to

offer customers the option to virtually try, explore and visualize purchases in their own homes has been an opportunity for retailers.

The popular game of Pokemon GO , its raging popularity and revenue in 2015 and 2016 made marketers and advisers sit up and take this technology seriously. This led other brands into investing in AR.

AR is mobile and personal and, therefore, hugely accessible to a rapidly growing smartphone market. AR is an inexpensive alternative to other media platforms as no specific media needs to be purchased.



Graph 2: Investments in AR/VR technologies
Source: Fast Company; Next Reality; VentureBeat, 2019

Current situation of AR industry:

The most well known augmented reality use case is gaming, thanks to the past pokemon go success.As can be seen in the increase in corporate and industrial investments it is also widely used in scenarios other than gaming. We'll explore in which contexts AR is being used currently.

Retail:

A good example of this environment is IKEA's Augmented reality app.
Built using Apple's new Augmented Reality ARKit, the app includes 3D and true to scale models of everything from sofas and armchairs, to foot stools and coffee tables. Giving you an accurate impression of the furniture's size, design and functionality in your home.
The user can place a virtual furniture item in their homes. This allows them to make sure it fits in the room and avoids annoying measuring and mistakes.

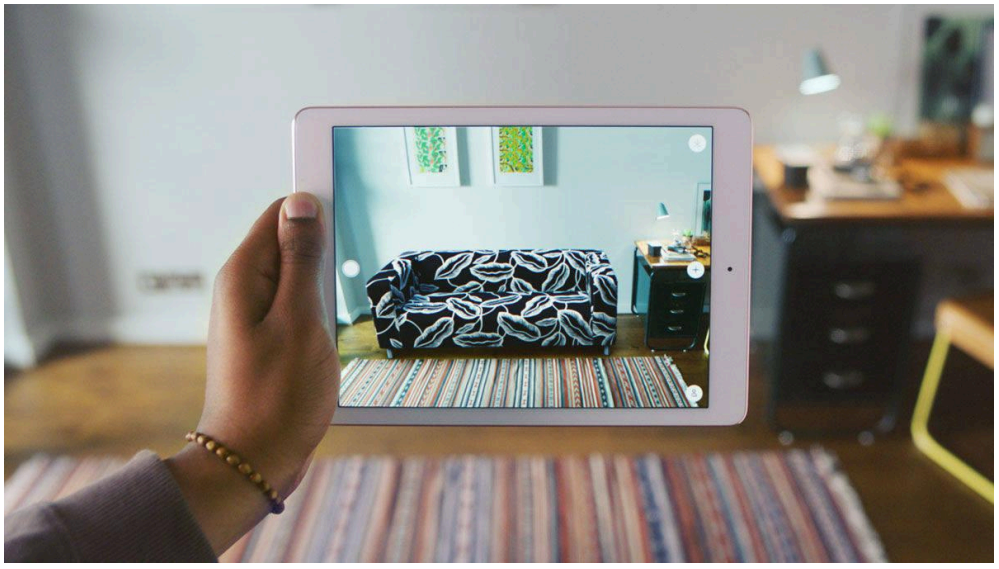


Image 3: Ikea's Place application demonstration.
Source: Ikea

Civil construction:

With the ability to provide real-time information, augmented reality is being used within the industry to increase efficiency, improve safety, streamline collaboration, manage costs and boost overall project confidence.

New developments in augmented reality are making it possible to generate 3D models directly on a 2D plan. Combined with 3D modeling software and building information modeling (BIM), construction companies can produce detailed, interactive models of building projects and present them to clients at the start of a project. This allows clients to get a

realistic view of project outcomes and make any changes before construction begins. Getting this level of client involvement early in the process helps prevent costly changes later and keeps clients engaged.

One major innovation in augmented reality is its ability for users to make changes to building models directly on the field site. Using a headset or mobile device, workers can easily display interior and exterior views of a structure and make modifications to the virtual plans while keeping the original view intact.

This application will be particularly useful for engineers, as it allows them to troubleshoot any errors in a virtual view before applying changes to the physical structure. Since this digital data is continuously updated, it removes the guesswork from project changes while improving workflow and preventing wasted materials.[4]

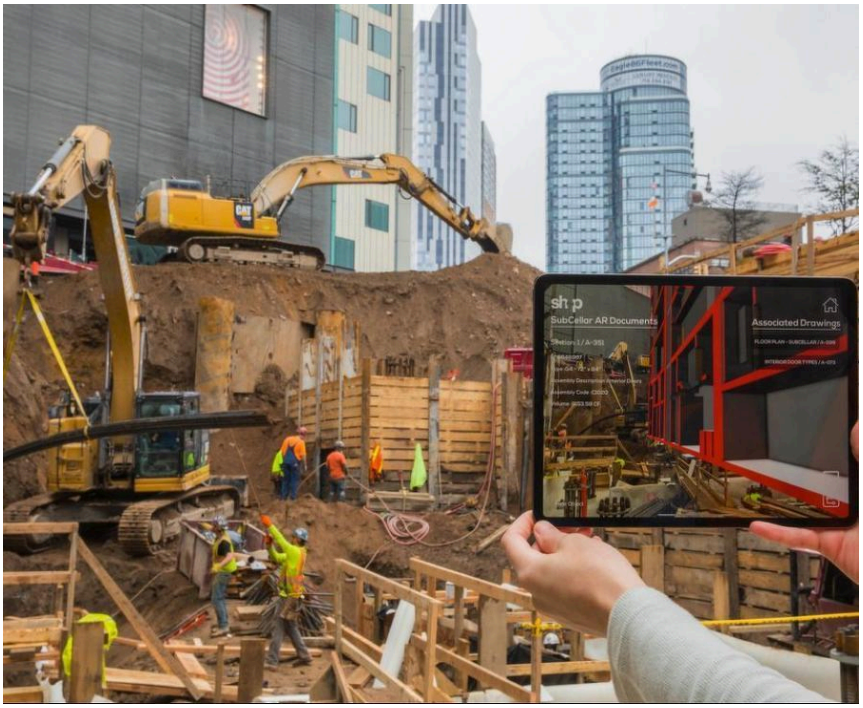


Image 4:Augmented Reality Comes to Construction Industry
Source: Augmented Reality Comes to Construction Industry : CEG

Improving accessibility.

AR devices and applications can serve as assistive technologies for people with disabilities, making physical environments more accessible by adding virtual elements. Multi-user AR experiences enable otherwise isolated users to form communities and support systems beyond the bounds of physical distance[5]

Another project where AR is used for accessibility is a focus on enabling Sign language to be seen by other AR users and understood via a real-time translation. The concept allows a person using sign to communicate to a person that does not understand sign. language, The

[4] 6 Applications for Augmented Reality in Construction
[5] Current and Potential Uses of AR/VR for Equity and Inclusion.

visual movements of the sign language user are interpreted and translated to the AR user either visually or via audio. This use of AR means that people that use sign language are able to communicate in their first language with a wider audience.[6]

A good example of this matter is the recent announcement of Google: “Breaking down language barriers with augmented reality”. In this video they talk about a prototype they have been working on. It consists of glasses that use Google translator technology to hear the person that’s in front of and display a translation into your language.
Understanding someone who speaks a different language, or trying to follow a conversation if you are deaf or hard of hearing can be a real challenge. If this project goes forward, I see this as a game changer for inclusiveness in many aspects of our lives.

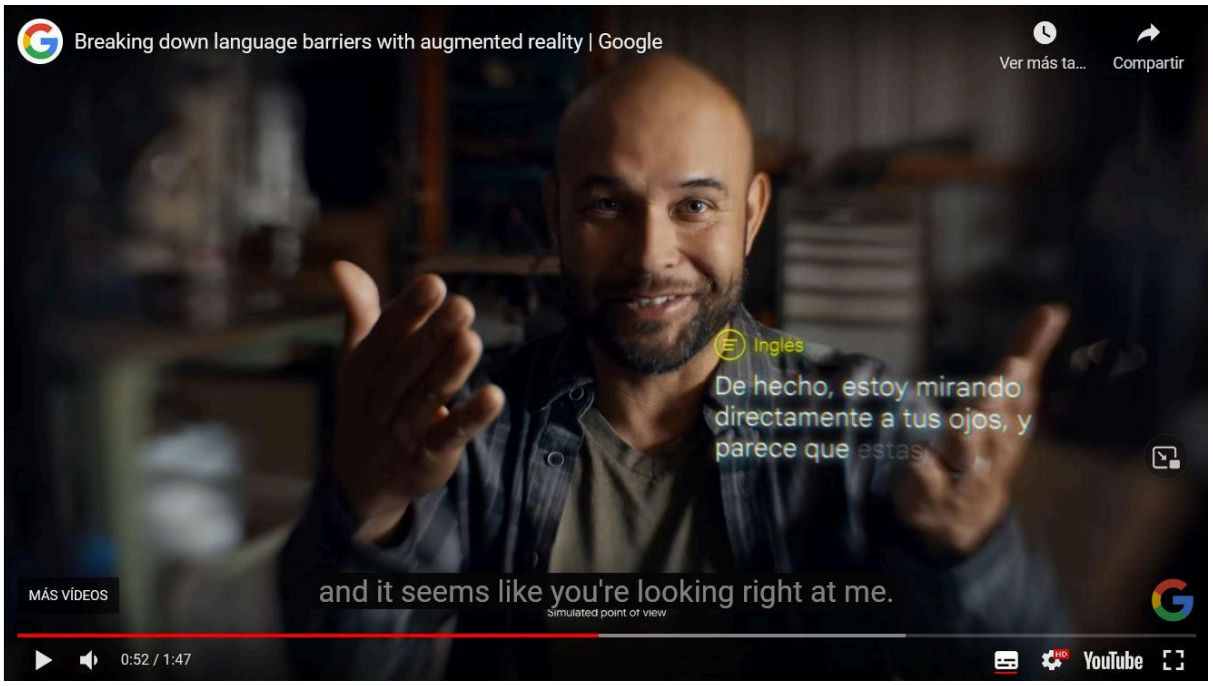


Image 5: “Breaking down language barriers with augmented reality. Source: Google company news.

Job Training:

Using AR technology, organizations can offer safer and more effective job training for employees at a cheaper cost. This technology also has the advantage of triggering the employee’s “memory palace” , a human element in learning that helps them recall facts and information more easily because they’ve experienced it “in reality”.

AR addresses the needs of multiple learning styles and has many benefits:

- Makes training visual, auditory and kinesthetic.
- Helps workers navigate the factory and warehouse more efficiently.
- Provides step-by-step visual and oral instructions in real time.
- Alerts and corrects missteps along the way providing real-time feedback.

[6] “Augmented Reality and Accessibility

When it comes to the working environment, AR makes working conditions much safer and aids workers in avoiding any harm as well as to prevent damage. These solutions predict non-planned work-related anomalies and possible malfunctions which reduces human and machine mistakes, consequently, increases safety in the workplace.

A good example of this are the work and assembly instructions.
AR work instructions and assembly guides which are adaptable and interactive are replacing complex and tedious manuals
Employees receive AR-enabled step-by-step manuals and interactive guides superimposed onto the assembly line through the use of the worker's smart headsets or glasses to facilitate a learning curve and easier hands free assembling process of engines, cars, turbines and more. This kind of use of the technology is interesting both for professionals aiming to increase their efficiency, and new hires to help them learn quickly.

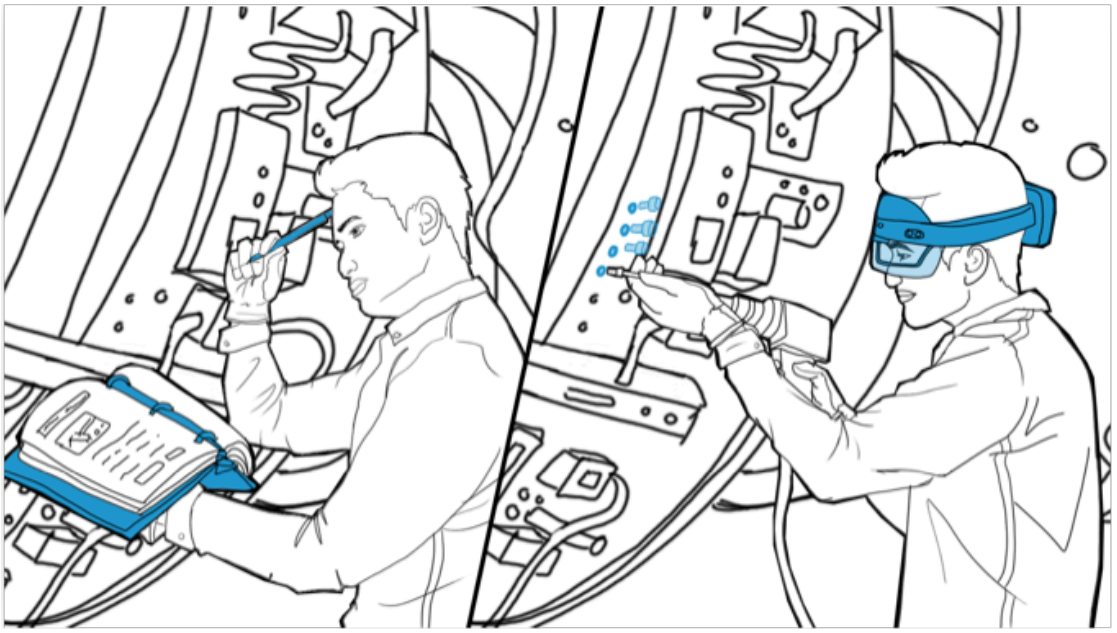


Image 6: Augmented Reality Assembly Instructions
Source:Interaptix.

Technologies related to AR.

AR Devices:

Among the augmented reality media, you can find a wide range of visual devices that are increasing at the same time as advances in the field of computing and optics.

We can classify the displays used in Augmented Reality as four: Heads ups displays(HUD's), Holographic displays, Smart glasses and Handheld based. But there are new technologies being developed , such as contact lenses.

Head up displays (HUD)

Head up displays were developed for mission critical applications like flight controllers and weapon system dashboards. But we are starting to see them in other places, for example cars.
The information is projected on a transparent screen mounted in front of the pilot solving the problem of shifting focus by using a type of collimating projector. The projected information is collimated(parallel light rays) focused on infinity so that the pilot's eyes do not need to refocus to view outside. [7]

Illustration 7: LMEIL Head-Up Display Car HUD
Source: Amazon

[7] Practical Augmented Reality by Steve Aukstakalnis.

Holographic displays:

The idea of this kind of device is to use light diffraction to generate three dimensional forms of objects in real space. True holographic displays create images that conform to the six depth cues by which we recognize 3D views in the real world.
These cues are: Perspective , Occlusion, Convergence, Accommodation, Stereoscopic vision (human eyes), Motion Parallax (Perspective changes as viewpoint moves).
This concept is still under hard research and development because it is very hard to create them with the 'air' as a vehicular element. There have been some advances in the last years with holographic-like televisions but this is mature enough to be considered a work of fiction.

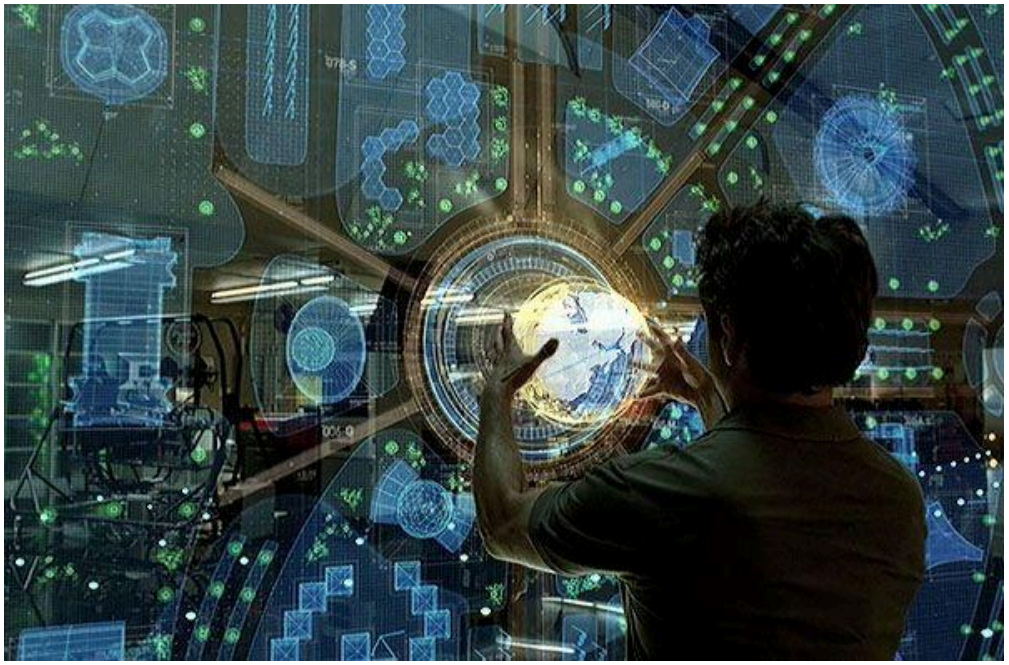


Illustration 8: Tony Stark interacting with an holographic display
Source: Iron Man Movie (2008)

Smart glasses:

Smart glasses have become one of the most popular types of AR.

There's two types:

Optical-see-through employs a mirror technology to allow views of the physical world to pass through the lens and graphically overlay information. The user views reality directly through optical elements such holographic wave guides and other systems that enable graphical overlay on the real world. Examples of this technology are Microsoft's Hololens, Magic Leap.

Video-see-through: Video-see through systems require the user to wear two cameras mounted on the display. These camera views are then combined with computer generated imagery for the user to see.

An important notation of smart glasses is the problem of alignment in AR.
It is defined as the task of overlaying a virtual model of an object on top of a real-world instance of the same object so the position orientation and scale of the virtual model matches with the pose and dimensions of the real-world object.
Accurate alignment of the virtual model with the real object requires accurate estimating and it's particularly challenging in optical-see-through devices because the headset is a moving frame reference. The real-world object can also move and change its shape if deformable.

That's why recomputing the transformation function every time the user moves their head or the object moves is computationally expensive. Additionally the system should also work in a varying illumination and noise in the environment.

Having talked about this topic we can difference glasses from anothers:
Glasses able to overlap and align synthetic and real information follow Azuma's definition of Augmented reality.
Glasses that only offer a head-up display experience even if they are context aware but not aligned with the real world don't follow Azuma's definition of Augmented Reality.

Illustration 9: Worker using Hololens 2
Source: Microsoft

Handheld AR:

Although it can be considered a type of video see through it deserves a mention. Hand held devices are usually mobile devices that include cameras.The effect of augmented reality can be presented on the screen of the device. Its inconvenient is usually low computing power and very bad manageability.

Its advantages are that a lot of components that Augmented Reality uses such as trackers, GPS, and access to the internet are already integrated. As mentioned before (Graph 1) mobile devices already have many users so buying a specific device is not necessary.

Augmented reality is capable of showing the user a realistic representation of the environment that has been added virtually, for It is important to determine the exact orientation and position of the user. Handheld AR is a good fit for these requirements.

Most common Handheld AR are phones, tables and Personal Digital Assistants (Smartwatches, Pocket-PCs)

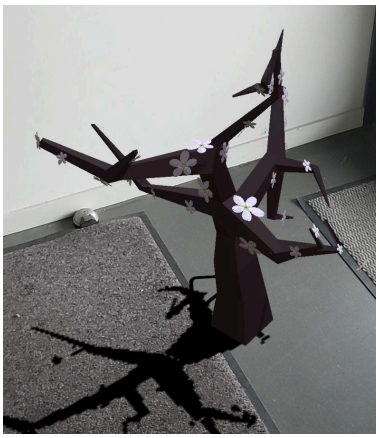


Illustration 10: AR realistic illumination demonstration. Source: Self.
Illustration 11: Augmented reality in a tablet device.
Source:https://www.management-circle.de/blog/augmented-reality-in-der-produktion-der-schluessel-fuer-den-erfolg/
Illustration 12: Augmented reality in a watch.
Source:https://www.sirris.be/blog/smart-watch-gets-ar-version

Contact lenses:

Special mention for this kind of device that is still under development.
These are biologic safe contact lenses, flexible that have circuits printed and diodes that can emit light. The fusion of the images are in the lens , which means minimum delays.
Depending on the approach we could have a HUD like lens in which the camera does not align with reality or lenses that follow Azuma's definition.

On 25th of January of 2021, a company by the name of Mojo announced their AR contact lenses. They are a smart contact lens with a built-in display that gives you timely information without interrupting your focus. The most notable thing about these lenses is that they include sensors so they could follow Azuma's definition of Augmented reality. By detecting the edges of the objects surrounding the person you can help people with vision impairment by contrasting objects brighter.[8]

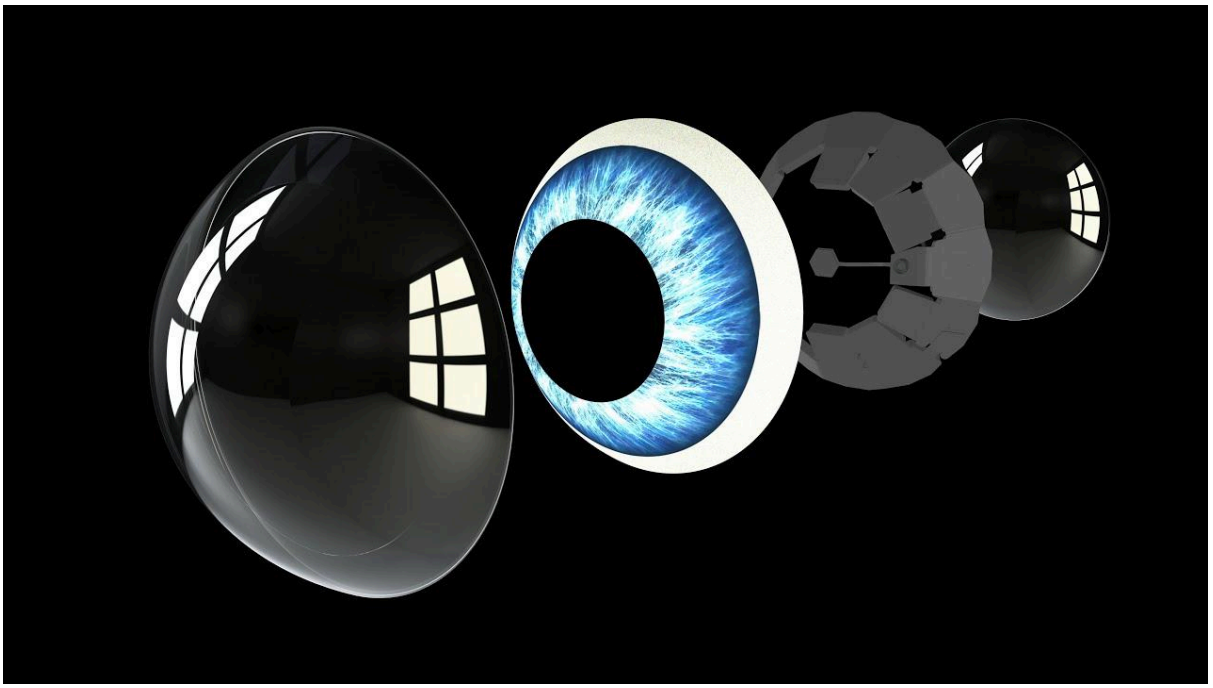


Illustration 10: mojo contact lens.
Source: mojo.vision

Tracking types:

In order to locate our virtual component into the scene, it's necessary to identify the environment, in this part we'll talk about how most of the tracking types are used in Augmented Reality.
Even though there's a wide range of tracking techniques as show on the table 1, we will use a different classification because most of them are being used only in specific circumstances for a specific need of an environment.

[8] Mojo vision webpage.

Tracking Techniques		Precision	Sensitivity	Expenses	Advantages	Disadvantages
Sensor-based tracking	Optical tracking	Accurate	Sensitive to optical noise	Expensive	Precise and robust when implemented in a controlled environment	The sensitivity of sensors towards noise and complex computation decreases the execution speed
	Magnetic tracking	Less accurate	Sensitive to nearby electronic devices	Expensive		Less accurate compared to optical tracking. Noise sensitive Sensors lead to a lack of accuracy with distance
	Acoustic tracking	Less accurate	Sensitive to temperature or humidity in the environment	Expensive		Slower execution
	Inertial tracking	Accurate	Sensitive to a small shift in the axis of rotation or the position		No external reference needed	Problems may arise in this system even if there is a small shift in the axis of rotation or the position
Vision-based tracking	Marker based tracking	Accurate		Reasonable cost	The marker information related to the position and identity attributes in the database	
	Markerless tracking	Robust tracking		Expensive	Reduces the quantity of data that is required to extract. Allows natural features for tracking instead of artificial	A lot of computational difficulties are involves

Table 1: Characteristics of different tracking techniques

We can classify the most used tracking types as two: marker based and markerless.

Marker based:

Using computer vision techniques, the system can try to recognize a specific image and, what is also essential, what is the 3D relative position of the image detected related to the camera. With this 3D relation, the AR system can put a synthetic 3D object following the position, scale and orientation of the image, generating a true AR composition.
At the beginning, only specific markers with a well-defined set of properties were possible, but currently it is possible to use any image, as far as the image can be recognized (it contains a minimum set of 'singular' points, normally with high gradient variations. The marker-based tracking is based on the mobile phone technology where the camera is the only source for tracking. This is the simplest setup possible. Environments with reflective surfaces or have repetitive features are difficult to track in some circumstances. In such situations if markers are added to the environment tracking becomes much simpler and easier.[9]

[9] Ashwini K Ba*, Preethi N Patilb, Savitha Rc Tracking methods in Augmented Reality.

In order to increase recognition speed when tracking you have to take in account the clear geometry, the form, the contrasts, the monochrome colors and the frames.

Image target:

To display an augmented content right onto the environment, we need to know that the user is pointing the camera at that particular place. The software detects and tracks the image by comparing extracted natural features from the camera image against a known target resource database. This can be achieved by placing a distinctive picture or shape on the environment.That picture will be recognised and the virtual content can be displayed immediately, tracked to the appropriate place on the scene. The user can also move the target around and see the virtual world “stick” to the real surface of the page.

We call the distinctive picture that can be recognised by the device, the marker. A marker can be anything, as long as it has enough unique visual points. Images with lots of corners and edges work especially well.Typical examples include any print media, such as logos, packaging, posters or brochures.

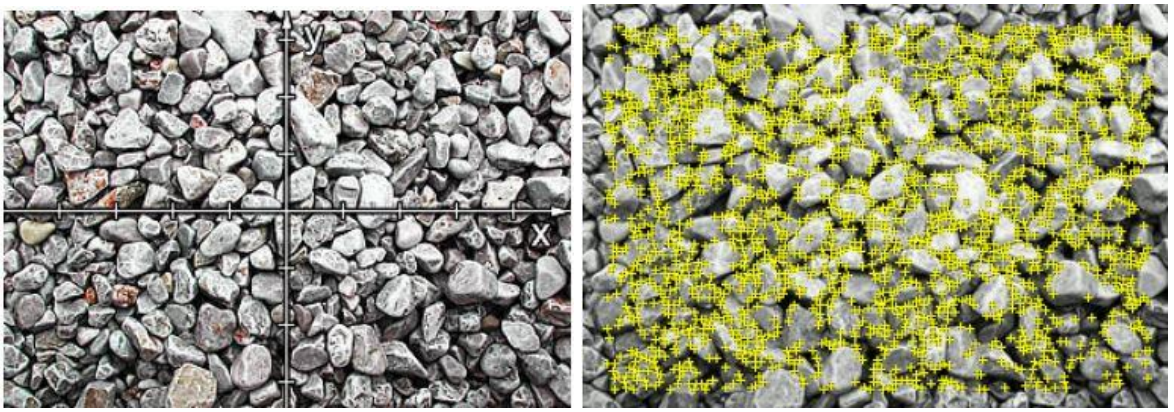


illustration 11:
First one Image Target with coordinate axes for explanation.
Second one: Image showing the natural features that the Vuforia Engine uses to detect the Image Target.
Source Vuforia.

Cylinder Tracking:

This kind of target allows you to detect and track images wrapped into cylindrical and conical shapes. It is based on image tracking but instead of recognizing plane images, it is able to recognize cylinder objects like Soda cans, coffee cups, mugs, drum containers, and beverage bottles.

Illustration 12: Use of cylinder target.
Source: Vuforia.

Multi targets:

A Multi Target is a collection of multiple Image Targets combined into a defined geometric arrangement such as boxes. This allows tracking and detection from all sides and can serve numerous use cases in, for example, marketing, packaging, and in instructional contexts. Start by creating your Multi Targets in the Vuforia Target Manager and upload your images fitting the dimensions of your Multi Targets.[10]

Marker-less tracking based.

Markerless Augmented Reality is used to denote an AR application that doesn't need prior knowledge of a user's environment to overlay 3D content into a scene and hold it to a fixed point in space.

This kind of tracking makes use of the device sensors such as cameras, gyroscope, accelerometers, haptic sensors and location services in order to register 3D objects in the real world. Marker-less AR offers the most control to the user as it allows the user to choose where they would like to place the content.

[10] Vuforia Multi targets page.

Markerless AR detects objects or characteristic points of a scene without any prior knowledge of the environment(in most cases), such as walls or intersection points. The technology is often associated with the visual effect that combines computer graphics with real-world imagery. The first markerless systems used a device's location services and hardware to interact with available AR resources and define its location and orientation in space.

Object recognition:

Also known as model target consists in recognizing and tracking physical objects in order to superimpose digital content into them to produce an augmented reality experience.
This enables a real-time 360º experience around the object.

How this works can be described into 3 steps:

1. The software generates an image of the object. This generation can be done via 3D models or using a set of images in order to generate the target.
2. The software recognizes the object within the real-world environment through feature points. In order for this to work, the camera finds matches between the reference and frame images.
3. Once the object is recognized through an identifiable constellation of feature points, the digital model is placed accordingly. Then the user can interact or manipulate the 3D digital object.

This kind of recognition works best for objects that have only a limited number of changing or dynamic parts. The targets are usually pre-defined.[11]

Location based AR.

This kind of tracking works by reading data from a device's camera, GPS, digital compass, and accelerometer while predicting where the user is focusing as a trigger to pair dynamic location with points of interest in order to provide relevant data or information.

This works best on smartphones since almost all of them provide location detection. Thanks to this we can tie information and virtual objects in a specific location to be displayed when a user's device data matches the location.[12]

With camera + IMU + GPS is possible to implement geographical AR solutions, such as Pokemon Go famous game, although, due to the GPS, with an important degree of error and with many problems to implement occlusion (when the digital element is hidden by a real element, situation where the digital element is not generally occluded).

[11] AR object recognition, Round table learning
[12] Digital Promise Types of AR.

Illustration 13: Blippar's Indoor visual positioning
Source: Blippar Youtube channel.

Projection-based AR

Projection AR, sometimes also referred to as spatial AR, is a method of delivering digital information within a stationary context. It focuses on rendering virtual objects within or on a user's physical space. It is one of the simplest forms of AR where light is projected onto a surface. The interaction occurs by touching the projected surface physically.

In projection AR the user is not limited to any device as virtual objects are integrated directly into the environment; users and target objects are also able to move around the environment within a specified zone, in which both the fixed projector and supporting camera for tracking are placed. Projection-based AR methods may be used to create illusions about depth, position, and orientation of an object.[13]

Using projection-based AR, it is easy to implement graphical representation that ordinary lighting techniques cannot express. This technique can project high-definition images or video and change the object shape visually with the flow of time.

Slam-based solutions:

SLAM (Simultaneous Localization and Mapping) is a new step that allows, using at least a camera and allowing additional sensors, to get a spatial mapping of the environment (mapping) and, at the same time, to localize the user regarding the environment; allowing in

[13] Digital Promise types of AR.

this way an outstanding solution to the physical layer and even giving the user the possibility of dynamically put 3D objects into the environment in real-time

How SLAM works with AR applications can be described in the following steps:

- The optical system consists of a camera stack which includes the lens, shutter and image sensors. The inertial system is made up of accelerometers, which measures acceleration and a gyroscope, which measures orientation. Together, they help the device determine its position (x,y,z) and orientation (pitch, yaw, roll), 6-degrees-of-freedom (6DoF)
- As moving the device to look at AR content, the device is essentially capturing many photos of the environment and comparing them to figure out its position.
- For each photo it captures, it is also identifying key features in the environment that are visually unique and interesting in nature such as the edges, corners, ridges of unique objects in the scene.
- By comparing two images and their respective key features and using the sensor data from the device's IMU, the device can figure out its position through stereoscopic

With the current technology and SLAM techniques, now it is possible to map the environment spatially (3D reconstruction), this means the device can understand the shape or structure of real objects in the scene, making occlusion and collision possible

Occlusion: is the ability for virtual objects to hide behind real-world objects
Collision: is the ability for virtual objects to collide with real-world objects

When virtual objects respond to real-world physics as if they are real, this makes the AR experience so much more believable

SLAM allows dynamically anchoring new 3D elements into the map obtained. This is the case of apps such as IKEA that allows you to place furniture in AR in an environment without the need of a preliminary scanning.

We can also use SLAM mapping possibilities to create in a first instance a mapping of the environment we want to augment. The generated map is stored and can be edited with an external tool, where we can add any kind of virtual elements anchored in the desired positions. Then when the final user starts the AR build solution, the device will compare the cloud of points obtained with the map previously stored in order to localize the user and add the synthetic elements that were anchored.

The new Apple devices have started to integrate LIDAR (Light Detection And Ranging), a kind
of ToF camera based on infrared laser to generate this map which lets you generate a pretty accurate textured map of a room.

Development tools:

Thanks to the rising popularity of Augmented reality , there are plenty of tools in the market available for everyone for all kinds of platforms. To classify these tools, we'll divide them into three:

To start, the frameworks used in development . They are the systems that hold the functionalities of AR and act as the main structure.

Afterwards we will focus on the technology involved in order to develop the AR applications itself, more specifically the one that is in charge of providing the stereo vision, interaction , localization and tracking , rendering and physics. In other words, the environment.

Lastly the software capable of creating the content of the AR applications, in particular, the 3D models, animations, 360º videos and sounds.

Frameworks:

ARCore:

ARCore is Google's platform for building augmented reality experiences. Using different APIs, ARCore enables your phone to sense its environment, understand the world and interact with information. Some of the APIs are available across Android and iOS to enable shared AR experiences.
ARCore uses three key capabilities to integrate virtual content with the real world as seen through your phone's camera:

- **Motion tracking** allows the phone to understand and track its position relative to the world.
- **Environmental understanding** allows the phone to detect the size and location of all types of surfaces: horizontal, vertical and angled surfaces like the ground, a coffee table or walls.
- **Light estimation** allows the phone to estimate the environment's current lighting conditions.

ARCore is designed to work on a wide variety of qualified Android phones running Android 7.0 (Nougat and later). Even though it's main focus is android it also has some features compatible with IOS devices running IOS 11.0 or later like cloud anchors and Augmented faces.[14]

[14] ARCore development documentation page

ARKit:

ARKit is Apple's platform for building augmented reality applications.
ARKit combines device motion tracking, camera scene capture, advanced scene processing, and display conveniences to simplify the task of building an AR experience. You can create many kinds of AR experiences with these technologies using the front or rear camera of an iOS device.
Its latest version (ARKit 6) includes the following features:

- **4k video**: perfect for apps that integrate virtual and real-world content together for video creation.

- **Depth API**: The advanced scene understanding capabilities built into the LiDAR Scanner allow this API to use per-pixel depth information about the surrounding environment. When combined with the 3D mesh data generated by Scene Geometry, this depth information makes virtual object occlusion even more realistic by enabling instant placement of virtual objects and blending them seamlessly with their physical surroundings

- **Motion Capture:** Capture the motion of a person in real time with a single camera. By understanding body position and movement as a series of joints and bones, you can use motion and poses as an input to the AR experience — placing people at the center of AR

- **Scene Geometry**:Create a topological map of your space with labels identifying floors, walls, ceilings, windows, doors, and seats. This deep understanding of the real world unlocks object occlusion and real-world physics for virtual objects, and also gives you more information to power your AR workflows.

- **People Occlusion**: AR content realistically passes behind and in front of people in the real world, making AR experiences more immersive while also enabling green-screen-style effects in almost any environment. Depth estimation improves on iPhone 12, iPhone 12 Pro, and iPad Pro in all apps built with ARKit, without any code changes.[15]

[15] ARKit developer page:

Vuforia:

Vuforia is an software development kit (SDK) for the development of augmented reality in mobile devices that enables the creation of augmented reality applications. It uses computer vision technology to recognize and track planar images and 3D objects in real time. Developers can easily add this functionality to any application, allowing it to recognize images and objects, and interact with spaces in the real world.
The virtual object then tracks the position and orientation of the image in real-time so that the viewer's perspective on the object corresponds with the perspective on the target. It thus appears that the virtual object is a part of the real-world scene.

The Vuforia SDK supports a variety of 2D and 3D target types including ‘markerless’ Image Targets, 3D Model Target, and a form of addressable Fiducial Marker, known as a VuMark.

Additional features of the SDK include 6 degrees of freedom device localization in space, localized Occlusion Detection using ‘Virtual Buttons’, runtime image target selection, and the ability to create and reconfigure target sets programmatically at runtime.

The vuforia fusion feature allows the developer to provide the best possible AR experience on a wide range of devices. Fusion senses the capabilities of the underlying device (such as ARKit/ARCore) and fuses them with Vuforia Engine's features, allowing developers to rely on a single Vuforia API for an optimal AR experience.[16]

8th wall:

Contrary to the other examples, the 8th wall is a WebAR. WebAR, or web-based augmented reality, enables augmented reality (AR) to work within a browser. Web AR opens up new ways to connect with users by engaging them in extraordinary, interactive experiences anywhere they are—all with no app required.

It’s a very versatile way to develop for smartphones because once you develop something you can deploy it across smartphones, computers, AR and VR headsets. A marker is used to orient the scene, and then current JavaScript 3D rendering libraries are used to depict a 3D object shown on top of whatever is in front of the cell phone camera.

It’s main advantages are

- Makes up less memory since you don’t have to download an app.
- Fast deployment time with fewer costs.
- Can be run on pretty much any browser.
- Simple to implement cross-platform.

[16] Vuforia developer page

Environment:

In order to interact with the content we create and to define the logic behind the interactions we will need an engine. They are called development environments(IDE), in our case we'll discuss some game engines used when developing AR and other software.
A game engine provides tools and programs to help you customize and build a game; it gives you a head-start in making your own game.

Unity:

Unity is a 3D-based, multi-platform real time game engine. It's a user-friendly and convenient development tool that provides an easy to use editing interface. Unity is compatible with most 3D modeling software which allows teams to work in a unified environment. The engine offers a primary scripting API In C#, as well as a drag and drop feature.

It also has a growing community of millions of users and provides great documentation about its functionalities that makes the learning process undemanding.
Unity fits this project because it's a very versatile engine that can be used to develop all kinds of applications , from XR applications to WebGL pages. It's a modular tool not too hard to set up.

It's also very popular in the mobile game field, 72% of the top 1,000 mobile games were made with Unity (https://unity.com/our-company)

Someone of the most popular games that you may have heard of developed with unity are:

Illustration 14: Unity games
Source: unity most popular games, google

Unreal Engine:

Epic Games Unreal Engine is a complete suite of creation tools for game development, architectural and automotive visualization, linear film and television content creation, broadcast and live event production, training and simulation, and other real-time applications.
Unreal Engine is free to download, and comes fully loaded and production-ready out of the box, with every feature and full source code access included.

First showcased in the 1998 first-person shooter game unreal and although initially developed for the first person shooters it has been successfully used in a variety of other genres including platformers fighting games mmo rpgs and other rpgs as well written in C++ the adrial engine features a high degree of portability supporting a wide range of platforms the unreal engine is a complete suite of creation tools for developing everything from independent hits to blockbuster franchises as an established industry-leading solution aerial engine delivers high quality and proven performance that a lot of people are using to develop fantastic projects.

Epic games is trying to expand their user base to include other industries that have nothing to do with video games. Unreal Editor provides a visual interface made up of viewports and windows to enable you to import, organize, edit, and add behaviors/interactions to your game assets.[17]

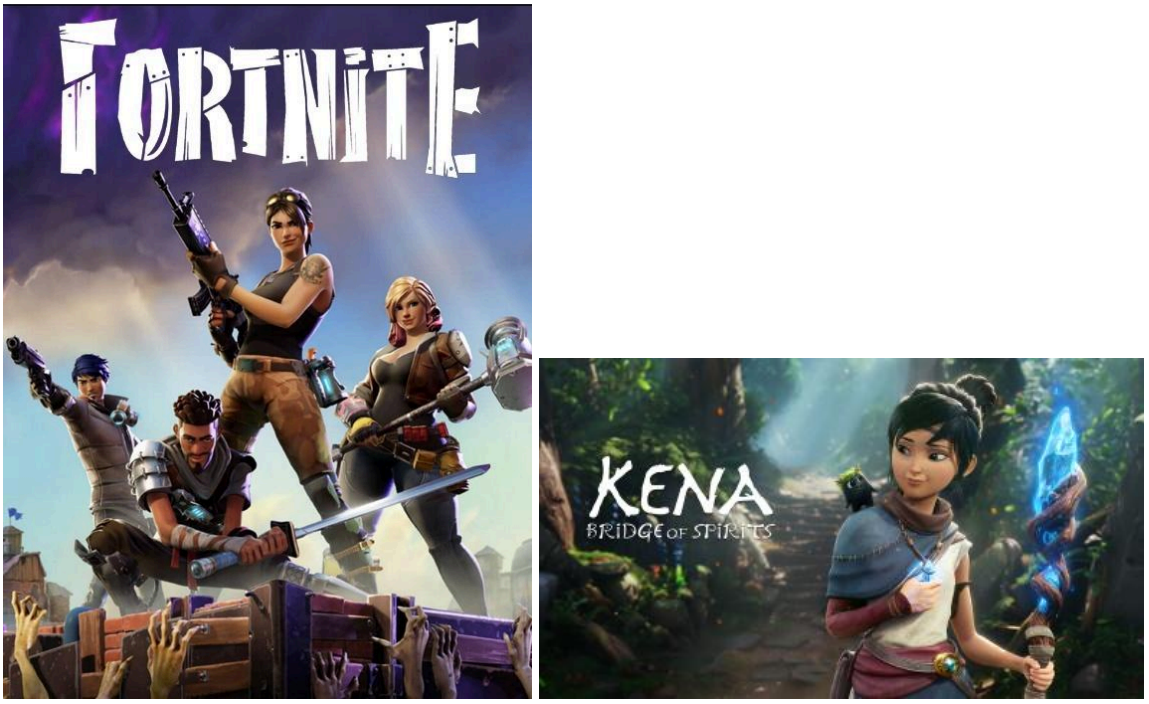


Illustration 15: Unreal Engine games
source: most popular unreal engine games, google.

[17] Youtube: “What is Unreal engine used for”:

Android Studio:

Android studio is the development environment integrated for the Android platform. Provides a unified environment where you can build apps for Android phones, tablets, Android Wear, Android TV, and Android Auto. Structured code modules allow you to divide your project into units of functionality that you can independently build, test, and debug.. 2022[18]

The official language for Android development is Java. Large parts of Android are written in Java and its APIs are designed to be called primarily from Java. It is possible to develop C and C++ app using the Android Native Development Kit (NDK)

Layout editor helps to build the layout quickly by adding different attributes either by hard-code or drag and drop. The preview of the codes can be seen easily on the visual editor screen and changes can be made accordingly by resizing it dynamically. This will make testing the application process more facile and more exhaustive.

Android has a great feature of Emulator which is exactly like the android phones to test how the application looks like in physical devices. It gives real-time experience to the Android applications. It allows you to test your applications faster and on different-different configuration devices like tablet, android phone etc. It helps you to make your application development life cycle shorter and more efficient.[19]

More importantly is compatible with android focused frameworks for augmented reality, making it a good candidate to develop AR applications.

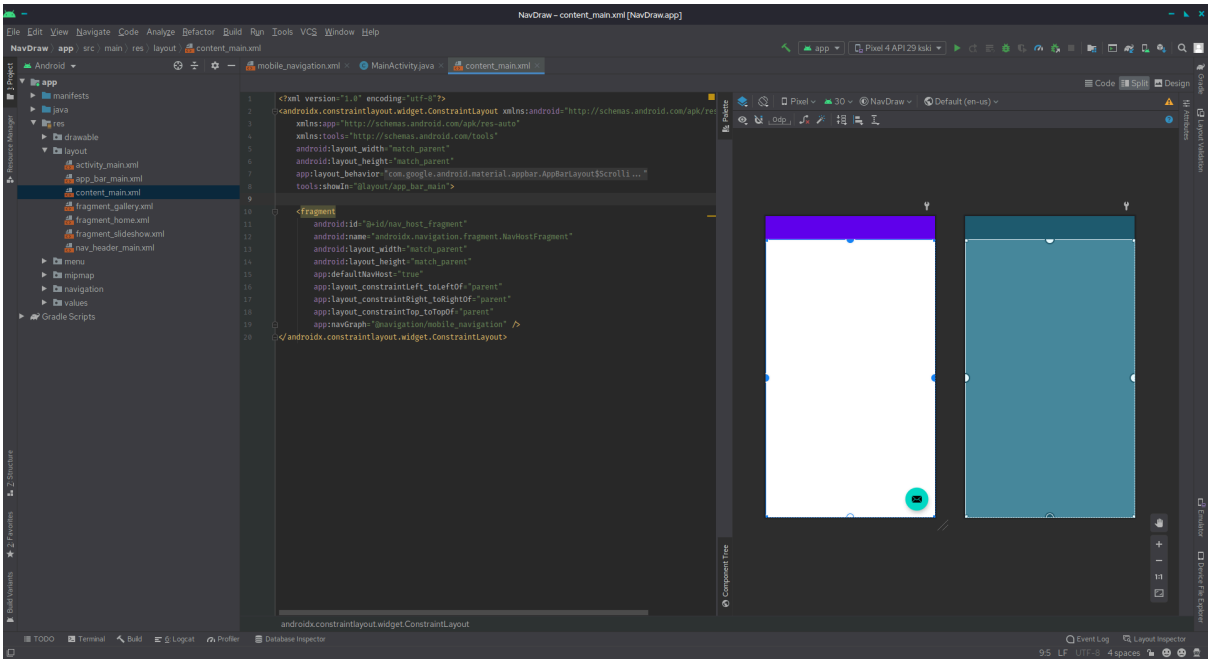


Illustration 16: Android studio IDE.

[18] Android studio page
[19] Sengar Anuradha, Features of Android Studio for developers.

Source: Wikipedia.

Content creation:

Although this is not strictly necessary when developing augmented reality applications because of the availability of plenty of 3D models and animations in asset stores, you want to represent your way of seeing the world and translating it into the application.
In order to achieve this you can use 3D computer graphics software tools for creating this content.

3-D software is a type of computer graphics software that enables the design, development and production of 3-D graphics and animations. 3-D software allows users to visualize, design and control an object, environment or any graphical element within a three-dimensional scope.[20]

Some of the most used 3D software available are: Blender(free software), Zbrush(suited for modeling intricate details,) , Maya(very powerful and customizable , Photoshop(mainly used for editing images, perfect for creating your targets) or Max3D(long history in the industry).

Illustration 17: 3D computer graphics software examples.
Source: Google search engine.

[20] Technopedia, *¿What is 3d software?*

Application:

The philosophy behind AR is to enhance experiences giving the user extra meaningful information about its context.
One of the most exciting applications of Augmented reality is in the education system. Parents and teachers are continually looking for new and inventive ways of keeping the students focused and engaged. In order to accomplish this task, they need to provide the students with something exciting. The QR markers can be printed inside textbooks or even directly on the assignment to provide the student with an experience unlike any other. It's one thing to tell or read about a story from a history book or any other subject, but to actually see it live out in front of you is a whole different thing.

That's why after doing some research on the topic the application is going to be developed as an AR book.

AR books are either printed or digital texts that have triggers to show additional 2D or 3D layers of content via an AR app. They allow readers to immerse themselves in highly captivating experiences, visualizing different concepts, adding gamification elements to the text, and allowing interaction with virtual models.[21]

Choosing an environment to develop:

The deploying device target is going to be phones, since these are the most common devices found in everyday life.
In order to decide which environment.

Why Unity?

Why Vuforia?
Apart from having prior experience working with this framework ,I've chosen this framework because of his vuforia fusion feature. Being able to develop integrating ARcore and ARkit features in a single place is very convenient.
The 8th wall framework is also very interesting for its portability, but needing access to the internet in order to use the applications is something not every school has the infrastructure ready for.

Prototyping

The conception of the idea , a first glance of the first version of what the application was going to be about.

[21] PostIndustria Augmented reality educational books.

The objective of the application was to showcase different AR interactions that could be used when interacting with an AR book.
In order to achieve this the objective was to make a set of pages each one of them with a different interaction:

- First one: Visualization of some topic in an augmented reality way.
- Second one: A more interactive screen of a topic of a book.
- Third one: An interactive timeline, in which the interaction of the user would bring extra information of some sort(videos, animation) to the experience.
- Fourth one: An interactive experiment showcasing a chemical reaction that in a physical lab it would be very dangerous to perform.

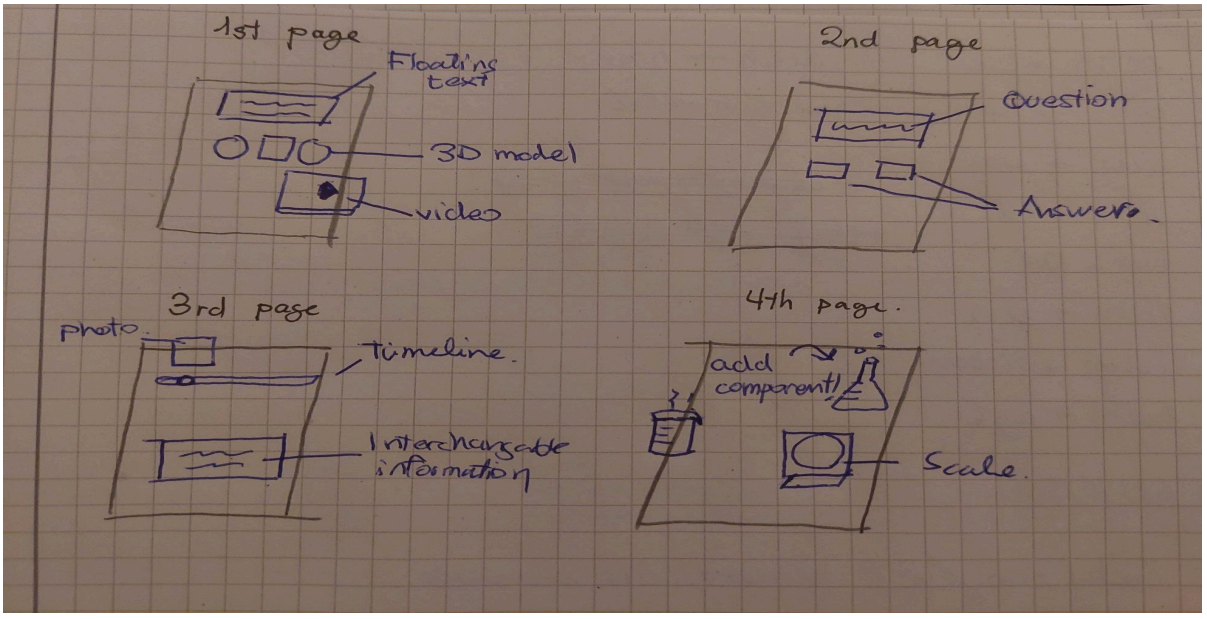


Illustration 18: Drawing of the first prototype of the application.

At first, the topic of the pages were going to be different from one another, to showcase different situations in different subjects, but I got recommended to make all of them for the same topic.

Conception of the application:

The topic chosen for the application is chemistry, something I had trouble understanding when I was studying. Being able to visualize certain things other than images and text, is a very good way to make another person understand something.

For the tracking type the most fitting of them is the Image target, since it is the most suitable for this project. The pages of a book are always the same; the images and text of them are perfect feature points for the software to identify.

The book is based on a spanish chemicalbook developed by "*Instituto Superior de Formación y Recursos en Red para el profesorado del Ministerio de Educación, Política Social y Deporte"*
http://recursostic.educacion.es/secundaria/edad/3esofisicaquimica/impresos/curso_completo.pdf

The first example is a visualization of augmented reality information via a floating text and a 3D model of the chemical bond structure, often used for representing certain reactions.

The second page is an interactive test about the topics of the page itself.

The third page is a timeline where the contents of the page are changed depending on the date selected on a slider.

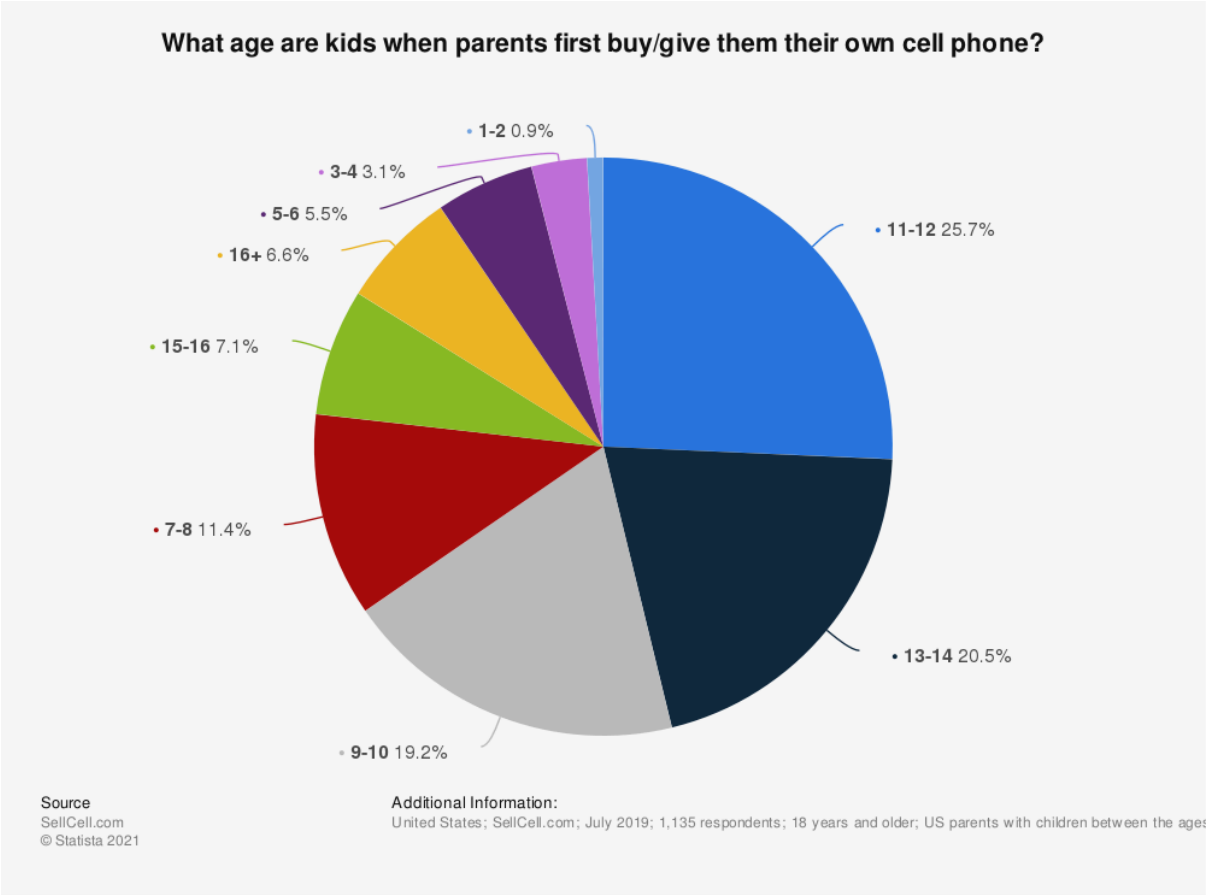
The fourth page is a showcase of an experiment in which you create coal from Sugar and sulfuric acid. It's based on an experiment one of my classmates did when he was in highschool.

Illustration 19: "Obtenció del carbó a partir de sucre" - III Concurso MCEV 2014
Source: Youtube

Target of my application:

In this case, because of the content of the book , the target of my application are students from 3º ESO, (14-15 years, Klasse 9), but since the content of the augmented reality is customizable , we'll discuss the target application of AR books in schoolsl.

The next graph represents which ages kids get their first cell phones, necessary to the use of the application.



Graph 4: Age of cell phone acquisition, source Statista.

This is of course, without taking in account if the schools can provide devices to their students or not. Which is a trend in recent years to have tablets dispositives available for the students.

Besides having a mobile device, it has to be compatible with Vuforia technologies, it also varies depending on the tracking type, but since we are using Image target it is less demanding.

IOS: Vuforia View is supported on devices running iOS 14.0 or later.

Android:Vuforia View is supported on devices with an Android operating system with version 8.0 and later.[22]

[22] Vuforia Help Center.

How can this help in comparison to traditional education?

As seen in some of the use cases, sometimes using AR to educate a worker is just overall better, because of the costs, time consumption, and way of visualization…
For the education context this can not always be the case, because kids behave very differently, they might not be motivated, or not care about the subject, but one thing available in this context is the gamification of topics.
The act of gamification is to apply typical elements of a game playing (point scoring , competition, rules) to an activity , in our case teaching.

Video Games offer powerful new opportunities for educators, AR technology enables the development of games which take place in the real world and are augmented with virtual information, AR Games can give educators powerful new ways to show relationships and connections. Additionally, they provide educators with highly interac- tive and visual forms of learning

Benefits of using Augmented Reality in educational environments as single benefits:

They increase **motivation**; students are more eager, interested and engaged to deal with the new technology as well as teaching and learning content. This also includes users having the will to continue learning using the AR technologies after class and being more proactive.

Users pay more **attention** to the technology and thus to the teaching and learning content. The use of smartphones and having to interact with a physical element promoted the interaction with classmates and professors. Having an interaction where you are receiving some feedback is more interesting than just reading a sheet of paper. Users experience higher satisfaction regarding the learning process or their educational progress. Students have more fun running around interacting with the environment than sitting down.

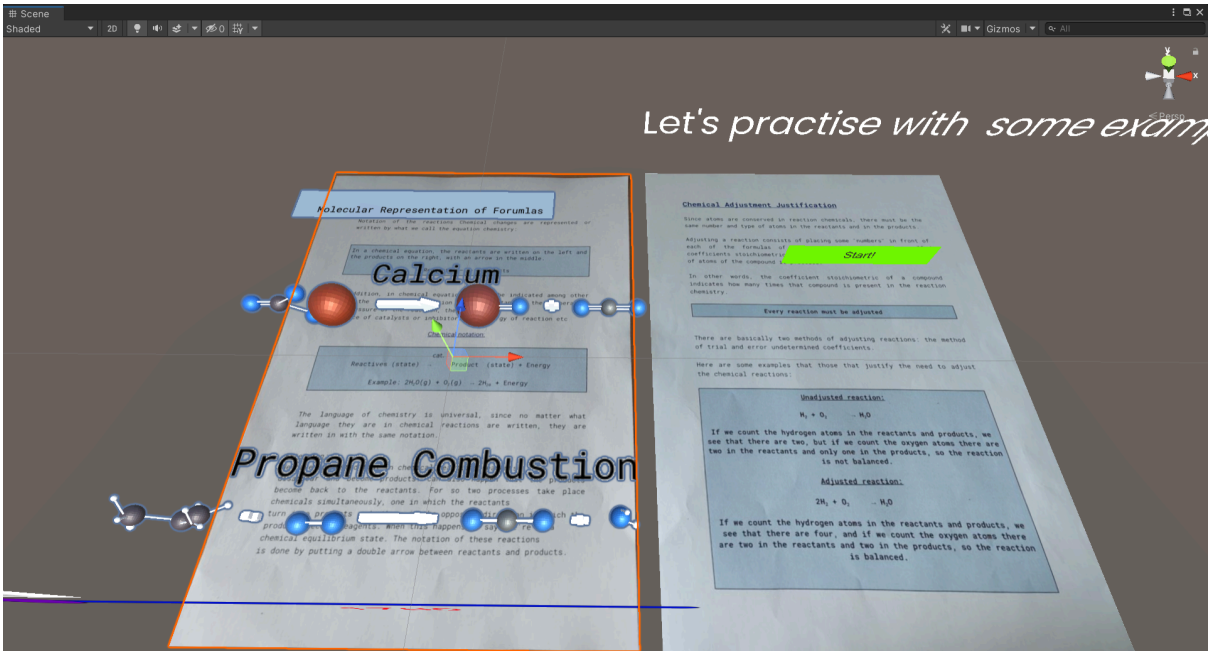
AR is more detailed when representing models, compared to the traditional wooden blocks models. It also increases the accessibility to information, having a superimposed information integrates very nicely and doesn’t interfere with the learning process.

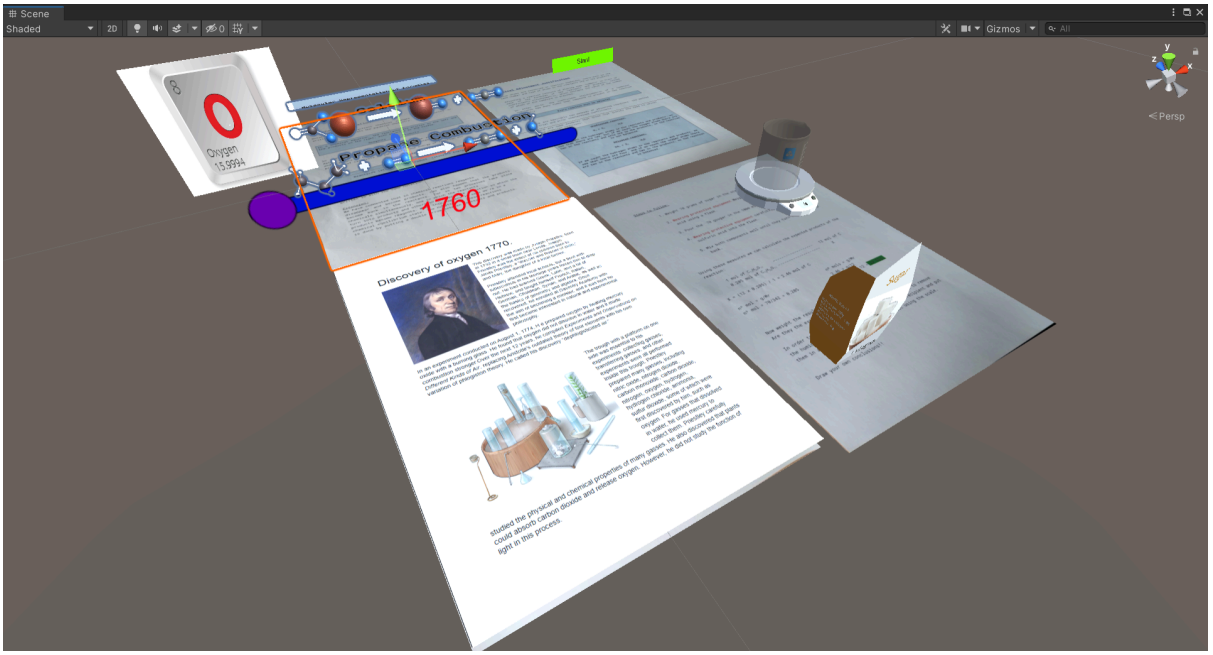
Lastly, the most important benefit of them all is the reduced costs. There are some scenarios where traditional learning is too expensive, for example laboratories. AR applications not only reduce direct costs, such as needed materials, but also time for preparing classes.

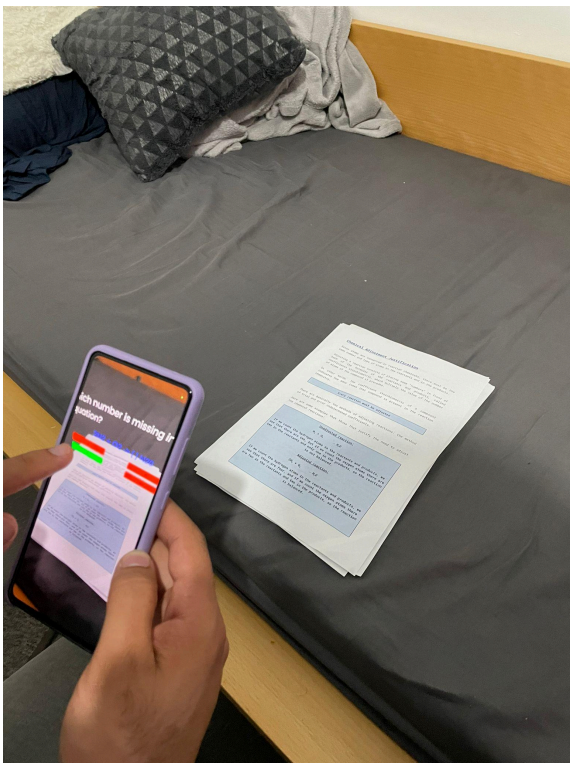
AR should not be considered a magic solution for educational environments, it doesn’t work everywhere. Each AR application is unique and might not fit well into the subject that’s trying to be taught. I believe there’s a lot of previous research to be done before considering the development of the application.
Special user groups (e.g. hand-icapped people) can benefit in different as well as additional ways due to their requirements to learning methods and the characteristics of AR.

Showcasing the application:

Here are some illustrations of the IDE and people using the application and giving me feedback.





The main feedback I got about the application is that it needs some indicators in some places because they were not sure what to do for the next actions.

Conclusion and Future work:

I consider Augmented reality a notable technology which I will spend more time learning, since a lot of big companies are investing so much towards its investigation. It's a beneficial technology that can help society which can be used as an aiding tool if it's integrated in our daily lives.
It's exciting to see the new advances of AR that are being announced over the years even if they are not affordable for me.
AR is definitely eligible to be used in educational environments to improve learning, the main point It stands out is its interactivity and being able to be used in different situations. With this work I've learned that it is not enough to just create an AR application, it's important to analyze the environment that is going to be used and which people are going to use it.

I wish I could have teamed up with a design student to help me make the application look better. That's why for future work I would love to join a team and create a good looking application, because I think that's a very important part of AR applications.
It would be also interesting to see a real scenario of students using my applications. In my research I've found some research about it, but it's not the same reading it on a paper that seeing the reactions of the kids in person.

A good future work for this would be a systematization of steps to do in order to implement an AR application in a concrete environment.

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