REALITIES

Virtual and Augmented Reality

State of the Art Technology Report

Co-funded by the Erasmus+ Programme of the European Union

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[Project number: 612618-EPP-1-2019-1-DE-EPPKA2-KA]

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Publication date: January 2023

VAM*Rs project

VAM*Rs project—University Business Cooperation for Promoting Virtual, Augmented and Mixed Reality Applications within Small and Medium-sized Manufacturing Companies is a 3-year project (January 2020 to December 2022) funded by Erasmus+, envisaging to promote the use of VR/AR/MR in the manufacturing industry, and help Europe's educational and economic actors to initiate promising developments and cooperation. The main aims of the VAM*Rs project are to support and enable SMEs in the manufacturing sector to adopt VR/AR/XR technologies into their business operations, through a University-business cooperation. An essential element of this objective is the creation of the State of the Art report to establish an neutral and independent overview of the current state of the art of VR/AR/MR hardware and software available on the market, including all information relevant for manufacturing SMEs, and to assess which system fits best to their needs and frameworks, free from commercial bias.

The VAM*Rs project is led by the Fachhochschule des Mittelstands (Germany), in cooperation with the following project partners:

- Centre for Advanced Research and Development in Educational Technology LTD (Cyprus);
- European Network for Transfer and Exploitation of EU Project Results (Austria);
- Federación Vizcaina de Empresas del Metal (Spain);
- Katholieke Unversiteit Leuven – Faculty of Engineering Technology (Belgium);
- Tampere University of Technology (Finland);
- Wakeone Oy (Finland);
- Tallinn University of Technology (Estonia);

- National Research Council of Italy (Italy);
- Parbleu (Netherlands);
- 3DQR GmbH (Germany).

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Contents

About the Report

Dear Reader! At VAM Realities, we sincerely hope that this document will help you to discover the benefits of extended reality technologies! In fact, the purpose of the present report is threefold.

First, we discuss some basic terminology, concepts, and key issues of VR and AR. That way, you will have a better understanding of how to choose the necessary technology and apply it to achieve the desired result.

Second, the report aims to provide the you with up-to-date information about the state of Virtual and Augmented Reality technology (abbreviated as VR an AR, respectively) in three separate chapters: *hardware*, *software*, and *use cases*. Thus, studying the provided material grants you an understanding of the current situation in VR/AR. Trends and opportunities should become better visible.

Third, the report is specifically targeting representatives of small and medium enterprises (SMEs). On the other hand, the general reader interested in these technologies will likely find the provided information useful. The reader is generally assumed to have at least a basic technical background, but it is not critical to understand most of what follows.

Here is a brief summary of the report's chapters.

Virtual and Augmented Reality Technologies

A gentle introduction to VR/AR technology focusing on those aspects that SMEs could find most important in adopting the technology.

Hardware

In order to work with VR/AR, relevant hardware must be used, most notably head-mounted displays (HMDs). In this part, you learn about the state of the art devices that are available on the market.

Software

Most applications are built for VR or AR using certain software, both open source and commercial. In case of turnkey[1] VR/AR platforms, content must be created for them. All of this can be done using the state of the art software applications that are described in this part.

Use Cases

In this part, you are presented with some existing VR/AR solutions. This can provide further ideas about developing relevant products and/or services.

Finally, use the Index for quickly locating the content based on keywords.

The report will be updated as relevant information is revised and new technology becomes available. It is therefore advised to check the website of VAM Realities at `https://vam-realities.eu/` to receive timely updates.

[1] Product that is ready for immediate use

Note to Companies and Developers of VR/AR Hardware and Software Solutions

With the State of the Art report, VAM Realities partners aim to cover as much ground as possible and to provide our readers with the best possible information regarding hardware devices, software and use cases where VR and AR technologies are concerned. Therefore, we are looking for your involvement in this process as well. Here are a few ways you can contribute:

- Provide VAM Realities partners hardware for evaluation. We cannot review what we do not have access to—this gives you the opportunity to get achieve better exposure for your products since the reviewed products will be presented in the State of the Art report as well as in the upcoming web catalog. We are interested in both HMDs/glasses as well as accessories.
- We are also looking for successful use cases for VR/AR technology. Hence, we ask you to share with us success stories as well and we will gladly review them and include them in the report.

The information about getting in touch with us for arranging the above mentioned contributions will be published on the VAM Realities website and in the next update of the State of the Art report. It is expected that the report will be updated at least two times per year.

Virtual and Augmented Reality Technologies

Basic Concepts

In this section, you will be briefly introduced to the concepts of Virtual Reality (VR) and Augmented Reality (AR). Some core principles of using these technologies are also outlined.

Virtual Reality

We begin by establishing some terminology and concepts. *Virtual Reality*—VR—is an enormously powerful medium allowing for an unprecedented level of human-machine and human-human interactions leveraging present day computing, visualization, and motion tracking technology, whereby the user is "transported" into an artificial reality from the visual and auditory perspective. The key aspects of VR are [2]

- The effect the user experiences as "being there" in the virtual environment also known as *immersion*;
- A full, freely navigable 360 degree viewport which is used to realistically visualize the virtual environment, objects, AI entities as well as other VR users;
- Human-machine interactions that provide complete freedom for the user to manipulate the perceived environment and objects therein.

From the key aspects above, one can also outline some of the benefits of applying VR and AR in specific fields:

- The effect of immersion can significantly improve learning outcomes. The user perceives the virtual environment as real, so a trust relationship is established. In the environment, arbitrary content can be created. The possibilities of thus improving user experience are unlimited;
- Since a feeling of familiar 3D space is achieved, any activity that involves learning or making use of *spatial relations* between subjects and objects can be remarkably enhanced. This can be used for anything—from advanced data visualizations generated by, say, the Large Hadron Collider that the user can easily explore, to advanced design applications where the user designs a city district and can perceive the distance relationships between various buildings much more clearly;
- Interactions in the virtual world can be powered by the full suite of computer graphics (CG) tools to allow for arbitrary manipulation of the virtual world resulting also in changes in the real world. A simple example would be a 3D design application: the user-painted 3D object is printed out using a 3D printer in the real world.

While the VR technology has been discussed by research scientists for a long time, until recently its use was limited to select research institutions and training centers. With the advent of inexpensive, *head-mounted displays* (HMDs) driven by motion tracking technology, VR leaped into everyday activities—and what is more important in the context of the present report—into real-life industrial applications. To complement the above potential applications, further examples include:

- Advanced process and system visualizations;
- Professional training—including simulated military operations;
- Architectural walkthroughs and virtual tourism;
- Psychological therapy and rehabilitation;
- Immersive 3D modeling and design.

Augmented Reality

Augmented Reality (AR) is a close relative of VR, yet is different in working principle. While VR completely replaces the environment perceived by the user and thus constrains the user's motions to the confines of the surrounding real-life physical environment, AR actually enhances, that is, *augments* the existing environment by adding artificial objects and subjects to it while also providing the user with the ability to interact with them. This, on one hand, provides certain advantages—at least in terms of user's physical safety—but is also limited in its ability to recreate a full environment since the beneficial effect of full immersion is not completely achieved.

For AR, using a headset is not necessary. It can be instead used with mobile devices like tablets and smartphones—using the integrated cameras to understand the surrounding environment, the intelligent augmentation applications place artificial objects and subjects on top of the identified surfaces. The user then sees them on the display of the device.

From the applications point of view, AR is different, as it does not replace the world around the user and rather complements it with interactable computer-generated objects and subjects. Some application ideas can be put forth:

- Visualization for medical applications like surgery;
- Supporting overlays for hardware maintenance services;
- Analysis of telemetry data from an industrial stream, manipulation of industrial equipment.

Sometimes the two concepts—VR and AR—are combined into a single term known as Mixed Reality (MR), though there is some debate around misuse of at least the MR concept. On the other hand, as of 2021, the eXtended Reality (XR) is used as an umbrella term referring both to AR and VR. Another important umbrella term involving both VR and AR is *spatial computing* that stems from the above discussion of utilizing *space* in VR/AR as opposed to the limitations of the typical 2D manipulations.

An in-depth study of VR as a technology is provided in the comprehensive book by Jason Jerald [1].

Key Hardware Properties

In order to use VR or AR in a project one should determine the most suitable device for the envisioned application. In what follows, we describe several key aspects of the hardware components to enable the reader to make an educated decision on choosing the appropriate hardware platform.

In what follows, we only discuss HMD-based VR and AR solutions. After all, it was HMDs that allowed VR to step outside the few select labs across the world and into the mainstream spotlight.

First we need to discuss how typical VR HMDs work:

1. The user wears the headset.
2. The user sees the dynamic stereogram through the lenses which is formed out of two separate and slightly offset images for the left and right eyes. An example stereogram[2] is shown in Figure 1.
3. The headset blocks the surrounding environment. The user is immersed into the artificial environment.
4. The tracking technology (be it outside-in or inside-out tracking) follows the user's movements to accurately change the viewpoint in the artificial environment.
5. The user observes and interacts with the artificial environment.

The 3D aspect of VR is not really a novelty—in fact, 3D cinema has been around for quite a long time. Items 4 and 5 are more important since they allow for the user to navigate the artificial environment and interact with it in a familiar way. The illusion of presense is achieved.

[2]To view it, you can use the cross-eye method as discussed at https://www.kula3d.com/how-to-use-the-cross-eyed-method

Figure 1: An example stereogram: statues from Caesar's Palace, Las Vegas, NV, USA. Unlike VR, not adjusted for lens distortion. You can use the cross-eye method to observe the 3D effect. NB! Please only use the cross-eye method if you feel comfortable doing it. With VR, no effort to cross your eyes is necessary as combining the images is done optically by the lenses. Original stereo pair from https://www.flickr.com/photos/3dimka/albums/72157594285944391

Room scale, locomotion and teleportation

In the following discussion mostly concerns VR because using it results in the actual immersion of the user into the artificial world whereas with AR the user still perceives the real world environment. We also assume that the intended use of VR is the one where the user is in standing position, since for sitting position the issues described below are nonexistent.

Room scale refers to the ability of the VR system to track the movements of the user in a fairly large area. It is supported by practically all modern AR/VR devices. Depending on the tracking solution, it may be the full room, or just a specific area thereof. While room scale tracking clearly provides benefits in making movement in the virtual environment realistic, it also presents a challenge as the safety of the user must be ensured.

To overcome the challenges presented by the spatial differences in the artificial environment and the real surroundings, several techniques can be applied. One of the most common ones involves the enabling of *teleportation* in the virtual environment. The user uses the *motion controller*—a device that allows to manipulate the VR environment—to choose the location in the virtual world where he wants to be. If it is an allowed target area for the teleport jump, the user is instantly transported to the desired location. Teleportation, therefore, solves the issue of limited space while still

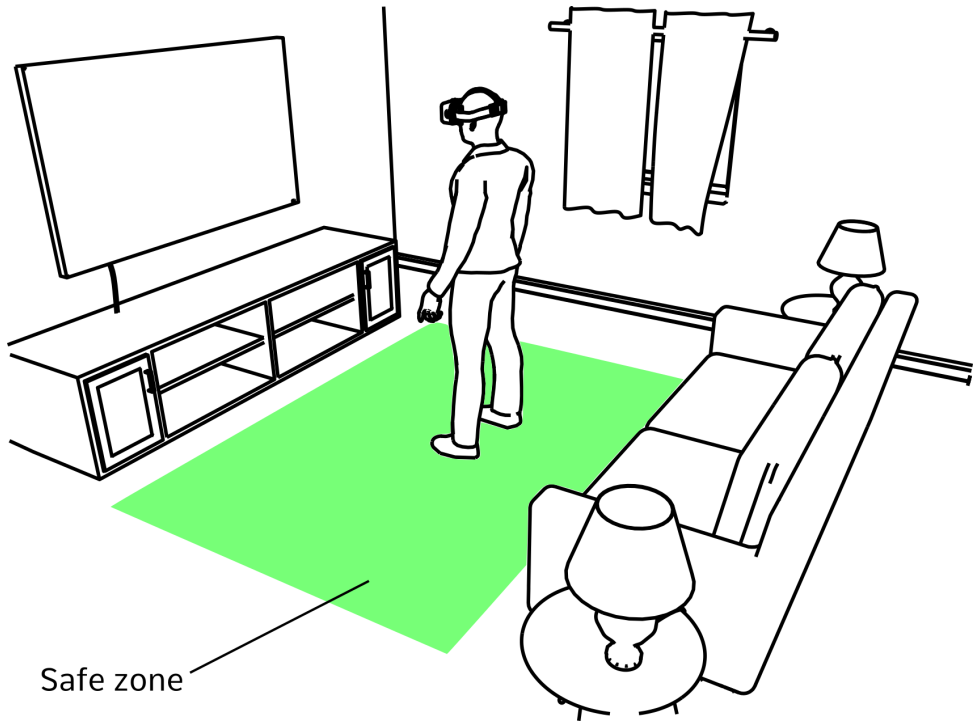


Figure 2: Using VR in a residential environment. It is important to mark the safe zone before running immersive content in the HMD.

allowing the user to naturally navigate the environment in the confines of the safe zone. There is also a drawback, however—teleportation is by no means a common real-life experience, hence constant use of it contributes to breaking immersion.

Comfort and safety during and after use

If one were to pick a reason for VR not yet gaining widescale adoption, it is perhaps this—concerns over comfort and safety. While contemporary HMDs are much more comfortable than early mass-market headset prototypes from 2014–2015 such as Oculus Rift DK1 and DK2, their continued use still has some implications for wellbeing, health, and safety. Hence it is very important to discuss the most critical points below and provide some insight into how certain issues can be remedied to provide the XR user with the best possible experience.

Field distance and vergence distance conflict This issue is also known as *accommodation-vergence conflict* [1]. The situation is depicted in Figure 3. In the real world, there is no difference between vergence distance and focal distance from the perspective of the observer. On the other hand, in VR an illussion is created with optics, however, in essence, the user is looking at a screen that is located quite close to his or her eyes. It is not a commonplace experience for the user. Using modern headsets seems to alleviate this issue since the so called *screen door effect*—due to which the users can actually perceive a screen in front of them—is reduced due to better display resolution

and other optical tricks. However, in general, there is no real solution where VR HMDs are concerned. As long as persistent immersion is achieved, this effect becomes less pronounced.

Another associated issue is setting of *interpupilary distance* (IPD) [3]. Most HMDs make the physical adjustment of the IPD possible, however, some do not. For VR experiences that are intended to be comfortable to most users, this is clearly a necessary feature typically implemented as a physical slider that can be used to adjust the distance between the centers of the lenses in the HMD to match the IPD of the user.

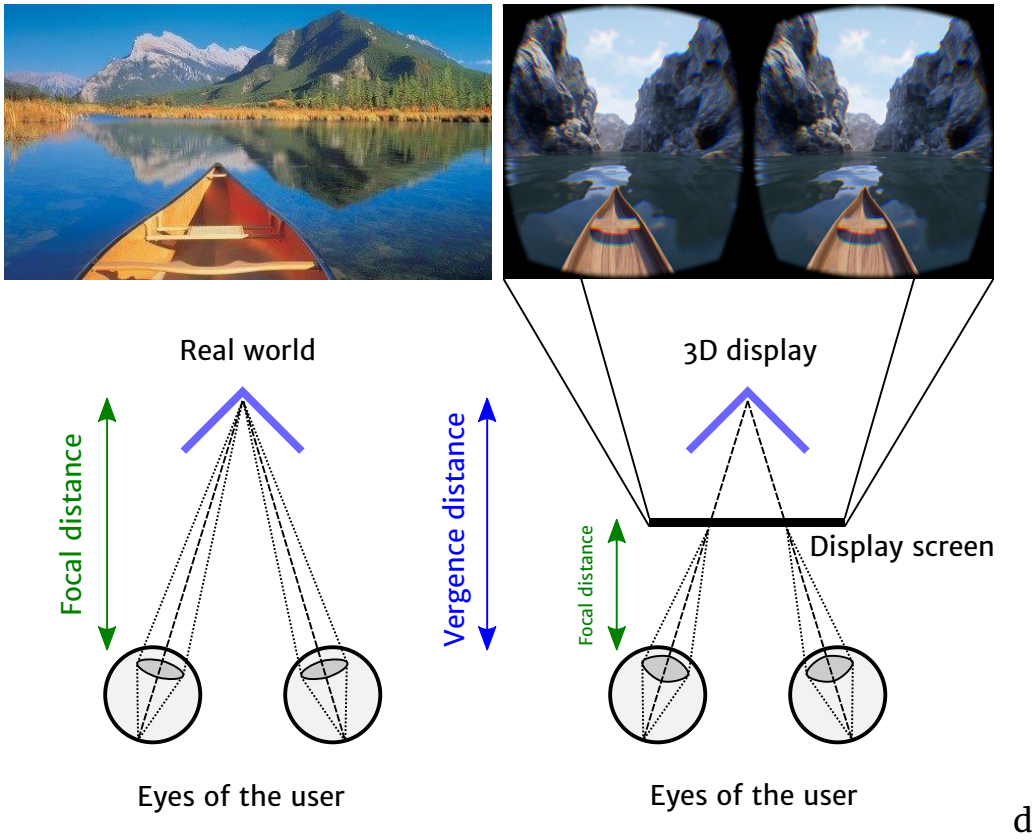


Figure 3: Differences in the visual system when looking at real world objects and when using an HMD. Cross-eye method also works for the boat stereogram on the right.

Motion sickness Motion sickness in VR is apparently primarily caused by sensory conflict whereby the user is moved around the virtual world without the user exhibiting physical movement or feeling any movement through vestibular sensations. For example, early HMDs had the user begin to float around the virtual environment when HMD tracking was lost. Similarly, moving through the virtual environment was done using a joystick. Another classic example is a driving simulation. The aftereffect of motion sickness can be quite profound with symptoms such as discomfort, nausea,

[3] Interpupilary distance is a measurement of the distance between the centres of your two eyes

dizziness, headaches, disorientation that can last for many hours after using VR. It is therefore advisable to exert as much effort as possible to reduce the effect of motion sickness [1]. Some solutions are as follows.

For situations where the user must move beyond the boundaries of room scale tracking, one can try to implement movement involving some typical actions the user would perform for actual movement but without physically stepping in any direction—in other words, motion cues should be implemented. This can include lifting feet, swinging arms (such as when running) and so forth. Of course, one can also consider using VR treadmills, such as the Virtuix Omni[4].

In the latest generation of VR HMD hardware, motion sickness is mitigated by making the screen refresh rate much higher than our visual system can perceive thus alleviating the negative effects of visually induced motion sickness.

For VR simulations where the users must be stationary (like driving simulators), some form of additional feedback can be implemented in the playseat, such as force feedback.

Tracking and display delays Another source of sensory conflict is tracking and display delays. The former occurs when the tracking technology cannot for some reason perform as designed and is sending updates to the system handling the display of the virtual environment too late. This can happen when tracking is lost, for example, due to the tracking system being obstructed (outside-in tracking) or does not have a feasible sensory input to work of off (inside-out tracking) like when the user operates in a completely dark room. The latter occurs when the virtual environment cannot be rendered due to high complexity of the computer graphics and lacking hardware support for it. Both, however, result in the user perceiving the environment as being unstable leading to rather unpleasant effects similar to the ones experienced with motion sickness. Here are a few suggestions to remedy both undesired conditions.

First, tracking delays can be avoided by properly setting up the tracking environment and ensuring that the sensors that are involved in tracking are functioning as intended. For example, for outside-in tracking, the real working environment that shall host the VR setup must not allow blocking or moving the base stations, reflective surfaces that could confuse the VR tracking system should also be minimized. For inside-out tracking, the real working environment must typically be well-lit and present features that allow the camera-based system to function properly—think about a solid, uniformely colored floor versus a texture-colored carpet (the latter is preferred).

[4] A good overview of the technology: https://www.youtube.com/watch?v=qGFuedKS9Mg

Second, display delays can be fixed in two main ways: optimizing the computer graphics features of the virtual environment or acquiring more powerful CG-supporting hardware, usually for a desktop-based VR experience this means a graphics processing unit (GPU) upgrade. For standalone VR, though, upgrading hardware is not an option, unless a better VR device is available (for example, replace Gear VR with Oculus Quest 2).

Fatigue As we have seen, the biggest contributors to negative aftereffects of using VR are motion sickness and various delays leading to the virtual environment being perceived as unstable and thus causing sensory conflict. General fatigue is another effect that should be taken into account. While fatigue arising to physical movement is normal, one has to take into account, especially in the case of VR, that wearing the HMD for a long time is tiring due to multiple factors: the user must wear the HMD with a relatively tight fit which causes some discomfort; it gets hot in the HMD, both naturally and because the HMD has to dissipate heat. The latter is especially concerning with wireless adapters for desktop VR.

Hence, to ensure that users do not experience excessive fatigue from the use of VR or AR, it is suggested to organize the work in a way that allows to work with HMDs in short sessions, 30 to 40 minutes each. Some users can also prefer longer sessions, but fatigue should still always be taken into account.

As the technology evolves, fatigue induced by wearing the HMD for longer periods becomes less pronounced.

Injuries during use Injuries during use mostly refers to using VR where the user is immersed into the artificial world and while reacting to what is happening there can accidentally bump into or hit some real world objects or other people. While this issue is most prominent with VR gaming, it should still be carefully thought through for any other fully immersive experience.

To circumvent this problem, modern HMDs use technologies like the VR Chaperone (SteamVR) or VR Guardian (Oculus Rift). The idea is fairly simple. Before the user can have the VR experience, a safe zone must be set up. This is typically done such that the safe area bounds are established by the user—the user walks around the safe zone while having the trigger pressed on the motion controller. Once the area is defined, and while in the VR experience, a grid will appear (similar to what is shown in Figure 4) at any time when the user approaches dangerously close to the boundaries. The user must then stop immediately and make a few steps back to arrive in the safe zone. While certainly a helpful reminder, it is not entirely foolproof, especially in cases where fast decision making and physical action (e.g., as with the throwing mechanic) is necessary in the VR environment. Though safety is of course of primary

importance, it should be noted that the grid contributes significantly to breaking immersion.

Hygiene In a situation when the VR/AR headset must be worn continuously by multiple users it also becomes necessary to provide all health protection measures related to hygiene.

Where continuous and immediate change of user of a VR or AR headset is planned, one could use several headsets in rotation. The just used headset is cleaned while the clean one is given to the next user. The users could be also given single-use gloves and special masks, although the latter reduce comfort without bringing too much benefit. So, the cleaning aspect should rather be addressed.

Cleaning can be done by using some form of disinfectant where it is sprayed onto a cloth and the cloth is used to wipe the insides of the HMD and all parts that make contact with the user's face. However, this may not be the most efficient approach due to the nature of materials used in HMDs [1]. Another approach that is considered more safe is to use UVC radiation to disinfect the HMD. An example of that is Cleabox technology[5] [4]. An example of one of their products is depicted in Figure 5. Unfortunately, UVC can also harm the materials of the HMD, so this solution also has drawbacks. In any case, careful study of all documentation related to Cleanbox is advised, especially if the desire is to disinfect very expensive equipment, such as Varjo XR-1.

Conclusion While it may seem that AR and VR in particular have quite a few problems regarding comfort and safety, this is because the technology is still rather new. The current issues also harbor numerous opportunities for those who can tackle them. In any case, developing content for AR and VR is a relatively safe bet—the technologies are clearly mature enough to no longer be considered gimmicky[6] and are definitely going to evolve along with the rest of the technology [3] yielding many useful applications.

Supporting hardware

This section is devoted to the discussion of different additional requirements for running VR and AR. Indeed, there are quite a few considerations to take into account. The rest of this section is organized as a use-case item list. The two major categories for

[5] https://www.cleanboxtech.com/

[6] One could consider 3D television sets intended for home use to belong to this category. Once of interest, the technology has rather quickly been abandoned.

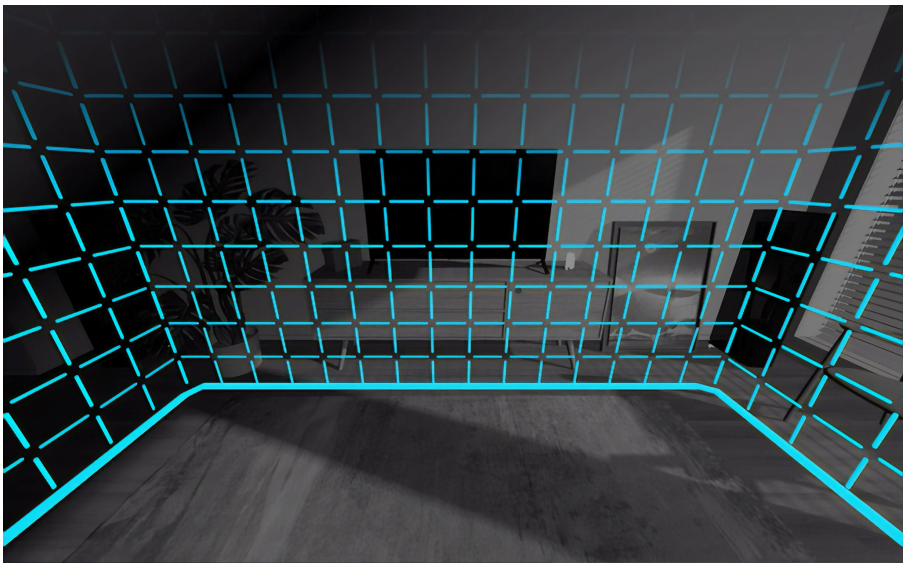


Figure 4: Oculus Rift Guardian grid that appears on the perimeter of the user-defined safe zone. The user should stop progressing in the direction indicated by the grid to avoid potential injury or property damage. Image source: https://uploadvr.com/how-to-disable-quest-guardian/

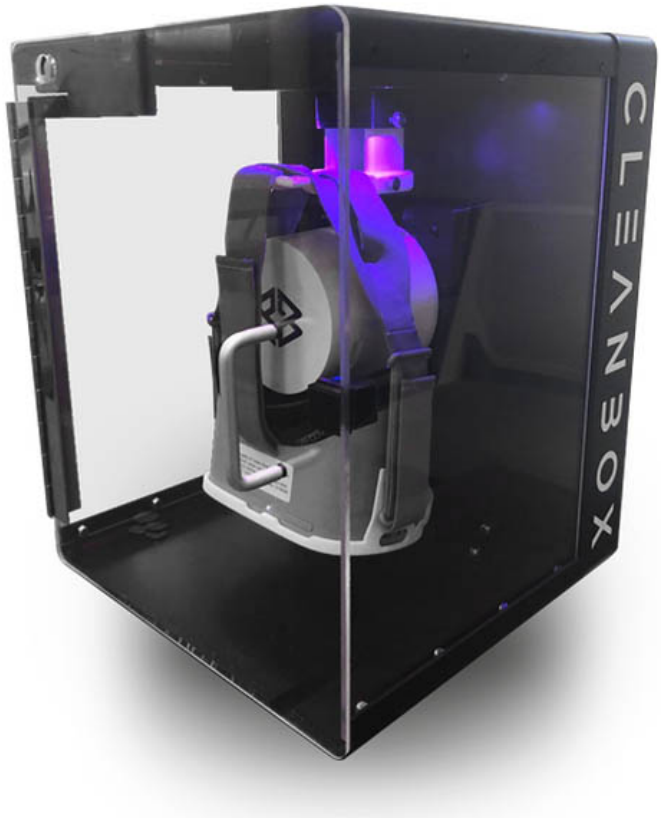


Figure 5: Cleanbox CX-1. The VR headset is placed inside and disinfected with UVC light. Image source: https://www.cleanboxtech.com/

applications are deployment (you just want to make use of XR hardware hosting existing software projects or as a partner in a larger project) and development (you want to have the capacity to develop content or applications for XR).

Deployment What concerns deployment, it is essentially a choice dictated by the quality requirements of the end product.

- Choose a **standalone headset** like the Oculus Quest or Pico Neo for VR and Microsoft HoloLens for AR if a compromise in visual fidelity is acceptable and additional accessories apart from the standard controllers are not required. Standalone headsets are typically based on smartphone platforms and are wireless. Because standalone headsets run on a battery, the downside is that the working time will directly depend on it.
- Choose a **tethered headset** like HTC Vive Pro for VR or Varjo XR-3 for AR, if the end product must have maximum visual quality. In this case, however, the HMD acts more like a display attached to a computer, so the computer must have enough processing power to accommodate the headset ensuring that best possible quality and tracking performance are achieved. In this case, it is always necessary to check with the manufacturer of the HMDs for the requirements that they state for them. For example, for running Varjo XR-3 one needs a PC with a minimum of NVidia RTX 2080 Ti performance equivalent graphics card and a native Thuderbolt 3 port which are rather steep requirements. For general tethered VR, there are two options. For on-the-go VR, look for a notebook which is categorized as VR ready. This typically means that it will support all current mainstream VR headsets. For stationary VR, choose a desktop with a powerful enough graphics card—check with the manufacturer website whether the GPU is VR ready, and enough random access memory—the minimum suggested amount is 8GB. The CPU is rarely the bottleneck for deploying VR, so any modern CPU with at least 4 cores and running at 3GHz or better is recommended.

Please note that provided above are just examples of headsets you can consider. A more thorough account of up-to-date HMD hardware is presented in the Hardware chapter of this report.

Development The requirements for XR development are rather different. In what follows, we review different cases based on specific development needs.

- **General AR/VR development** using *Game Engine* technology. A single development desktop computer should have a fairly powerful CPU. More CPU cores will be useful for all sorts of compiling jobs (compiling shaders and code), but single

core performance is also important. Having a separate desktop computer which is used only for compilation tasks is sometimes beneficial. In terms of RAM, at least 32GB is recommended. Also choose a high-end GPU. In terms of storage, 1TB SSD (for operating system and tools) and 4TB HDD (for storing project files) have proven to be a successful combination in many cases. However, you should also have weaker machines for testing purposes, in case you do not know the client configuration and assume it can be less powerful than the development machine.

- **Photogrammetry** (automatic generation of 3D models of the objects or environment). Use the PC specifications for general AR/VR development, but pay close attention to GPU performance specifications and VRAM. The latter must be as large as possible to ensure smooth photogrammetry job runs.
- **360 immersive video**. Same setup as for photogrammetry, except the GPU VRAM requirement is somewhat eased. Storage plays a much more important role, so making use of efficient network attached storage solutions is practically a must in this case.

Specific requirements will vary across the broad range of development needs. The list above is not by any means exhaustive, and will be gradually updated with more use case scenarios and recommendations.

Wired or wireless

As it was discussed in Deployment of XR solutions section above, standalone HMDs are typically wireless, though some can also be used in tethered mode to replicate the experience of visually superior wired headsets. There are, however, solutions for wired headsets as well that allow to either help to better manage the cables that are running to the headset or convert the headsets to wireless headsets.

For stationary uses, i.e., when the VR setup shall not move from a given area, cable management is the preferred solution. An example of a cable-managed setup is shown in Figure 6. The user is still confined to the VR area with the cable, but the risk of tripping over the wire or entangling it is mitigated.

Yet another option is to use wireless adapters for the specific HMDs assuming that they are available for those devices. On the one hand, the wireless adapter does provide the user with the freedom to move about in the room freely, however, there are also several important drawbacks:

- The set up of the complete VR system becomes more complicated requiring the user to install and configure additional hardware.

Figure 6: A cable management solution for the HTC Vive HMD. Image source: https://techblog.steelseries.com/2016/05/11/ikeasavedmefromdyinginvr.html

- Apart from the wireless adapter, the user must also carry a battery pack.
- The wireless adapter can get very hot during operation that can even result in physical trauma.

An example of a wireless adapter sold for HTC Vive Pro and Vive Cosmos HMDs is shown in in Figure 7.

Finally, another option to make a wired headset wireless is directly wearing a performant computation device—a special pack or a laptop—to which the HMD is connected directly. The obvious drawback is that any device that provides the necessary performance for high quality VR will be rather large and heavy.

Outside-in or inside-out tracking

Outside-in tracking This is a technology that allows to track the user using *base stations* also known as *lighthouses*—external devices that emit infrared radiation picked up by the HMD, motion controllers and other devices used in the tracking system. This setup is depicted in Figure 8a. For this system to work, base stations must be set

Figure 7: The Vive Wireless Adapter attached to a Vive Pro (left) and Vive Cosmos (right). Image source: https://www.vive.com/eu/accessory/wireless-adapter/

up properly to cover the area intended for VR activities. While specific setup instructions will be included with the particular tracking system, the general set up checklist is as follows:

1. Decide on how to deploy the base stations. For SteamVR, the best option is to mount them on walls to ensure they are always stationary, but if this is not feasible, then using special stands, like microphone stands (see Figure 8a for an example) can also be used.

2. The base stations must always be stationary (e.g., mounted to a wall). If they are moved during operation, tracking calibration is lost and very unpleasant effects may occur for the VR user as discussed in the Comfort and safety during use section.

3. Make sure there is enough base stations to cover the intended area. Typically at least two base stations are needed for sufficient coverage.

4. Set the base stations up so that the rays emitted by them are not blocked by anything else. One typical situation is when there are multiple individuals in the vicinity of a base station, they can interfere with the operation of the tracking system. For multi-user VR set ups, setting up the base stations could become more tricky.

5. Limit the number of reflective surfaces in the area where VR will be used because they may interfere with the correct operation of the tracking system.

As it can be seen, the most obvious use case for outside-in tracking is stationary use. This includes office spaces with a dedicated VR area, seated VR applications such as VR simulators and so on. This set up will also work well for motion capture workflows where more trackers are used apart from the HMD and motion controllers.

One more use case of this type of tracking is when arbitrary objects or subjects need to be tracked. In this case one would use a device like the HTC Vive Tracker.

Inside-out tracking This variant of tracking does not require setting up any external devices for tracking the user and motion controllers. Everything is handled with the cameras built into the HMD. This is the typical configuration for standalone mobile-based VR devices such as Oculus Quest.

The checklist is shorter as well, though there are also some limitations:

1. Use the HMD in a well lit room.
2. Prefer an environment having distinct textural features. For example, instead of a reflective floor surface consider a textured carpet.

Inside-out tracking appears to have enough benefits to drive mass-market appeal due to its plug-and-play nature.

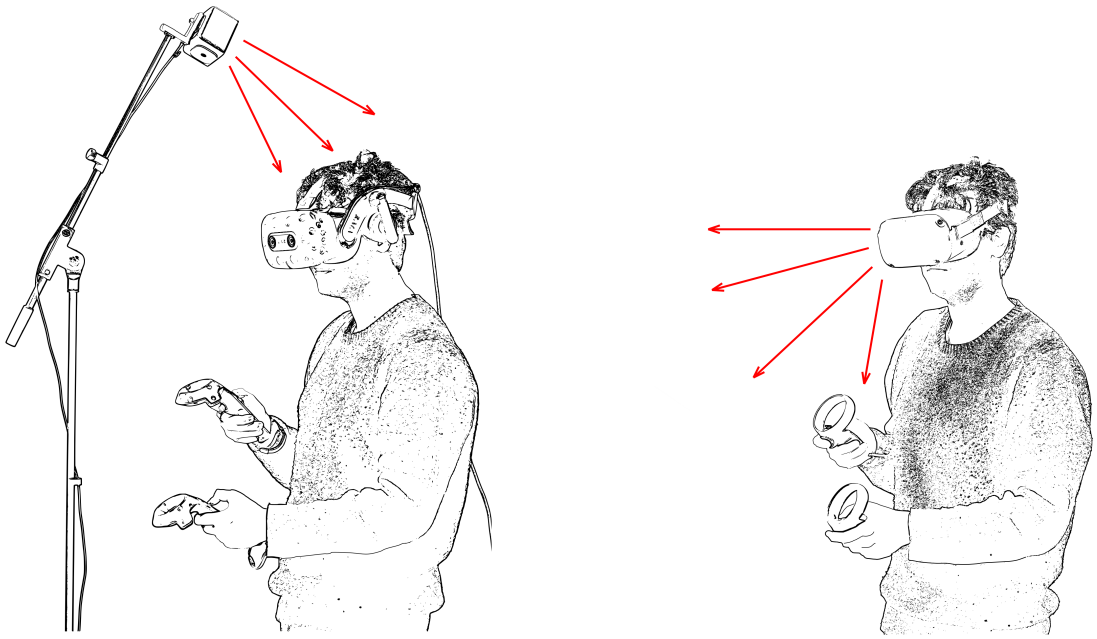
The drawback is that adding more devices to be tracked is not trivial in case of inside-out tracking. The user is mostly limited to using the included motion controllers and in some cases also hand tracking.

Interactions with motion controllers, hand tracking, and eye tracking

Both VR and AR are unimaginable without means to interact with the artificial environment. Therefore, it is important to discuss some of the specific solutions that can be used for implementing those interactions.

Motion controllers and joysticks Motion controllers are devices that are used to manipulate the artificial world. Examples of these controllers are shown in sketches in Figures 10a through 11. The controllers are tracked and in virtual or augmented reality will replicate the motions of the real life controllers. Orienting the controllers, the user can perform various actions using specific buttons. The controllers typically feature the following buttons:

- *Grab button*—a button that is located on the side of the controller and can be reached by the fingers that also hold the controller in place. In the artificial environment, it is generally used for picking objects up ("grabbing" them).
- *Trigger button*—located under the index finger and is meant mostly for games in the shooter genre, but can be used for any other purpose. In some default VR templates, this button is also mapped to picking objects up. Another typical



(a) Outside-in tracking. This approach requires setting up *base stations* around the perimeter of the action area. The base stations emit invisible rays that are caught by the headset, in this case HTC Vive Pro Eye, and motion controllers. This enables tracking the headset and the motion controllers assuming the base stations are strictly stationary. Indeed, the most common applications for this type of tracking are stationary—for example, when the user is expected to be seated for the majority of the time, though "room scale" is of course supported in this type of tracking as well.

(b) Inside-out tracking. This approach does not require setting up additional trackers, because the sensors (like cameras) are built into the headset itself and through those sensor the headset tries to make sense of the environment so that any movement the user does results in a shift in what the cameras see and this is translated to head tracking. Motion controllers are also tracked by the cameras. Newest headsets also support automatic hand tracking. This example: Oculus Quest 1. One potential problem with this type of tracking is that it depends on the textures of the surrounding environment and it does not work well in a dark environment.

Figure 8: Outside-in versus inside-out tracking solutions for VR and AR

example is clicking virtual buttons that are highlighted when the user points the controller at them.

- *Thumbstick*—a circular pad used for situations where direction of a certain action has to be chosen by the user (for example, the location or orientation of the teleport target).

Other buttons are used for various other actions and purposes like accessing menus, pausing the application, etc.

Other important features of motion controllers are that they are wireless and that they provide force feedback. So, for example, when the user in VR touches a certain object, the controller begins to vibrate thus indicating contact with a surface. Indeed, force feedback is a very important feature to bring the experience of the VR user as close as

possible to the usual experiences since simulating actual tactile experiences is rather difficult and costly.

Hand tracking Many users prefer to use their hands in VR and AR without any specific controller. This is indeed possible due to hand tracking technology which in the best case can accurately track all fingers individually.

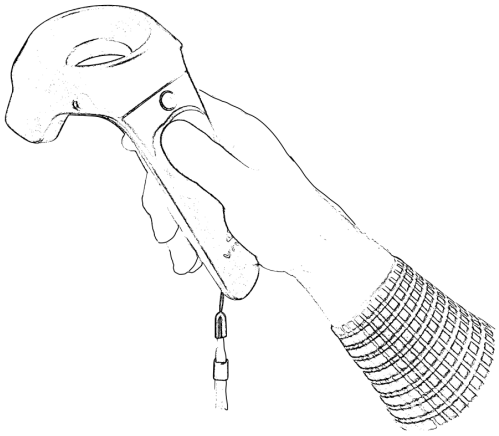
It is a good bet to look for this functionality in headsets with inside-out tracking as typically it will be implemented as part of the tracking pipeline since cameras are used for tracking anyway. To tethered HMDs that do not support this feature it is possible to add it via add-ons like Leap Motion Controller[7].

The issue, however, is that a pure hand tracking implementation—without any additional mechanism—does not provide haptics. One possible solution is to use ultrasonic arrays. An example of this solution is depicted in Figure 9. However, for many uses, the price for this type of haptic device could prove to be prohibitively high.

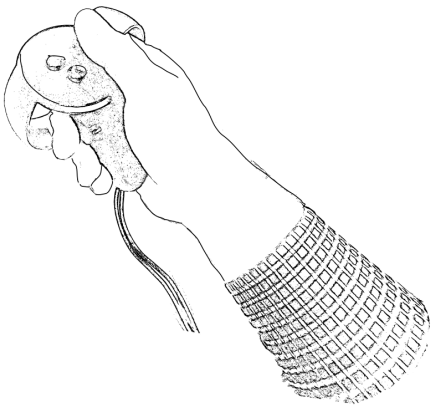
Figure 9: STRATOS Explore haptic device used by two users in VR. The haptic device is capable of delivering tactile experiences to the users. Image source: https://www.ultraleap.com/product/stratos-explore/

As a kind of compromise between hand tracking, finger tracking and haptics lies the Valve Index controller depicted in Figure 11. It is firmly attached to the palm of the user and can be used as a controller, has haptics, but provides finger tracking as well.

[7]Since the acquisition of Leap Motion company by Ultrahaptics, the Leap Motion Controller is available under the Ultraleap brand: https://www.ultraleap.com/



(a) HTC Vive Motion Controller. This was one of the first controllers introduced with the original HTC Vive HMD and is still used with a variety of high-end hardware such as Varjo XR-1. Features a rechargeable battery that can be charged using a micro USB cable. Controllers for left and right hands are identical and are assigned during software setup.



(b) Oculus Touch CV1 Controller. It is smaller and overall more comfortable. Each controller uses a single AA battery. Controllers are made individually for the left and right hand. Features an analog thumbstick for additional control possibilities.

Figure 10: Controllers for VR applications. For actual interactions make sure to use the supplied tie to secure the controllers around the user's wrists for safety purposes.

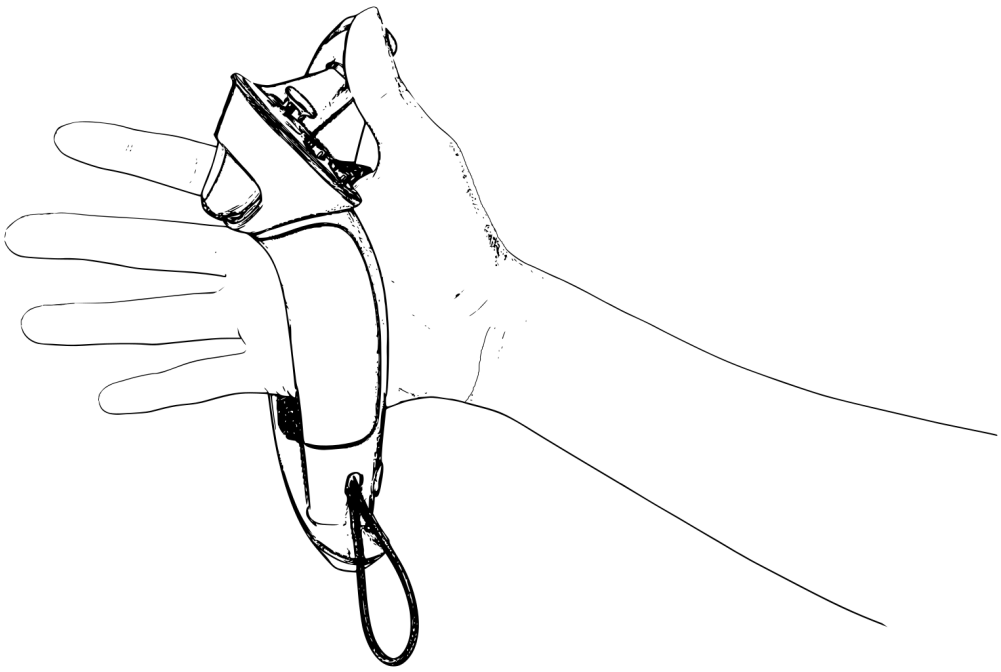


Figure 11: Valve Index controller (also known as Valve Knuckles) with finger tracking . The controllers are tightened around the palm, but allow for free finger movement while still providing force feedback. This makes these controllers one of the most flexible ones in terms of applications at the time of writing (January 2023).

Eye tracking Eye tracking is very important for understanding the XR user's behavior either in a fully virtual environment or in the augmented reality setting. Eye tracking makes possible to understand where the user is looking, so it is a great opportunity to figure out the user's items of interest in a VR scene and assuming that some form of object detection and recognition is enabled, also in AR scenes. An example of an obtained heat map is shown in Figure 12. This also works for behavioral analysis applications.

Figure 12: An example VR gaze heat map obtained using eye tracking. Image source: https://www.worldviz.com/virtual-reality-eye-tracking-for-research-solutions

Eye tracking can also be used as an interaction mechanic. For example, an scene element (say, button) becomes active when the user is looking at it in VR. This approach can also be used to, e.g., trigger help text for certain scene elements.

Furthermore, precise eye tracking opens the doors to a technology referred to as *foveated rendering*. This technology allows the rendering engine to focus only on the part of the scene which the user is looking at. Because humans can only see clearly in a very limited area of the field of view, the technology can mimic the same. The rest of the scene can thus be rendered with lower fidelity freeing computational resources that would have otherwise gone to drawing the complete scene in high fidelity.

Eye tracking can also be used for user identification. On one hand, this allows to easily identify users wearing the headset and use this information for authentication purposes for logging into certain services or to apply a suitable configuration of the headset (like eye tracking calibration) individually for each user. But obviously this also has some very serious privacy implications. Hence, such use of eye tracking must definitely be made known to the end user and the respective applications carefully thought through.

At the time of writing (January 2023), eye tracking is available in a few of the more expensive HMDs such as Varjo XR-3.

Voice commands To conclude this section, it also makes sense to mention one more method for interaction with AR or VR which is *voice commands*. The user speaks aloud the command to interact with either AR or VR, or to activate certain functions on the HMD. To provide a concrete example, with Microsoft HoloLens it is possible to, e.g., start recording a video of the AR environment by saying "take a video". Other examples for MS HoloLens can be found here: https://docs.microsoft.com/en-us/windows/mixed-reality/design/voice-input

Value for money and return on investment

Anyone who has been following the XR market in the recent years will know how fast it is changing with hardware becoming better, cheaper and more accessible, but here we provide a brief account on the value you get when investing into development with XR technologies and also on the return on investment (ROI).

Concerning infrastructural investments, due to the rapid nature of evolution of XR equipment, the current generation of HMDs should be treated like other IT equipment such as office computers. One specific item to keep in mind is that even old generation HMD hardware can be used to develop XR experiences in principle. Besides that, due to the relatively high prices of HMD hardware, just like office hardware, they can be rented. Thus, from the investment perspective there are several options where specifically development of XR applications is concerned:

1. Purchase older generation hardware, use it for developing XR applications, rent equipment when it is needed to test the applications on modern HMDs. One catch here is the necessity to somehow emulate, e.g., the motion controllers of all other XR hardware platforms. Although software frameworks typically provide automatic switch options depending on the type of HMD used, it is still necessary to test the application on other platforms to ensure correct operation.
2. Purchase current genereneration hardware, develop cutting edge XR applications with the newest features. The value of the hardware will drop over time, but it will still be possible to use this hardware to continue developing XR experiences in the coming years.
3. Rent current generation hardware.

A question is often raised about the process of deploying XR applications to multiple platforms, e.g., to both desktop XR and mobile XR. This is more of a software framework and development related question than one related to hardware. However, it is perhaps not feasible to rent current generation hardware for maintenance purposes, therefore when this sort of development is concerned, it is suggested to invest into actually purchasing the required HMDs.

Let us now discuss return on investment. To quote directly from Kress [3]:

> Unlike in the previous AR/VR boom of the late 1990s, contemporary investors, market analysts, and AR/VR/MR system integrators, as well as enterprise users, expect to see a real return on investment (ROI) for these unique technologies in the next five years, as underlined by the Gartner Hype Cycles for Emerging Technologies.

Furthermore, Kress goes on to outline the sustainability aspect of "MR for enterprise". The ROI there is said to be "mainly cost avoidance" and related to the following applications:

- Faster learning curves in training for new employees, higher productivity and efficiency;
- Lowering of downtime, waste, and operational costs;
- Collaborative design, remote guidance, better servicing and monitoring;
- Higher QA in manufacturing;
- Enhanced product display, demos, better user experiences.

Specific sectors that are said to have shown a tangible MR ROI are concentrated in

- Manufacturing—automotive, avionics, heavy industrial products;
- Power, energy, mining and utilities;
- Media and telecommunications;
- Healthcare and surgery;
- Financial services;
- Retail, hospitality and leisure fields.

Even in the light of this information, it does not mean that other fields cannot be considered for R&D as well, though obviously it will be associated with more risk. However, it is expected that many opportunities will arise for applying XR technologies, so these opportunities should be discovered as quickly as possible.

Finally, we will comment on the gaming industry. While perhaps less relevant for enterprises unless they specifically represent game design studios, the information that can be obtained from, e.g., Steam Hardware Survey[8], especially information about the consumer VR market, is still rather valuable because it reveals important trends in the development of XR technology.

[8] Available at https://store.steampowered.com/hwsurvey/ [Nov 2020]

Further reading

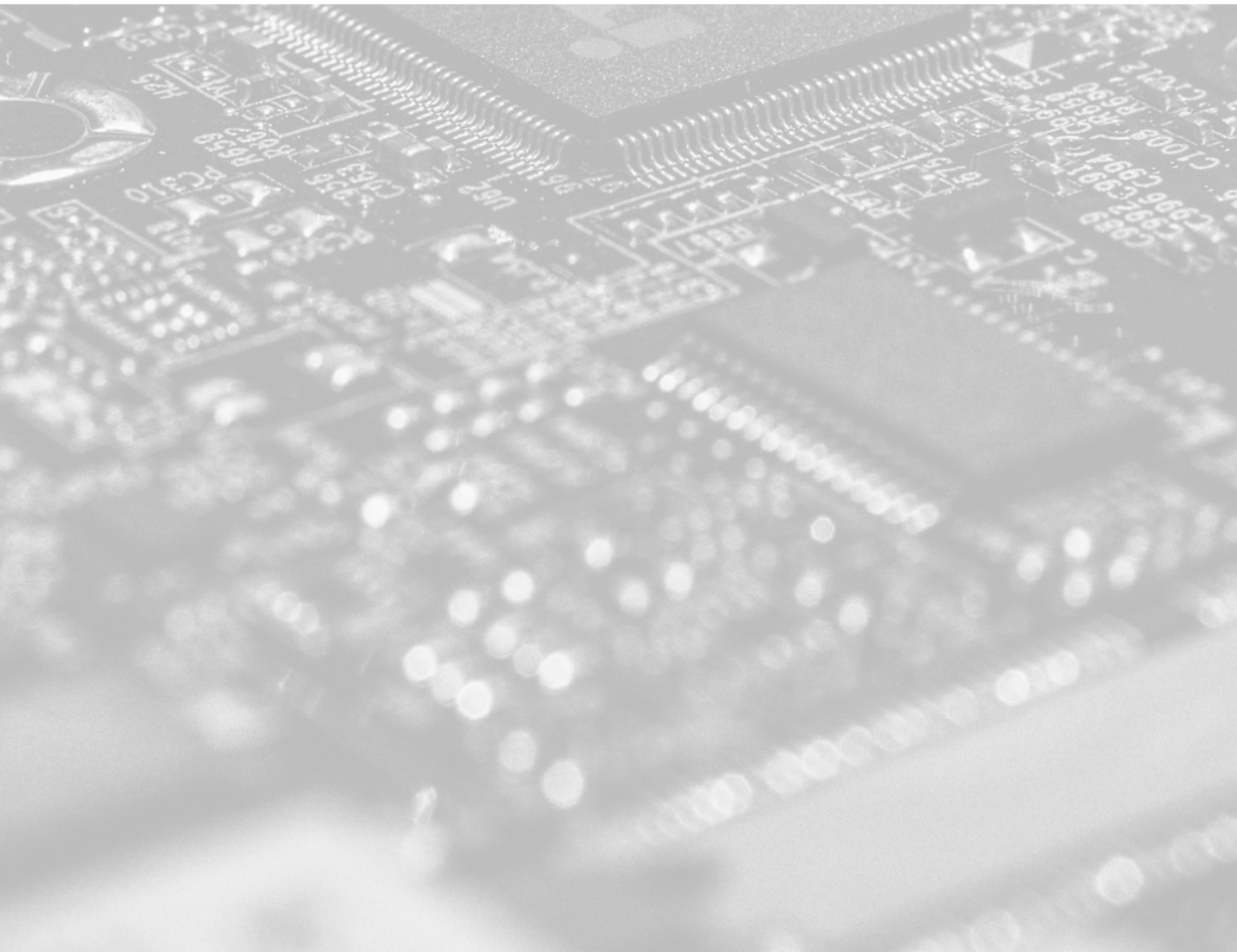
[1] J. Jerald, *The VR Book: Human Centered Design for Virtual Reality*. Association for Computing Machinery and Morgan & Claypool Publishers, 2016.

[2] W. R. Sherman and A. B. Craig, *Understanding Virtual Reality: Interface, Application, and Design*. San Francisco, CA, USA: Morgan Kaufmann Publishers Inc., 2002.

[3] B. C. Kress, *Optical Architectures for Augmented-, Virtual-, and Mixed-Reality Headsets*. SPIE, 2020.

[4] D. A. Georgeson, "Cleaning and disinfecting cradle for virtual reality visors," US patentus US10 328 166B2, 2019. [Online]. Available: https://patents.google.com/patent/US10328166B2/en

Hardware



How to Read This Chapter

This chapter provides information about the state of the art hardware necessary for providing VR and AR experiences. In the chapter, VAM Realities partners focus on those hardware devices that they have had experience with. Hence, upcoming VR and AR devices are not considered. The interested reader can look into news considering new technology by subscribing to a website, such as https://www.roadtovr.com/ or https://uploadvr.com/ (no affiliation with VAM Realities partners). Since the report is intended to be updated at regular intervals, new devices will eventually get covered in it. In fact, the developers are encouraged to get in touch with VAM Realities partners to provide them with the possibility to evaluate new devices thus making the report more complete.

Disclaimer. It is important to note that the assessment of all the hardware items is done to the best of the experience and knowledge of VAM Realities partners and does not represent any particular corporate interest. There is a star rating system provided for each hardware device. With the rating for each criterion (*affordability*, *interactivity*, *set up time*, and *technical difficulty*) VAM Realities partners attempted to provide a score against an average baseline as perceived by a typical small- or medium enterprise. Having the scores at hand should allow to make educated choices regarding the balance of all four ratings when the SME decides on a business idea, model, or strategy geared towards a particular use case involving specific VR and/or AR technologies.

Each entry in this chapter has a certain structure. Let us discuss the elements of the structure and how to interpret them.

Hardware photos These are photos of the discussed device. For each HMDs, we try to provide three views: the perspective view, left view, and front view. The photos are original, or are linked to the source. The idea is to give the reader a better understanding of the looks and ergonomics of each device.

Note that some device pictures showcase devices with stickers applied to them and pointing to certain organizations. Most of the times these stickers are applied per agreement between one of the project partners and the corresponding organization as part of the arrangement for making the device available to project partner. Whenever possible, we use clean photos to ensure neutrality.

Year of release The entries are sorted such that the most recent ones are presented first in the report. Typically, the more recent the device, the better the experience will

be for the end user. However, it makes sense to remember that older devices, though not recommended for new designs, can still be used for development purposes.

Use domain Here, first we specify what the intended usage domain of this device is: VR, AR, or both. Also, be vary of the other two attributes that can be found in this section: whether the hardware item is a **development kit**, and whether it is deprecated and not recommended for new design.

Commercial attributes Here, it is specified whether the device is commercial or open source, and the primary developer is listed.

Price range If the reader desires to purchase the device, here the expected price is provided as a range.

Website Link to the official website of the item where more detailed information about the specific entity is provided. If the link does not work anymore, the reader can try to use the Wayback Machine located at `https://archive.org/web/` to quickly get related information, if it is available.

Keywords A list of keywords which best characterize the given item. These can also be found in the Index.

Ratings The ratings are provided for reference and are based on the evaluation of the VAM Realities partners. Each criterion has a range from one (lowest) to five (highest) and its value is represented by filled starts. There are four criteria in total:

- **Affordability**: a lower rating means the item is not really affordable, while a higher rating means that it is easy to afford said item;
- **Interactivity**: a lower rating means that the item has few features that allow to interact with the XR environment, while a high rating means there are multiple features supported (e.g., hand tracking, gestures, eye tracking, voice commands);
- **Set up time**: the higher the rating, the more time is needed to set up the device;
- **Technical difficulty**: the higher the rating, the more prior knowledge is necessary to operate the device as intended.

Pros and cons A list of advantages and drawbacks of the specific item as seen from many perspectives (usability, comfort, etc.).

Display attributes If the core function of the item is to act as a display, this is where essential characteristics of the device will be found. Specifically, how the device is intended to be used (e.g., "head-mounted"), and, if it is an HMD, additional information is provided about the field of view (FOV), per-eye resolution of the built-in display(s), and whether it is a standalone device.

Interaction caps Interaction capacity of the device, if available. Will provide information about what sort of interaction mechanics are built into the device.

Data storage How the data required for the operation of the device is stored. For standalone devices it will likely be "internal", whereas for tethered devices it will be "external".

Description Description of the device based on the experience and knowledge of VAM Realities partners. This can be treated as a mini-review. This also typically includes additional information about technical specifications.

Relationships to other items Information about relationships to other hardware, software and use cases. For example, Unreal Engine 4 has first class support for developing for Microsoft HoloLens 2, hence this information is provided.

Review summary Finally, in this chapter, a review summary of all hardware devices is provided based on categories of devices (i.e., whether a given device is VR, AR, or both VR and AR use case compatible). Use that to quickly locate a device geared towards a specific purpose.

Canon EOS R5C with Canon dual fisheye lens

General facts

Year of release	2022
Use domain	VR
Commercial info	Manufactured and/or developed by Canon
Price range	7300 EUR to 9100 EUR

Image source(s): https://www.newsshooter.com/2021/10/06/canon-eos-vr-system-rf-5-2mm-f2-8l-dual-fisheye-lens/

Official website https://www.canon.co.uk/

Affordability	Interactivity	Set up time	Technical difficulty
★★★☆☆	★☆☆☆☆	★★☆☆☆	★★★☆☆

Pros and cons

- ✓ excellent picture quality (8k, 60fps, 45Mpix)
- ✓ dual fisheye lens delivers true 3D with natural parallax
- ✗ dual fisheye lens needs manual focussing, no autofocus
- ✗ In the highest resolution, video files are unmanageably large (e.g. 3,6 GB for 1min30sec)
- ✗ free EOS VR Utility software can only manage video footage of less than 2 minutes and no RAW files. For larger files, a €60/year subscription is necessary.

Technical attributes

Display attributes Hand-held; Standalone; Marker-based

Data storage Internal

Canon EOS R5C with Canon dual fisheye lens description

The Canon RF 5,2mm F2.8L Dual Fisheye-lens can only be used with the Canon R5 body and the R5C body. The R5C has a built-in cooling fan and is capable of continuous video recording while video recording with the R5 body is limited to 10 à 20 minutes.

The R5C has the following features (source: https://www.canon.co.uk/cameras/eos-r5c/):

- full frame 8k sensor: Capture professional 8K, 30fps footage (60fps with external power supply)
- 45 Megapixel images: Shoot high-resolution 20fps (electronic) and 12fps (mechanical) images

- Long duration recording: Record 8k footage without limitations with a new active cooling system
- Dual Pixel CMOS AF: Reliable auto focus performance featuring Eye AF and EOS iTR AF X
- Cinema RAW Light: Internally record professional 12-bit RAW footage up to 2.6Gbps
- XF-AVC and MP4: Options for 4:2:2 10-bit XF-AVC 810Mbps recording and HEVC 540Mbps
- HDR recording formats: Produce high dynamic range content with Canon Log 3, PQ and HLG capture
- Cinema EOS functions: Waveform Monitor, False Colour, Timecode and more
- Robust and compact design: Compact and lightweight (680g) body with dust and moisture resistance

The Canon RF 5,2mm F2.8L Dual Fisheye-lens has the following features (source: https://www.canon.co.uk/lenses/rf-5-2mm-f2-8l-dual-fisheye-lens/):

- Dual fisheye lens: Capturing a perfectly aligned stereoscopic image onto a single Full Frame sensor
- 190° field-of-view: Capturing an ultra-wide viewing angle for a more immersive experience
- 60mm baseline length: Providing a natural stereoscopic viewing experience
- F2.8 aperture: Exceptional performance in low light
- UD elements and SWC coatings: Professional image quality for sharp, high contrast images, with reduced ghosting and flare
- Dual EMD units: Precise control and synchronisation of the aperture ensures even exposure between the two left and right images
- L-series quality: Designed and built to perform in demanding conditions
- Built-in rear gelatin filter holder: For increased flexibility when shooting in bright conditions

Varjo XR-3

General facts

Year of release	2020
Use domain	VR and AR
Commercial info	Manufactured and/or developed by Varjo
Price range	6000 EUR to 10000 EUR
Official website	https://varjo.com/products/xr-3/
Keywords	wired hmd; gaze tracking; hand tracking; depth sensing; human eye resolution

Affordability	Interactivity	Set up time	Technical difficulty
★★★☆☆	★★★★★	★★☆☆☆	★★★☆☆

Pros and cons

- ✓ Incredible visual fidelity with a wide field-of-view
- ✓ Includes both eye and hand tracking
- ✓ Includes LiDAR scanners for high quality depth sensing in the real world
- ✓ Very flexible and suitable for demanding mixed reality applications
- ✓ Easier connection to the user's computer
- ✗ Quite expensive mostly due to a per user account subscription model
- ✗ Requires a rather powerful computer to operate including a top-of-the-line graphics card

Technical attributes

Display attributes	Head-mounted; Binocular; FOV: 115°; with per eye resolution of 1920x1920; Wired

Interaction caps Gaze tracking; Camera sensor; Hand tracking

Data storage External

Varjo XR-3 description

As of December 2020, Varjo XR-3 is the company's new flagship mixed reality headset. Mixed reality is achieved by means of a pass-through of a high-resolution video feed from front-facing cameras. Compared to XR-1, this headset is no longer considered to be a development kit, and the improvements are clearly visible in almost every aspect of the new device. Most notably, the visual artifacts introduced by the early design of the headset's optical system that was used in XR-1 can no longer be seen in this new headset. Apart from that, the headset itself is less expensive and expands on almost all features of its predecessor: (1) It offers a wide field-of-view of 115 degrees; (2) Better resolution of the displays at 1920x1920 per eye; (3) Full hand tracking support with integrated Ultraleap technology; (4) Depth awareness made possible with the integrated LiDAR scanners, this, for example, allows better real-time occlusion and in conjunction with the cameras can be used to reconstruct the 3D world surrounding the user; (5) Simpler connection to the computer (Thunderbolt 3.0 port is no longer required). All of the above features result in perhaps the best mixed reality headset on the market as of 2021 — the offered visual fidelity has to be seen to be believed. The complete feature set makes the device incredibly flexible. For instance, although the headset still makes use of base stations for room scale tracking, it is also possible to implement inside-out tracking with the device (currently a beta feature). The device also became more comfortable to wear, it is less heavy than XR-1, and more ergonomic. On the downside, in order to use or develop for the headset, a rather costly software subscription is required which may make it out of scope for smaller companies, though it should not at all be a problem for big industries or academic partners (for the latter, a special program exists that allows to get software subscriptions at generously reduced rates). Overall then, this is the best mixed reality device on the market that comes with many features. The most prominent use cases will be in the domain of realistic simulations.

Relationships to other items

Use case: Training and Simulation Just like with XR-1, Varjo XR-3's primary field of application is accurate, detailed simulations. This includes driving and flight simulations that are specifically tailored to the process of personnel training. Mixed reality cameras also work with green screens, so it is possible also to have a real, physical steering wheel or flight stick placed in front of the user in the real environment while

overlaying the parts which are covered by the green screen with the actual simulation thus creating a very accurate and immersive experience. Depth sensing allows to create accurate occlusions for, e.g., the user's hands, which may appear inside a VR environment.

Microsoft Hololens 2

General facts

Year of release	2019
Use domain	AR
Commercial info	Manufactured and/or developed by Microsoft
Price range	3000 EUR to 3600 EUR
Official website	https://www.microsoft.com/en-us/hololens

Affordability	Interactivity	Set up time	Technical difficulty
★★☆☆☆	★★★★★	★★★★☆	★★★★☆

Pros and cons

- ✓ Excellent resolution and visual fidelity
- ✓ Straightforward and user-friendly
- ✓ Ergonomic design, lightweight and comfortable to wear (fits over eyeglasses)
- ✓ Gaze tracking is integrated. The device's eye-tracking system enables users to interact with certain interface elements using only the eyes
- ✓ No wire connection required
- ✓ Precise hand-tracking provides great interaction with the virtual world
- ✓ Voice input enables control over device operation
- ✗ Limited field of view, although improved over Microsoft Hololens 1
- ✗ Only 2-3 hours of battery life with active use
- ✗ Expensive

Technical attributes

Display attributes	Head-mounted; Binocular; FOV: 52°; with per eye resolution of 2048 x 1080; Standalone
Interaction caps	Gaze tracking; Camera sensor; Motion sensor
Data storage	Internal

Microsoft Hololens 2 description

Microsoft Hololens 2 is a pair of smart glasses for mixed reality experiences, developed and manufactured by Microsoft. It was announced on February 24, 2019 at the Mobile World Congress in Barcelona, Spain. The headset improves the overall experience and expands the field of view over its predecessor, Microsoft Hololens. The new design is lighter (566 g) and gives greater comfort for the user by placing the battery at the back of the head. Four visible light cameras are used for head tracking and two IR cameras for eye tracking. Hand gestures and the exact finger's positions are tracked as well, enabling users to grab, move and scale objects in a natural way. Six-degree of freedom (6DoF) world-scale positional tracking and spatial mapping via real-time environment mesh provide the understanding of the surroundings. It comes with a Qualcomm Snapdragon 850 Compute Platform, 4-GB LPDDR4x system DRAM and 64-GB UFS 2.1 of internal storage. The device includes Wi-Fi and Bluetooth connection. The see-through holographic lenses and the built-in spatial sound enhance the immersive mixed reality experience. Hololens 2 is specially aimed at business customers. Microsoft has demonstrated several applications across industries in industrial equipment maintenance, auto manufacturing, and medical procedures, among others.

Relationships to other items

Software: Unity and PiXYZ Plugin With the Hololens 2 Development Edition, Microsoft offers Unity Pro \& PiXYZ Plugin trials to make the design of real-time 3D experiences more straightforward. By pairing Unity with the PiXYZ Plugin, the aim is to create real-time interactive and virtual experiences based on CAD data for the Hololens 2 more easily.

Software: Unreal Engine 4 Unreal Engine 4 provides support for Hololens 2. Developers have access to APIs for the platform's unique features, such as streaming and native deployment, finger tracking, gesture recognition, meshing, voice input, spatial anchor pinning, and more.

Use case: Industrial training and simulation Workers in manufacturing facilities can be provided with mixed reality visual guidance and step-by-step instructions. Analyses of components and assemblies can be performed with the Hololens 2 to eliminate errors and improve product quality.

Use case: Healthcare Care teams can hold virtual patient consultations, display real-time spatial information to improve communication, accelerate diagnoses and reduce time-to-treatment. Health care professionals are empowered to rapidly coordinate and share imaging results as well as to better contextualize physician-patient conversations.

Oculus Quest

General facts

Year of release	2019
Use domain	VR
Commercial info	Manufactured and/or developed by Facebook
Price range	400 EUR to 700 EUR
Official website	https://www.oculus.com/quest
Keywords	head mounted display; wireless hmd; motion controller

Affordability	Interactivity	Set up time	Technical difficulty
			

Pros and cons

- ✓ Doesn't require additional hardware
- ✓ Due to the latest beta launch of Oculus Link, you'll be able to use your Quest in the Unity Editor
- ✓ Inside-out tracking works well
- ✗ Less powerful than wired headsets
- ✗ Sometimes uncomfortable
- ✗ Screen is still grainy

Technical attributes

Display attributes	Head-mounted; Binocular; FOV: 100°; with per eye resolution of 1440x1600; Standalone
Interaction caps	Controller; Camera sensor; Motion sensor
Data storage	Internal

Oculus Quest description

Oculus Quest is a VR head-mounted display released in 2019 by Facebook. It is an evolution of the Oculus Go launched on the market in 2018. The headset is standalone,

it doesn't require to be connected to an external PC and it is controlled by two hand-held controllers. The headset support six degrees of freedom (6DoF) thanks to two motion controllers as well as sensors located on the sides of the headset, this means that the user is free to move anywhere without a cable in the way and that the movements are translated into VR. Oculus Quest can be set up for standing use (go around) or stationary use. Oculus Quest is based on the Oculus SDK, but it can also be used in Unity3D using the XR platform.

The Quest is rather light at 571g, its battery runtime is about 3 hours. The OLED displays have a 72Hz refresh rate. It is based on the Qualcomm Snapdragon 835 processor and has 4GB of RAM.

Oculus Quest has been discontinued due to the launch of Oculus Quest 2. However, it can still be used for development purposes.

Oculus Rift S

General facts

Year of release	2019
Use domain	VR
Commercial info	Manufactured and/or developed by Facebook
Price range	450 EUR to 550 EUR
Official website	https://www.oculus.com/rift-s/

Affordability	Interactivity	Set up time	Technical difficulty
★★★★★	★★★★☆	★★★☆☆	★★★☆☆

Pros and cons

- ✓ Inside-out tracking
- ✓ Reasonably-priced
- ✗ Wired

Technical attributes

Display attributes	Head-mounted; Binocular; FOV: 115°; with per eye resolution of 1280 x 1440; Wired
Data storage	Internal

Oculus Rift S description

Oculus Rift S is a second generation device in the Rift lineup. In comparison to the original Rift, the S-version has no need for external tracking as it utilises inside-out tracking technology. Device has 6DOF inside-out tracking through 5 built-in cameras.

Rift S is a reasonably priced consumer device for basic VR use. It is starting to get a little bit dated and does not shine in any technical aspect so other alternatives should also be compared.

Valve Index

General facts

Year of release	2019
Use domain	VR
Commercial info	Manufactured and/or developed by Valve
Price range	800 EUR to 1400 EUR
Official website	https://store.steampowered.com/valveindex/
Keywords	wired hmd; comfort; motion controller

Affordability	Interactivity	Set up time	Technical difficulty
			

Pros and cons

- ✓ Excellent picture quality with a very high 144 hz refresh rate and high field of view
- ✓ Unique Valve Knuckles controllers enable advanced interactivity via haptic finger-tracking
- ✓ Quite comfortable to use despite its weight
- ✓ High-quality off-ear headphones and microphone integrated into the headset
- ✗ Installation might seem intimidating to new users, but the guided setup is actually quite easy
- ✗ A higher setup time due to external beacons and cables decreases mobility

Technical attributes

Display attributes	Head-mounted; Binocular; FOV: 114°; with per eye resolution of 1440x1600; Wired
Interaction caps	Controller; Haptic; Motion sensor
Data storage	External

Valve Index description

Valve Index is a wired VR headset that is powered by an external laptop or desktop PC. It has a very high refresh rate of 144hz which is much higher than in any other VR headset. The headset features six degrees of freedom (6DoF) which means that as the user moves in the real world, they will also move in a similar way in the VR environment.

Valve Index uses unique Valve Knuckles controllers which include haptic finger-tacking sensors. The controllers track each finger separately which provides an intuitive interaction method for VR. This feature enables the user to for instance grab 3D objects in VR as they would in real-life.

Setting up the Valve Index requires a certain level of IT skills from the user and it can take some time because it uses external beacons to track the headset and the controllers. However, the Valve installation guide and software is very intuitive and easy to use. On the other hand, the external beacons do provide more accurate tracking when compared to inside-out camera tracking which can be important in tasks which require high precision.

Valve also offers continuing support and future development for the headset. Valve Index uses the SteamVR platform.

Valve Index is recommended for organizations which deal with advanced and highly-detailed visual content and want more advanced interactivity and features in their VR solution. The price is somewhat higher than other common PC-powered headsets (e.g. the Oculus Rift) but the extra cost is justified due to its advanced features and visual clarity. However, the Valve Index is considerably cheaper than the highest-end Varjo headsets.

Varjo XR-1

General facts

Year of release	2019
Use domain	VR and AR; **Development kit**
Commercial info	Manufactured and/or developed by Varjo
Price range	10000 EUR to 15100 EUR
Official website	https://varjo.com/products/xr-1/
Keywords	wired hmd; gaze tracking

Affordability	Interactivity	Set up time	Technical difficulty
★★☆☆☆	★★★★☆	★★★☆☆	★★★☆☆

Pros and cons

✓ Exceptional visual fidelity	✗ Heavy
✓ Integrated gaze tracking	✗ Very expensive
✓ Low latency mixed reality	✗ Relatively narrow field of view

Technical attributes

Display attributes	Head-mounted; Binocular; FOV: 87°; with per eye resolution of 1920x1080 with 1440x1600; Wired
Interaction caps	Gaze tracking
Data storage	External

Varjo XR-1 description

Varjo XR-1 is the company's flagship mixed reality headset. It uses advanced technology to provide a superior visual fidelity that the company is calling "human eye resolution visual experience". The headset is equipped with a mixed reality camera making it possible to use the headset for high-fidelity AR applications. It also has integrated gaze tracking. The device is compatible with SteamVR and as such HTC

Vive lighthouses, motion controllers and trackers can be used with the headset. In mixed reality mode, markers can be used to insert virtual objects into the surrounding environment. It should be emphasized that these features come at a hefty price tag; the device also requires a powerful desktop computer to operate properly: at the time of writing, the recommended desktop specifications include native Thunderbolt 3 support and an Nvidia RTX 2080 Ti graphics card. The user should consult Varjo's website for updated specifications.

Relationships to other items

Use case: Training and simulation Varjo XR-1's primary field of application is accurate, detailed simulations. This includes driving and flight simulations that are specifically tailored to training personnel. Mixed reality cameras work with green screens, so it is possible also to have a real, physical steering wheel or flight stick placed in front of the user in the real environment while overlaying the parts which are covered by the green screen with the actual simulation thus creating a very accurate and immersive experience.

HTC Vive Pro

General facts

Year of release	2018
Use domain	VR
Commercial info	Manufactured and/or developed by HTC
Official website	https://www.vive.com/eu/product/vive-pro/
Keywords	comfort; wired hmd; motion controller

Affordability	Interactivity	Set up time	Technical difficulty
★★★★☆	★★★★★	★★☆☆☆	★★★☆☆

Pros and cons

- ✓ Higher resolution screens
- ✓ Built-in headphones
- ✓ comfort
- ✓ Vastly improved ergonomics
- ✗ The initial setup process can be a bit complex
- ✗ Very expensive
- ✗ DisplayPort only connection
- ✗ 90Hz rather than 120Hz refresh rate

Technical attributes

Display attributes	Head-mounted; Binocular; FOV: 110°; with per eye resolution of 1440x1600; Wired
Interaction caps	Controller; Camera sensor; Motion sensor
Data storage	External

HTC Vive Pro description

The HTC Vive Pro is the upscale version of the HTC Vive, developed and released by HTC. With respect to the previous version, the HTC Vive Pro has a different design and some enhanced features: resolution, audio, and Room-Scale play space. The redesign

has improved the balance of the headset for a more comfortable experience. The resolution of the dual-AMOLED displays is 2880 x 1600 allowing for a field of view of 110 degrees and with a refresh rate of 90 Hz. That's 1400 x 1600 per eye compared to 1080 x 1200 per eye on the HTC Vive. HTC Vive Pro is equipped with a High-performance Hi-Res certified headphones with a built-in amplifier and 3D spatial sound, dual microphones with active noise cancellation. By adopting the new base station the Room-Scale play space can be increased from 4x3 meters up to 10x10 meters.

The headset and IPD can be easily adjusted by the user to achieve maximum comfort. The Vive Pro makes use of SteamVR Tracking version 2.0. Room-scale tracked area can be up to 33' x 33' using four SteamVR Base Station 2.0. The included two base stations support up to 16'5" x 16'5".

New users should look into getting an HTC Vive Pro Eye as this more recent version also had integrated eye tracking.

Magic Leap 1

General facts

Year of release	2018
Use domain	AR
Commercial info	Manufactured and/or developed by Magic Leap
Price range	2100 EUR to 3000 EUR
Official website	https://www.magicleap.com/en-us/magic-leap-1
Keywords	gaze tracking; comfort

Image source(s): https://unsplash.com/photos/rcrYhAP2d_w

Affordability	Interactivity	Set up time	Technical difficulty
★★☆☆☆	★★★☆☆	★★★☆☆	★★★☆☆

Pros and cons

- ✓ The headset is lightweight and comfortable
- ✓ The headset can display high-end AR experiences
- ✓ Developer and enterprise support currently available
- ✗ High price, limited availability in Europe
- ✗ Relatively fewer apps than in the HoloLens
- ✗ Low field of view
- ✗ Future uncertainty due to Magic Leap being startup company
- ✗ The wired processing unit can limit mobility

Technical attributes

Display attributes	Head-mounted; Binocular; FOV: 50°; with per eye resolution of 1280x960; Standalone
Interaction caps	Gaze tracking; Camera sensor; Motion sensor
Data storage	Internal

Magic Leap 1 description

Magic Leap 1 is a set of wearable see-through AR glasses that were released in 2018 as a direct competitor for the Microsoft HoloLens AR glasses. Magic Leap 1 was initially marketed towards consumers, but due to the high price on the headset, the company later pivoted their use more towards the enterprise market.

Magic Leap 1 uses several cameras and sensors to map out its surroundings. Different digital assets can then be presented to the user directly in the observed environment via the AR glasses. The digital content can also interact with the 3D mapped environment.

Unlike Microsoft HoloLens, the Magic Leap 1 also includes a separate processing unit which is connected to the AR glasses. The processing unit is called the Lightpack and it can be clipped on the user's trousers or pocket. The glasses also include speakers

with spatial audio capabilities. The headset is controlled by a single hand-held controller or by hand gestures. The headset also tracks the user's eyes.

The headset is availabe as the standard model, developer suite and as an enterprise suite.

Pico G2

General facts

Year of release	2018
Use domain	VR
Commercial info	Manufactured and/or developed by Pico Interactive
Price range	200 EUR to 350 EUR
Official website	https://www.pico-interactive.com/us/G2.html

Affordability	Interactivity	Set up time	Technical difficulty
★★★★☆	★★☆☆☆	★★★☆☆	★★★☆☆

Pros and cons

- ✓ The headset is lightweight
- ✓ Wire connection is not required
- ✓ High screen resolution
- ✓ Price is reasonable
- ✓ It includes access to the content of the Viveport resource library of HTC VIVE
- ✓ It utilizes the VIVE WAVE VR Open Platform, making content development easier to create for a common platform
- ✗ Battery life only lasts for 2-2.5 hours with active use
- ✗ Device does not support focus adjustment. When wearing eye glasses, it is recommended not to take them off
- ✗ Can become uncomfortable to wear after long periods of time
- ✗ Controller batteries cannot be recharged
- ✗ 3DoF headset and controller diminish the immersive experience

Technical attributes

Display attributes	Head-mounted; Binocular; FOV: 101°; with per eye resolution of 1440 x 1600; Standalone
Interaction caps	Controller; Motion sensor
Data storage	Internal

Pico G2 description

The Pico G2 is a standalone VR headset made by Pico Interactive, a manufacturer from China. This all-in-one VR headset, also known as the Pico Goblin 2, is the follow-up to its predecessor, the Pico Goblin. The device is very lightweight (268g) and it comes with a three-degree of freedom (3DoF) headset and a single 3DoF controller. Pico G2 features two 3.5" LCD displays that provide a combined resolution of 2880 x 1600 (3K) with a refresh rate frequency of 90Hz, a Qualcomm Snapdragon 835 CPU, 4GB of RAM and 32GB of internal storage capacity with up to 256GB of micro-SD card expansion. The headset integrates a 3500 mAh headset battery that lasts for 2 - 2.5 hours with active use. It is powered by the Android system 8.1. To download apps, the Viveport resource library and the official Pico store can be used. It is also possible to order the Pico G2 Pro version, which includes 64GB of internal storage and one external RGB camera. A 4K display version of the Pico G2 with a 75Hz refresh rate is also available.

Relationships to other items

Software: Unity Pico Interactive includes the software development kit PicoVR Unity SDK to support development in Unity with Pico devices

Software: Unreal Engine 4 Pico Interactive includes the software development kit PicoVR Unreal SDK to support development in Unreal Engine 4 with Pico devices

Pico Neo

General facts

Year of release 2018

Use domain VR

Commercial info Manufactured and/or developed by Pico Interactive

Price range 400 EUR to 750 EUR

Official website https://www.pico-interactive.com/us/neo2.html

Affordability	Interactivity	Set up time	Technical difficulty
★★★☆☆	★★★★☆	★★★☆☆	★★★☆☆

Pros and cons

- ✓ Good hardware parameters
- ✓ No wire connection required
- ✓ 6DoF headset and motion controllers without the use of external sensors
- ✗ Only 2-3 hours of battery life with active use
- ✗ Device does not support focus adjustment. It is recommended not to take off eye glasses
- ✗ With the non-business version, interactivity is reduced

Technical attributes

Display attributes Head-mounted; Binocular; FOV: 101°; with per eye resolution of 1600 × 1440; Standalone

Interaction caps Controller; Camera sensor; Motion sensor

Data storage Internal

Pico Neo description

Pico Neo is a standalone VR headset released in 2018 by the company Pico Interactive. The business edition comes with a six-degree of freedom (6DoF) headset and 6DoF motion controllers. For non-business customers, only a 3DoF trackpad controller is

included. In the business version, controller tracking is implemented by means of ultrasonic emitters on the headset and ultrasonic sensors on the controllers. Head tracking is implemented using two cameras located in front of the headset. With this technology, the device can track both head and controller movements without external sensors. In addition, Pico Neo features two 3.5" LCD displays, each with a resolution of 1600x1440 pixels per eye and a refresh rate frequency of 90Hz, built-in dual speakers, a Qualcomm Snapdragon 835 processor, 4GB of RAM and 64GB UFS2.0 of ROM, supporting up to 256 GB of expanded storage. It is powered by a modified Android system. Pico Neo has access to the Vive Wave platform, meaning that content can be accessed through Viveport and the official Pico Store.

Relationships to other items

Software: Unity Pico Interactive includes the software development kit PicoVR Unity SDK to support development in Unity with Pico devices

Software: Unreal Engine 4 Pico Interactive includes the software development kit PicoVR Unreal SDK to support development in Unreal Engine 4 with Pico devices

Samsung Odyssey

General facts

Year of release	2017
Use domain	VR
Commercial info	Manufactured and/or developed by Samsung
Price range	300 EUR to 600 EUR
Official website	https://www.samsung.com/us/support/owners/product/hmd-odyssey-mixed-reality
Keywords	comfort; head mounted display

Affordability	Interactivity	Set up time	Technical difficulty
★★★☆☆	★★★☆☆	★★☆☆☆	★★★☆☆

Pros and cons

- ✓ Comfortable headband makes prolonged use easier
- ✓ Increased quality when compared to stand-alone headsets
- ✗ Officially discontinued, limited availability from sellers
- ✗ Headsets has cables and it needs to be connected to a PC which can be complicated for many users

Technical attributes

Display attributes	Head-mounted; Binocular; FOV: 101°; with per eye resolution of 1440x1600; Wired
Interaction caps	Controller; Camera sensor; Motion sensor
Data storage	External

Samsung Odyssey description

Samsung Odyssey is a VR head-mounted display released in November 2017. An upgraded Odyssey+ was also launched in 2018. The headset is connected to an external PC (either laptop or desktop) and it is controlled by two hand-held controllers which

are registered by the headset (the headset doesn't require external beacons which lowers setup time). The headset support six degrees of freedom (6DoF), which means that as the user moves in the real world, they will also move in a similar way in the VR environment. Samsung Odyssey can be set up for standing use (which allows more freedom for the user to move around) or for a more limited sit-down experience.

Samsung Odyssey is based on the Microsoft Windows Mixed Reality platform, but it can also be used in the SteamVR platform. Setting up the headset requires some knowledge from the user because they have to handle and troubleshoot all of the software updates themselves (Windows and driver updates as well as platform updates in SteamVR). However, the Odyssey uses inside-out tracking which means that it does not require any external beacons.

The Odyssey is quite comfortable to use despite its weight (644 g) and it has good earphones integrated into the headset. It is a decent option for those who need something more powerful than a stand-alone VR headset but can't quite afford the more advanced VR headsets, such as Valve Index and Varjo headsets. However, the headset has been officially discontinued, making its availability more limited when compared to many other headsets.

iPad (ARKit)

General facts

Year of release	2017
Use domain	AR
Commercial info	Manufactured and/or developed by Apple
Price range	500 EUR to 1500 EUR
Official website	https://www.apple.com/ipad/

Affordability	Interactivity	Set up time	Technical difficulty
★★★☆☆	★★★★☆	★★★★★	★★★★☆

Pros and cons

- ✓ Big screen size
- ✓ New models are powerful devices
- ✓ Mature and robust hardware
- ✓ Well developed application distribution channels
- ✗ Might be a bit expensive for industrial scale utilization

Technical attributes

Display attributes	Hand-held; Mobile; Markerless
Interaction caps	Touchscreen; Camera sensor; Motion sensor
Data storage	Internal

iPad (ARKit) description

As Apple published ARKit framework in 2017, they also upgraded iPads to become AR capable devices. As Android tablets based on ARCore are still hard to come by, Apple's iPads are an excellent fit for mobile AR use cases which require a bigger screen that a mere iPhone would provide. As hardware, developer tools and distribution channels are mature and well developed, AR capable iPads are a valid option even for industrial companies searching for a propers solution for their AR scaling efforts.

HTC Vive

General facts

Year of release	2016
Use domain	VR
Commercial info	Manufactured and/or developed by HTC Vive
Official website	https://www.vive.com/eu/product/#vive%20series
Keywords	room-scale tracking; wired hmd; motion controller; teleportation

Image source(s): https://amazon.com/

Affordability	Interactivity	Set up time	Technical difficulty
★★★☆☆	★★★★☆	★★☆☆☆	★★★☆☆

Pros and cons

- ✓ technology is sharp and immersive
- ✓ big play area which allows users to move in 3D space
- ✓ two screens – one for each eye – and over 70 sensors to track user's movements
- ✗ uncomfortable to wear for long periods of time
- ✗ long setup time
- ✗ requires no less than five power outlets

Technical attributes

Display attributes	Head-mounted; Binocular; FOV: 110°; with per eye resolution of 1080x1200; Wired
Interaction caps	Controller; Motion sensor
Data storage	External

HTC Vive description

HTC Vive is a VR head-mounted display released in 2016 by HTC and Valve. It works plugged into a pc equipped with a VRReady graphic card. HTC Vive is controlled by two had-held controllers. The headset support six degrees of freedom (6DoF) thanks to a laser-based inside-out positional tracking system developed by Valve called lighthouse.

HTC Vive is based on the SteamVR platform. Setting up the headset requires a lot of time and some knowledge from the users because several steps are required in order to download and install the software as well as to register to the SteamVR platform.

HTC Vive can be coupled with a Vive Wireless Adapter allowing to connect the Headset with the Computer wirelessly.

This is one of the early headsets that can still be used for development purposes, however, it is not recommended for new designs.

PlayStation VR

General facts

Year of release	2016
Use domain	VR
Commercial info	Manufactured and/or developed by Sony
Price range	300 EUR to 650 EUR
Official website	https://www.playstation.com/it-it/explore/playstation-vr/
Keywords	comfort; head mounted display

Image source(s): https://asia.playstation.com/en-hk/press-releases/2017/1h/1h/20170829-psvr/

Affordability	Interactivity	Set up time	Technical difficulty
★★★★★	★★★☆☆	★★★★★	★★★★☆

Pros and cons

- ✓ Price
- ✓ Simple setup
- ✓ Comfortable to wear even with glasses
- ✗ Processor unit needs to be unplugged to power down
- ✗ Motion control tracking is hit and miss.
- ✗ Works only with PS4 and PS5
- ✗ Limited opportunities in organizational use

Technical attributes

Display attributes	Head-mounted; Binocular; FOV: 100°; with per eye resolution of 960x1080; Wired
Data storage	External

PlayStation VR description

PSVR is a virtual reality headset developed by Sony Interactive Entertainment released in October 2016. It can work only plugged into a PlayStation Consolle (PS4) and needs to be coupled with a PS camera to play VR games. PSVR is just for the visualization while the tracking is provided by PS Camera.

An initial setup is required before using the PSVR.

PSVR is currently one of the best-selling and used VR headsets on the market.

Google Cardboard Viewer

General facts

Year of release	2014
Use domain	VR
Commercial info	Manufactured and/or developed by Google
Price range	0 EUR to 50 EUR
Official website	https://arvr.google.com/intl/fi_fi/cardboard/get-cardboard/

Keywords motion sickness; head mounted display

Affordability	Interactivity	Set up time	Technical difficulty
★★★★★	★☆☆☆☆	★★★☆☆	★★☆☆☆

Pros and cons

- ✓ Cheap way to test VR
- ✓ Various Cardboard viewes available from different sellers
- ✗ Low-level of immersion and interactivity
- ✗ Uses the smartphone's battery quickly
- ✗ Simulation sickness is quite common

Technical attributes

Display attributes Head-mounted; Binocular; FOV: 90°; with per eye resolution of Variable (depending on the smartphone); Mobile

Data storage Internal

Google Cardboard Viewer description

Google Cardboard is a smartphone-based mobile VR headset which was released in 2014. With Google Cardboard, the user launches a Google Cardboard compatible app in their smartphone and slots their smartphone in the Google Cardboard Viewer to be used as a screen and places the headset before their eyes. Google Cardboard is a very simple and cheap way to experience VR. However, the level of immersion and interactivity are very low when compared to other more advanced VR headsets.

Google Cardboard has been one of the most popular ways to experience VR because they were shipped for free with many products when VR was initially starting to gain popularity. Users can also make a Google Cardboard Viewer themselves based on instructions provided by Google, or purchase a Viewer from various sellers. Google Cardboard development platform became open-source in 2019.

Google Glass

General facts

Year of release	2014
Use domain	AR; **Development kit**
Commercial info	Manufactured and/or developed by Google
Official website	https://www.google.com/glass/start/

Image source(s): https://www.google.com/glass/start/

Affordability	Interactivity	Set up time	Technical difficulty
★★★☆☆	★★★★☆	★★★★★	★★★☆☆

Pros and cons

- ✓ Google Glass will show you text messages as well as emails you receive and allow you to reply to them via voice commands.
- ✓ Multiple options are made available which allows the user to use either voice commands or small hand gestures for operating this device.
- ✓ The video and camera capabilities
- ✓ This user friendliness and freedom is one of the USPs of this project.
- ✗ Google Glass can be easily broken as it is a sensitive device.
- ✗ The face recognition technology can be easily misused and it might turn out to be offensive for that person.
- ✗ The video and camera can be misused and anybody can capture anything without letting the other person know about it.

Technical attributes

Display attributes	Head-mounted; Monocular; Standalone
Interaction caps	Camera sensor; Motion sensor; Touchpad
Data storage	Internal

Google Glass description

Google Glass is a pair of AR glasses mainly aimed for industrial purposes. It contains a microcomputer built in the frame, a touchpad near the right temple and a plastic cube in the right eyes field of vision that outputs the provided information. It's designed to intuitively fit your field of vision and extend the experienced environment with visual and auditory information. It also provides the possibility of a real time connection to other Google glasses that can stream the vision of the person wearing it or provide second hand information.

Android-based smartphones (ARCore)

General facts

Use domain	AR
Commercial info	Manufactured and/or developed by Various
Official website	https://developers.google.com/ar/discover/supported-devices
Keywords	hand-held

Image source(s): https://unsplash.com/photos/NrMGL5MR8uk

Affordability	Interactivity	Set up time	Technical difficulty
★★★★★	★★★☆☆	★★☆☆☆	★★★★☆

Pros and cons

- ✓ Almost everyone already has a smartphone with some AR capabilities built-in
- ✓ Employees carry a smartphone with them everywhere
- ✓ New AR apps are easy to learn due to the familiar user interface
- ✓ As the company's smartphones eventually get replaced, the new devices will likely support more advanced AR
- ✓ Little to no additional AR hardware costs
- ✗ Compatibility problems with different AR apps due to the heterogeneity of smartphones
- ✗ Most smartphones cannot yet support the most advanced AR functionalities

Technical attributes

Display attributes Hand-held; Mobile; Markerless

Android-based smartphones (ARCore) description

Even though Augmented Reality (AR) can be used with headsets that have been specifically designed for AR, one of the most common ways to utilize different AR apps is still with a smartphone. Newer android-based smartphones support more advanced AR functionalities that are based on the ARCore development kit (see the link for a list of supported devices). With ARCore it is possible to develop more advanced AR apps that use more accurate motion tracking and 3D space sensing. ARCore uses the smartphones camera and various other sensors to idenfity the space around the user, position the user in relation to the surrounding environment, and insert digital objects into the user's view. ARCore can for example accurately identify different flat surfaces. Digital objects can then interact with the environment in an accurate way,

so for example if a digital ball is rolling down a table, it will fall once it reaches the end of the table.

For organizations, these devices offer the lowest barriers for adopting AR because most of the employees will likely already have a smartphone that can support different AR functionalities. Moreover, as the company replaces its current smartphone install base, the newer smartphones will likely have even better AR functionalities than before. Simple AR apps, such as remote collaboration tools, can therefore be adopted quite easily to support the company's business processes. Some employees might also already be familiar with smartphone-based AR due to the popularity of Pokemon Go and other consumer AR apps, which can lower the barriers for adopting AR in the enterprise-context. Smartphone-based AR apps are also relatively easy to learn to use because the interaction methods and the user interface are already familiar to the user.

HP Reverb G2

General facts

Use domain	VR
Commercial info	Manufactured and/or developed by HP
Price range	600 EUR to 800 EUR
Official website	https://www8.hp.com/us/en/vr/reverb-g2-vr-headset.html

Affordability	Interactivity	Set up time	Technical difficulty
★★★★☆	★★★★☆	★★★☆☆	★★☆☆☆

Image source(s): https://amazon.com/

Pros and cons

- ✓ Price is reasonable
- ✓ High resolution
- ✓ HP has partnered with Valve on multiple development fronts (audio, lenses, SteamVR compatibility)

Technical attributes

Display attributes	Head-mounted; Binocular; FOV: 114°; with per eye resolution of 2160 x 2160; Wired
Data storage	External

HP Reverb G2 description

HP Reverb G2 is the successor of Reverb G1 which was one of the leading Windows Mixed Reality headsets in the market. Headset resolution is one of the best available having a remarkable 2160 x 2160 LCD panels per eye. HP compares it to having 2,5 times the pixels of Oculus Rift S. Lenses are designed by Valve who is a pioneer in the new rise of VR and has been involved in producing excellent hardware (HTC Vive, Valve Index). Also audio is designed by Valve. Headset hosts inside-out tracking with four cameras. This is a very viable alternative for industry use.

Nreal Light

General facts

Use domain	AR; **Development kit**
Commercial info	Manufactured and/or developed by Nreal
Price range	500 EUR to 1500 EUR
Official website	https://www.nreal.ai/specs/

Affordability	Interactivity	Set up time	Technical difficulty
★★★★☆	★★★☆☆	☆☆☆☆☆	★★★★☆

Image source(s): https://immersive-technology.com/augmentedreality/nreal-light-give-hands-on-experience-with-ar-version/

Pros and cons

- ✓ Very light
- ✓ Relatively cheap
- ✗ Form factor might not fit all faces
- ✗ Product is very new and untested in demanding environments.

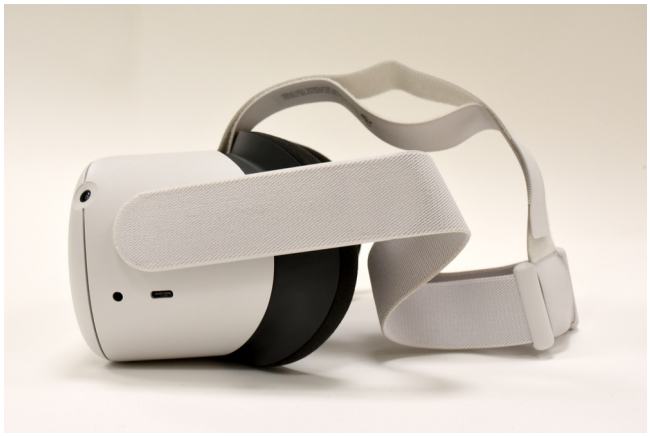
Technical attributes

Display attributes	Head-mounted; Binocular; FOV: 52°; with per eye resolution of 1920 x 1080; Mobile
Data storage	External

Nreal Light description

Nreal's Light AR glasses are one of the most portable ones in the marketplace today. They're tethered so you need a smartphone containing Qualcomm Snapdragon 845 or a never processor to run provide computing power and Android app support. Image quality in Nreal's glasses has been surprisingly good in comparison to their very small form factor. They are "one size fits all" so they might not be the best fit for persons with certain types of facial features, which should be taken into account from the ergonomics perspective. At the time of writing availability is still quite limited. All-in-one enterprise model is said to launch at the end of 2020.

Oculus Quest 2



General facts

Use domain	VR
Commercial info	Manufactured and/or developed by Facebook
Price range	350 EUR to 650 EUR
Official website	https://www.oculus.com/quest-2/

Affordability	Interactivity	Set up time	Technical difficulty
★★★☆☆	★★★★☆	★★★☆☆	★★☆☆☆

Pros and cons

- ✓ all-in-one system
- ✓ price
- ✓ weight
- ✓ resolution
- ✗ LCD display offers slave images
- ✗ the strap in uncomfortable
- ✗ the cable to use Oculus-link is sold separately and costs 99 €
- ✗ Requires a Facebook account

Technical attributes

Display attributes	Head-mounted; Binocular; FOV: 110°; with per eye resolution of 1832×1920; Standalone
Interaction caps	Controller; Haptic; Camera sensor
Data storage	Internal

Oculus Quest 2 description

Oculus Quest 2 is the most advanced all-in-one VR Head Mounted Display (HMD) on the market and has been released on the market in 2020 by Facebook. As the previous release, the Oculus Quest does not require to be plugged into a pc to run, the user is free to move anywhere without a cable in the way and it is controlled by two hand-held controllers which are registered by the HMD (the HMD doesn't require external beacons which lowers setup time). The HMD supports six degrees of freedom (6DoF)

thanks to two motion controllers as well as sensors located on the sides of the headset, which means that as the user moves in the real world, he also moves similarly in the VR environment. Oculus Quest can be set up for standing use (go around) or stationary use.

Compared to the first version there are pros and cons. The elegant fabric finish of the first model is now replaced by a clear plastic. The cameras for external tracking remain, the intrapupillary adjustment and the strap that keeps the viewer glued to the face change.

In the Oculus Quest 2 there is inside a unique LCD panel, instead of the two OLED panels of the previous version, with a resolution of 1832x1920, almost 8 megapixels in total, divided in two. For this reason, the correction of the intrapupillary distance is done by acting through hardware on the lens and then with a software compensation directly on the panel with different levels: 58mm, 63mm and 68mm.

Oculus 2 is equipped with a powerful processor, the Snapdragon XR2, 6 GB of RAM , 64 or 256 GB of storage and has a refresh rate of 90 Hz. The autonomy of the device is estimated between 100 and 140 minutes depending on the level of brightness and the type of application running. The audio is integrated.

Although it is lighter than the previous version after several gaming sessions appears clear that the fit of the first Oculus was much better. The elastic band chosen by Oculus is uncomfortable, it is difficult to adjust precisely and after a while, it loosens, it does not allow a quick switch from one head to another. If well tightened it compresses a little too much.

The LCD panel provides an increase in terms of definition but a worst contrast: the image is washed out and the black is not black but grey.

The HMD can be used by downloading and running the application from the Oculus Store or in the developer mode. To activate the developer mode the user must install the Oculus app on a mobile device, use the Facebook credentials to register, pair the device with the app and enable the developer mode.

Once the developer mode is activated the developer can build and test their application on the HMD.

With the release of Oculus Link the HMD can be plugged to a pc, if it has a graphic card VR ready compatible, and be used as a viewer, demanding the computation to the pc. Oculus link is very useful for the developer because allows previewing the game/application in development directly from the platform engines (e.g. Unity and Unreal) without building the application on the device.

Unfortunately with Oculus Quest 2, with Oculus Quest was included, the cable to connect the HMD to the pc is not in the package and it costs 99€.

iPhone (ARKit)

General facts

Use domain	AR
Commercial info	Manufactured and/or developed by Apple
Price range	300 EUR to 1500 EUR
Official website	https://www.apple.com/iphone/

Affordability	Interactivity	Set up time	Technical difficulty
★★★★★	★★★☆☆	★★★★★	★★★★☆

Pros and cons

- ✓ Huge installed base
- ✓ Mature and robust hardware technology
- ✗ Use cases for consumers are difficult to uncover

Technical attributes

Display attributes Hand-held; Mobile; Markerless

Data storage Internal

iPhone (ARKit) description

In 2017 Apple brought augmented reality (AR) support into their iPhone mobile phones line by introducing ARKit framework. ARKit made iPhones great devices for implementing markerless mobile AR applications. ARKit has developed considerably since the beginning and will develop in the future. Currently there is an installed base of several hundred million AR capable devices. AR capable device models can be found here: https://www.apple.com/augmented-reality/.

Iristick

General facts

Year of release	2019
Use domain	AR
Commercial info	Manufactured and/or developed by Iristick
Price range	1850 EUR to 1850 EUR
Official website	https://iristick.com/

Affordability	Interactivity	Set up time	Technical difficulty
★★☆☆☆	★★★☆☆	★★★★☆	★★★★☆

Image source(s): https://www.displaydaily.com/images/2019/October/Display_Daily/AWE_Euro/iri-z1-features.jpg

Pros and cons

- ✓ 8 hours full shift battery life
- ✓ Unrestricted field of view
- ✓ feels like a normal pair of glasses
- ✓ 5x zoom
- ✗ wired connection with smartphone

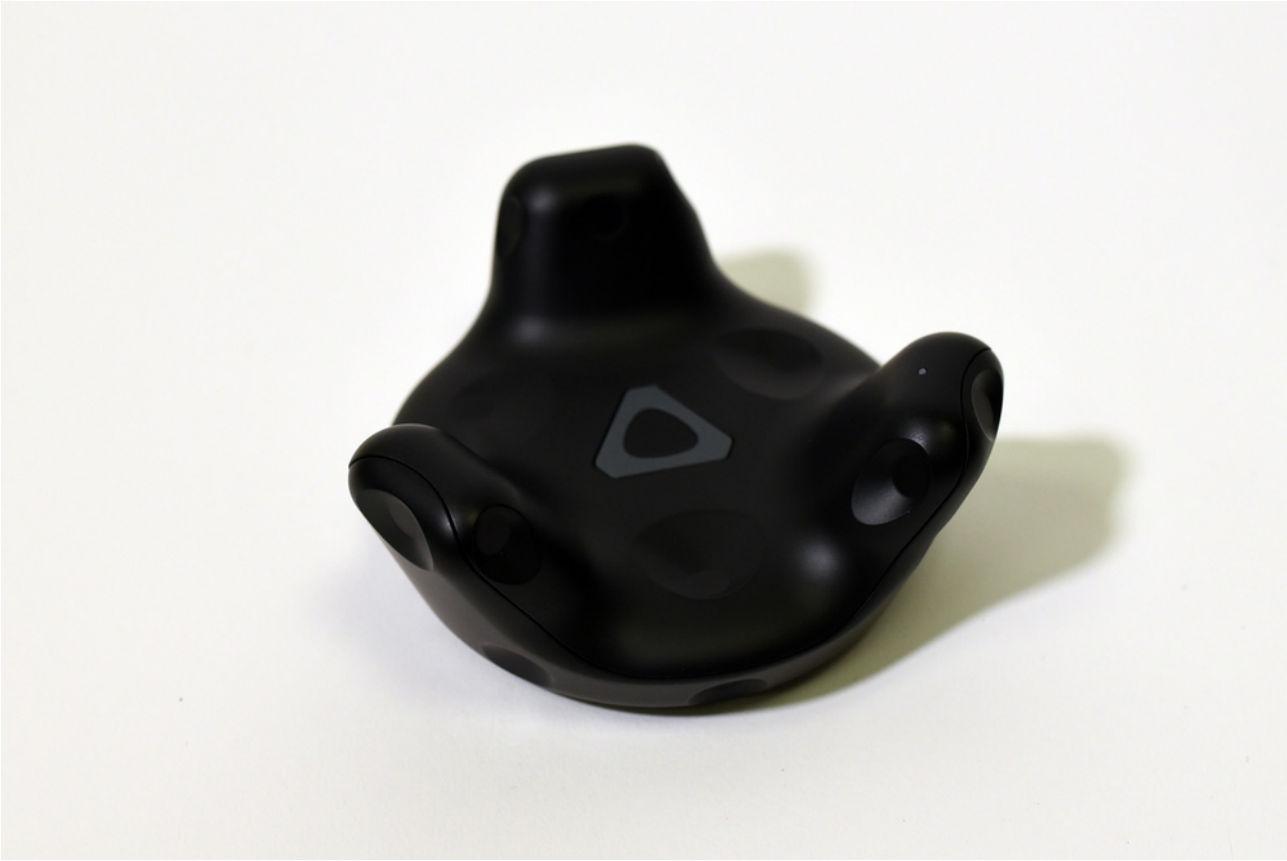
Technical attributes

Interaction caps	Voice sensor; Motion sensor; touchless finger gesture zone
Data storage	Both

Iristick description

Iristick.Z1 are industrial smart safety glasses. They can be used for handsfree remote assistance, but also for step-by-step guidance of the operator and for picking support.

HTC Vive Tracker



General facts

Year of release	2017
Use domain	VR
Commercial info	Manufactured and/or developed by HTC
Price range	50 EUR to 100 EUR
Official website	https://www.vive.com/eu/accessory/vive-tracker

Affordability	Interactivity	Set up time	Technical difficulty
★★☆☆☆	★★☆☆☆	★★★★☆	★★☆☆☆

Pros and cons

- ✓ The device is versatile, converting into various accessories in VR
- ✓ Setup process is relatively simple
- ✓ High tracking fidelity of spatial position and orientation
- ✗ Each added tracker needs an extra dongle that require an empty USB port
- ✗ It takes roughly three hours to charge a Vive Tracker via computer's USB port
- ✗ No native haptic feedback integrated in the tracker nor in many of the peripherals, which reduce the feeling of interaction with the virtual object
- ✗ Not much content developed for it
- ✗ The device is expensive
- ✗ Available pheripherals for the trackers are limited and very expensive
- ✗ Hard for developers to design new pheripherals that work with the Vive Trackers

Technical attributes

Interaction caps Motion sensor

HTC Vive Tracker description

The Vive Tracker is a small motion tracking accessory that can attach to real world objects and bring them into virtual reality. It was created by the Taiwanese company HTC and it is designed to work with the HTC Vive VR headset. The device communicates with the host computer wirelessly and each tracker needs its own wireless USB receiver. So, for each Vive Tracker, a free USB port is necessary. It can be attached to different real world peripherals developed by HTC, such a tennis racket, a ping pong paddle or a toy gun. Then, the tracker takes basic input from the peripheral it's attached to, gathering its dimensions and sending the data to the lighthouse

sensors, which then track the object in real time. For that, the device integrates eighteen SteamVR IR sensors to maximize the tracking fidelity of its spatial position and orientation. The Vive Trackers have 1500mAh lithium-ion batteries, providing up to four hours of continuous use.

Relationships to other items

Hardware: HTC Vive The Vive Trackers are specifically designed to work in the HTC Vive ecosystem. Therefore, it is required to own a HTC Vive headset, accessories and pheripherals to make the most out of this device.

ClassVR Premium (set of 8 HMD's in a special box)

General facts

Use domain VR and AR

Commercial info Manufactured and/or developed by Avantis Systems Ltd.

Image source(s): https://www.classvr.com/school-virtual-reality/teaching-vr-headset/

Price range 4400 EUR to 5000 EUR

Official website https://www.classvr.com/

Affordability	Interactivity	Set up time	Technical difficulty
★★★★☆	★★★☆☆	★★★★★	★★★★★

Pros and cons

- ✓ The monitoring application, ClassVR Portal, is a web application and so it is independent of the operating system used.
- ✓ Teachers can upload their own resources
- ✓ Teachers can monitor every connected headset with the ClassVR Portal.
- ✓ A head tracking system allows the teacher to detect which students are not looking at the presented topic.
- ✓ Every VR application comes with worksheets for students and lesson plans for the teacher.
- ✗ The vast collection of resources is aimed at secondary and high-school students, although the website has a dedicated web page called 'ClassVR for universities' with some examples of professors using ClassVR.
- ✗ The vast collection of resources is aligned with American standards

Technical attributes

Interaction caps Controller; Gesture control

Data storage Both

ClassVR Premium (set of 8 HMD's in a special box) description

The latest device from this classroom VR solution comes with: A new and improved 2K HD fast switching display, a high performing Qualcomm processor made specifically for AR and VR devices, a 100 degree field of view, upgraded optics, front facing camera and an all new body to complement the new device features.

VR Ink Pilot Edition

General facts

Use domain	VR and AR; **Development kit**
Commercial info	Manufactured and/or developed by Logitech
Price range	600 EUR to 800 EUR
Official website	https://www.logitech.com/en-roeu/promo/vr-ink.html
Keywords	pen; drawing

Affordability	Interactivity	Set up time	Technical difficulty
★★☆☆☆	★★★★☆	★★★☆☆	★★★☆☆

Pros and cons

- ✓ Allows for wireless drawing in VR or AR
- ✓ Tracked accurately
- ✓ Both 3D and traditional 2D drawing possible
- ✓ Support for major game engines
- ✗ If used continuously with force feedback, battery drains very quickly
- ✗ Rather steep price tag
- ✗ Dated Unreal Engine support in SDK
- ✗ Only for use with SteamVR, needs the lighthouse system to work

Technical attributes

Interaction caps Controller; Haptic

VR Ink Pilot Edition description

The VR Ink Pilot Edition is a lighthouse-tracked physical pen that can be used in either virtual or augmented reality for 3D or 2D drawing. This product is a development kit meant to explore various possibilities of interacting with content in VR or AR. It also comes with a large drawing pad which can be used for 2D drawing. Pressure sensitivity is enabled in two possible ways: for 3D drawing, a pressure-sensitive button is provided that the user must press to regulate stroke width. For 2D drawing, the pen tip is used to register the applied pressure. The battery on the pen runs for about 3 hours, but the pen can be also used while being charged. Many interesting possibilities open up to engineers leading to use cases where a pen-like interaction can be beneficial (not only drawing, but sculpting, etc.). Software/driver support is provided for major game engines such as Unity and Unreal Engine through the free SDK. Intended as a combination for Varjo and HTC Vive Pro, and needs SteamVR and lighthouses for tracking.

Vuzix Blade Upgraded

General facts

Use domain	AR
Commercial info	Manufactured and/or developed by Vuzix
Price range	950 EUR to 1100 EUR
Official website	https://www.vuzix.com/products/blade-smart-glasses-upgraded

Affordability	Interactivity	Set up time	Technical difficulty
★★★☆☆	★★☆☆☆	★★★★☆	★★★★☆

Pros and cons

- ✓ Can be linked with Alexa
- ✓ Blade OS is based on Android OS and thus many people can develop apps for the Blade
- ✓ Affordable selling price of around
- ✗ The built-in 8 Megapixel camera is OK but most smartphone cameras perform better.
- ✗ Bulky shape

Image source(s): https://www.vuzix.com/products/blade-smart-glasses-upgraded

€1000.

✓ impact resistent meeting EN166 and ANSI 287.1 safety standards

Technical attributes

Interaction caps	Voice sensor; touchpad + smartphone control + head motion tracking
Data storage	Both

Vuzix Blade Upgraded description

Vuzix Blade Upgraded are smart glasses delivering a hands-free connection between a digital system and the real world. They allow to show information (job instructions, numbers, picking locations, time, directions,...) to the user and collect data (from QR codes, barcodes,...). The user can control this device by voice. The Vuzix Blade Upgraded comes with an autofocus 8MP HD camera, built-in stereo speakers, noise cancelling mics, full color display for the right eye, Wi-Fi and Bluetooth, microSD card slot, full UV protection lenses with ANSI Z87.1 safety certification and inserts that ensure vision corrections for different users.

Review Summary

In the following tables, a review summary of the hardware devices is provided for your convenience. The tables show VR, AR and VR/AR devices separately. Let us recall the criteria:

- **Affordability**: a lower rating means the item is not really affordable, while a higher rating means that it is easy to afford said item;
- **Interactivity**: a lower rating means that the item has few features that allow to interact with the XR environment, while a high rating means there are multiple features supported (e.g., hand tracking, gestures, eye tracking, voice commands);
- **Set up time**: the higher the rating, the more time is needed to set up the device;
- **Technical difficulty**: the higher the rating, the more prior knowledge is necessary to operate the device as intended.

Please note that these criteria are provided to the best of the VAM Realities partners' experience with the given hardware devices.

Table 1: Review summary for hardware category: VR

Device	Affordability	Interactivity	Set up time	Technical difficulty
Canon EOS R5C with Canon dual fisheye lens	★★★☆☆	★☆☆☆☆	★★☆☆☆	★★★☆☆
Oculus Quest	★★★★☆	★★★★★	★★★★★	★☆☆☆☆
Oculus Rift S	★★★★★	★★★★☆	★★★☆☆	★★★☆☆
Valve Index	★★★☆☆	★★★★★	★★☆☆☆	★★★☆☆
HTC Vive Pro	★★★★☆	★★★★★	★★☆☆☆	★★★☆☆
Pico G2	★★★★☆	★★☆☆☆	★★★☆☆	★★★☆☆
Pico Neo	★★★☆☆	★★★★☆	★★★☆☆	★★★☆☆
Samsung Odyssey	★★★☆☆	★★★☆☆	★★☆☆☆	★★★☆☆

Table 1: Review summary for hardware category: VR (cont.)

Device	Affordability	Interactivity	Set up time	Technical difficulty
HTC Vive	★★★☆☆	★★★★☆	★★☆☆☆	★★★☆☆
PlayStation VR	★★★★★	★★★☆☆	★★★★★	★★★★☆
Google Cardboard Viewer	★★★★★	★☆☆☆☆	★★★☆☆	★★☆☆☆
HP Reverb G2	★★★★☆	★★★★☆	★★★☆☆	★★☆☆☆
Oculus Quest 2	★★★☆☆	★★★★☆	★★★☆☆	★★☆☆☆
HTC Vive Tracker	★★☆☆☆	★★☆☆☆	★★★★☆	★★☆☆☆

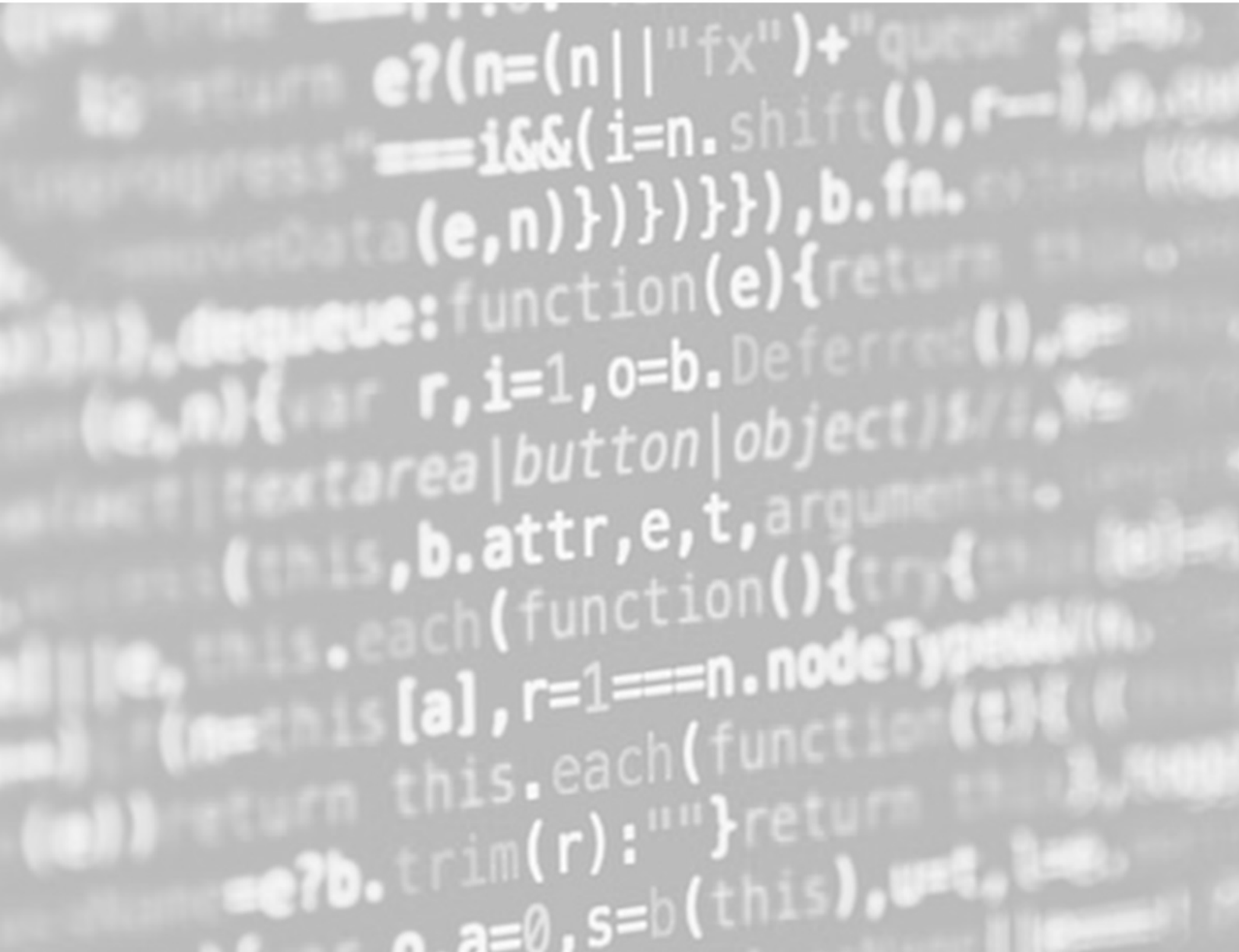
Table 2: Review summary for hardware category: AR

Device	Affordability	Interactivity	Set up time	Technical difficulty
Microsoft Hololens 2	★★☆☆☆	★★★★★	★★★★☆	★★★★☆
Magic Leap 1	★★☆☆☆	★★★☆☆	★★★☆☆	★★★☆☆
iPad (ARKit)	★★★☆☆	★★★★☆	★★★★★	★★★★☆
Google Glass	★★★☆☆	★★★★☆	★★★★★	★★★☆☆
Android-based smartphones (ARCore)	★★★★★	★★★☆☆	★★☆☆☆	★★★★☆
Nreal Light	★★★★☆	★★★☆☆	☆☆☆☆☆	★★★★☆
iPhone (ARKit)	★★★★★	★★★☆☆	★★★★★	★★★★☆
Iristick	★★☆☆☆	★★★☆☆	★★★★☆	★★★★☆
Vuzix Blade Upgraded	★★★☆☆	★★☆☆☆	★★★★☆	★★★★☆

Table 3: Review summary for hardware category: VR and AR

Device	Affordability	Interactivity	Set up time	Technical difficulty
Varjo XR-3	★★★☆☆	★★★★★	★★☆☆☆	★★★☆☆
Varjo XR-1	★★☆☆☆	★★★★☆	★★★☆☆	★★★☆☆
ClassVR Premium (set of 8 HMD's in a special box)	★★★★☆	★★★☆☆	★★★★★	★★★★★
VR Ink Pilot Edition	★★☆☆☆	★★★★☆	★★★☆☆	★★★☆☆

Software



How to Read This Chapter

In this chapter, the reader is acquainted with software applications and frameworks that can be used to either implement or to develop content for AR/VR experiences. Different structural elements for each entry are described next.

Images For each software item, a relevant screenshot is provided depicting, e.g., the graphical user interface or its part that is related to VR/AR. The images are original, or are linked to the source.

Year of release For software, year of release typically means rather "year of original release". This typically allows to put into perspective the state of development of a given software item.

Use domain Here, the intended usage domain of the software item is specified: VR, AR, or both. For some software this is not really meaningful information, because it is not used for building VR or AR directly, but is rather used in development of corresponding applications (for example, 3D modeling software). On the other hand, even such software applications nowadays provide VR or AR user interfaces to improve the development experience.

Software category In this paragraph, the general category of the software is specified (e.g., "Web development" or "Game engines").

Commercial attributes Here, it is specified whether the software is commercial or open source, and the primary developer is listed.

Website Link to the official website of the item where more detailed information about the specific entity is provided. If the link does not work anymore, the reader can try to use the Wayback Machine located at `https://archive.org/web/` to quickly get related information, if it is available.

Price range If the reader desires to purchase a license or subscription for/to the given software, here the expected price is provided as a range.

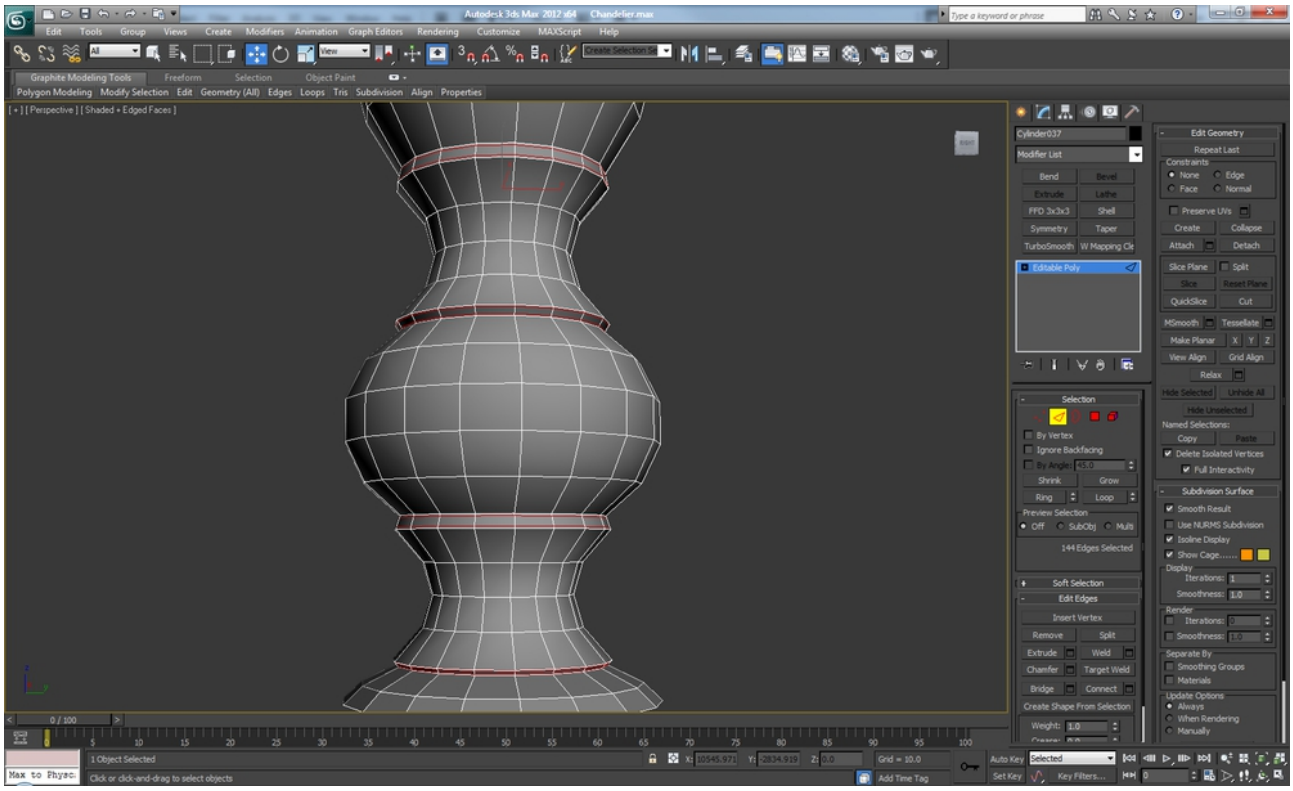
Software availability or tiers Some software is open source, some has free "community" edition and a paid "pro" edition, some is strictly commercial, but with different tiers having different features. This section serves to outline the different available options with relevant comments.

Pros and cons A list of advantages and drawbacks of the specific software application or framework as seen from many perspectives (usability, features, etc.).

Description Description of the software item based on the experience and knowledge of VAM Realities partners. This can be treated as a mini-review. This also typically includes additional information about technical specifications.

Relationships to other items Information about relationships to other hardware, software and use cases.

3ds Max



General facts

Year of release	1996
Use domain	VR and AR
Software category	3D Modeling
Commercial info	Developed by Autodesk
Official website	https://www.autodesk.com/products/3ds-max/

Pros and cons

- ✓ can import to and export from a wide variety of industry-standard 3D file formats
- ✗ price
- ✗ takes time to learn
- ✗ not cross-platform: it only works

- ✓ is one of the best modelling software
- on Windows

3ds Max description

3D Studio Max, is a professional 3D computer graphics program for making 3D animations, models, games and images. Within 3dsmax several modeling technics are available: Polygon modeling, Nurbs and Surface tool/editable patch object. 3ds Max can import to and export from a wide variety of industry-standard 3D file formats.

AltspaceVR

General facts

Year of release	2015
Use domain	VR
Software category	3D Modeling
Commercial info	Developed by Microsoft
Official website	https://altvr.com/

Software availability or tiers

Free	Software is free to use. More information: https://altvr.com/

Pros and cons

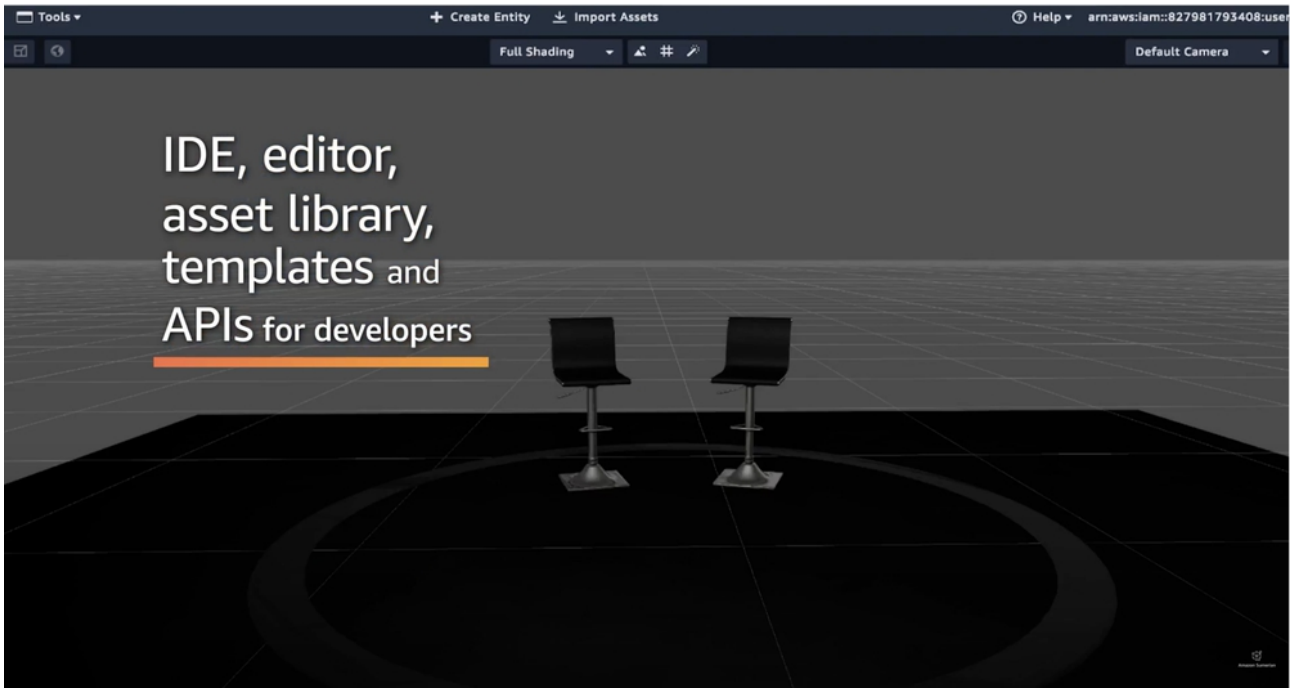
- ✓ Multiplatform and constantly developing
- ✓ Active platform, people and interaction found anytime
- ✗ Public, so not suitable for really secure meetings

AltspaceVR description

AltspaceVR is one of the leading social VR platforms at the moment. It was first developed as a startup after which it was acquired by Microsoft in 2017. You can attend live shows, meetups and organise your own events using the platform.

AltspaceVR is one of the most active platforms at the moment and, thus, a very good place to try out the possibilities of social VR interaction. Platform can be accessed using Oculus, HTC Vive and Microsoft Mixed Reality devices. Also, a new 2D mode for PC has been added lately.

Amazon Sumerian



General facts

Year of release	2018
Use domain	VR and AR
Software category	3D Modeling
Commercial info	Developed by Amazon
Official website	https://aws.amazon.com/sumerian/

Software availability or tiers

Free	Free Tier available based on usage volume More information: https://aws.amazon.com/sumerian/pricing/

Pros and cons

- ✓ Free Tier enables free testing
- ✗ Usability
- ✗ Aimed for developers, high barrier to try the platform out

Amazon Sumerian description

Sumerian is a browser-based authoring tool to create web-based immersive VR, AR and 3D experiences. It helps companies to bring a new dimension to their web and mobile applications. It is integrated tightly with AWS services which provides easy scalability and access to multitude of various complementing services such as machine learning and chatbots.

As you need to create an AWS account in order to access the platform, it is targeted mainly to software developers and the barrier to take it into use is reasonably high. Still, if you have the development capability, this might be a viable option to create an immersive addition into your web or mobile application.

Apple ARKit

General facts

Use domain	AR
Software category	3D Modeling
Commercial info	Developed by Apple
Official website	https://developer.apple.com/augmented-reality/

Image source(s): https://appleinsider.com/articles/17/09/15/video-a-sneak-peak-at-ios-11-augmented-reality-at-the-apple-park-visitor-center, http://www.tecground.com/apple-and-legos-multiplayer-ar-experience-looks-like-a-blast/

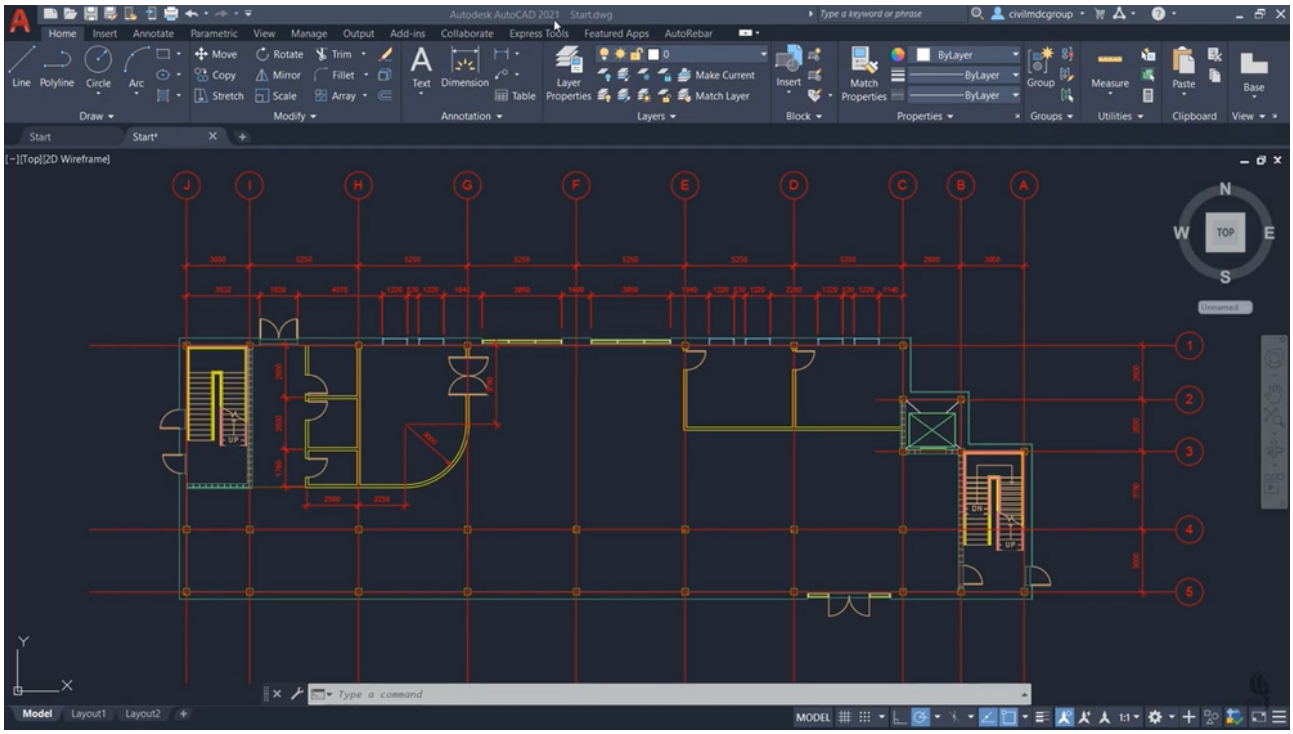
Pros and cons

- ✓ Support from Apple
- ✓ More Hardware in the future
- ✗ Only supported by Apple devices
- ✗ Still in its early stage

Apple ARKit description

Apples ARKit is an AR development platform for IOS devices. It processes and analyses data from motion sensors, gyroscope, GPS as well as the cameras to efficiently embed Augmented Reality scenes into your mobile devices camera picture in real time. It's important to understand that ARKit is not a standalone entity but merely a basis for AR applications to gather and interpret the information given by the aforementioned sensors. The Depth API in Version 4 is noteworthy as well as it provides an advanced implementation of scene tracking for more realistic and more complex AR realizations.

Autodesk AutoCAD



General facts

Year of release	1982
Use domain	Not directly with VR or AR
Software category	3D Modeling
Commercial info	Developed by Autodesk
Official website	https://www.autodesk.com/products/autocad/overview
Price range	300 EUR to 5950 EUR

Image source(s): https://www.youtube.com/watch?v=S_m4qx5_Zh8

Software availability or tiers

Paid prices for single-user license: 274 € for 1 month; 2.190 € for 1 year (183 € per month); 5.915 € for 3 years (165 € per month). More information: https://www.autodesk.de/products/autocad/overview?plc=ACDIST&term=1-YEAR&support=ADVANCED&quantity=1#internal-link-buy

Free free license for students, educators, and educational institutions available for 12-month (renewable); 30 day free trial version available. More information: https://knowledge.autodesk.com/search-result/caas/simplecontent/content/term-length-for-educational-licenses.html

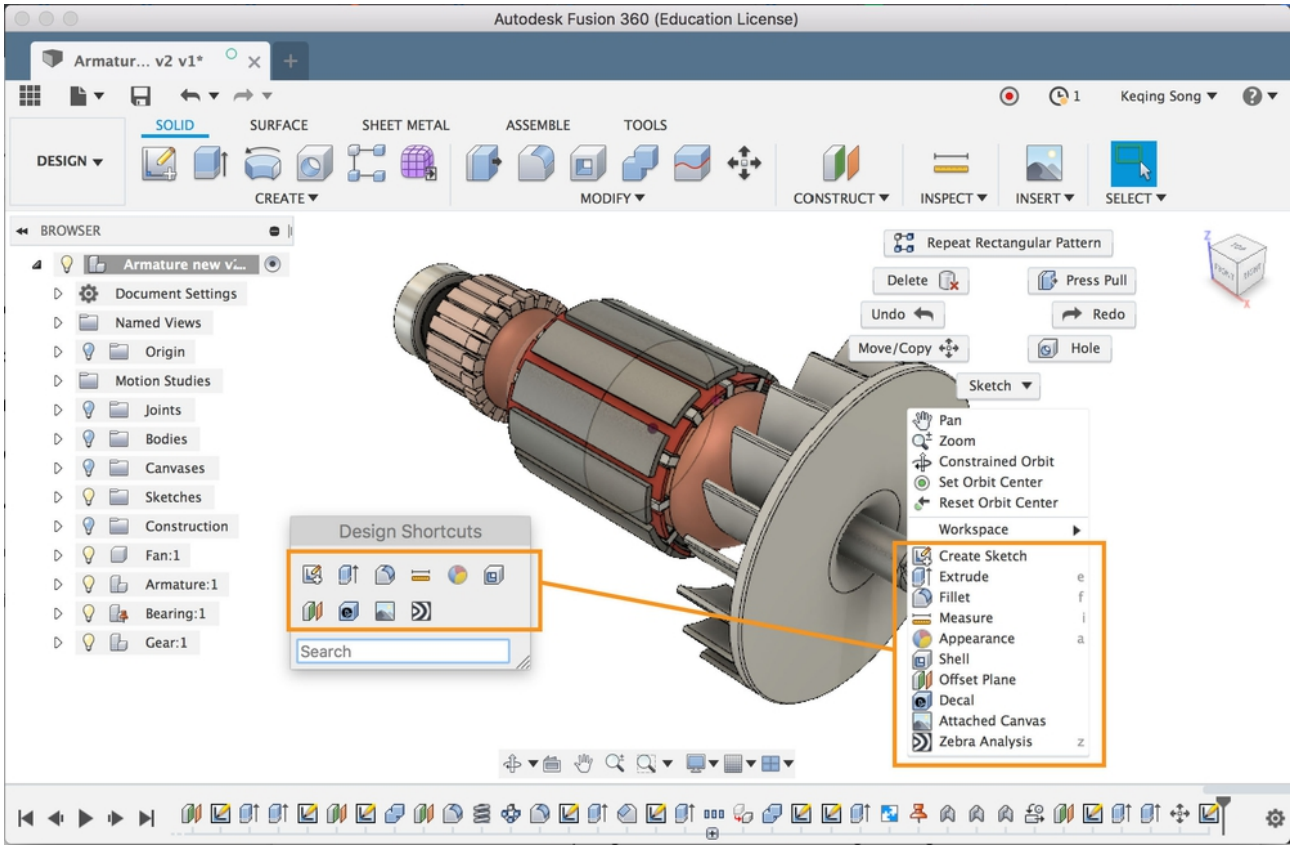
Pros and cons

- ✓ speeding up the time needed to implement design changes throughout the whole project
- ✓ increased accuracy compared to fixed designs on hard copy
- ✓ multiple people can work on one project at the same time online
- ✓ very customizable using APIs and a variety of third-party applications
- ✗ high initial costs in hardware, software and training
- ✗ limited number of file formats for importing and exporting

Autodesk AutoCAD description

AutoCad is a computer-aided-design software designed for 2D and 3D modelling and visualization. It is aimed to suit engineers, architects and construction professionals. It's possible to use the software for first drafts, go over to detailed drawings and finally 3D models but also deriving technical drawings from the latter. The other important part, this platform offers is the visualization with texture and material rendering, lighting and 3D navigation in and around the 3D model.

Autodesk Fusion 360



General facts

Year of release	2013
Use domain	Not directly with VR or AR
Software category	3D Modeling
Commercial info	Developed by Autodesk
Official website	https://www.autodesk.com/products/fusion-360/overview

Image source(s): https://www.autodesk.com/products/fusion-360/blog/wp-content/uploads/2018/05/skey_rightclick.jpg

Price range 0 EUR to 1400 EUR

Software availability or tiers

Free criteria to qualify for Fusion 360 for startups: - less than 3 years old; - 10 or fewer employees; - gross annual revenue below $100,000 USD; - have an online presence; - design or manufacture own physical products. More information: https://www.autodesk.com/products/fusion-360/startups#

Paid - 1 month for $60; - 1 year for $495 ($42 / month); - 3 years for $1.335 ($38 / month). More information: https://www.autodesk.com/products/fusion-360/subscribe?geoNavigationPreferredSite=US&plc=F360&term=1-YEAR&support=ADVANCED&quantity=1

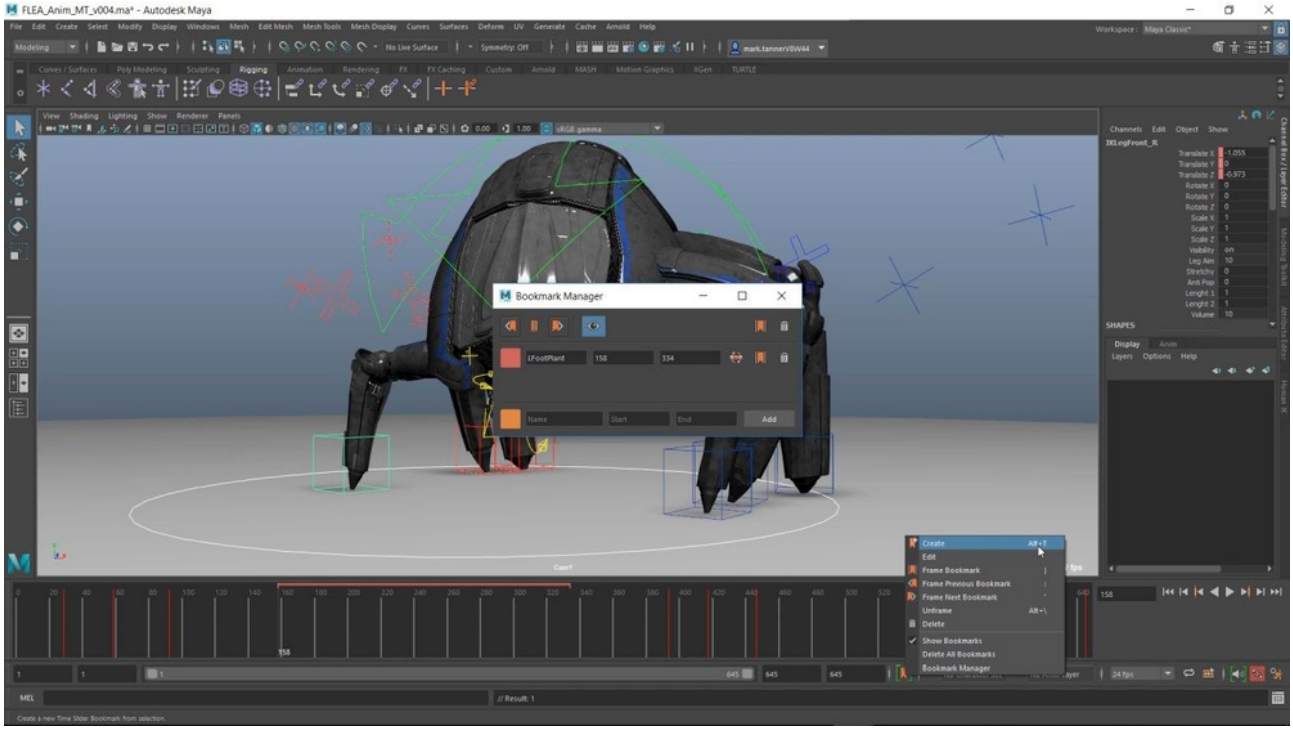
Pros and cons

- ✓ Industry standard precision modeling tools
- ✓ multiple users working on the same file on the cloud
- ✓ parametric design
- ✗ high RAM demand
- ✗ Weak support for organic sculpting

Autodesk Fusion 360 description

Fusion 360 is a cloud based platform by Autodesk that includes all steps of the product development process. It contains Computer-aided-design, -modelling and -engineering in one program without the necessity of converting your files. It is also possible to design and integrate electronic components, run heat and physical stress simulations and facilitate documentation. It's aim is to guide the engineers through the whole development stage from first design to machining and assembly whilst offering realistic simulations to uncover stability and design flaws early, thus reducing the overall development and production cost.

Autodesk Maya



General facts

Use domain	VR and AR
Software category	3D Modeling
Commercial info	Developed by Autodesk
Price range	250 EUR to 4400 EUR

Software availability or tiers

Free	More information: https://www.autodesk.com/products/maya/free-trial?support=ADVANCED&plc=MAYA&term=1-YEAR&quantity=1

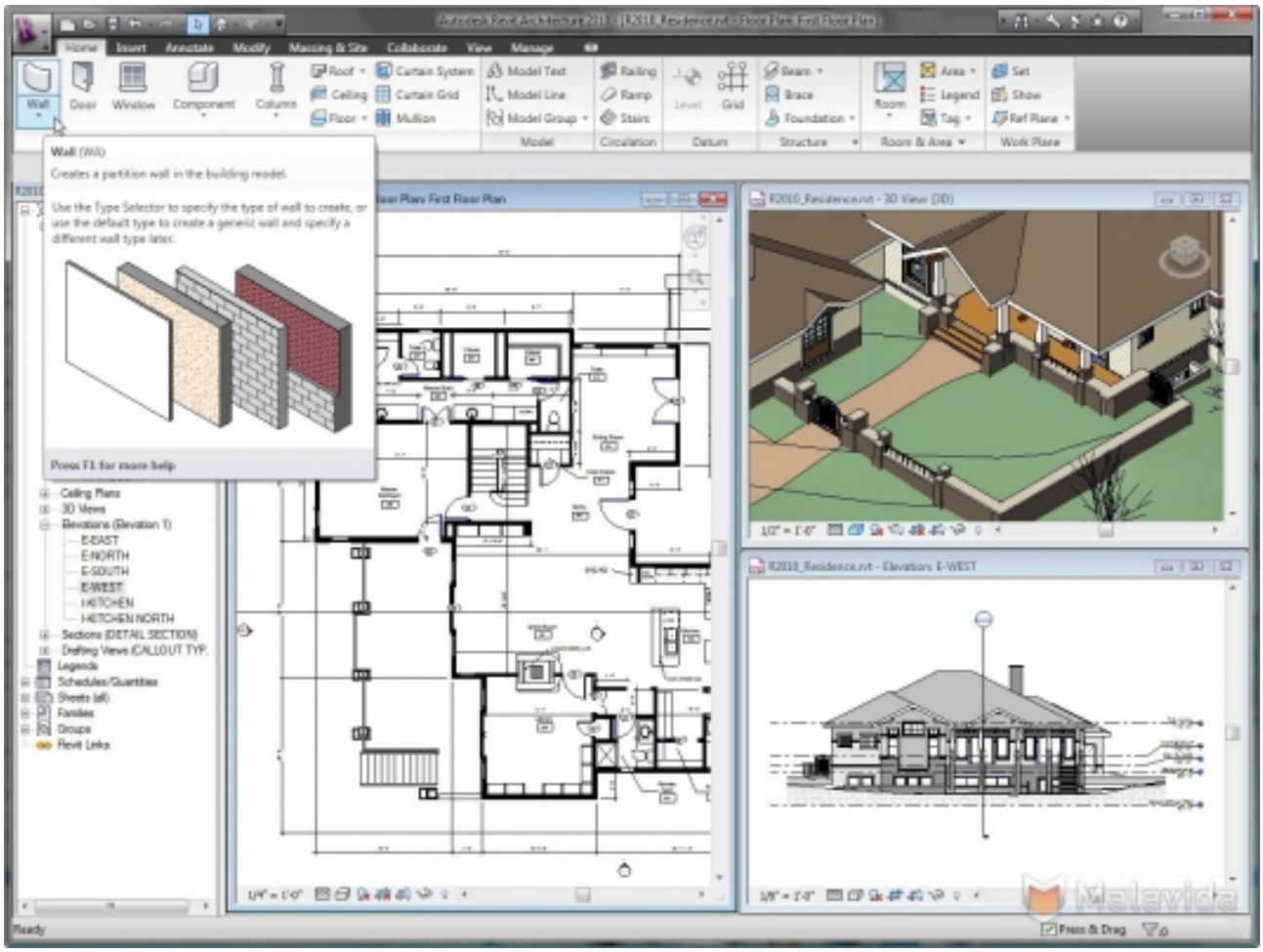
Pros and cons

- ✓ Well known and supported software.
- ✓ Creates good renders that has one of the best animation tools in 3d industry.
- ✓ It's easy to use.
- ✗ The program is a complete product for modeling, animation, shading and rendering 3d assets for static images and animation.
- ✗ There are some compatibility issues that require a mess of plugins to smooth out.
- ✗ The price tag: a single license means a $1,470/year subscription.

Autodesk Maya description

3D animation, modeling, simulation, and rendering software for film, TV, and games. Autodesk Maya 2020 software is supported on the following 64-bit operating systems and at a minimum, that runs on Windows, macOS and Linux. Initial release was on February 1998.

Autodesk Revit



General facts

Year of release	2020
Use domain	VR and AR
Software category	3D Modeling
Commercial info	Developed by Autodesk
Official website	https://www.autodesk.com/products/revit/overview
Price range	300 EUR to 6600 EUR

Software availability or tiers

Paid $305 mothly, $2425 yearly and $6550 for three years More information: https://www.autodesk.com/products/revit/overview

Pros and cons

- ✓ Advanced design features
- ✓ Supports the whole building life-cycle
- ✓ Large user community and extensive support
- ✓ The design can be visualized in various ways and exported for viewing in AR and VR
- ✓ Extensive collaboration features
- ✗ High price

Autodesk Revit description

Autodesk Revit is a Building Information Modelling (BIM) software package used by various architects, designers and contractos in the architecture, engineering and construction (AEC) industry. Users can design a building and its structural 3D elements with the software and attach various annotations and information into these elements. These elements can be accessed and updated throughout the buildings lifecycle from design to construction and finally maintenance and demolition.

Newer versions of the software can automate various routine tasks and it supports collaboration between different project stakeholders. The software also supports numerous visualization options and the user can also export the building design file to be viewed in AR or VR. This way the building design can be experienced in a more immersive fashion.

Blender

General facts

Year of release	2002
Use domain	VR and AR
Software category	3D Modeling
Commercial info	Developed by Blender
Official website	`https://www.blender.org/`

Pros and cons

- ✓ it's free
- ✓ great for animation and modelling
- ✓ addons created by the user to mimic
- ✗ it takes lots of practice and hard work to get it down

functionality of other paid software

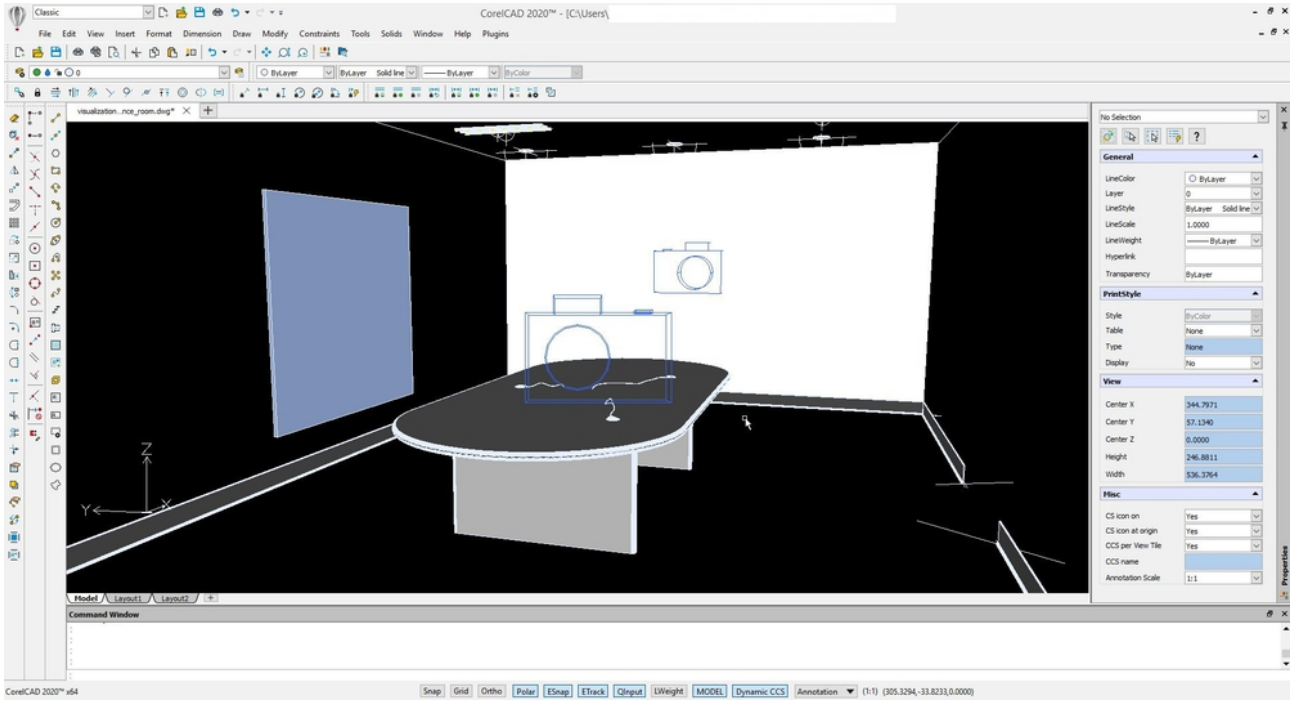
Blender description

Blender is a free and open-source cross-platform 3D creation suite, is one of the best alternatives to 3DS Max. With Blender 2.83 LTS and 2.92, a significant UI/UX overhaul has happened which made the software look and perform more comfortably to new users.

Blender is a fully-featured 3D modeling application which supports 3D modeling, UV unwrapping, texturing, raster graphics editing, rigging and skinning, physical simulations (including fluid and smoke), particle simulation, sculpting, animating, rendering in both real-time (EEVEE engine) and photorealistic (Cycles), and video editing and compositing.

The application supports import and export of some of the most important formats including OBJ, FBX, 3DS, PLY and STL.

CorelCAD



General facts

Year of release	2020
Use domain	Not directly with VR or AR
Software category	3D Modeling
Commercial info	Developed by Corel
Official website	https://www.coreldraw.com/en/product/corel-cad/
Price range	650 EUR to 850 EUR

Software availability or tiers

Paid	More information: https://www.coreldraw.com/en/product/corel-cad/

Pros and cons

- ✓ Support for the most common file formats
- ✓ Advanced design tools
- ✓ Available for both Windows and MacOS
- ✓ Cheaper pricing than many of its competitors
- ✗ Difficult to master
- ✗ Smaller user community because it is not as widely used as other leading software (e.g. AutoCAD)
- ✗ Might have some compatibility issues when transferring files between different authoring tools

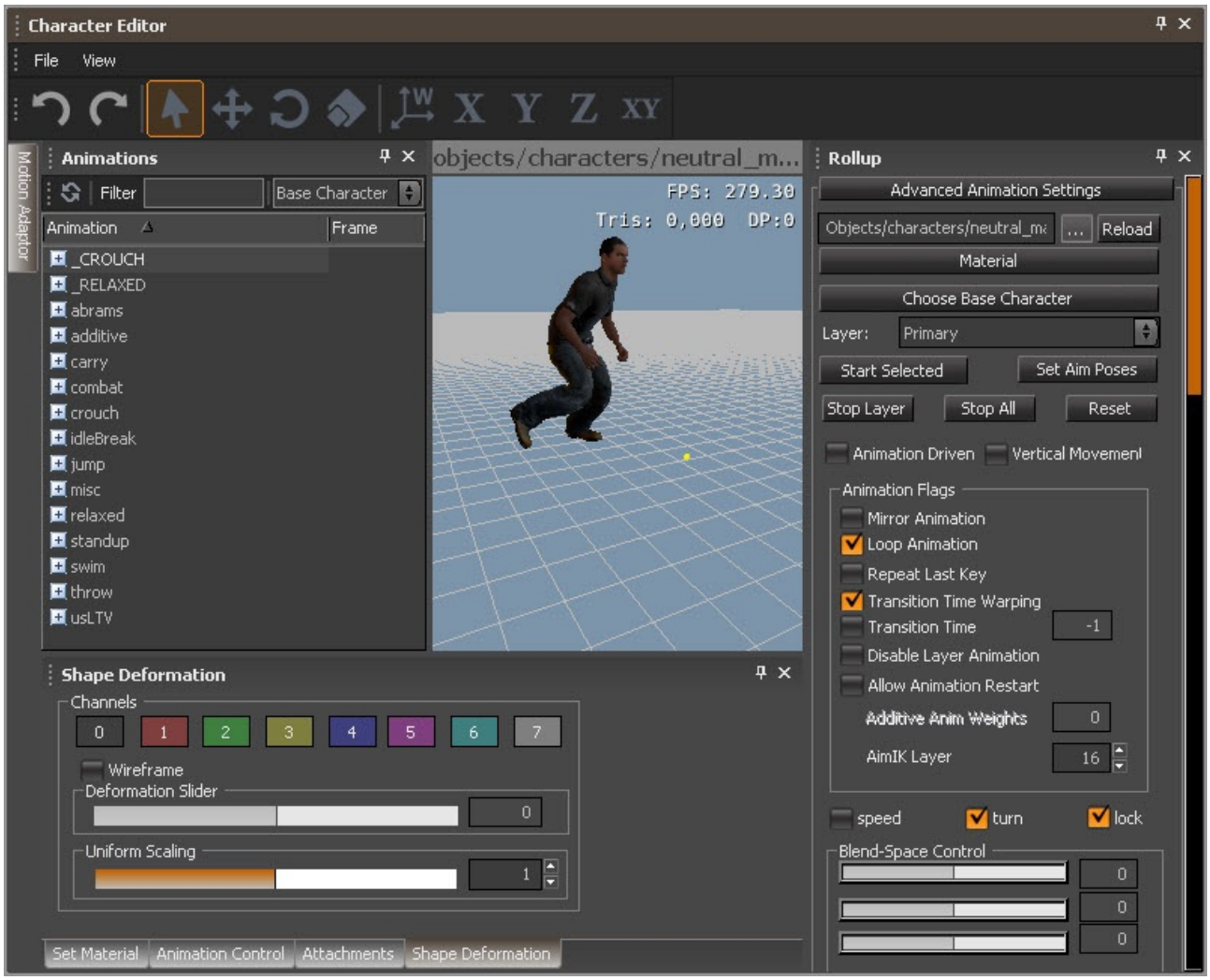
CorelCAD description

CorelCAD is a professional 2D/3D design and 3D printing tool for Windows and MacOS developed by Corel. The software is compatible with most of the industry-standard file formats such as .DWG, .STL, .PDF, and .CDR.

CorelCAD also includes many collaboration features for sharing your designs with other professionals. However, it doesn't include all of the more advanced design features found in AutoCAD.

The software has a free trial and a perpetual license can be purchased with a one-time payment. Those looking for a budget CAD option might want to look into CorelCAD in more detail.

CryEngine



General facts

Year of release	2002
Use domain	VR
Software category	3D Modeling
Commercial info	Developed by Crytek
Official website	https://www.cryengine.com/

Pros and cons

- ✓ CryEngine is capable of high graphical games.
- ✗ Does not officially support Augmented Reality.
- ✗ Documentation is limited compare with other game engines.

CryEngine description

CryEngine was initially released on 2002. The latest version is CryEngine 5.6 was released on September 2019. CryEngine officially supports VR development with VR devices including HTC Vive, Oculus Rift and OSVR. However, the game engine including documentation and functionality seem limited considering other game engines that are dominating the market. The press release on March 2018 reveals that CRYENGINE will have additional features including Augmented Reality development capabilities.

Google ARCore

General facts

Year of release	2018
Use domain	AR
Software category	3D Modeling
Commercial info	Developed by Google
Official website	https://developers.google.com/ar

Pros and cons

- ✓ multi platform
- ✓ motion tracking based on simultaneous localization and mapping (SLAM)
- ✓ constantly improving its under-
- ✗ Not all devices are fully supported
- ✗ Android Emulator for testing projects is required

standing of the real world environment by detecting feature points and planes

✓ free

✓ Depth understanding

✓ Light estimation

Google ARCore description

ARCore is Google's platform for building augmented reality experiences. It provides a set of tools to developers for creating AR experiences, the principals are:

- motion tracking, to understand and track its position relative to the world.
- environmental understanding, to detect the size and location of surfaces
- and light estimation, to estimate the environment's current lighting conditions.

ARCore is designed to work on devices running Android 7.0 (Nougat) and later.

ARCore is available for Android(Java), Android NDK, Unity, iOS and Unreal.

Google VR for everyone

General facts

Use domain	VR
Software category	3D Modeling
Commercial info	Developed by Google
Official website	https://developers.google.com/vr/

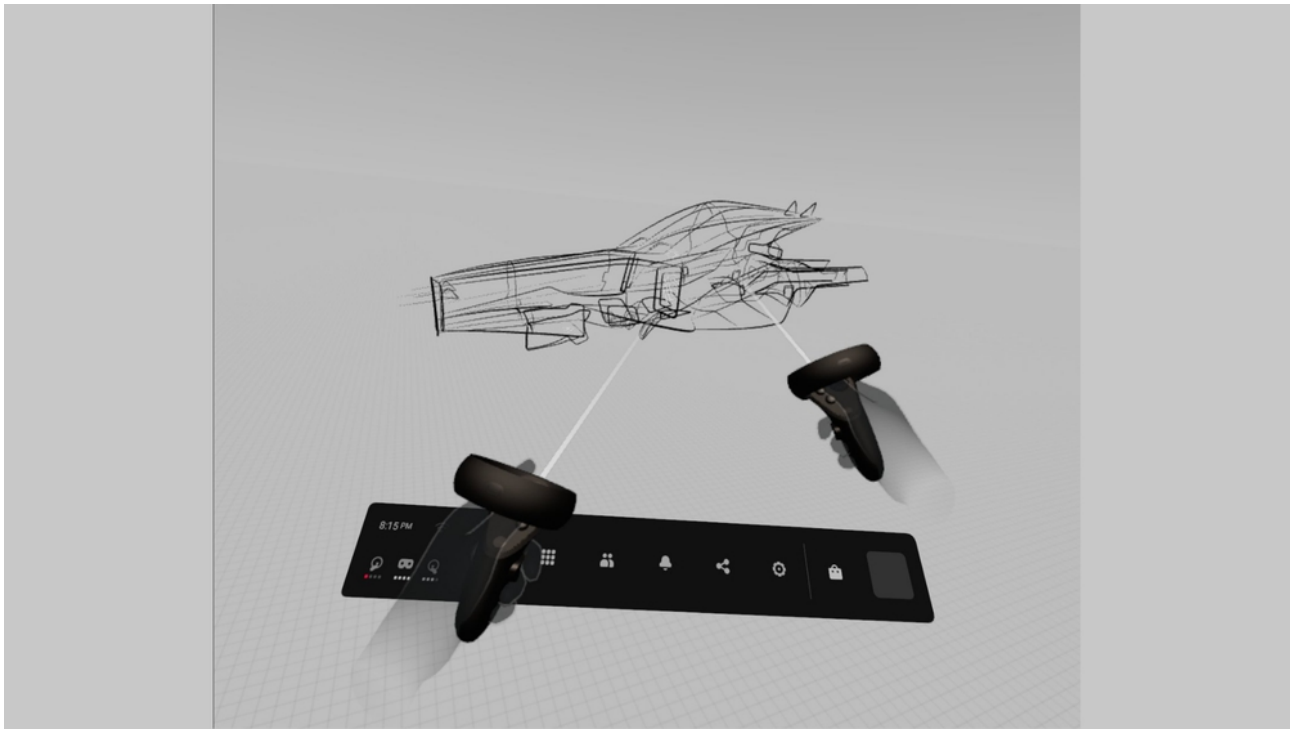
Pros and cons

- ✓ Free to use
- ✓ Available on all platforms
- ✓ lots of pre existing hardware

Google VR for everyone description

Google VR is an SDK for simplified development of VR applications for most available platforms, such as Android, Unity, Unreal, iOS and Web applications. It allows the average user to create applications that support VR functions, VR controllers and a special rendering process, which uses VR applications. Although in most cases, these applications can only be used with google daydream and cardboard. However, this sdk is the most available on the market and has the quality of Google products.

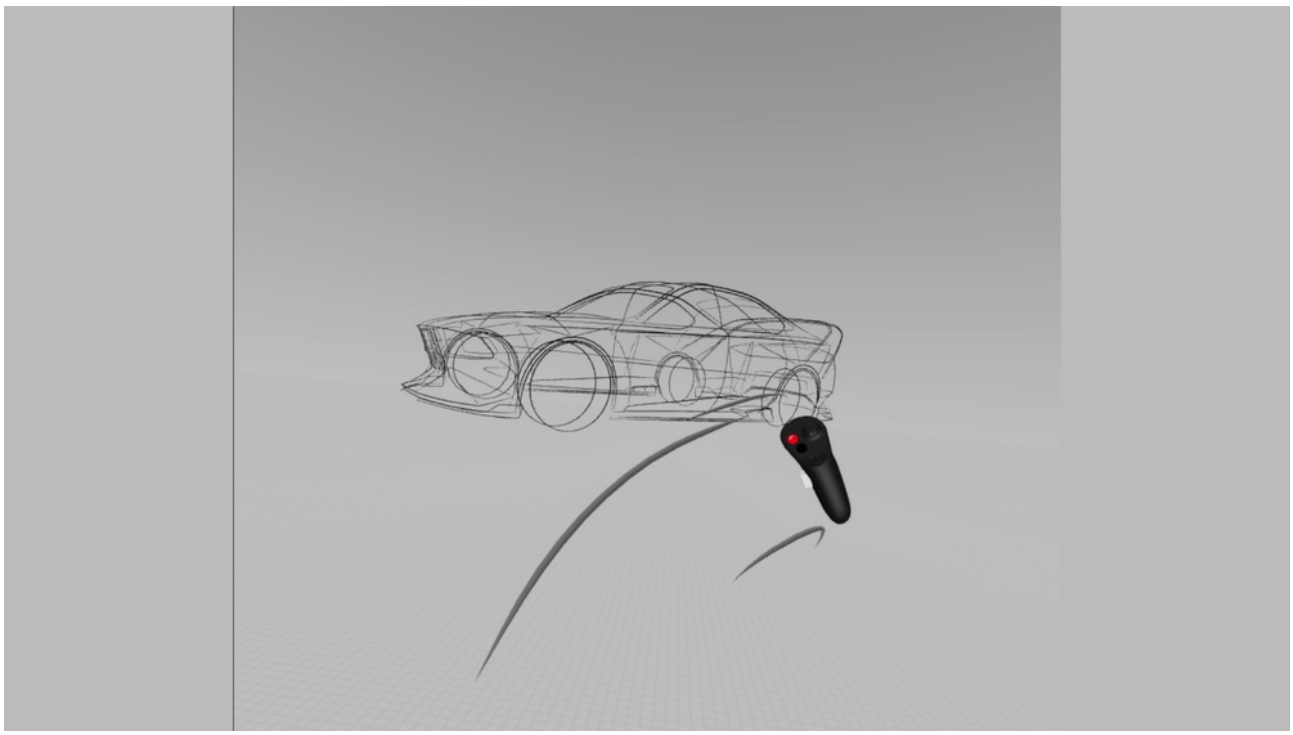
Gravity Sketch



General facts

Year of release	2017
Use domain	VR
Software category	3D Modeling
Commercial info	Developed by Gravity Sketch Limited
Official website	https://www.gravitysketch.com/
Price range	50 EUR to 1000 EUR

Image source(s): https://www.gravitysketch.com/



Software availability or tiers

Free Free trial available More information: https://www.gravitysketch.com/

Pros and cons

- ✓ Easy-to-use
- ✓ Very affordable to try-out

Gravity Sketch description

Gravity Sketch is an intuitive 3D design platform for cross-disciplinary teams to create, collaborate, and review in an entirely new way. You can import a 3D model (e.g.) CAD into the application and visualize it in VR. You have various modelling tools which you can use to inspect and modify the model.

Gravity Sketch is one of the most usable and easy ways of visualising 3D models in VR. They offer versions for business, education and individual use. Furthermore, they're working on making their application a smoother part of real life 3D design workflows.

- 6 creation tools - Geometry types: Mesh, NURBS, and SubD - Unlimited layers - Custom environments - Image and video import (.jpg, .png and .mp4) - Snapshot tool (.png) - Import/Export (.obj) - Sync all content in the cloud using LandingPad (asset management platform, accessible through a web browser) - Collaboration coming soon (sign up to LandingPad to stay informed)

Help Lightning

General facts

Year of release	2015
Use domain	AR
Software category	3D Modeling
Commercial info	Developed by Help Lightning
Official website	http://www.helplightning.com

Image source(s): http://www.helplightning.com

Price range 300 EUR to 450 EUR

Pros and cons

- ✓ Easy and fast: no need to move for the guidance of employees, assist newly recruited employees
- ✓ Flexibility and compatibility: Help Lightning integrates with CRM software and works on almost all mobile devices, AR glasses and web browsers
- ✓ Intuitive: for remote assistance of a technician, hand movements of the expert are merged into the technician's field of view
- ✗ Help Lightning uses a lot of bandwidth because of the bi-directional interactive video data streams

Help Lightning description

Help Lightning's Virtual Expertise is a remote assistance solution allowing experts to support technicians, students, customers,..... remotely. as if they were collaborating side-by-side.

Features:

- The way the supporting video stream from the expert's device is merged on the technician's mobile device, is patented.
- Connect to contacts with one click or send an invitation via email or SMS.
- Experts can draw directly on the screen with a user-friendly toolset.
- Freeze live video to synchronize video support with the actual work flow
- Photo Management: allows photo capture as well as photo import
- Guaranteed Encryption of data streams via SSL/TLS.

IC.IDO

General facts

Year of release	2017
Use domain	VR
Software category	3D Modeling
Commercial info	Developed by ESI Group
Official website	http://www.esi-group.com
Price range	10000 EUR to 20000 EUR

Pros and cons

- ✓ Physics: switch on real-time physics engine and interact with design
- ✗ No free version and no free trail version available

Image source(s): http://www.esi-group.com

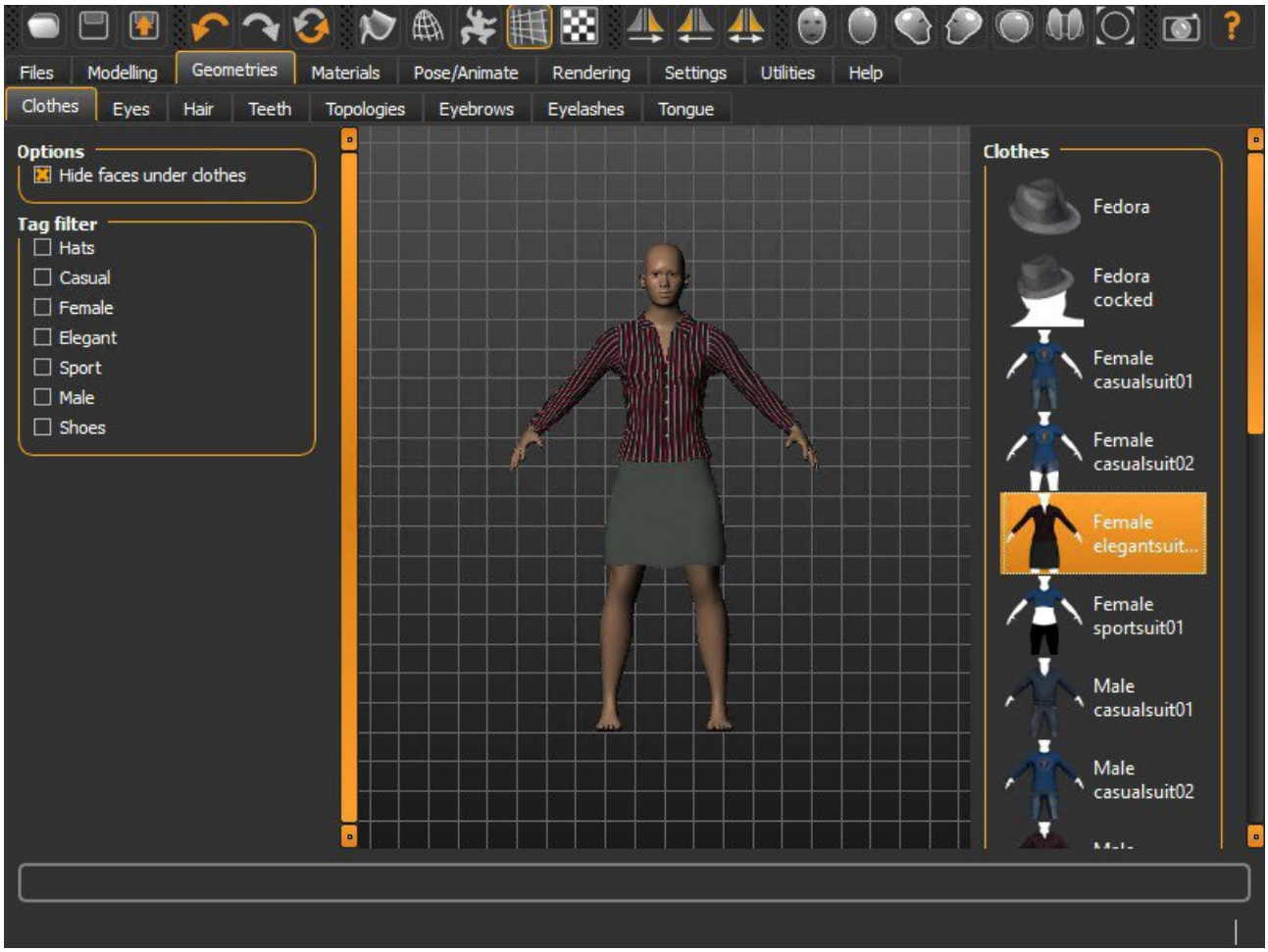
objects like in reality

- ✓ Interaction: grasp and move objects, assemble and disassemble solid pieces and flexibles while you see hands, forearms and upper arms
- ✓ CAD to VR: handle full CAD models right from a CAD program.

IC.IDO description

IC.IDO is virtual prototyping software. It allows to import a 3D product design directly from almost any CAD system and to check its accessability, serviceability and possible collisions, simulating at the same time hands, forearms and upper arms. The design can be changed and viewed in a HMD and users can interact with the design using their controllers. The user can control visualisation but also some physics (solids as wel as flexibles). The software connects to to PLM management systems and supports VR-SLI (Virtual Reality-Scalable Link Interface).

MakeHuman



General facts

Year of release	2000
Use domain	VR and AR
Software category	3D Modeling
Commercial info	Developed by MakeHuman Community
Official website	http://www.makehumancommunity.org/

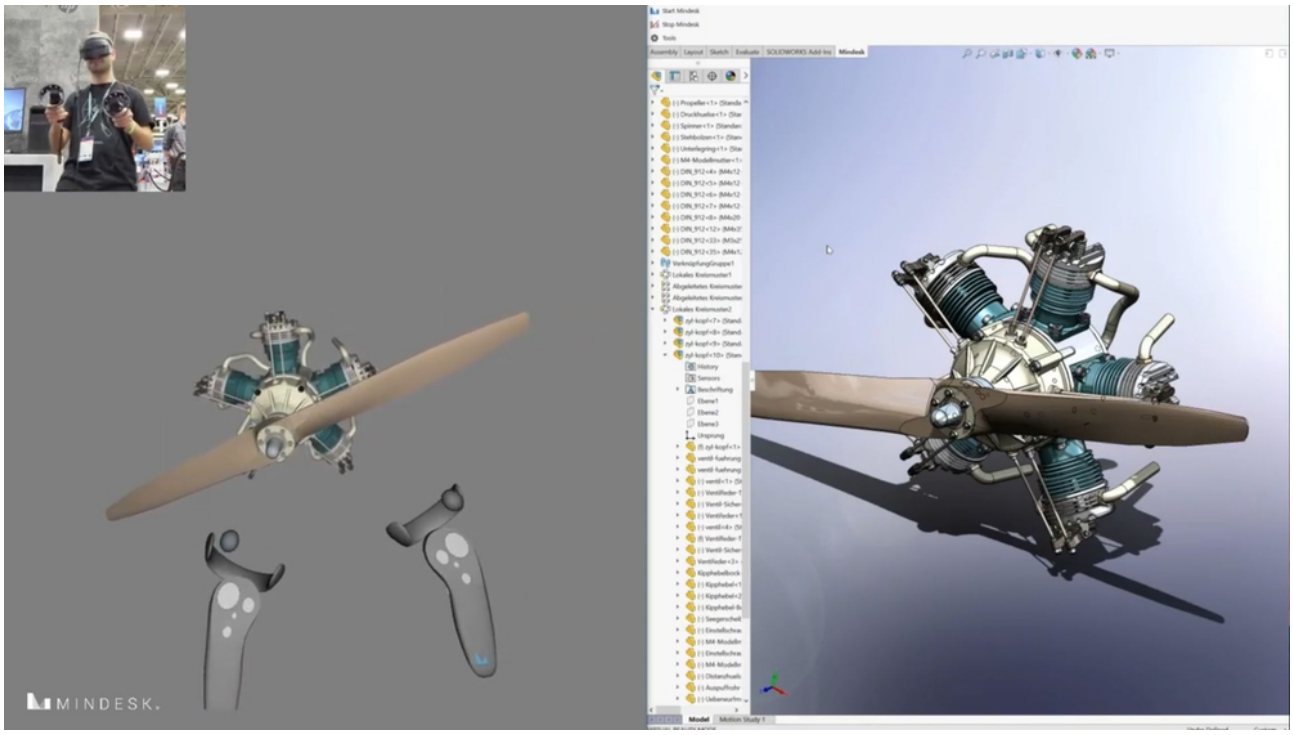
Pros and cons

- ✓ Allowing detailed customization, easy to use with convenient user interface and does not require any fee to start using it.
- ✗ Technical support may not be as efficient as commercialized other 3D modelling software.

MakeHuman description

MakeHuman is an open source 3D modelling software to make 3D human models. It is used as a basis for a lot of characters used in art of different styles and methods, like creation of comics and cartoons, animations etc. MakeHuman is also considered as a middleware for prototyping of photorealistic humanoids. Furthermore, it is used for VR and AR developments. It is written in Python that would presumably allow expanding Python based developed projects. Additionally, it is allowed to copy, modify, distribute and perform the work, even for commercial purposes, all without asking permission. With all normal usage of MakeHuman, the exported models end up being licensed Creative Commons Zero (CC0)

Mindesk VR



General facts

Year of release	2019
Use domain	VR
Software category	3D Modeling
Commercial info	Developed by Mindesk
Official website	https://mindeskvr.com/
Price range	450 EUR to 2000 EUR

Software availability or tiers

Paid	499€/year for freelancers, 1999€/year for professionals, custom pricing for enterprise. More information: https://mindeskvr.com/store/

Pros and cons

- ✓ No exporting of the design file required before VR viewing
- ✓ Immersive VR enables stakeholders to comprehend the design more effectively
- ✓ Supports several popular CAD software
- ✓ Supports parametric design in VR with Grasshopper
- ✓ Supports several 6DOF VR headsets
- ✓ Supports the most advanced Varjo headsets for detailed VR viewing
- ✗ Somewhat expensive
- ✗ Does not support all popular CAD software yet

Mindesk VR description

Mindesk VR is a software that eables users to collaborate with CAD files in real-time in VR. Mindesk VR has several plugins for different CAD software and it currently supports Rhinoceros 3D, Grasshopper and Solidworks. Mindesk VR uses the Unreal Engine for real-time rendering of the CAD files in VR.

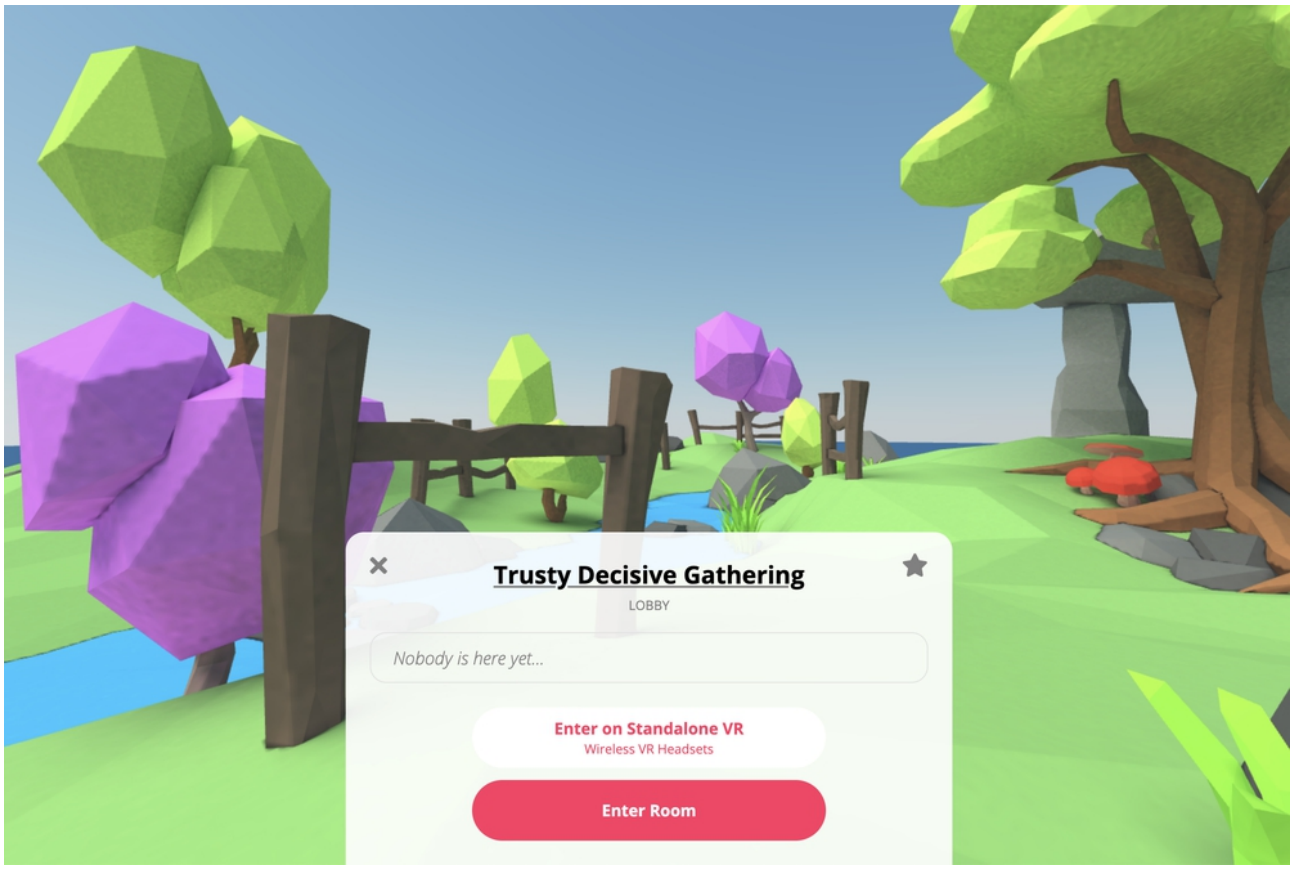
Mindesk VR does not require you to export your design file separately before viewing it in VR. Instead, you can directly open the design file in VR with a single click and the modifications that are made into the design in VR are transferred instantly into the CAD software. Mindesk VR also supports multi-user VR which enables effective collaboration between stakeholders. Examining the 3D design immersively in VR allows especially non-technical users and clients to better comprehend the design. Multiple design alternatives can also be presented to users in this way. This allows for more effective collection of feedback.

A VR headset with six degrees of freedom is required for Mindesk. Mindesk currently supports HTC Vive, Vive Pro and Cosmos; Oculus Rift, and Rift S; all the Windows Mixed Reality devices ; the Valve Index as well as the Varjo VR1 and VR2.

Relationships to other items

Software: Rhinoceros 3D Plug-in available for Rhinoceros 3D

Mozilla Hubs



General facts

Year of release	2018
Use domain	VR
Software category	3D Modeling
Commercial info	Developed by Mozilla
Official website	https://hubs.mozilla.com/

Software availability or tiers

Free	Open source platform from Mozilla More information: https://hubs.mozilla.com/

Pros and cons

- ✓ Browser based - highly accessible using almost any device
- ✓ Active developer community
- ✗ Browser creates constraints for experience fidelity and complexity
- ✗ Platform is very much in active development

Mozilla Hubs description

Mozilla published a web-based 3D platform for VR and 3D interaction first in 2018. As webXR technologies have been developing rapidly, Hubs is starting to become a very nice addition to the VR scene, especially because of its simplicity, ease-of-use and accessibility because a VR headset is not mandatory to participate into experiences on the platform.

Even though the basic functionality is still developing, Mozilla has open-sourced the codebase, thus giving everyone the opportunity to develop the platform further to better support their use case.

Oculus Medium

General facts

Year of release	2016
Use domain	VR
Software category	3D Modeling
Commercial info	Developed by Oculus until 2019/Adobe 2020 onwards
Official website	https://www.oculus.com/experiences/rift/1336762299669605/
Price range	0 EUR to 50 EUR

Software availability or tiers

Paid 29,99€ More information: https://www.oculus.com/experiences/rift/1336762299669605/

Pros and cons

- ✓ Intuitive to use
- ✓ Cheap software
- ✗ Only compatible with the Oculus Rift and Rift S
- ✗ Functionalities and features are limited for organizational use

Oculus Medium description

Oculus Medium is an immersive digital 3D sculpting tool for VR. It enables the user to create and paint digital sculptures in a 3D space with their VR headset and controllers. Oculus Medium currently only supports the Oculus Rift and Rift S headsets and the Oculus Touch controllers. Oculus Medium uses the controller's 6 degrees of freedom to track the controller's direction and movement when they create digital 3D assets.

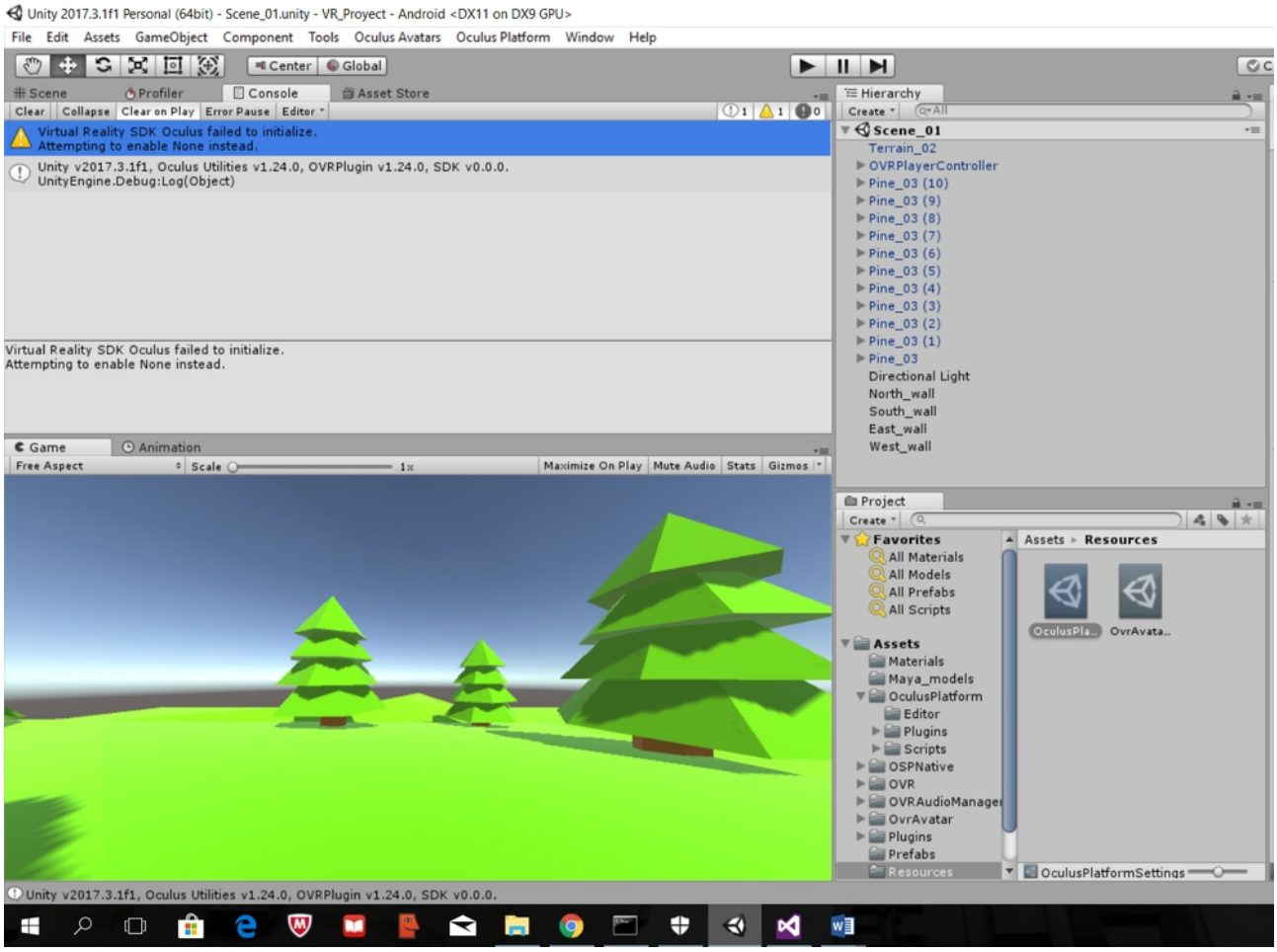
At the end of 2019, Adobe bought Oculus Medium and it will likely be released later as part of the Adobe software suite. However, in the meanwhile it can still be bought from the Oculus Store. The digital assets created in Oculus Medium can be exported in the OBJ. and FBX. file formats.

Relationships to other items

Hardware: Oculus Rift S The software is compatible only with the Rift and Rift S.

Hardware: Oculus Rift The software is compatible only with the Rift and Rift S.

Oculus Platform SDK



General facts

Year of release	2016
Use domain	VR
Software category	3D Modeling
Commercial info	Developed by Oculus
Official website	https://developer.oculus.com/downloads/package/oculus-platform-sdk/

Pros and cons

- ✓ documentation for Unity, Unreal Engine and Native C++ development available
- ✓ sample apps to demonstrate how to implement different features in fully-functional games and applications included

Oculus Platform SDK description

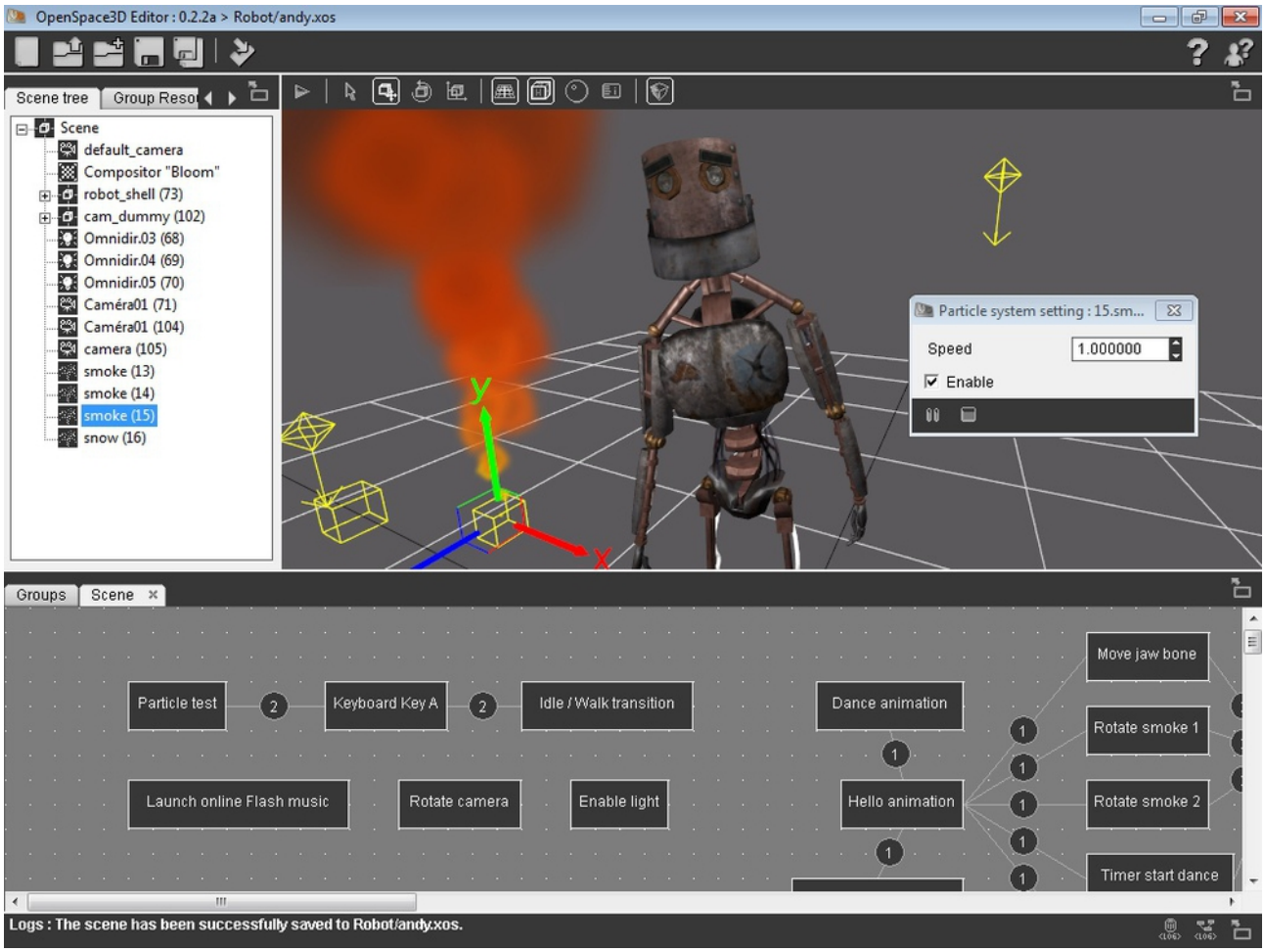
Oculus Platform is a Software development kit aimed at helping creating social VR-applications. It is designed to be compatible with all Oculus supported development environments and platforms. The download also includes examples of implemented features to showcase the possibilities. It is intended for developing fully functional VR applications and Games in Unity, Unreal Engine and C++ for Rift and mobile devices.

Relationships to other items

Software: Unreal Engine Oculus provides integrated support for Unreal Engine with the Oculus VR Plugin. The integration makes it easy to develop VR applications that target the Oculus Go, Oculus Quest, and Oculus Rift headsets.

Software: Unity It is documented how to set up the development environment to build Oculus apps in Unity. It contains information about hardware and software requirements, setting up Oculus devices, and installing Unity Editor and other necessary tools.

OpenSpace3D



General facts

Year of release	2013
Use domain	VR and AR
Software category	3D Modeling
Commercial info	Developed by I-maginer company
Official website	https://www.openspace3d.com/

Software availability or tiers

Free The developer company positions Open Source development platform that grants end-users to use the software free of charge. More information: https://www.openspace3d.com/softwarelogiciel/

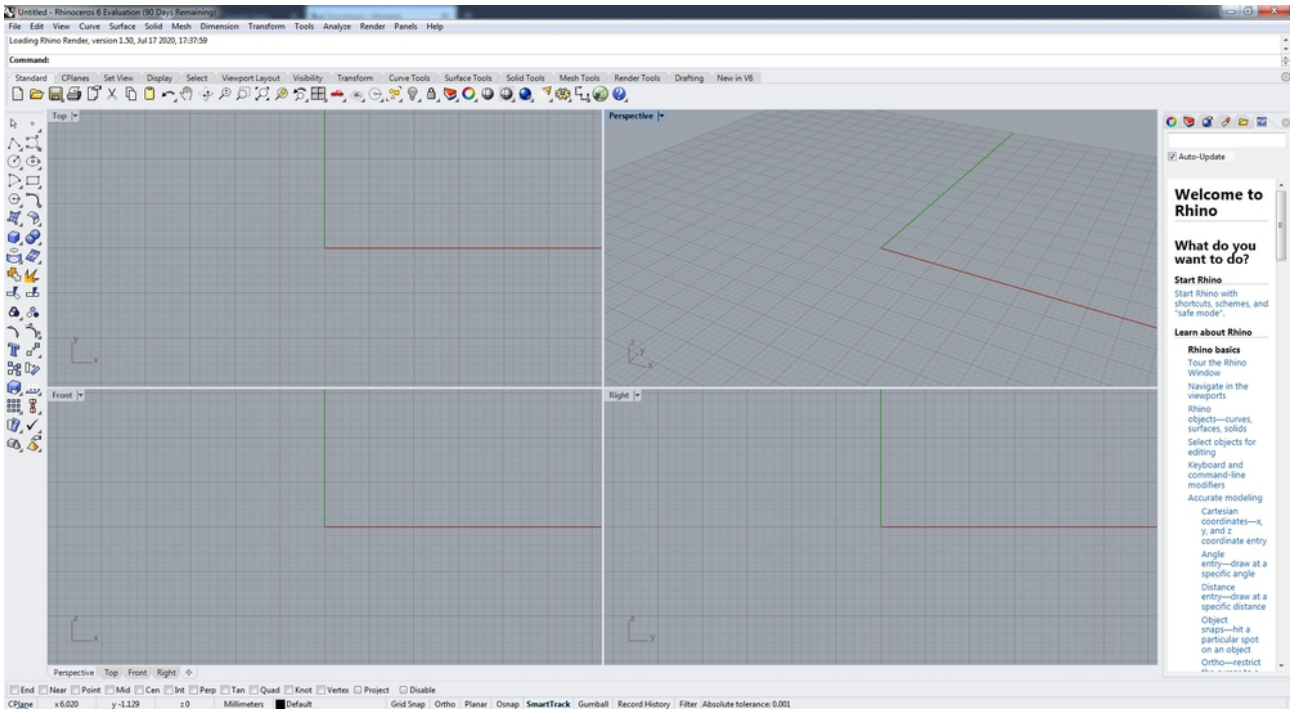
Pros and cons

- ✓ Support multi platforms including Windows, Linux, IOS, macOS, Raspberry Pi, Android.
- ✓ Allows creating multi user applications including chatting.
- ✓ Synchronizes developed applications on multiple devices

OpenSpace3D description

OpenSpace3D is a free software that allows to create virtual and augmented reality projects. The software supports two augmented reality techniques to develop AR based applications; feature marker and aruco fiducial marker detection. VR based applications are also convenient with native support of commonly used VR devices (HTC Vive, Oculus, Leap motion etc.). The software allows importing 3D models, editing imported objects and defining physical parameters for realistic applications. The software contains also visual scripting systems to ease the development process for individuals do not have advance programming experience. It is also possible to create realistic physics simulations with the Newton Dynamics physics engine.

Rhinoceros 3D



General facts

Year of release	2018
Use domain	VR and AR
Software category	3D Modeling
Commercial info	Developed by Robert McNeel & Associates
Official website	https://www.rhino3d.com/
Price range	450 EUR to 1000 EUR

Software availability or tiers

Paid	995€ per license More information: https://www.rhino3d.com/sales/

Pros and cons

- ✓ Extensible with plugins
- ✓ Design can be viewed in VR with the Mindesk plugin
- ✓ Accurate geometric design based on NURBS rather than polygon-mesh modeling
- ✓ Active community
- ✓ Parametric design supported with the Grasshopper scripting language
- ✗ Can seem complicated initially
- ✗ The software can be heavy

Rhinoceros 3D description

Rhinoceros 3D (often called Rhino or Rhino3D) is 3D design software used in computer aided design (CAD), rapid prototyping and 3D printing in various industries such as manufacturing. The software is available for Windows and MacOS. Rhino also includes a visual programming language called Grasshopper. Rhino primarily uses the 3DM file format but it is also compatible with over 30 other popular file formats (for importing and exporting) such as DWG and FBX. Compatibility can be further extended with plugins.

The digital design produced in Rhino can also be directly examined and edited in VR in real time with the commercial Mindesk VR software plugin. Once Mindesk VR has been purchased, the 3D design can be launched in VR directly from the software without the need for exporting. Because the 3D design can be edited in VR in real time, there is no need to export the model into VR and make the changes to the model separately in the design software.

Relationships to other items

Software: Mindesk VR

TechViz Share&Viz visualisation software

General facts

Year of release	2014
Use domain	VR
Software category	3D Modeling
Commercial info	Developed by Techviz
Official website	https://www.techviz.net/

Image source(s): https://www.techviz.net/

Software availability or tiers

Paid No pricing info available. You can try the software for free during 14 days. More information: https://www.techviz.net/

Pros and cons

- ✓ try before you buy: 14 days free trail available
- ✓ universal: works with almost all 3D applications and with almost any immersive display system
- ✓ fast: no data conversion needed

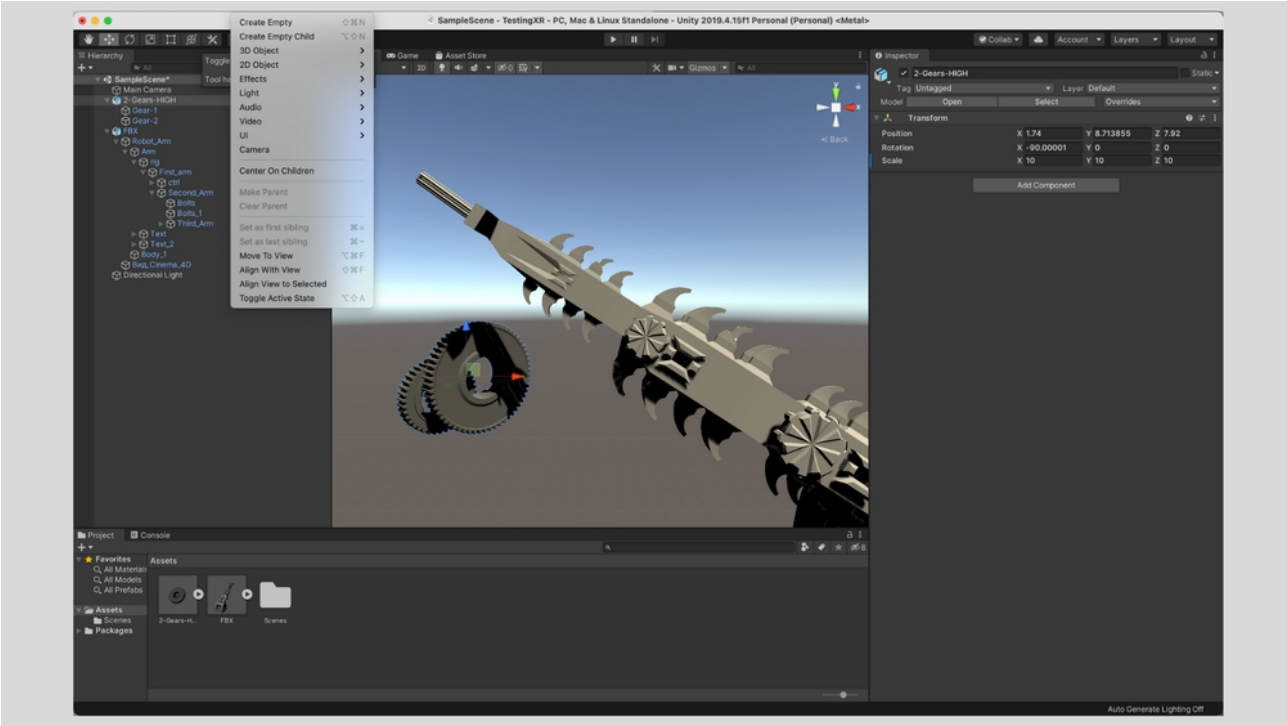
TechViz Share&Viz visualisation software description

Share&Viz is a 3D visualisation software aimed at several industries: automotive, construction, research, shipbuilding, energy, machinery, military, education, aeronautics, aerospace and pharmaceutical industry, to name the most important target sectors.

Share&Viz offers:

- real time visualisation without data conversion;
- virtual collaboration in reviewing 3D designs;
- video recording;
- Tracking of your hands: TechViz XLcan identify the hands position and status (opened/closed);
- compatibility with more than 250 3D applications like Catia, Navisworks, NX, Creo, etc.;
- compatibility with almost any immersive display system: HTC, Oculus, Dell, Meta, Pimax, XTAL, Windows MR, Cave, Workbench, etc.;
- compatible with SteamVR;
- runs on many platforms: web, Windows, Mac, Android but not yet on iOS;
- imitation of an operator in VR in his work environment, in real time;
- merging of 3D scenes of different applications into a single unified scene and merging of designs into a single prototype.

Unity



General facts

Use domain VR and AR

Software category 3D Modeling

Commercial info Developed by Unity Technologies

Official website https://unity.com/

Price range 0 EUR to 1800 EUR

Software availability or tiers

Free Free version available with certain conditions More information: https://unity.com/

Pros and cons

- ✓ Active developer community
- ✓ Wide range of integrations and tools available
- ✓ Asset store
- ✓ Frequent updates
- ✓ Cross-platform support
- ✓ Development using C#
- ✗ Prices for a large scale development organization

Unity description

Unity is one of the leading game development platforms available. Currently, they have also roughly 60% market share in all VR/AR applications, thus being the market leader. Current stable version is Unity 2019 LTS, although developers can access newer builds for more advanced features. Unity ecosystem is very strong including their asset store from which developers can purchase 3D assets to use in their applications. Furthermore, increasing amount of companies are integrating their solutions to Unity, thus improving the value of the ecosystem as a whole.

Unreal Engine 4

General facts

Year of release	2014
Use domain	VR and AR
Software category	3D Modeling
Commercial info	Developed by Epic Games
Official website	https://www.unrealengine.com/en-US/

Software availability or tiers

Free Unreal Engine 4 is available to everyone for free including all future updates and documentation. More information: https://www.unrealengine.com/en-US/download

Paid 5% royalty must be paid per product when the lifetime gross revenues from that product exceed $1,000,000 USD. More information: https://www.unrealengine.com/en-US/download

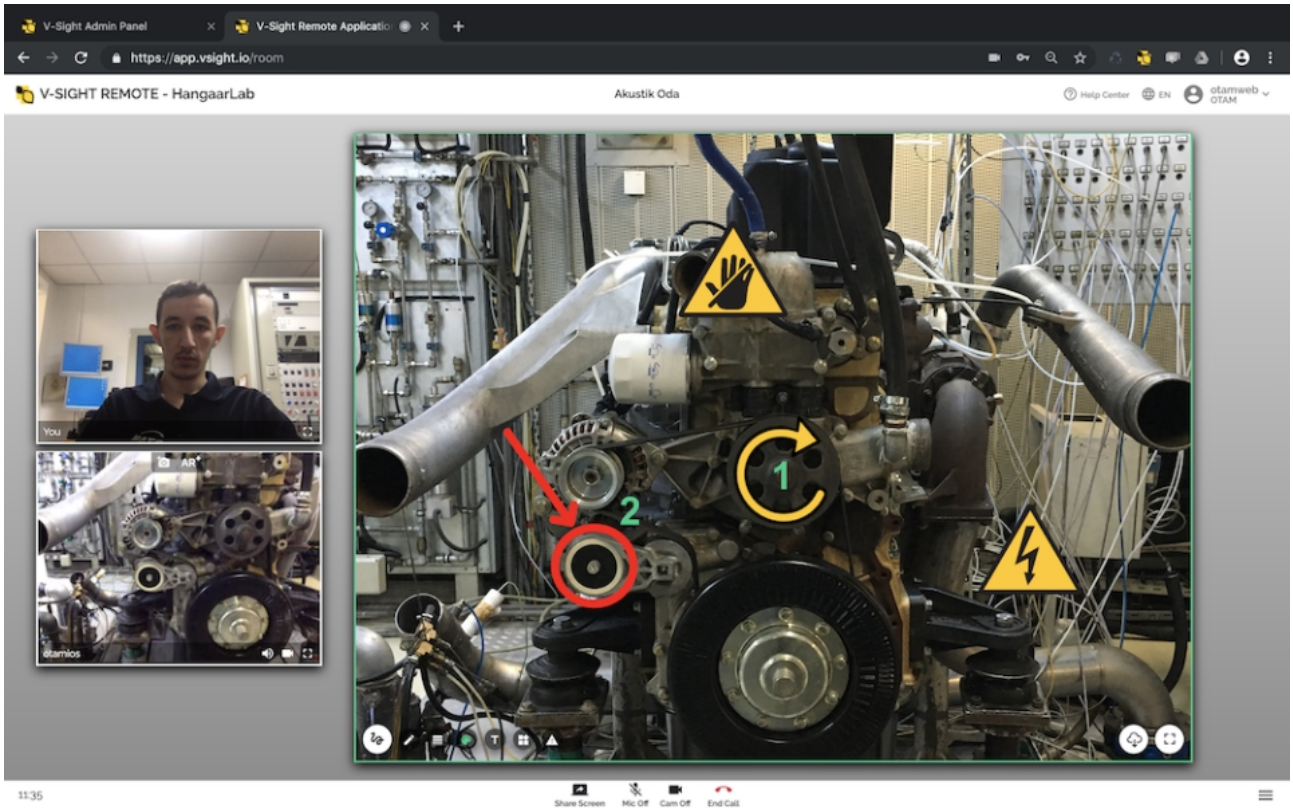
Pros and cons

- ✓ Visual scripting solution to allow developments without programming knowledge.
- ✗ The licensing model may not be the best fit for some business cases.
- ✗ Asset store of UE4 is smaller meaning that less amount of items than Unity store are available.

Unreal Engine 4 description

Unreal Engine 4 is the one of two well–known game engines which is a commonly used and powerful solution for VR and AR development purposes. In other words, Unity3D and UE4 are dominating the XR development. Unreal Engine 4.25 is the latest release on May 2020. UE4's Blueprint visual scripting system is one of the reasons to prefer UE4 to other real–time visualisation engines since it allows for rapid prototyping. Blueprint is a complete game–play scripting system based on the concept of using a node–based interface to create game–play elements from within Editor View. Furthermore, it is possible to compile Blueprints to C++ code for improving performance in the finished product.

VSight Remote



General facts

Year of release	2019
Use domain	AR
Software category	3D Modeling
Commercial info	Developed by VSight
Official website	https://www.vsight.io/

Image source(s): https://www.vsight.io/

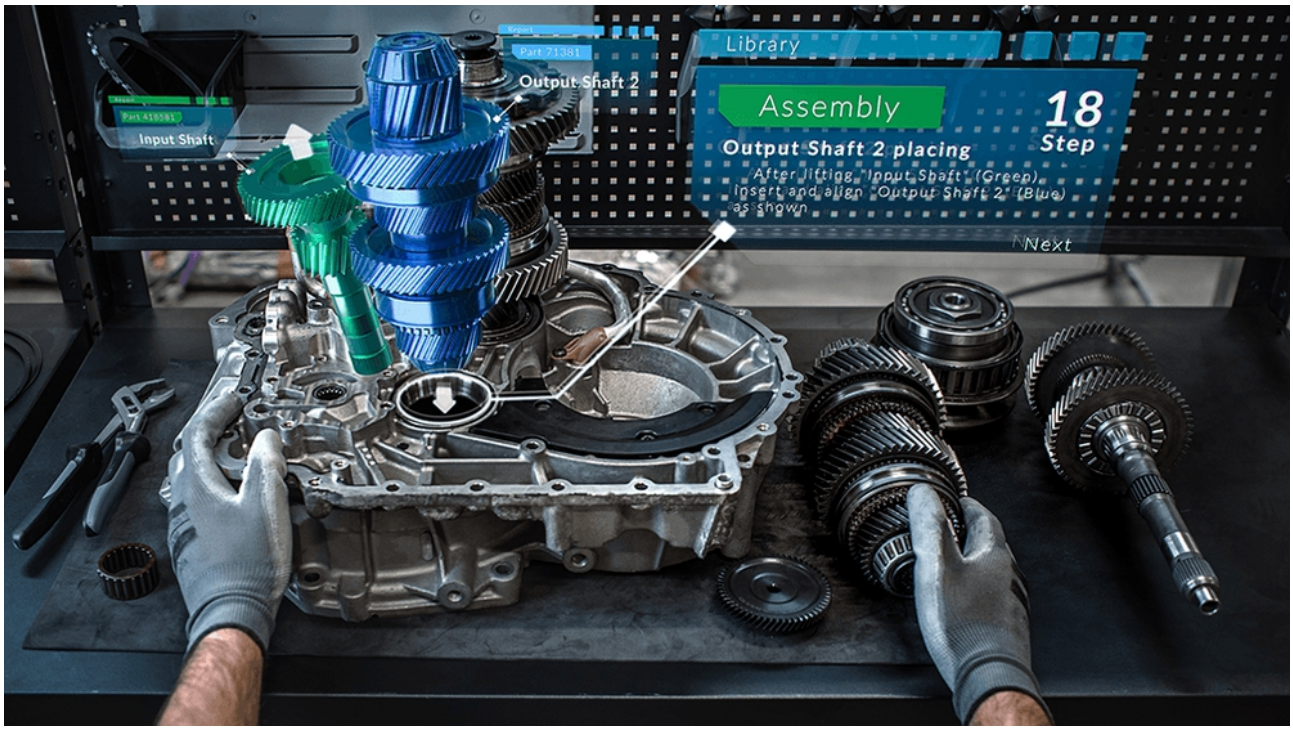
Pros and cons

- ✓ Remote collaboration: experts and technicians, students, customers,.... are able to work together without having to be physically side by side.
- ✓ Cost and time saving: don't lose time and money on traveling
- ✓ AR enabled platform: VSight Remote platform is equipped with effective AR tools to provide clear communication.
- ✓ Its instant translation function (German, English, French, Portuguese, Spanish, Turkish) works really well during remote assistance.
- ✓ VSight Remote integrates with ARCore Depth API for more accurate positioning of 3D elements and as a consequence more realistic experiences.

VSight Remote description

With VSight Remote, technicians in the workfield and experts can immediately connect to each other and solve the problems remotely. The software uses 2-way video and audio communications. The VSight Remote platform allows to consult manuals, step-by-step instructions, 3D models and the like as pdf, jpeg, png, obf or fbx files. Users can also add text, 3D objects and shapes and draw lines and arrows. The application is web based, works with iOS and Android and is used mostly for remote support during maintenance, training, audit and inspection tasks.

Vuforia



General facts

Year of release	2012
Use domain	AR
Software category	3D Modeling
Commercial info	Developed by PTC
Official website	https://developer.vuforia.com/
Price range	650 EUR to 1250 EUR

Image source(s): https://library.vuforia.com/articles/Solution/trained-model-target-datasets.html

Pros and cons

- ✓ integrated in Unity 3D
- ✓ Multiplatform; Android, iOS, UWP
- ✓ Good samples and documentation
- ✗ price

Vuforia description

Vuforia Engine is a software platform for creating Augmented Reality apps. It is natively integrated into Unity since version 2017.2.

Vuforia can recognize different kind of targets:

- Model Targets;
- Ground Plane;
- Image Targets;
- VuMark;
- Object Recognition;
- Cylinder Targets;
- Multi Targets;
- User Defined Targets;
- Cloud Recognition — demonstrates use of the cloud to recognize targets from a Vuforia Engine TMS cloud database;
- Virtual Buttons.

Hence, it is possible to integrate artificial objects into AR using the many different options listed above.

Relationships to other items

Software: Unity As of 2017.2, Unity integrates the Vuforia Engine

Hardware: Digital Eyewear The Unity Vuforia samples for HoloLens and Magic Leap show how to attach an AR experience to an Images, Model Targets and VuMarks. The Vuzix M400 and RealWear HMT-1 is supported similar to any Android device with the samples in the Core Features section.

Vuforia Chalk

General facts

Use domain AR

Software category 3D Modeling

Image source(s): https://www.ptc.com/en/products/vuforia/vuforia-chalk

Commercial info Developed by chalk.now@ptc.com

Official website https://www.ptc.com/en/products/vuforia/vuforia-chalk

Price range 0 EUR to 1100 EUR

Software availability or tiers

Free Free access during Covid-19 pandemic. More information: https://play.google.com/store/apps/details?id=com.vuforia.Chalk&hl=nl

Pros and cons

- ✓ Eliminates the need to travel and the associated travel cost
- ✓ Reduces repair time and the associated production downtime losses
- ✓ Enables experts to draw callouts in a technician's live view pointing to specific details, dangers or steps to take to avoid errors and accidents
- ✓ Empowers technicians, students, customers,... to solve on-site issues themselves with the support of an expert.
- ✓ Free access during Covid-19 pandemic!

Vuforia Chalk description

Chalk is a remote assistance application. When a technician and an expert start the application on their mobile device, the technician has to move the camera around to simultaneously localize an object and snap the area in view of the camera. Each of them can then draw digital 3D annotations that appear to stick to the object. Software features:

- can be operated with voice commands;
- a low bandwidth mode allows video streaming at high resolution/low frame rate to allow communication in areas with poor WiFi or 3G/4G signal strenght;
- at the end of a session, Chalk generates a session summary with subsequent snapshots of that Chalk call. This summary can be saved or shared;
- can be used on smartphone, tablet, laptop or desktop computer, and both with Android or iOS.

Use Cases

How to Read This Chapter

Use case examples are extemely important for the overall understanding of the field of XR. What are some good examples or successful applications of XR? With these chapter, we aim to answer some of these questions. Each entry in the chapter has the following structure.

Images For each use case, a relevant screenshot from the AR or VR experience is provided. The images are original, or are linked to the source.

Year of release This is the year of release of the software release corresponding to the use case.

Use domain Here, the intended usage domain of the software item is specified: VR, AR, or both.

Use case categories In this paragraph, the categories of the use case are specified (e.g., "Walkthrough" or "Film-making and 360 Video"). The categories are also represented by keywords that can be found in the Index under the *use case* keyword.

Commercial attributes Here, it is specified whether the use case implementation is commercial or open source, and the primary developer is listed.

Website Link to the official website of the item where more detailed information about the specific entity is provided. If the link does not work anymore, the reader can try to use the Wayback Machine located at `https://archive.org/web/` to quickly get related information, if it is available.

Price range If the reader desires to purchase a license or subscription for/to a the software corresponding to the use case, here the expected price is provided as a range.

Description Description of the use case based on the experience and knowledge of VAM Realities partners. This can be treated as a mini-review. This also typically includes additional information about technical specifications.

Relationships to other items Information about relationships of this item to other hardware, software and use cases.

AR design visualizations (on location)

General facts

Use domain	AR
Use case categories	Design, Architecture, Collaboration
Official website	https://hbr.org/2017/11/a-managers-guide-to-augmented-reality

AR design visualizations (on location) description

Presenting new product or building designs to clients in an understandable manner can be difficult and costly. Building physical prototypes for example can take months or years and they can only be viewed at certain locations. Moreover, these types of demostrations are often not that immersive or interactive. As a new solution for this use case, Augmented Reality (AR) technology can now be used present the design in the actual location in an impressive and visual manner.

As an example, an architect can take the clients to the planned building location and present the building to the clients with AR. This can be beneficial for the clients as they can more easily examine the surroundings from different angles and see how well the design fits in with its surroundings. Smartphones, tablets and AR helmets can all be used to present the design. In these types of use cases, Virtual Reality (VR) is now often used to present new product design to clients. However, AR visualizations can have a lower barrier for use, especially for users who do not want to put a VR device on their heads. Viewing a building for example via a tablet is easy for users who do not have much experience wth AR or VR and requires minimal training and instructions.

These kind of AR apps also provide an easy, intuitive and cost-efficient way for companies to present a wide array of their products at industrial fairs and expos because the company doesn't have to take any physical models of products with them. The products can be rotated and examined from different angles in AR. More advanced functionalities, such as blowing up a product into its component parts for examination is also possible.

Numerous AR apps can be used to present a company's products with AR. These include Wakeone XR Showroom, 3DQR Studio, Augment, ARki, and Visual Link IT.

Architectural design coordination in VR

General facts

Use domain	VR
Use case categories	Design, Architecture, Collaboration
Official website	https://www.bimplus.co.uk/technology/virtual-reality-aids-architect-design-coordination/

Image source(s): https://unsplash.com/photos/ZkRVjJivs9Q

Architectural design coordination in VR description

During architectural design, many different professional and stakeholders need to contribute to the overall architectural plan. Coordinating these design activities between these stakeholder groups has always been difficult and time-consuming. In this regard, new developments in Virtual Reality (VR) technology are now providing interesting possibilities to make this process more efficient and effective.

Examining the architectural design in VR collaboratively can help identify design clashes which can then be resolved in the design software. Due to the visual and immersive nature of VR, professionals from different areas of expertise can more easily share and collaborate with each other. This kind of Social Virtual Reality can make collaboration more interesting and appealing than examining the same content on a 2D screen.

Users can create text or voice annotations and attach them to design objects. This information is then transferred back into the design software as completable tasks. Direct manipulation of architectural design files is not yet available, but is likely coming in the future as it is already available in the CAD context with Minsite VR.

Previously, exporting the design file into VR has taken hours of even days, which has slowed down this process significantly. However, recent updates in various software now enable users to export the model into VR with a single click in minutes. This has eliminated one of the most significant barriers for using VR in design coordination.

Solutions in this area include IrisVR Prospect and InsiteVR Resolve (available for free trial). These tools plugin to existing design software and workflows such as SketchUp, Revit, Navisworks and BIM 360. These tools can be used with various VR devices, such as Oculus Go and Quest as well as different wired VR headsets like Oculus Rift and HTC Vive.

Architectural walkthrough in VR

General facts

Year of release	2017
Use domain	VR
Use case categories	Walkthrough, Design, Architecture
Commercial info	Developed by Recreation Lab
Official website	https://link.springer.com/chapter/10.1007/978-3-319-60928-7_26

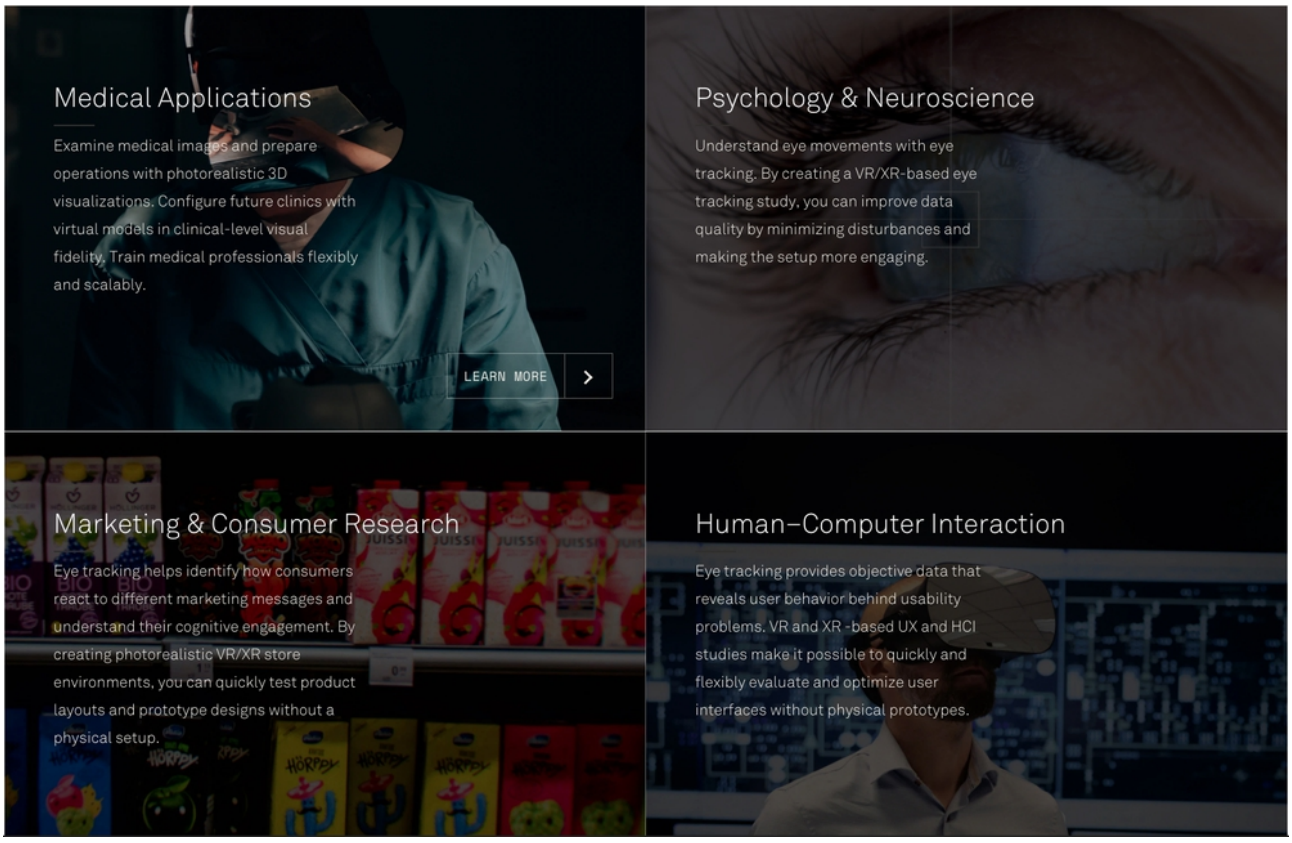
Architectural walkthrough in VR description

This is a fully immersive application of physical environment that is a research and development center of Tallinn University of Technology. The center meets descent number of intercontinental visitors daily with interests of prototypes, futuristic applications, start-up ideas etc. The center welcomes over 50000 visitors yearly. The application is created as a test-bed for intelligent systems integration to VR and self-learning activities with sociological aspects by significant experimental platform. The application integrates computer graphics and simulation, dynamic interaction in real-time, computational intelligence, motion capturing. Although the immersive environment seems unique, the process for creating the virtual environment is generic. *Unreal Engine 4 (UE4)* is chosen to design the virtual environment and Blueprints (UE4) to implement game mechanics. *Maya 3D* is a software with the purpose of animation, modeling, simulation, and rendering is used to create objects and meshes. *OpenCV* is a opensource computer vision library and it is implemented to display a webcam in virtual environment. Teleportation feature of VR technology is implemented for the application. That feature allows users to move independently and effortless in computer simulated realistic architecture. The application can serve with Oculus Rift Development Kit 2 (DK2) and HTC Vive.

Relationships to other items

Software: Unreal Engine The application is designed by Unreal Engine 4. Interactions such as open and close doors, switch lights, turn on and off display screens are implemented by Blueprints.

Behavioral Research in VR



General facts

Use domain	VR
Use case categories	Research
Commercial info	Developed by Varjo
Official website	https://varjo.com/solutions/research/
Price range	5000 EUR to 10000 EUR

Behavioral Research in VR description

Varjo is a Finnish startup manufacturing an extremely high-resolution VR headset. Headset includes very accurate eye-tracking technology which enables new types of research scenarios. Using Varjo's solution it is possible to track what is behind users'

reactions and behaviors as they interact with objects, environments and virtually any stimuli. Solution can be used for medical applications, psychology and neuroscience, marketing and consumer research and human-computer interaction research.

Designing in VR

General facts

Year of release	2017
Use domain	VR
Use case categories	Design
Commercial info	Developed by Meilenstein Digital GmbH
Official website	https://meilenstein-digital.de/virtual-reality-vr-innenarchitektur-innenraum-bzw-produkt-konfigurator/

Image source(s): https://meilenstein-digital.de/virtual-reality-vr-innenarchitektur-innenraum-bzw-produkt-konfigurator/

Designing in VR description

A German Enterprise designed a platform to use virtual reality in interior design. This solution makes it possible to easily change wall colour or flooring and switch between different options of furniture in real time. This technology's most important advantage is its time and cost efficiency, where before an artificial showroom would have had to be rendered in a 3D environment and all changes would have had to be rerendered. They even offer an AR solution on Laptop or mobile devices if a VR device isn't easily accessible.

End-user participation in design in VR

Image source(s): https://fortune.com/2017/02/14/samsung-new-york-fashion-week/, https://wwd.com/business-news/media/refinery29-facebook-vr-360-platform-releases-nyfw-videos-virtual-reality-10360812/, https://jingdaily.com/from-live-streaming-to-vr-brands-capture-attention-of-chinas-digital-fashionistas/

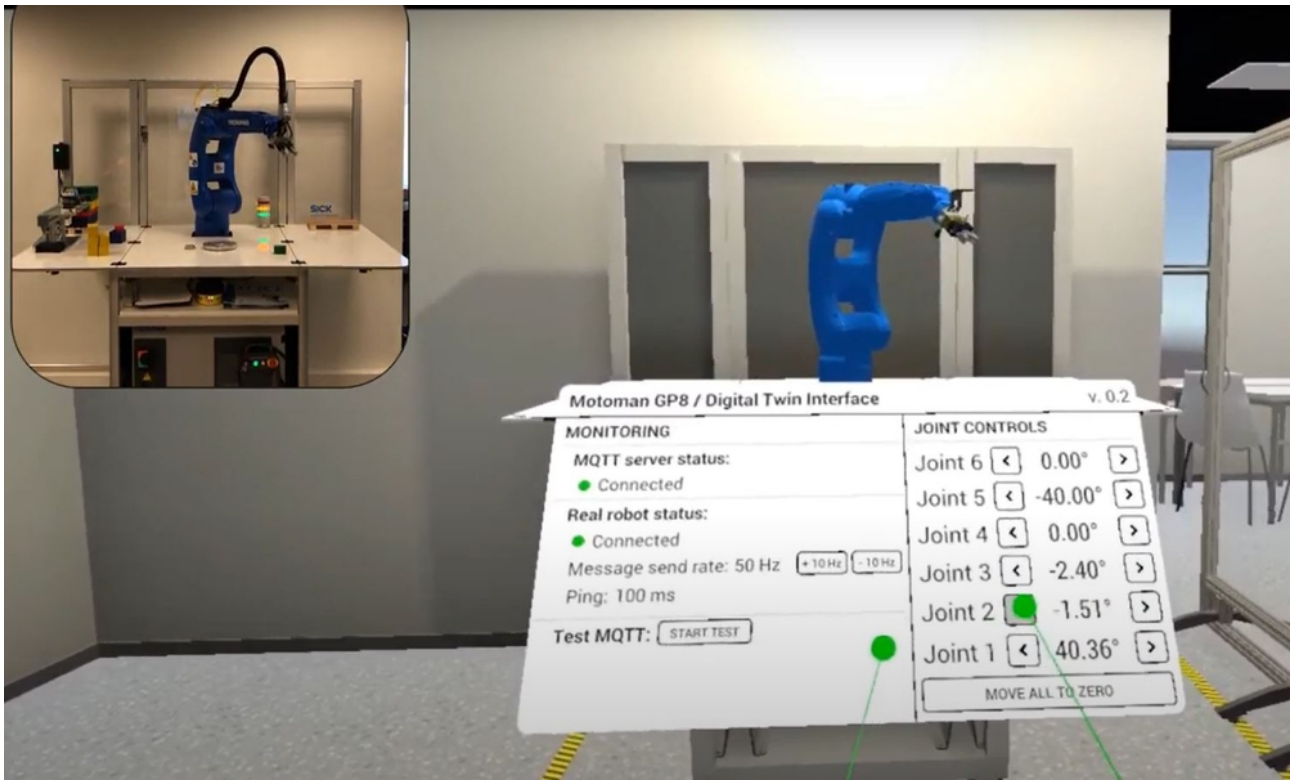
General facts

Year of release	2017
Use domain	VR
Use case categories	Walkthrough, Design, Film-making and 360 Video
Commercial info	Developed by Samsung
Official website	https://www.ftlmoda.com/

End-user participation in design in VR description

In 2017 the New York fashion week made it possible for fashion design enthusiasts all over the globe to participate in Milans "Dreaming of Italy" show. The actual show was filmed a week earlier and then prepared for people all over the globe to be an immersive VR experience. The invited audience could see the show in 360° and even interact with the items and the brands got the chance of raising the viewer numbers. The end-users big advantage was saving the travel cost and still being able to participate in this event.

Industrial Digital Twins in VR



General facts

Year of release	2018
Use domain	VR
Use case categories	Training, Engineering and Robotics
Commercial info	Developed by Taltech Department of Mechanical Engineering
Official website	https://ivar.ttu.ee/research/

Industrial Digital Twins in VR description

Digital Twin industrial use for the VR development is created based on a real industrial robot - Yaskawa Motoman GP8. The robot is a compact which provides a payload of 8 kg. It is often used for high-speed assembly and handling applications. The digital twin of the robot is created by the game engine - Unity3D for the VR experience. The

digital twin also has an interface to monitor MQTT server status, real robot status (connected or not) and communication frequency rate. The interface also allows users to control six joints of the robot individually. The VR application is served by HTC Vive at the time.

Relationships to other items

Software: Unity The application was designed by the game engine.

Hardware: HTC Vive The application is served by HMD device.

Learning work tasks in VR

General facts

Use domain VR and AR

Use case categories Walkthrough, Training, Education

Official website https://www.wuv.de/karriere/wie_firmen_virtual_reality_zur_weiterbildung_nutzen

Learning work tasks in VR description

Deutsche Bahn is using VR Systems from 2018 to instruct their train attendants. With the help of virtual reality, workflows for employees can be taught in conference rooms without the need of physical attendance on the ICE 4. Realistic training scenarios allow the company to save money while providing a better experience, closer to reality than presentations did before. Furthermore supervisors and trainees have the possibility to see on a screen what the subject is experiencing on the VR headset.

Look into 3D machine designs with Techviz XL

General facts

Year of release	2016
Use domain	VR
Use case categories	Design, Manufacturing
Commercial info	Developed by Techviz
Official website	https://www.techviz.net/

Image source(s): https://www.engineering.com/story/real-time-physics-simulation-in-icido-10-virtual-reality

Look into 3D machine designs with Techviz XL description

CNH is using Techviz XL(French software), for already 4 years. This software is used to support Design for Manufacturing and Design for Assembly. This software allows to look into 3D machine designs delivered through their Team Center platform, to check a design's manufacturability and to detect assembly issues in an early design stage, preventing expensive redesign cycles. The software is used in two ways, using a HTC Vive (single user) or using a projector and a screen while people look at the screen wearing 3D glasses (multi user). Mirroring the HTC Vive is not used because it makes the audience dizzy. The strength of this software solution is that clients all over the world can work together in real time. They display their 3D project immediately from any application on any VR system and without any data conversion. CNH uses Team Center (Product Lifecycle Management software from Siemens) to manage their product designs. The accompanying viewer gets the graphical information from Team Center and renders the 3D model for the VR headset in real time. So with the viewer, designers can look at their design from all sides, even from the inside! Four years ago, this has been the trigger for them to choose for this software together with the affordable price (€100 000 compared to around €400 000 for the most expensive equivalent software from a competitor). At this moment, it is difficult to estimate the ROI of this application. In the past, design engineers made the technical design and after some office operations manufacturing engineers scrutineered the technical drawings, checked the manufacturability and looked for assembly issues. Most of the times the files were sent back to the design engineers to redesign parts. Thanks to this VR application the number of rework cycles has been reduced significantly.

MagicMirror

General facts

Use domain	AR
Use case categories	Design, Manufacturing
Commercial info	Developed by STIIMA CNR

Official website https://www.youtube.com/watch?v=1pYC_twB_pc

MagicMirror description

Magic Mirror (MM) is a tool for supporting new approach to the customized shoe purchasing. When the user is involved in the customisation process, the shoes being customized obviously are not directly available in the shop. In this context, the MM allows the user to see himself with his preferred shoes before they are built: he looks at himself on a large screen (that plays as a mirror) and sees in realtime himself wearing the selected shoes. The user can move forward, backward and he can turn on a side to see the shoes in various positions.

The MagicMirror has been patented in 2005 and in 2012 won the Laval Virtual Award as best digital solution in the business and services category

Mixed Reality Quality Control at Renault trucks

General facts

Year of release	2017
Use domain	VR and AR
Use case categories	Manufacturing, Automotive
Commercial info	Developed by Vuforia from PTC + Hololens from Microsoft + engineers from Renault trucks
Official website	https://www.youtube.com/watch?v=TXVj2nf1YHw

Mixed Reality Quality Control at Renault trucks description

Renault Trucks in Lion (France) has worked many days to elaborate a case in which they use Vuforia from PTC with Microsoft Hololens in which they load CAD data. This

Image source(s): https://www.renault-trucks.co.uk/

mixed reality application is used for quality control on a truck engine. They don't use it in production. It was just a proof of concept by which they learned a lot about this technology. The biggest problem was to import CAD data into the module. They are waiting for the moment a process or product engineer can control all these data himself. Until now, they still need software developers and experts for such applications.

Natuzzi Augmented Store

General facts

Use domain	AR
Use case categories	Design
Commercial info	Developed by Hevolus and Microsoft
Official website	https://www.natuzzi.com/news/natuzzi-launches-its-first-augmented-store-907.html

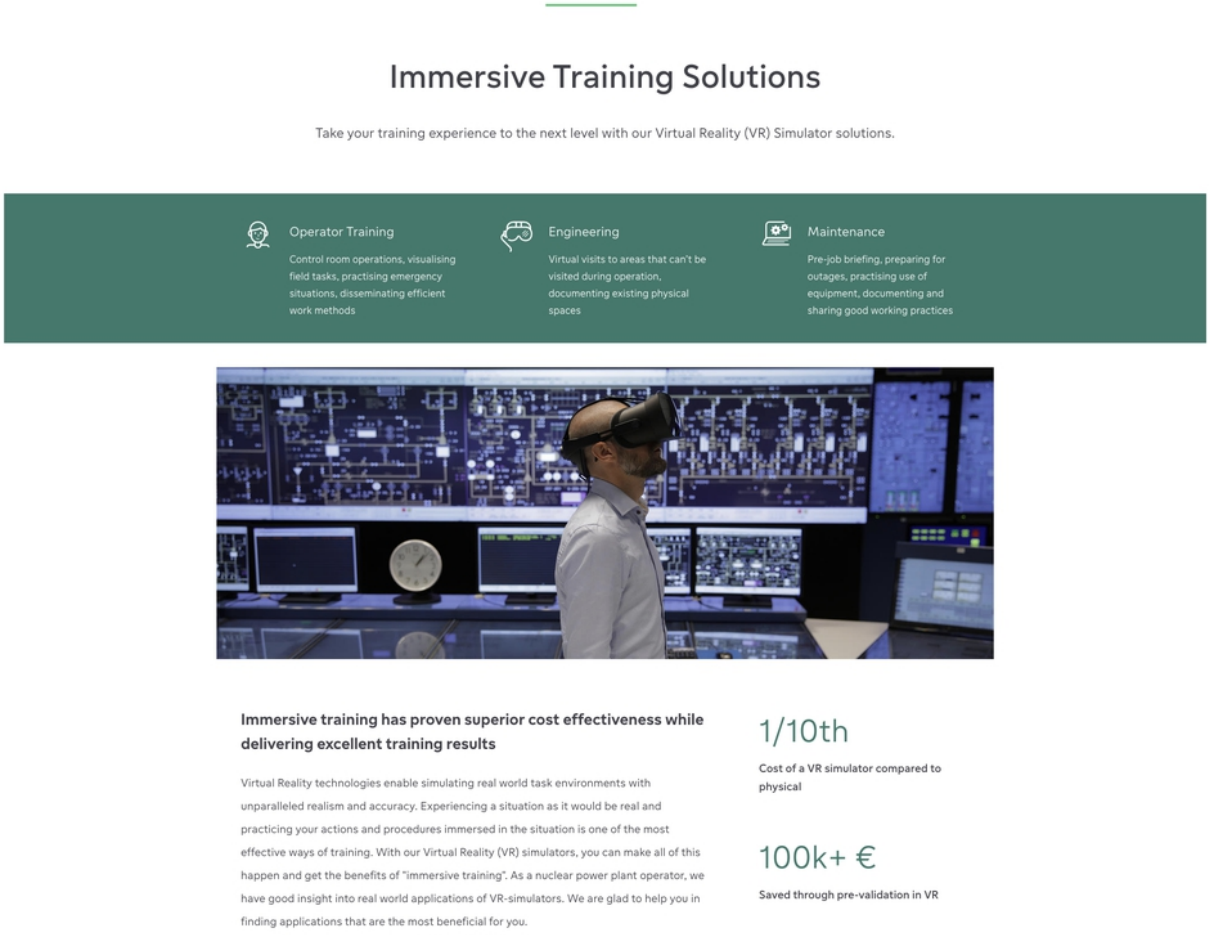
Natuzzi Augmented Store description

In May 2019, Natuzzi Italia inaugurated an Augmented Store within its Madison Avenue location in New York. This new customer experience combines virtual and augmented reality with holographic displays and advanced 3-D modeling with the help of Microsoft and Hevolus Innovation.

Customers can see products from an endless virtual showroom, in various colors, finishes, and settings, by wearing the Microsoft HoloLens. Natuzzi Italia can then co-design an interior project via a scaled 3-D model using HoloProject technology, allowing customers to take home 360-degree renderings accessible on their phone.

Consumers can mix and match furniture in a mockup floor plan of their space for realistic visualization of what the room will look like with the chosen products, which makes the process so much simpler. Instant visualization of both the style and scale of a piece within one's own personal space is a service that was logistically impossible without the technology.

Nuclear Power Plant Control Room Training in VR



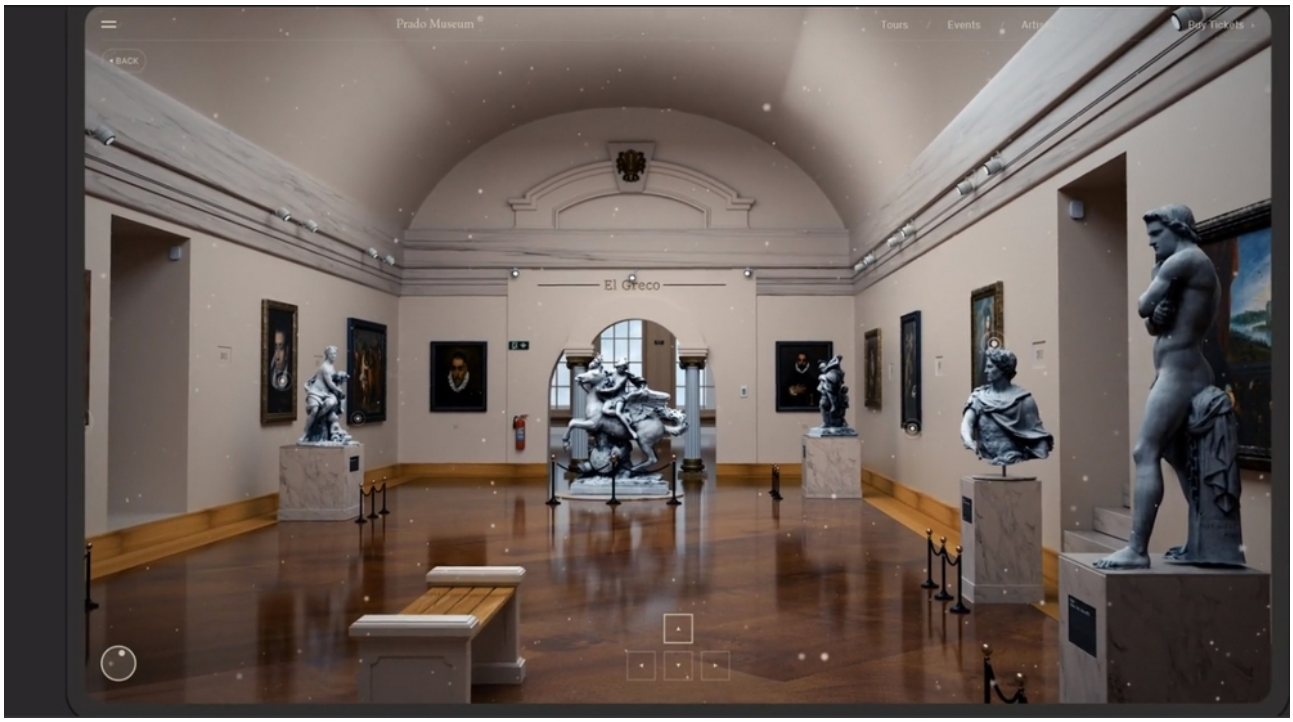
General facts

Year of release	2019
Use domain	VR
Use case categories	Training, Simulation
Commercial info	Developed by Fortum
Official website	https://www.fortum.com/products-and-services/power-plant-services/nuclear-services/operation-maintenance/immersive-training-solutions

Nuclear Power Plant Control Room Training in VR description

Fortum has been leading the way in using VR in training control rooms employees at a nuclear powerplant. Their solution is multi-user including spatial audio and connected to a simulator with actual data. Benefits include training scenarios that are not possible in traditional simulators, cost effective implementation of training simulators and earlier validation and verification of control room design. Fortum also offers their approach as a service to other companies.

Prado Museum



General facts

Year of release	2019
Use domain	VR
Use case categories	Cultural Heritage
Official website	https://www.behance.net/gallery/73878699/Prado-Museum-Website-with-Virtual-Reality-Experience

Prado Museum description

One of the benefits of virtual reality is its ability to make experiences accessible for many. While a trip to a far-afield museum or gallery might once have involved years of saving up to make the trip of a lifetime, now eager art fans can “enter” an increasing number of cultural institutions virtually.

The Prado Museum (Museo Nacional del Prado) in Madrid has experimented with VR technology in its website design, giving users a completely immersive experience of navigating the museum's galleries, without the need to be physically present.

Presenting architectural designs to clients in VR

General facts

Use domain	VR
Use case categories	Design, Architecture, Collaboration
Official website	https://www.forbes.com/sites/charliefink/2020/07/01/walk-through-buildings-before-they-are-built/#2e4cd5d838d5

Presenting architectural designs to clients in VR description

In the past, architects have used miniature models and 2D drawings to demostrate their proposed design to clients. However, this can be costly and inefficient because

building the physical models can take a lot of time and it is hard to modify them later in a significant way. Moreover, it is not easy for clients and end-users to comprehend how the design would work for them because the users cannot view the design in one-to-one scale from their own perspective. Virtual Reality (VR) is now providing exciting ways to address these problems.

VR allows especially non-technical clients to better comperehend the design of the architect as VR enables the client to fully immerse themselves into the digital model of the building design. VR enables the user to understand the space spatially which can help them provide more accurate feedback on the design. This can help avoid costly re-designs later on in the project. For example, end-users can examine their future work space in VR and provide effective tips on how to make the space can better support them in their daily tasks. VR also allows faster design iterations as changing the design in the design software and exporting it back into VR takes less time than modifying physical models.

Getting the digital design file into VR has been time-consuming in the past, but tremendous progress has been made in this area in the last few years. Many design and BIM (building information management) software can now be combined with VR software plugins that allow near-instant exporting of the design into VR. Optimizations in VR visualizations also make it possible to view large design files in VR even with standalone VR headsets such as the Oculus Quest. The users also do not have to be in the same location, but can access the design review from a location of their choice.

There are numerous VR software available for architectural visualizations. These include InsiteVR Resolve, IrisVR Prospect, and the Wild. Many of these tools allow cross-platform access to VR with various different devices. They can also be integrated with various different design software and workflows, such as Navisworks, Revit, SketchUp, BIM 360 and Rhino. Similar solutions are also availabe for different industry contexts.

Presenting contextual information to users via AR

General facts

Use domain	AR
Use case categories	Training, Manufacturing, Information access
Official website	https://hbr.org/2017/11/a-managers-guide-to-augmented-reality

Image source(s): https://unsplash.com/photos/CyX3ZAti5DA

Presenting contextual information to users via AR description

Companies usually have a lot of digital information stored in their information systems. However, providing users access to relevant information in their actual use context can be difficult. For example, a maintenance crew might want to access various historical maintenance and performance data of an industrial machine. Currently this information might be manually accessed via a web site or a workstation. However, finding this information can be time-consuming and is prone to human error (the user might accidentally access data that is related to another machine). As a solution for these problems, Augmented Reality (AR) is now providing intriguing ways to enable users an easy way to access relevant information in the actual use context.

These AR apps can work in several ways. The app can for example identify the object (e.g. machine or a building) via a QR code and the provide the user access to all relevant information relating to the object in the AR app. More advanced AR apps use 3D point clouds and location information (e.g. GPS) to identify the relevant object and provide access to information. As an example, a building information model (BIM) can be overlayed on a building which allows maintenance to locate different ducts and machines in the building mroe accurately as well as view information related to these objects.

Besides accessing information, some of these solutions also allow the user to input information into the relevant information systems via the AR app, or control the device (e.g. change the operating parameters of an AC unit). However, many of these solutions need to be custom-developed and tailored to fit the company's information systems. Despite this, the potential benefits can be significant as users can solve problems quicker and avoid potential mistakes when they have access to all of the relevant information necessary to carry out their work tasks. These apps can be used with smartphones and tablets or with AR helmets.

Product marketing in VR

General facts

Year of release	2018
Use domain	VR
Use case categories	Manufacturing, Automotive
Commercial info	Developed by Wakeone
Official website	https://xrshowroom.fi/en/

Product marketing in VR description

Product marketing in VR provides benefits especially for manufacturing companies. Usually large machines and complex products are difficult to move and visualise in a way that potential customers actually understand the benefits of the technology. In VR people can easily visit factories, look inside machines, see how whole processes work and immerse themselves in a focused way into familiarising themselves with just the presenting company's product.

There are various software providers offering solutions. Here are some examples:

XR Showroom by Wakeone (https://xrshowroom.fi/en/)

XR marketing platform especially for SME manufacturing companies. Includes both VR and AR functionality and supports all major VR headsets.

ZeroLight (https://zerolight.com/projects#bmw)

ZeroLight offers a configurator and VR functionality for marketing purposes especially for automotive sector.

Product marketing with AR

General facts

Use domain	AR
Use case categories	Design, Marketing
Commercial info	Developed by 3DQR
Official website	https://3dqr.de/de/

Image source(s): https://ikea-unternehmensblog.de/article/2019/ikea-place-app

Product marketing with AR description

Ikea, the furniture store chain, launched their App IKEA-Place in 2018. This application is designed to give a first impression on the products and how they fit in the customers homes. It's freely accessible and based on Apple's ARKit. All available products are represented three-dimensionally and true to scale, so the customer wouldn't need to measure his interiors anymore. It is aimed to reduce retours by decreasing the risk of miscalculations and wrong measurements.

Promoting banking with VR

General facts

Year of release	2018
Use domain	VR
Use case categories	Design, Gaming, Education
Commercial info	Developed by Recreation Laboratory
Official website	https://recreation.ee/company_project/swedbank-vr-experience/

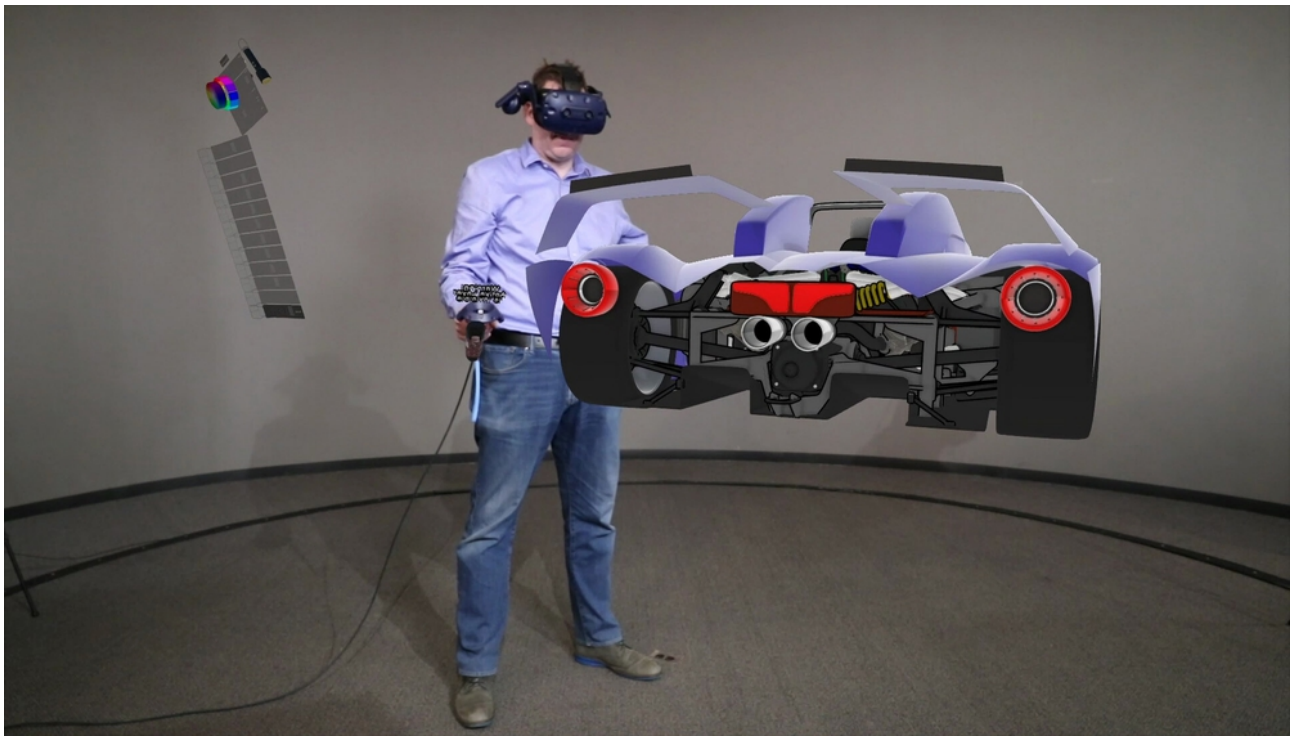
Promoting banking with VR description

Swedbank VR Experience is the gaming-oriented VR application is completed in cooperation with a private bank in Estonia. The bank is using the first version of the application actively for marketing purposes on various fairs, in their headquarters among Baltic countries to exhibit the innovative and entertainment sides of their business.

The application consists of three main components: starting screen with a custom UI form, tutorial level and main game level. The main level is situated in the hill-top virtual environment and let the users perceive in a borderless environment. Secondly, the tutorial level keeps the player in boundaries helps to complete the specific tasks. The tutorial level is designed as a modern circle shaped hall with a dome. The tutorial environment is simple and induces the player to take desired actions leaving only minimal possible distractions. The tutorial level gives an understanding of employed functions in the application such as teleportation, interactions etc.

User data is collected optional in three phases of the experiment. The user data is categorized based on age group, gender, education, previous gaming experience and hours spent weekly on physical activities. Users are asked to choose the best fit option based on multiple choice questions. The data collection is only activated by filling up the form and accepting to share the data for research and development purposes for each user. In the game, there are four different items for the defined goal; yellow leaf, green leaf, orange leaf, and coin. Each item rewards the player with 1, 2, 3, 10 points respectively. The coin is designed based on logo of the commercial company that awards the player greatest. The default duration of game is 2 minutes and can not be changed.

Remote VR meetings



General facts

Use domain	VR
Use case categories	Design
Commercial info	Developed by Ford
Official website	https://vrscout.com/news/ford-car-design-remote-vr-collaboration/

Image source(s): https://www.cnbc.com/2019/05/08/ford-designers-using-virtual-reality-to-work-with-colleagues-remotely.html

Remote VR meetings description

Corona has further complicated the f2f interaction between teams. Ford is using VR to remotely collaborate on car design from multiple locations across the world. Team members are using HTC Vive headset to connect into the same session with other people from around the world. They have design and review tools at their disposal which allow them to identify mistakes and make corrections before entering into the physical clay prototyping phase of the car design process.

Remote collaboration support with AR

General facts

Use domain AR

Use case categories Training, Social Networking, Collaboration

Official website https://medium.com/@NextRealityNews/15-remote-assistance-apps-driving-enterprise-augmented-reality-21afba83ebc9

Remote collaboration support with AR description

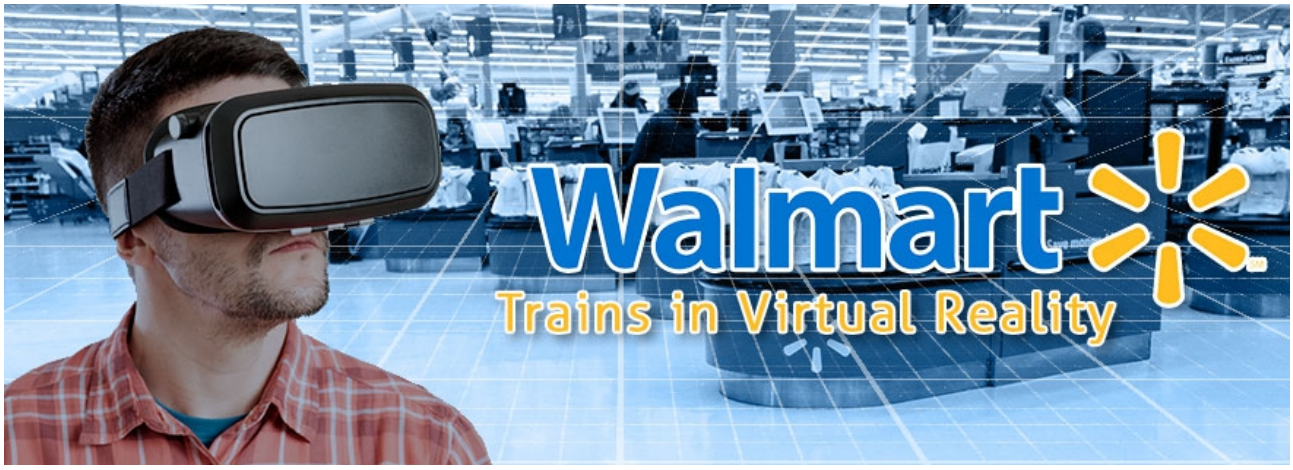
Most manufacturing and industrial companies need to provide maintenance and other operational support for their products. As many companies sell their products globally to numerous clients, providing this support can be costly and time-consuming. Currently, many companies send their maintenance crews and engineers directly to the location, which can take a lot of time and lead to serious downtime for clients. However, new remote collaboration solutions have now begun to emerge which use Augmented Reality (AR) to provide users with an easy way to understand the problem and give visual instructions on how to fix it.

Remote AR collaboration tools connect two users remotely via a video call. The user that is on location can then visually demostrate the problem to the remote expert. Most remote AR collaboration tools can be used either with smartphones or with AR helmets such as the Microsoft HoloLens, depending on whether the employee who is fixing the problem needs to have both hands free during the operation. The remote expert can usually connect to the call either with a smartphone, AR helmet or with a PC.

Both users can draw and insert various digital objects directly into the video call to provide visual instructions to each other. This can help especially in noisy locations or if there's a language barrier between the collaborators. Some tools also allow digital files such as maintenance manuals to be viewed within the app. Depending on the sophistication of the device where the app is used, the digital content can either be in 2D or tied directly in the environment as persistent 3D objects. These remote collaboration apps can be used for diagnosing the problem before a maintenance crew is sent onsite (so that they have all of the necessary equipment with them) or the problem can often be solved immediately with the remote assistance provided by the expert. This can lead to reduced maintenance and support costs (e.g. on travel) and to higher customer satisfaction due to lowered downtime and prompt solving of problems.

Numerous Remote AR collaboration tools are now available. These include DeltaCygniLabs' Pointr, Microsoft Dynamics 365 Remote Assist, Scope AR's Worklink, RemoteEye, and TeamViewer Pilot. More tools can be found via the provided link.

STRIVR



General facts

Year of release	2015

Use domain	VR
Use case categories	Training
Commercial info	Developed by STRIVR
Official website	https://www.strivr.com/

STRIVR description

Immersive Learning lets users practice anytime, anywhere, allowing the employees to practice on-demand, operating safely, and receiving feedback and scores in real-time about their performances. The STRIVR software platform allows to create, manage and experience immersive training, the typical use cases are: front-line process, store operations, new process or equipment rollout, and lean methodology training.

A use case where immersive training has shown to be a great solution to reduce the training time without interrupting the regular business flow is Walmart. Typically, the installation of new pickup towers requires the employee to learn a new way of operating with them.

By using immersive training the employees can be trained before the equipment is installed, do not need to wait for the trainer to be on-site, by using virtual teachers. Moreover, Walmart reported a trim of the time needed for training from eight hours to 15 minutes.

Safety training in VR

General facts

Use domain VR

Use case categories Walkthrough, Training, Education

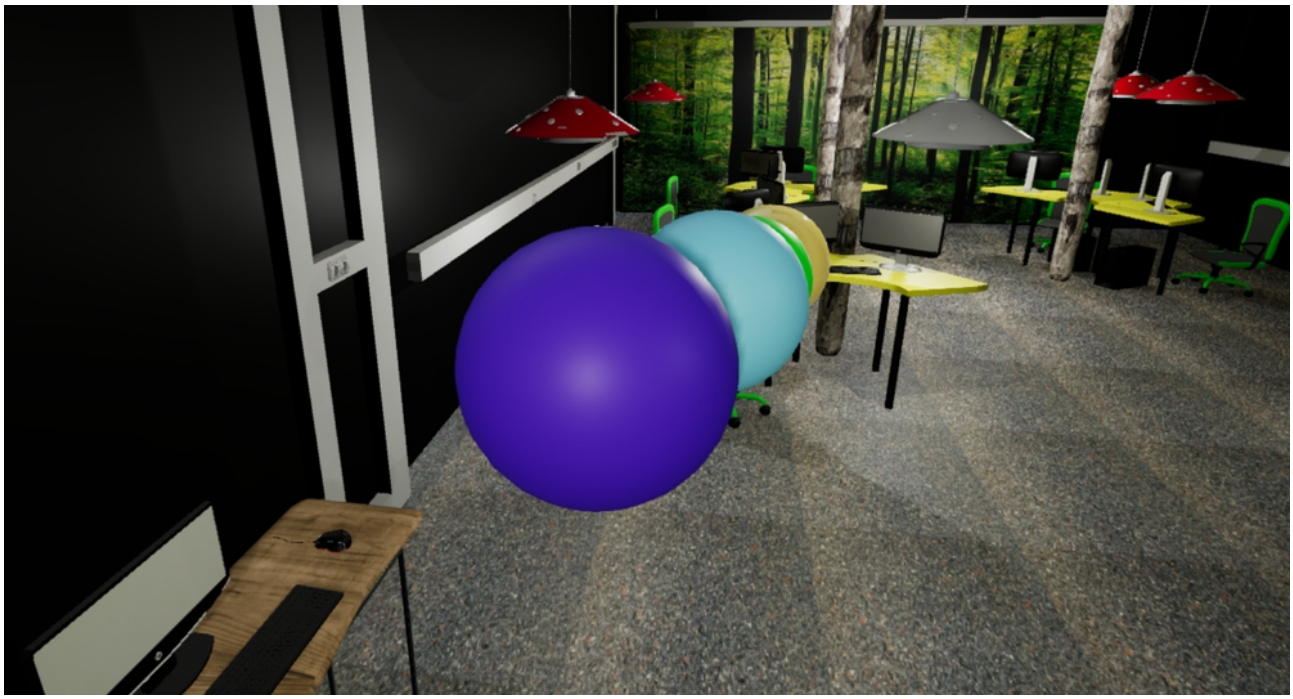
Commercial info Developed by Sentient Computing

Official website https://www.immersivelearning.news/2020/03/03/sicherheitstraining-in-der-virtuellen-realitaet-2/

Safety training in VR description

From early 2019 Lufthansa's flight attendants are training security checks in VR-hubs. Whereas they had to get into a plane model before and perform annual security refreshers in a group of up to 20 people, Lufthansa's employees now absolve their training individually. Each person goes into a 9 x 3 x 3 meters big box and puts on a VR headset. A supervisor can watch how each individual performs the virtual security scan via a monitor that shows the flight attendants field of view. This setup is not the first project of this kind, but at this point it's unique in Europe.

Sound localization in VR



General facts

Year of release	2018
Use domain	VR
Use case categories	Design, Education, Engineering and Robotics
Commercial info	Developed by Recreation Laboratory
Official website	https://jcomss.fesb.unist.hr/index.php/jcomss/article/view/410

Sound localization in VR description

The application introduces a technological readiness to achieve real time data communication for virtual reality experience. The application is devoted for a synesthesia laboratory to be developed during the course of related research activities. The application also investigates an acoustic localization method to the problem of locating

the sound source in a room. Kalman filter is applied to reduce motion noise generated by the uncertainty of sound source location prediction. Dominant features from the audio spectrum of the sound source are extracted and mapped to the object representing the sound source in the VR environment. The application can be considered as a VR system prototype with the complete experimental configuration. The developed application can be used in subject based testing following an ethics committee approval. if the prospective applications are envisioned to be used for real-life medical and artistic applications, further development efforts must also be exhibited towards an embedded system prototype. Furthermore, due to its importance in medical and industrial applications, implementing the synesthetic experience in augmented reality should be investigated since the resulting application may complement the actual real-life environment.

Surgical Simulations in VR

General facts

Use domain VR

Use case categories Training, Simulation

Image source(s): https://varjo.com/blog/vr-is-the-future-of-surgical-training-and-vr-1-is-the-piece-of-the-puzzle-thats-been-missing-arne-schlenzka/

Commercial info Developed by Osgenic

Official website https://www.osgenic.com/

Surgical Simulations in VR description

VR can help improve the training of healthcare professionals in many ways. One important area is surgical training. Osgenic is a Finnish startup that has, in partnership with Varjo, developed a surgical simulation training. It includes not just the 3D virtual environment and high-resolution VR headset but also a hardware to simulate actual haptics of making an incision. This approach provides a degree of realism unattainable with many other solutions.

TechViz at CNH

TECHVIZ

General facts

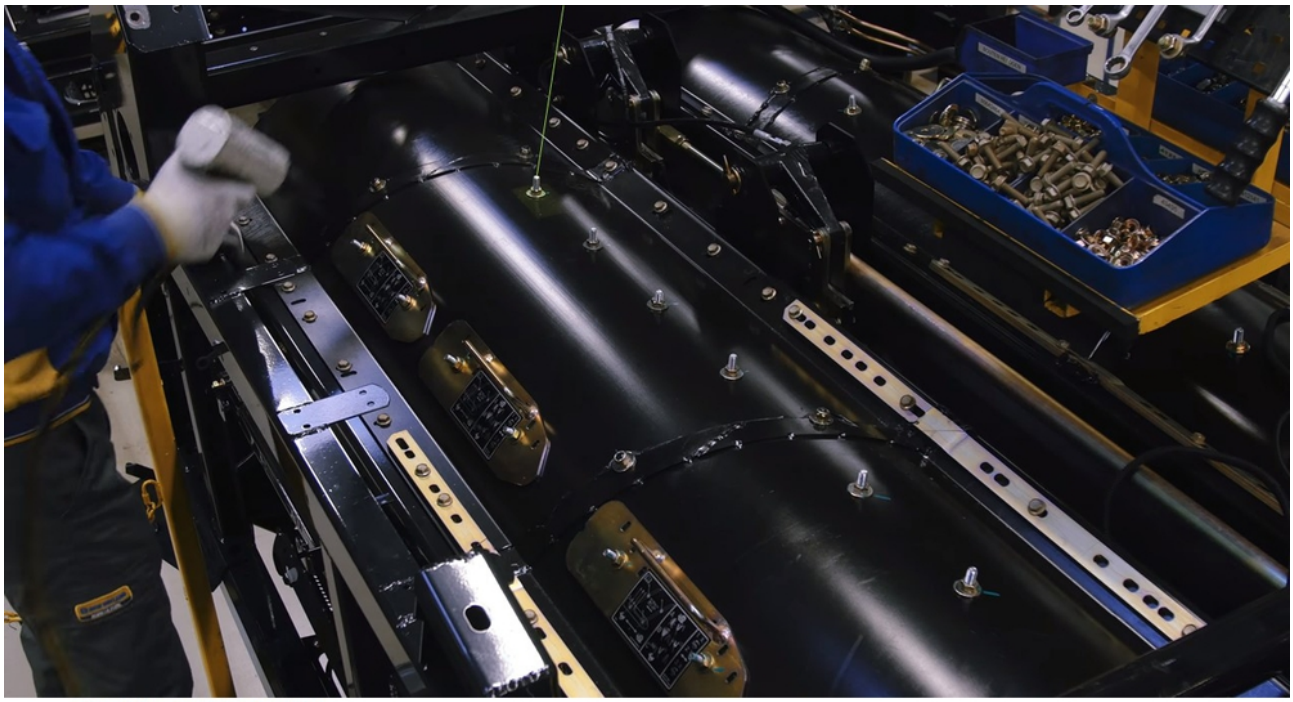
Use domain	VR
Use case categories	Design, Manufacturing
Commercial info	Developed by TechViz
Official website	https://www.techviz.net/

TechViz at CNH description

CNH usesTechViz (French software) for already 4 years. This software is used to support Design for Manufacturing and Design for Assembly. The software allows to look

into 3D machine designs delivered through their Team Center platform, to check a design's manufacturability and to detect assembly issues in an early design stage, preventing expensive redesign cycles. The software is used in two ways, using a HTC Vive (single user) or using a projector and a screen while people look at the screen wearing 3D glasses (multi user). Mirroring the HTC Vive is not used because it makes the audience dizzy. The strength of this software solution is that clients all over the world can work together in real time. They display their 3D project immediately from any application on any VR system and without any data conversion. CNH uses Team Center (Product Lifecycle Management software from Siemens) to manage their product designs. The accompanying viewer gets the graphical information from Team Center and renders the 3D model for the VR headset in real time. So with the viewer, designers can look at their design from all sides, even from the inside! Four years ago, this has been the trigger for CNH to choose for this software together with the affordable price (€100 000 compared to around €400 000 for the most expensive equivalent software from a competitor). At this moment, it is difficult to estimate the ROI of this application. In the past, design engineers made the technical design and after some office operations manufacturing engineers scrutineered the technical drawings, checked the manufacturability and looked for assembly issues. Most of the times the files were sent back to the design engineers to redesign parts. Thanks to this VR application the number of rework cycles had been reduced significantly.

Use of ARKITE Interface Mate at CNH Industrial



Source: https://arkite.com/references/

General facts

Year of release	2019
Use domain	AR
Use case categories	Manufacturing
Commercial info	Developed by ARKITE
Official website	https://arkite.com/references/

Use of ARKITE Interface Mate at CNH Industrial description

CNH Industrial implemented the ARKITE Human Interface Mate. We use this equipment in 3 different workstations. This technology projects instructions, buttons, instruction video's, colour marks, text,... on the table, on the product, on inventory bins,

on tools,... At this moment, the ARKITE system is used as an experiment in the production process of the baler and it is used as a validated application in the production process of the combine. In the latter, it supports the operator in a welding station and in a human assembly station where it shows the operator the sequence of the bolts and nuts he has to fasten. For the production of the combines CNH Industrial was looking for a solution to support complex standard operating procedures (SOP). The operators needs to follow a process of 72 screws in sequence with 3 different torques. Arkite's Human Interface Mate guides the operator by visual instructions. By linking HIM with automation, tools will only work at the right sequence, at the right position and with the according torque. If the operator goes to a wrong position the tool will be disabled.

Virtual city modeling in VR

General facts

Year of release	2016
Use domain	VR
Use case categories	Walkthrough, Design, Architecture
Commercial info	Developed by Recreation Laboratory
Official website	https://www.a-lab.ee/edu/theses/defended/1252

Virtual city modeling in VR description

The district located in Tallinn is created by using 3D modelling and physics engine software; Blender and Unreal Engine 4. The application is developed to let users have realistic walkthrough VR experience. Therefore, served by Oculus Rift as a primary HMD device. The application included two main types of apartment blocks were mainly constructed in Soviet Era, Ice Hall and surrounding objects (roads, traffic lights, signs,

playground, bus stops etc.) based on real environment. Most of models were created by developers in house. There is only an exception of using available content materials in physics engine for creating the ground. However, the lights and landscape are modified to reach most realistic immersive environment. The references were photos, street maps and physical visits for created 3D models. The application was also subject for two thesis in Bachelor degree.

Volvo Augmented Reality Driving Game

General facts

Year of release	2011
Use domain	AR
Use case categories	Gaming

Official website https://www.youtube.com/watch?v=mX_B6Kgti38

Volvo Augmented Reality Driving Game description

The Volvo use case highlights how Augmented Reality can improve the brand Equity.

For the launch on the market of the S60, Volvo decided to aim at a younger target by creating a YouTube masthead allowing users to play the Augmented Reality Driving Game with their phones. With 88% lift in purchase intent and 240% lift in brand favorability, they beat all industry benchmarks.

Results: 9.6% interaction rate; 192,319 engagement clicks in masthead; 293% increase in traffic to volvocars.com.

Warehouse safety training

General facts

Use domain	VR
Use case categories	Training
Commercial info	Developed by SupportSquare
Official website	https://vil.be/project/ar-vr-training-for-logistics/

Warehouse safety training description

It is a VR application for warehouse safety training. In a computer generated virtual warehouse, the user should start an order picking round. While he is looking for the right items, elevator trucks and people move around in the warehouse and a lot of unsafe situations are present (incorrectly positioned pallet, leaking vessel,...). The goal for the user is to identify all hazards and take a picture of them. At the end he gets a score and he receives feedback on undetected hazards. The warehouse safety application has been developed during the VIL project in co-operation with SupportSquare, which is a supplier of VR applications. The application has been developed in 2020 and is useful for many different kinds of companies.

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