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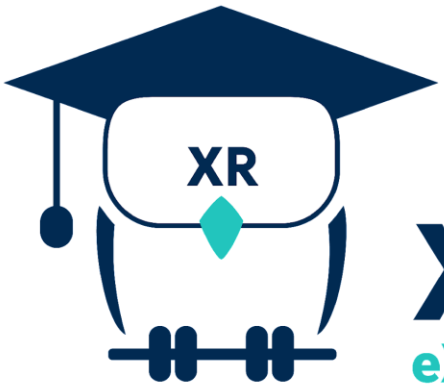

XR4ED
eXtended Reality for EDucation

D3.2
Synergy of XR4ED platform

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List of Acronyms

Acronym	Description
CA	Consortium Agreement
DoA	Description of Action
FS	Financial Statements
GA	Grant Agreement
PO	Project Coordinator
WP	Work Package
XR4ED	Extended Reality for Education

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Executive Summary

The specific deliverable entitled “Synergy of XR4ED platform” gathers and classifies a list of existing repositories and libraries which could be compatible with our platform, or that we could build new modules containing and expanding existing technologies.

More specifically, this document focuses on providing a complete list of platforms for VR development, as well as current repositories for creating XR experiences, modeling and animating avatars, and providing 3D content for educational purposes.

Many of those libraries are publicly available, but require to have programming skills and experience with game engines in order to include them in the development of an XR project. Our platform will incorporate some of them in a transparent way for the final user, that should be an educator without programing knowledge. Therefore, we will need to develop usable graphics interfaces that can simplify the development process so that the educator can focus its efforts in the class preparation as opposed to the complexity of a VR development.

1 Introduction

1.1 Overview

The purpose of the present deliverable entitled “Synergy of XR4ED platform”, is to study the state of the art for each module of XR4ED, and to gather and classify a list of existing repositories and libraries which could be compatible with our platform, or that we could build new modules containing and expanding existing technologies. The objective is to fully understand the state of the art and be aware of similar platforms that have been recently developed or are currently under development in order to evaluate their potential and limitations. With this information we will then plan the XR4ED platform with the goal of being accessible and easy to use for professionals in the education field that do not have programing experience.

In this context, the present deliverable aims to fulfil the following main objectives:

- Identify the responsibilities of all technical partners within the consortium.
- Gather state of the art libraries for each of the technical modules and for the overall platform.
- Ensure proper co-ordination and communication channels among partners during the technical development of the project.

1.2 Structure of the Document

The structure of this document is as follows:

- Section 2 provides an overview of the modules within the XR4ED platform
- Section 3 presents existing repositories, APIs, platforms and tools for XR
- Section 4 summarizes augmented reality toolkits
- Section 5 lists existing repositories for social and collaborative XR
- Section 6 describes existing platforms for education in XR
- Section 7 refers to repositories for XR avatars
- Section 8 focuses on repositories for 3D Assets
- Section 9 presents conclusions

2 XR4ED Overview

The main objective of the XR4ED project is to conceive, establish, and uphold a sustainable on-demand educational platform with an emphasis on promoting the collaborative efforts of the European Union's education technology (EdTech) and extended reality (XR) communities. This initiative seeks to consolidate and streamline access to prevailing solutions while concurrently fostering Europe's preeminence in pioneering advancements.

XR4ED will offer a platform where educators without prior programming experience or computer science knowledge, will be able to build their own XR classes. Therefore, we need to provide a framework where any educator could be able to create a classroom, include 3D content from a marketplace, and through an easy-to-use GUI be able to create the desired educational experience adapted to the students. The overall structure of the XR4ED platform is shown in Figure 1.

At its core, XR4ED aims to facilitate educational, learning, and training endeavors. XR4ED, serving as a dynamic platform, seeks to invigorate and streamline the adoption of XR systems across educational domains. Crucially, this initiative also confronts issues pertaining to accessibility by affording a unified hub for all stakeholders within the XR technologies and education realms. To this end, XR4ED encompasses an exhaustive catalog of XR solutions coupled with a Marketspace, which empowers both the EdTech and XR communities to proffer and endorse their market-ready solutions. Educators, students, guardians, and educational administrators are poised to efficiently navigate and locate fitting educational resolutions tailored to their distinctive needs, concurrently acquainting themselves with the array of products available within the market landscape.

Extended reality (XR) [1] refers to a category of immersive and projected technologies that merge the physical and virtual worlds to create new environments where users can interact with digital content in more natural and intuitive ways. XR encompasses a range of technologies, including virtual reality (VR), augmented reality (AR), and mixed reality (MR). VR involves creating a fully immersive, computer-generated environment that users can experience through headsets or other specialized hardware. AR involves overlaying digital information onto the user's view of the physical world, typically using a smartphone or tablet camera. This technology can be used to enhance the user's understanding of a real-world environment or to create new, interactive experiences. MR combines elements of both VR and AR to create a hybrid experience that blends digital content with the physical world.

In XR4ED, we attempt to cover all of the above definitions including VR, AR and MR. However, the way that XR is defined in XR4ED differs from the generic XR in the following aspects:

- Has a clear and specific purpose, which is to enhance the teaching and learning process, by achieving various educational goals and outcomes, such as improving knowledge, skills,

attitudes, and behaviors (https://www.xrtoday.com/virtual-reality/the-state-of-xr-in-education-and-training-in-2022/).
- Requires a pedagogical and instructional design approach, which involves aligning the XR content and interaction with the learning objectives, the learner characteristics, and the assessment methods [2].
- Faces different challenges and opportunities, such as the cost and accessibility of XR devices and platforms as well as the ethical and social implications of XR technologies (https://www.purdue.edu/innovativelearning/teaching/module/extended-reality-xr/).

Technologically speaking there are also differences between the XR4ED solution compared to other educational XR solutions. This includes the following aspects:

- A lot of support on social XR environments with emphasis on realistic representations on humans including realistic body language, eye gaze, head motion and lip-synchronization.
- Artificial Intelligence (AI) takes care of the interpretation of the teaching material allowing for interactive discussion between intelligent teachers and students.
- AI generative content for generating teaching material that can be used by the educators to create their own XR learning experiences.
- Integration of multilingual support for XR teaching scenarios (i.e., lectures and seminars) into the classroom.
- Activation of various panoramas, allowing users to immerse themselves fully in the educational content while obscuring physical surroundings.
- PowerPoint, textual and video Integration allows for hybrid, interactive and immersive XR learning experiences.
- A marketplace that allows not only educators but also any developer to upload relevant content (i.e., 3D models, avatars, videos, textual information, images, animations, sounds, powerpoint presentations and other documentation) that can be used for teaching and learning purposes.
- A user-friendly authoring tool allowing the educators to easily design, create and deploy their own XR learning experiences.

This is thus a very ambitious project since the range of challenges for each of these two ends of the XR concept can be quite different. However, for educational purposes, sometimes AR may be desirable because the overlay that it provides adds virtual content over real world objects, and thus allows us for example to see a real patient with overlaid internal organs so that we can better understand the relative positions of those organs. On the other extreme, we may want to be immersed inside a virtual heart and from there, follow the flow of blood through the body to better understand the inside of the organs.

At XR4ED our goal is to build a novel platform that can offer both ends of the XR concept and seamlessly allow us to move from one end to another, to adjust the educators' syllabus to the concepts being

explained. In VR we wish the educator to easily build applications where full 3D virtual words can be created and provide customizable interaction and navigation metaphors. This will allow the educator to decide the most suitable ways in which the student could navigate and collaborate with others. In AR we may not need navigation, since we display the information with respect to the real environment, and we may also not need avatars representing the other users, but they can improve the learning experience as virtual teachers that adjust the lesson, vocabulary and depth of contents to the student age and leaning abilities.

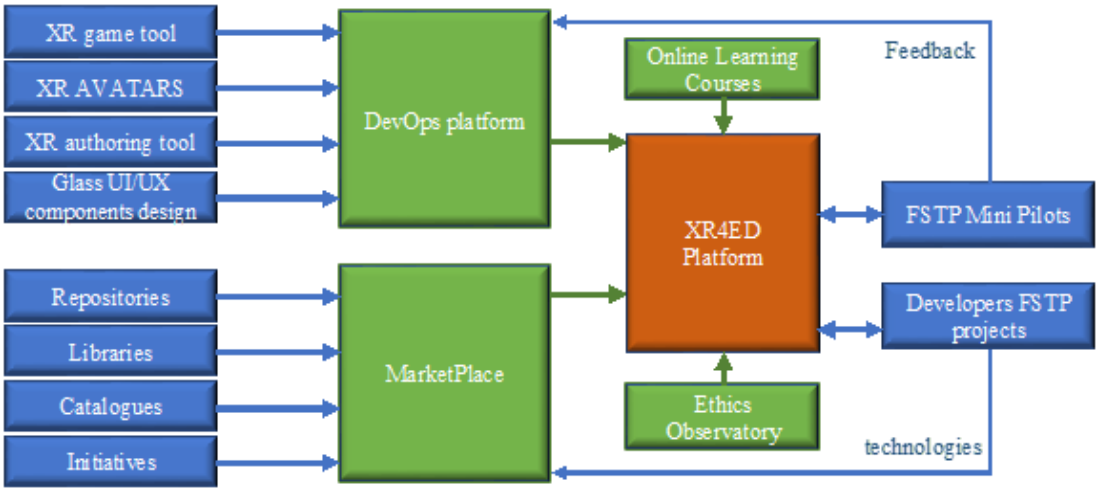


Figure 1. XR4ED overview

2.1 XR DevOps Platforms

The DevOps platform will be a web-based application that integrates with multiple 3rd party tools to provide DevOps services but also with collaborative tools. The platform will also provide integration possibilities with pedagogical add-ons to the XR applications. It will use REST APIs for connection with the back-end. The back-end of the DevOps platform will be built on PHP and will use cloud services for security and scalability. The users will be able to login also through their GitHub accounts, this will provide us with easy onboarding.

2.2 XR Marketplace

The marketplace is a web-based application dedicated to desktop computers (see Figure 2). Users will be able to visualize a preview of the services with a brief description of them. Any external user can

create/prepare external applications so they can be integrated with XR4ED services via Marketplace. In this document we provide a list of existing repositories and libraries with 3D resources that could be incorporated in XR4ED marketplace in order to build virtual classrooms, obtain 3D models of objects needed for the lessons, or avatars that will enhance the collaborative experience of the classroom.

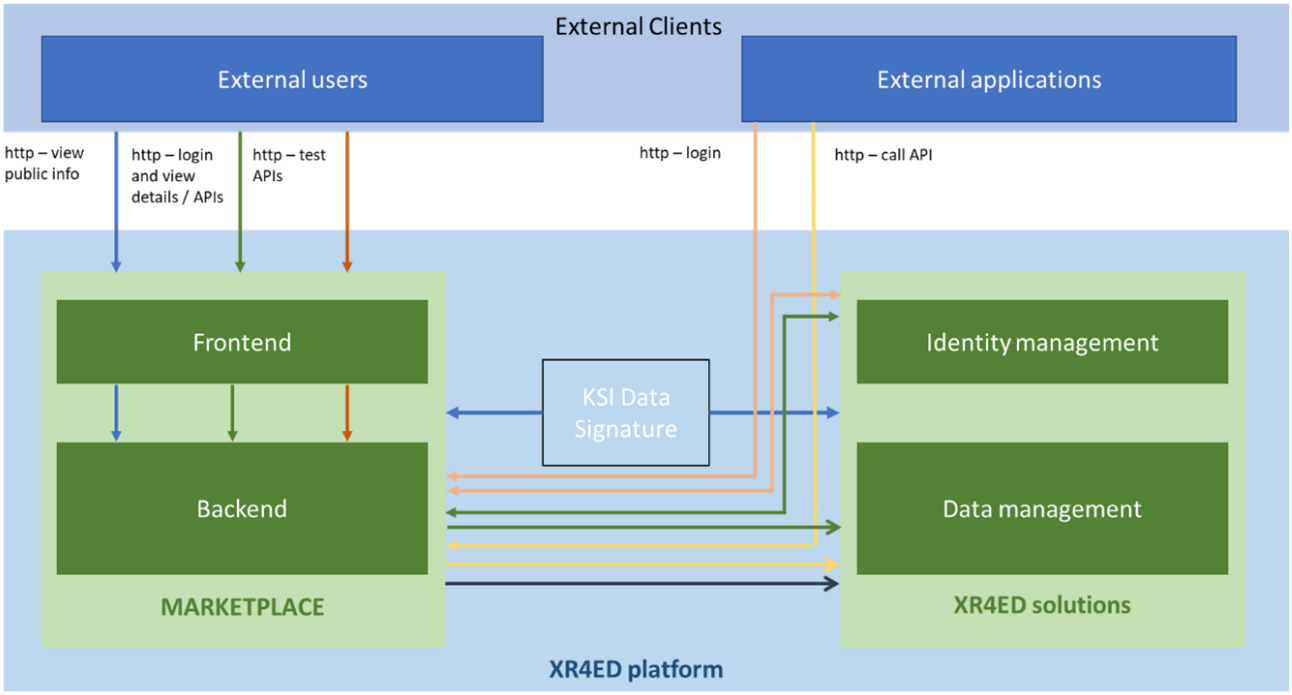


Figure 2. XR4ED marketplace

3 Existing repositories, APIs, platforms and tools for XR

In this section we summarize a list of existing APIs and tools to develop XR applications. More specifically the following ones:

- XR Unity Framework
- VRTK
- OpenXR
- OpenVR
- WebXR

3.1 XR Unity Framework

Unity enables the development of extended reality (XR) applications across multiple platforms and devices with its XR plug-in framework. Additionally, Unity offers a set of packages that add features and developer tools for building XR games and applications. The Unity packages that support XR development are divided into two categories: XR provider plug-ins and feature and tool support packages.

XR provider plug-ins provide support for XR devices and platforms. For instance, the Apple ARKit plug-in enables augmented reality (AR) applications to run on iOS devices, and the OpenXR plug-in allows applications to run on multiple VR and mixed reality (MR) systems.

Feature and tool support packages offer features and tools for developing XR applications. For example, the XR Interaction Toolkit package provides a set of tools for creating interactive experiences in XR.

The XR Unity Framework is the foundation for XR development in Unity. You can add support for an XR device to a project by installing and activating the relevant XR plug-in. You can add or remove plug-ins from a project at any time. Unity supports many XR plug-ins, such as the Oculus plug-in, which supports Oculus Rift, Meta Quest 2, and Quest Pro devices, and the OpenXR plug-in, which supports any device with an OpenXR runtime, including Meta headsets, Vive headsets, Valve SteamVR, HoloLens, Windows Mixed Reality, and others.

3.2 VRTK

The Virtual Reality ToolKit (VRTK) is a collection of reusable solutions for common problems in VR development. VRTK aims to increase productivity by speeding up the process of creating VR experiences, from prototyping to building complete solutions.

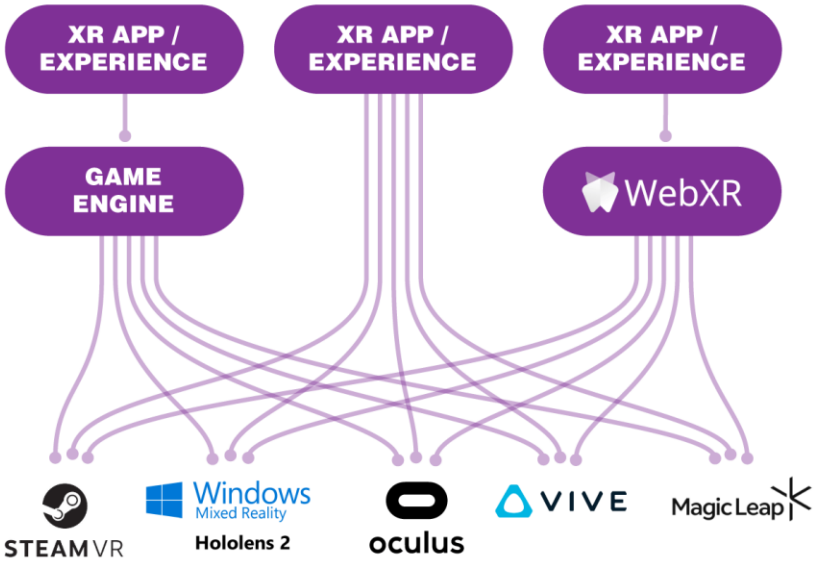
The developers behind VRTK are passionate about making VR development accessible to everyone, from experienced developers to beginners who have a great idea but don't know how to bring it to life. VRTK is designed to be easy to understand, so even beginners can feel comfortable turning their creative ideas into experiences. However, VRTK also has enough power and flexibility to allow developers to build their perfect solutions without having to reinvent the wheel.

VRTK is released under the MIT License, which means it is free to use for personal or commercial projects. It is available to download from GitHub or the Unity Asset Store: https://github.com/ExtendRealityLtd https://assetstore.unity.com/packages/tools/utilities/vrtk-v4-tilia-package-importer-214936

3.3 OpenXR

https://www.khronos.org/openxr/

To program an eXtended Reality (XR) application involving a specific device for a specific platform, applications and engines should use the proprietary code of the device manufacturer for that platform. That process should be repeated and adapted for different devices and platforms. So, without a suitable standard, XR applications and engines require specific extra work for each platform, and each new input device needs customized driver integration.



Before OpenXR: Applications and engines needed separate proprietary code for each device on the market.

Figure 3. Tools for XR development and integration with dedicated SDKs

Developed by the Khronos Group (a consortium of companies that includes AMD, Apple, Arm, Google, IBM, Intel, and Nvidia, among others) OpenXR is the OpenGL of the XR ecosystem. It is an open-source, cross-platform, and royalty-free software platform that enables the creation of XR experiences by providing high-performance access directly into diverse XR device runtimes across multiple platforms.

OpenXR provides a set of APIs that allow developers to access the hardware and software capabilities of a wide range of devices, including smartphones, tablets, PCs, and head-mounted displays (HMDs). These APIs provide a standardized way for developers to access features such as cameras, sensors, and display devices, which allows them to create XR experiences that are consistent across different devices and platforms.

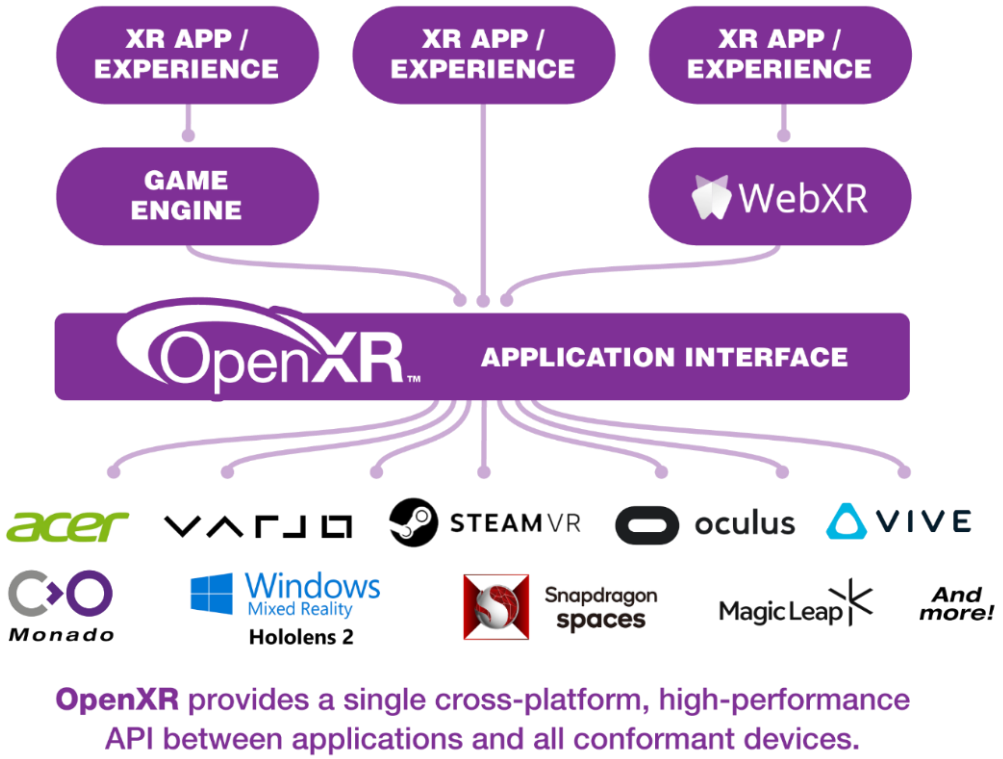


Figure 4. OpenXR current API

Developers can create experiences that are platform-agnostic, meaning they can be deployed on a variety of devices without the need for custom code or modifications. This makes it easier for developers to reach a wider audience and for users to access a wider range of applications.

OpenXR also provides integration with popular game engines such as Unity and Unreal Engine, integration with popular operating systems such as Android and iOS, and support for a wide range of programming languages, including C++, Java, and Python.

3.4 OpenVR

https://github.com/ValveSoftware/openvr

OpenVR is an open-source programming interface created by Valve to allow communication with a VR system. Up until recently, and thanks to its openness and support from its creators, OpenVR was supported by almost any of the major high-end headsets there was in the market (HTC Vive, Oculus Rift),

and even some mobile headsets. That means that if we used this API for talking with the virtual reality system in our VR application, we were able to run it in each one of the previously mentioned platforms with zero modifications.

The OpenVR and OpenXR both are competitive standards: they are both open-source codebases that allow developers to create a broad range of devices that would be compatible with virtual reality or augmented reality. But it turns out that being more recent, OpenXR is compatible with OpenVR, meaning that you could use any OpenVR compatible device through its correspondent API within OpenVR.

3.5 WebXR

https://immersiveweb.dev/

The WebXR Device API provides access to input (pose information from headset and controllers) and output (hardware display) capabilities commonly associated with XR devices. It allows you develop and host VR and AR experiences on the web.

Some of the benefits of doing XR on the web include having an instant deployment to every XR platform with a WebXR enabled web browser, and compatibility with new hardware that might appear in the future. Also, no app stores or large downloads are required because users get immediate access to your experience without needing to leave your web site.

Finally, since the rendering is handled by WebGL, which has been around since 2011, you gain the benefit of WebGL's rich development tool ecosystem and a large, active developer community.

Therefore, WebXR defines a standard API for all devices, the same way OpenXR and OpenVR do, but focusing on integrating devices into our browsers.

4 Augmented Reality Toolkits

Augmented reality (AR) involves overlaying digital information onto the user's view of the physical world, typically using a smartphone or tablet camera. This technology can be used to enhance the user's understanding of a real-world environment or to create new, interactive experiences. AR experiences are typically engaging and captivating for users. AR toolkits empower developers to create interactive content that captures users' attention and delivers a memorable experience. These toolkits are generic, but they vary a lot in terms of functionality and offer different possibilities. The effectiveness of an AR software tool depends on your specific use case, technical requirements, and development expertise. Some of them make it easier for educators to design educational AR experiences whereas others require the knowledge of programming skills. This section first gives a brief overview of challenges for developing AR applications. Then it displays why AR Toolkits are useful for modern AR development. Finally, it describes the most important AR toolkits that can be used in the XR4ED project.

4.1 Challenges for Developing AR Applications

The design and development of AR applications has two main technical challenges: estimating the camera's position and orientation (pose) in the real world (called tracking), and superimposing multimedia content with images taken from the camera (called registration). When a user is moving, the position is changed in terms of position and orientation and the superimposed information (i.e., 3D models, images, text, videos, and sounds) must remain aligned with the position and orientation of real objects. The alignment of superimposed information in the real environment depends on accurate tracking of the viewing pose. This must be calculated relative to the real environment and the annotated objects. As a result, a key capability for accomplishing correct alignment is a tracking system that accurately estimates the user's 6 DOF pose (or camera pose if the user views the world through a camera).

The AR tracking solutions are classified in sensor-based, vision-based, and hybrid tracking techniques. The latest software development in AR toolkits allows us to make use of the state-of-the-art solutions and achieve very reliable applications. Sensor-based tracking techniques are based on sensors such as magnetic, acoustic, inertial, optical and/or mechanical sensors. They all have their advantages and disadvantages which are out of the scope of this deliverable to be discussed. Vision-based tracking techniques use image information to track the position and orientation of a camera. Computer vision methods are used to calculate the camera pose relative to the real-world objects. Some algorithms use fiducial markers in prepared environments (marker-based tracking) while others are based on a marker less approach. Many hybrid tracking solutions combine sensors and computer vision technologies to provide closed loop-type tracking. Vision-based tracking has low jitter and no drift, but it is slow, and outliers can occur. Compared to vision-based tracking methods, sensors tracking offers attractive

complementary features. It is fast and robust and can be used for motion prediction when rapid changes occur.

4.2 Usefulness of AR Toolkits

AR toolkits provide developers and creators with the tools, resources, and frameworks needed to create engaging and interactive AR experiences. They allow developers to harness the potential of AR without having to master complex technical details which are usually algorithmically very complex. AR toolkits can be used across various industries, including gaming, education, marketing, healthcare, manufacturing, and more. This versatility allows developers to create AR experiences tailored to different needs. They also streamline the development process, encourage innovation, and contribute to the development and adoption of AR technology in various fields. They are nowadays useful for the following reasons:

- Rapid Prototyping: This is probably the most significant reason why AR toolkits are essential. Programmers can quickly prototype and test ideas, iterating on concepts and refining their applications without the need for extensive coding from scratch.
- Cross-Platform: Most AR toolkits are designed to work on multiple platforms, such as iOS, Android, and web browsers. This enables developers to reach a broader audience and target users across different devices.
- Advanced Features: The latest progress in computer graphics as well as computer vision algorithms have been incorporated in several AR toolkits. As a result, they incorporate advanced AR features allowing developers to create more immersive and interactive experiences.
- Performance: AR toolkits are designed for stable and reliable performance. They undergo extensive testing and optimization, ensuring that AR experiences work well across different devices and platforms.
- Efficiency: They provide several pre-made components and functionality, saving developers time and effort. These components can include features such as tracking, recognition, visualization, and interaction, allowing developers to focus on the creative aspects of their projects. They also provide a cost-effective solution by eliminating the need to build everything from the ground up
- Community Support: Another very important aspect is that the popular AR toolkits have active developer communities. This provides a platform for sharing knowledge, tutorials, code samples, and troubleshooting, fostering collaboration and learning. Unfortunately, this is the case only for the well-established ones.
- Learning Curve: For those just starting out in AR, understanding the fundamentals of AR can be daunting. AR Toolkits makes learning much easier by providing user-friendly interface and documentation.
- Ease of Development: AR toolkits abstract complex technical processes, making it easier for developers with varying levels of expertise to create AR applications without starting from

scratch. They also allow for customization. Developers can adjust parameters, behaviors, and interactions to match their specific project requirements.

In the case that no extensive programming knowledge is required for designing interactive AR experiences for the classroom, recent research has examined 26 AR toolkits, and identified only five toolkits as shown in Figure 5 [3].

Toolkit	*Programming Skills*	*Level of Interactivity*	*Source [Date of Access]*
ARToolkit	High	static	ARToolKit (2021)
osgART	High	static	OSGART (2021)
ImageTclAR	medium	dynamic	ImageTcl (2021)
Studierstube	High	dynamic	Studierstube (2021)
DWARF	High	dynamic	Dwarf (2021)
Instant Reality	High	dynamic	InstantReality (2021)
Google Poly	Low	static	GooglePoly (2021)
Unity	High	dynamic	Unity (2021)
Unreal Engine	High	dynamic	Engine (2021)
Google ARCore	high	static	ARCore (2021)
ARKit	high	dynamic	ARKit (2021)
Layar	high	static	Layar (2021)
Vuforia Studio	low	dynamic	Vuforia (2021a)
Blippar	low	dynamic	Blippar (2021)
Wikitude	high	static	Wikitude (2021)
Metaio	low	static	Metaio (2021)
AWE	low	dynamic	AWE (2021)
AR Media Studio	low	dynamic	Inglobe Technologies (2021a)
Spark AR Studio	medium	dynamic	SparkAR (2021)
Snapchat Lens Studio	medium	dynamic	Snap Inc. (2021)
A-Frame	medium	dynamic	A-Frame (2021)
MR Toolkit	high	dynamic	MRToolkit (2021)
DesignAR	low	static	Designar (2021)
MagicBook	low	static	MagicBook (2021)
VEDILS	low	static	Vedils (2021)
Areeka	low	dynamic	Areeka (2021)

Figure 5 Toolkits according to programming skills and level of interactivity [3]

According to the survey in [3], there are several tools which require a low amount of programing skills. However, apart from Vuforia Studio, the level of functionality available is limited compared to the more technologically advanced toolkits (ARCore and ARKit). In such cases, the use of an authoring tool is also required so that educators can design effective classroom experiences.

4.3 Important AR Toolkits

4.3.1 Google ARCore (Android)

https://developers.google.com/ar

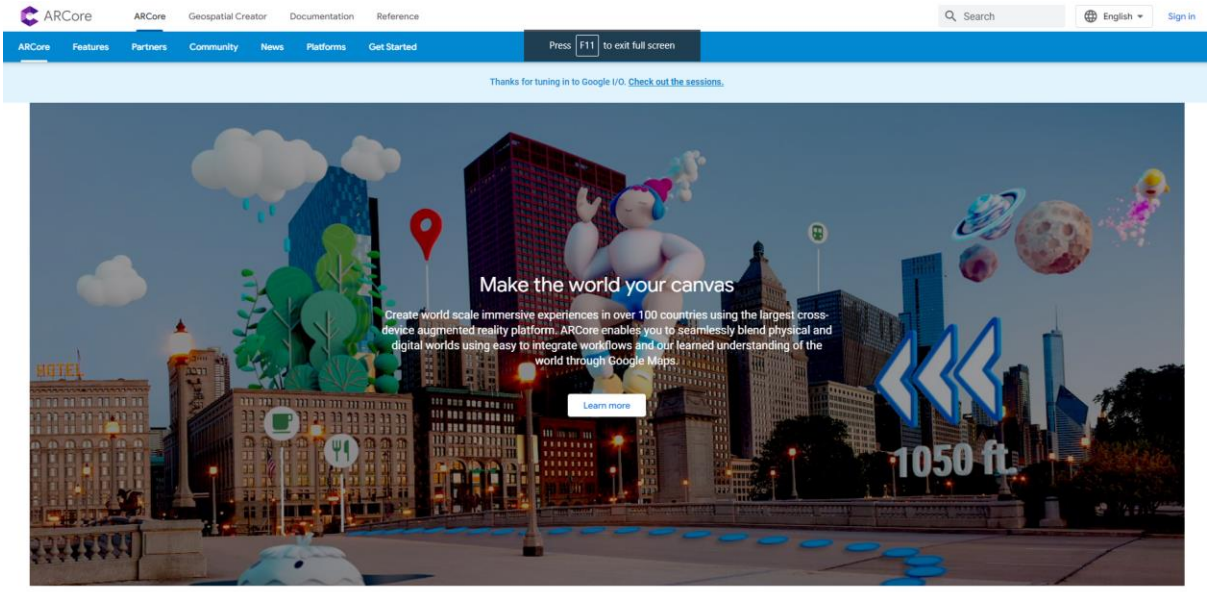


Figure 6. Google ARCore

ARCore provides several tools for creating interactive AR experiences. The SDK is offering cross-platform APIs to build new immersive experiences on Android, iOS, Unity, and Web. In addition to tracking the location of the mobile device as it moves, ARCore is also developing its own perception of the outside world. The motion tracking component of ARCore uses the phone's camera to find interesting objects, or features, and monitors their movement over time. ARCore determines the location and orientation of the phone as it moves across space using a combination of the movement of these points and information from the phone's inertial sensors. The mobile device that uses ARCore can estimate the environment's current illumination conditions through light estimation. It can also determine the size and placement of flat horizontal surfaces like the ground or a coffee table thanks to environmental understanding.

4.3.2 ARKit and RealityKit (iOS)

https://developer.apple.com/augmented-reality/

ARKit is focused for iOS but similarly to ARCore it uses Visual Inertial Odometry (VIO) to accurately track the environment without the use of markers. Without the need for additional calibration, VIO uses Core Motion data and camera sensor data to enable high accuracy tracking. The ability to analyze the viewpoint and locate horizontal planes in space is a feature of ARKit. ARKit can track and place objects

on smaller feature points as well as detect horizontal planes like floors and tables. This could be advantageous for experiments in the classroom.

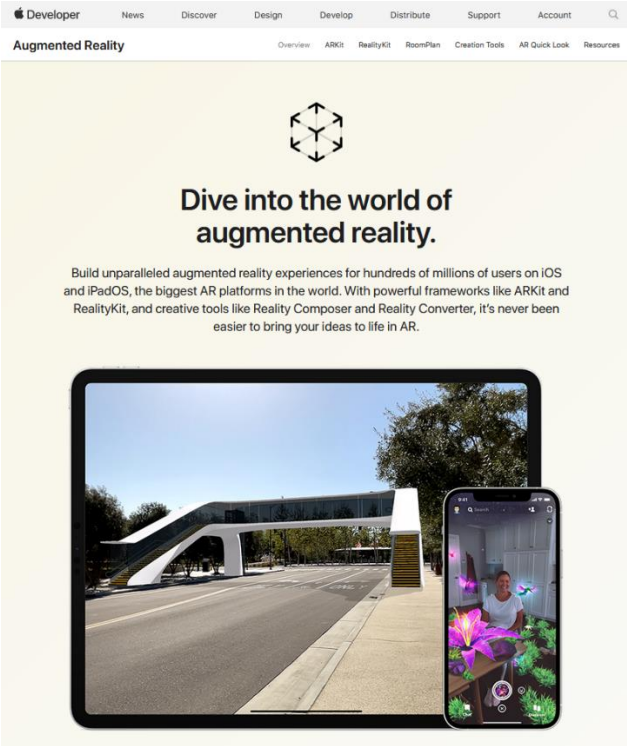


Figure 7. ARKit and RealityKit (iOS)

Apple also offers RealityKit, where it is possible to easily customize and control the AR experiences that are developed. The programmer has more control over the rendering pipeline and more flexibility to build entirely new worlds in augmented reality with APIs like Custom Rendering, Metal Shaders, and Post Processing. Additionally, using cutting-edge photogrammetry algorithms and the Object Capture API, it is possible to quickly create one-of-a-kind 3D objects that are optimized for AR.

4.3.3 Wikitude

https://www.wikitude.com/

Wikitude is another mobile AR technology toolkit which provides a development framework utilizing image recognition and tracking, and geolocation technologies. The SDK includes several features such as image recognition and tracking, 3D model rendering, video overlay, location-based AR and SLAM technology. The cross-platform SDK is available for Android, iOS and Windows operating systems. One

of its strengths is the ability to create AR content that is linked to specific geographic locations, making it suitable for applications like tourism, real estate, and navigation.

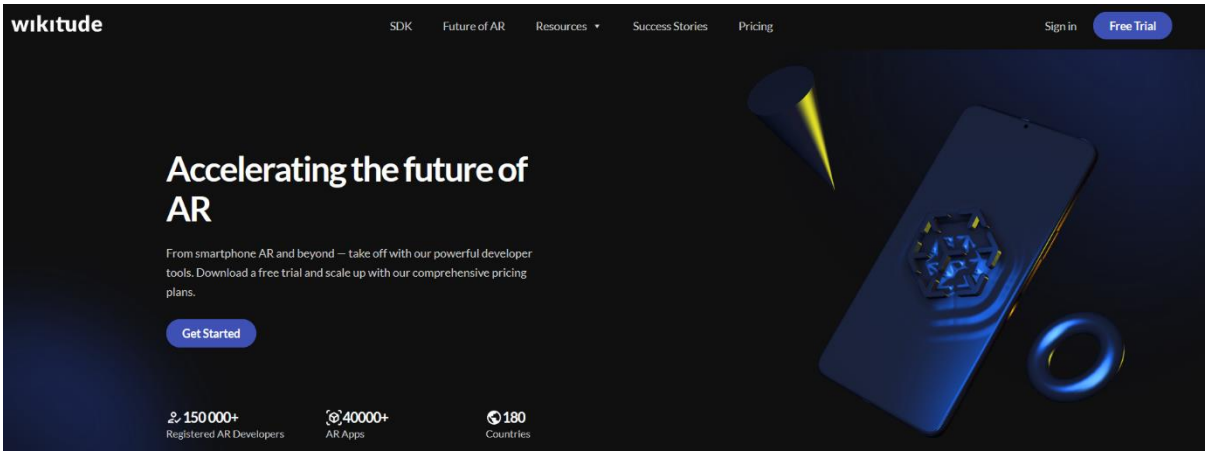


Figure 8. Wikitude

On the downside, depending on the complexity of the desired AR experiences, there might be a learning curve associated with mastering the tools and features that Wikitude provides. Also, while Wikitude offers a free trial version, access to certain advanced features or commercial usage may require purchasing a subscription or licensing, which could be a consideration for smaller development teams or individuals.

4.3.4 Vuforia

https://developer.vuforia.com/

Vuforia is an AR platform by PTC that specializes in computer vision and object recognition. It's often used for creating marker-based AR applications where real-world images act as triggers for digital content. Vuforia provides tools for creating image targets, 3D objects targets, and even extended tracking, allowing AR experiences to be more stable and reliable. Vuforia supports extended tracking, which helps maintain AR content stability and continuity even when the markers are not directly in the camera's view. This enhances user experience by reducing tracking interruptions. Vuforia also offers a cloud recognition feature that enables developers to host image databases in the cloud, reducing the app's size and allowing for dynamic updates to recognition targets.

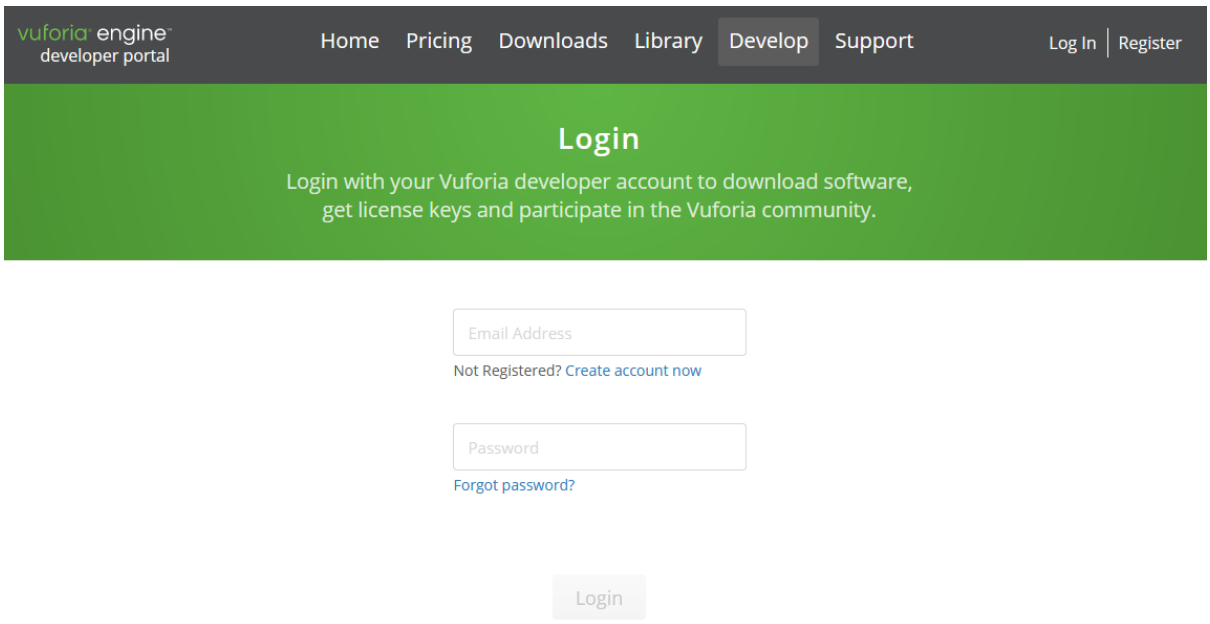


Figure 9. Vuforia

While Vuforia provides extensive features, its capabilities can be quite advanced, leading to a learning curve for new developers. Getting the most out of Vuforia might require time and effort to understand its functionalities. Moreover, integrating complex AR interactions, such as object recognition and interaction, might require additional development effort and a good understanding of the platform. Furthermore, advanced features and commercial usage might require a subscription or licensing fees.

4.3.5 Kudan

https://www.kudan.io/

Kudan's AR SDK aimed to provide developers with the tools necessary to build robust and feature-rich AR experiences. The Kudan AR SDK offered both marker-based and markerless tracking options. This versatility allowed developers to choose the best tracking method for their specific application. The SDK was designed to work on various platforms, including iOS, Android, and Unity. This cross-platform compatibility made it easier for developers to create AR apps for different devices. Kudan's SDK included features for tracking and interacting with 3D objects in the real world. This was useful for applications involving virtual object placement and interaction. SLAM technology is important for creating accurate AR experiences. Kudan incorporated SLAM capabilities to improve the tracking accuracy and stability of AR content.

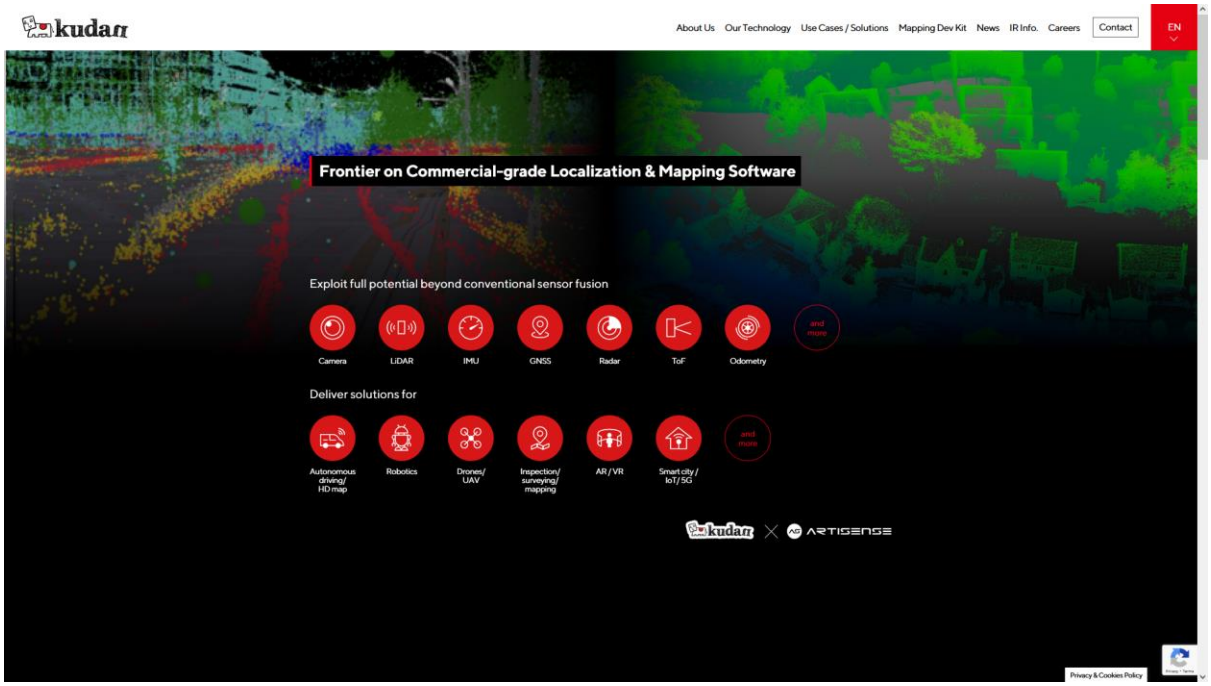


Figure 10. Kudan

On the downside the main disadvantages of the Kudan SDK are that it has a steeper learning curve compared to other AR development tools and has a limited community and resources. This might be attributed to the advanced features it offered and that it aced competition from other well-established toolkits (i.e., ARKit and ARCore). The frequency of updates, bug fixes, and support for the latest devices could be a concern for any AR development tool.

4.3.6 AR.js

https://ar-js-org.github.io/AR.js-Docs/

AR.js is an open-source JavaScript library that brings AR to the web. It allows developers to create AR experiences that can be accessed through a web browser, making it a convenient choice for sharing AR content without requiring users to install a dedicated app. AR.js utilizes markers or location-based tracking to overlay digital content onto the real world. Being open-source, AR.js is freely available for developers to use, modify, and contribute to. This fosters a collaborative community and allows for customization to meet specific project needs. Developers can customize the appearance, behavior, and interaction of AR content created with AR.js. This flexibility enables the creation of unique and engaging AR experiences.

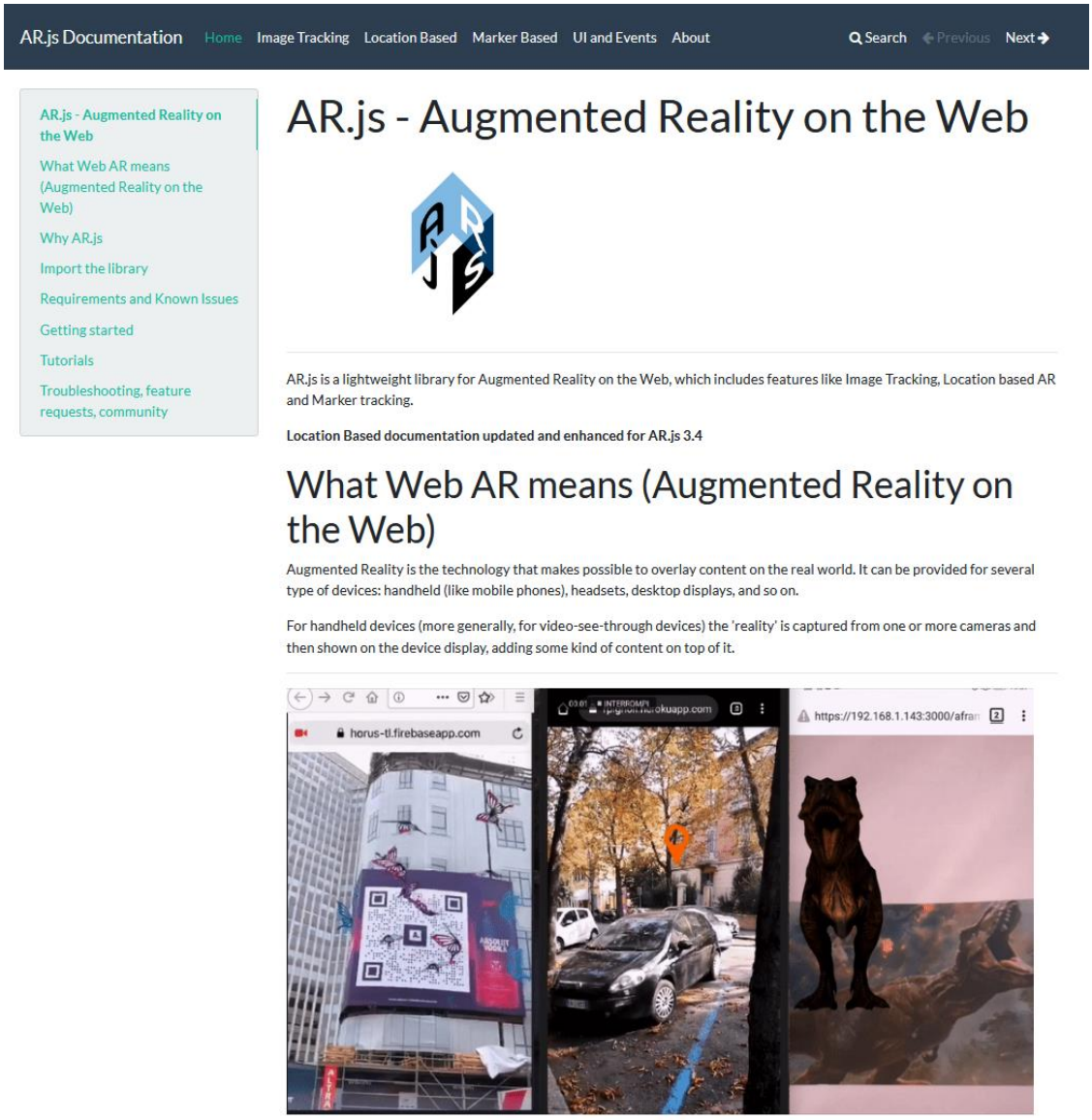


Figure 11. Ar.js

While AR.js offers marker-based AR experiences, it lacks some of the advanced features provided by dedicated AR development platforms. Moreover, the web-based AR experiences might not achieve the same level of performance and optimization as native AR applications, especially for complex or resource-intensive experiences. Finally, the quality of the AR experience can vary depending on the user's device, browser, and internet connection.

4.3.7 ZapWorks

https://zap.works/

ZapWorks is an AR creation platform that caters to both developers and non-developers. It offers a range of tools for creating interactive AR experiences, including image tracking, 3D model integration, animations, and scripting. ZapWorks aims to make AR development accessible to a wider audience with its user-friendly interface. While aimed at non-developers, ZapWorks also offers scripting capabilities for those who want to add custom functionality to their AR experiences. It provides a library of pre-made templates that users can modify and customize to create AR experiences quickly and the AR experiences can be published to iOS and Android devices, ensuring a wide reach among smartphone users.

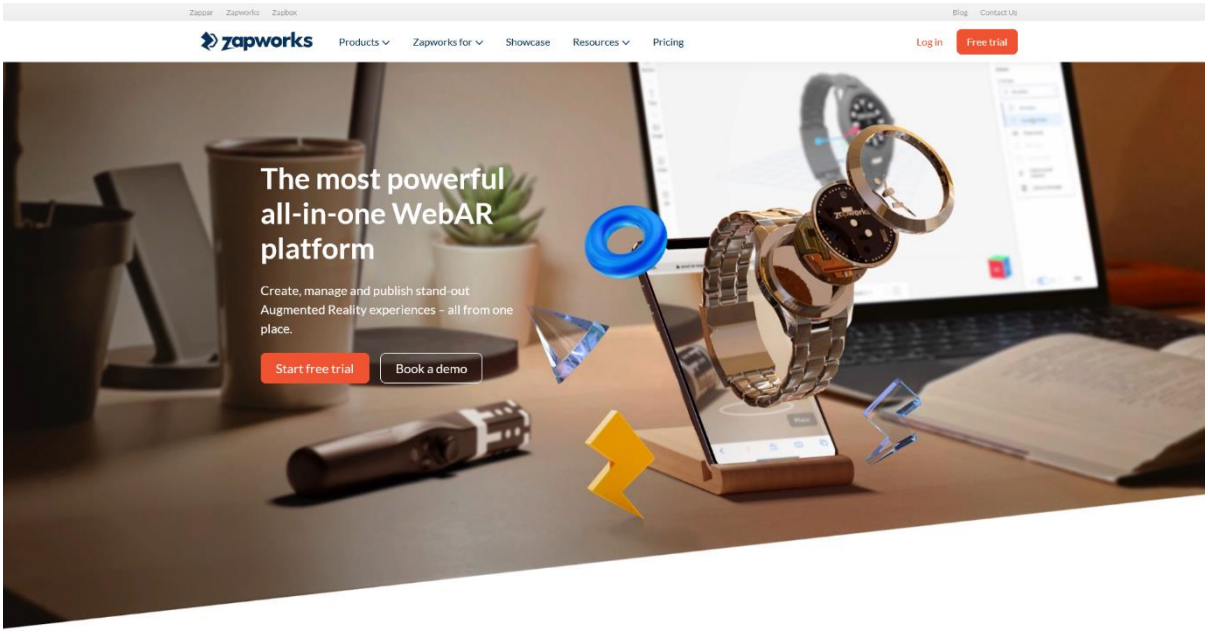


Figure 12. ZapWorks

While the platform is designed to be user-friendly, more advanced features or complex interactions might still require some learning and experimentation, even for non-developers. Moreover, it operates on a subscription-based model, and the cost might be a factor for individuals or small teams with limited budgets. Finally, to distribute AR experiences created with ZapWorks on app stores, you might need to go through the process of creating and submitting apps, which might involve additional steps and requirements.

4.3.8 MaxST AR SDK

https://developer.maxst.com/

MaxST AR SDK is a software development kit that focuses on marker-based AR solutions. It offers marker tracking, image recognition, and 3D rendering capabilities. This SDK is particularly known for its robust tracking performance and is often used for industrial applications such as maintenance and training. MaxST AR SDK provides documentation and resources to guide developers through the process of integrating AR into their applications. This can be particularly helpful for those new to AR development. The AR SDK enables developers to integrate 3D models, animations, and interactive elements into their AR experiences. This feature enhances the visual quality and interactivity of the AR content.

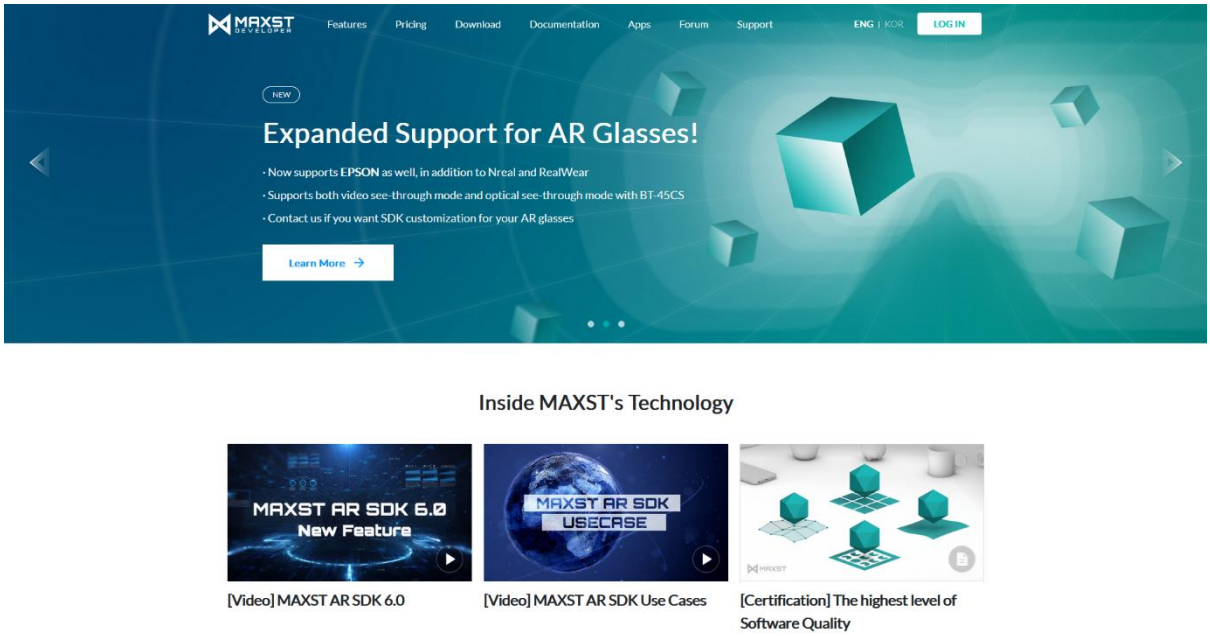


Figure 13. MaxST AR SDK

While the SDK provides strong tracking performance, working with more advanced features might have a learning curve, especially for developers who are new to AR development. Also, the AR development landscape is competitive, with other AR SDKs offering broader sets of features and more extensive developer communities. Furthermore, the SDK's capabilities such as object recognition or location-based AR are limited.

5 Existing repositories for social and collaborative XR

There are currently many popular repositories to build social VR experiences. In this section we summarize the most relevant ones that could be either incorporated in our platform or could benefit from our XR4ED tools. For example, the first one, Ubiq provides an efficient implementation of collaborative remote experiences that could be highly adequate for remote teaching. However, their current avatars are very simplistic and limited to upper body IK, so they could incorporate our more complete solutions to animate full body avatars.

In this section we have evaluated the following repositories for social VR:

- Ubiq
- RecRoom
- Mozilla Hubs
- Spatial
- VRChat
- VR United

5.1 Ubiq

https://ubiq.online/

Ubiq is a *Unity* VR networking library for research, teaching and development, maintained by the *Virtual Environments and Computer Graphics* group at *University College London*. *Ubiq*'s goal is to facilitate the development of fully collaborative VR projects. It includes message passing, room management, rendez-vous and matchmaking, object spawning, shared binary blobs, multiple synchronisation models, lighweight XR interaction examples, customisable avatars and voice chat across *Windows*, *Linux*, *Android*, *MacOS*, and *Javascript* running in the browser.

Instructions for setting up your own server are included. *Ubiq* does not rely on any third-party services, making it *GDPR*-safe for your experiments.

Ubiq is also a toolkit that focuses on facilitating the construction of Social Virtual Reality (*SVR*) systems. *Ubiq* is built on the *Unity* platform. It provides core functionality of many *SVR* systems such as connection management, voice, avatars, etc. However, its design remains easy to extend. *Ubiq* is open source (*Apache* License) and thus enables several use cases that commercial systems cannot.

Figure 14. Ubiq platform for collaborative VR

A first publication demonstrated examples and how it has been successfully used in classroom teaching: [4]. **Error! Hyperlink reference not valid.**

A more recent publication presents an extended framework called *Ubiq-Genie* for integrating external frameworks with the main *Ubiq* platform: [5].The proposed architecture of *Ubiq-Genie* is modular, allowing for easy integration of services and providing mechanisms to offload computationally intensive processes to a server. With *Ubiq-Genie* a new kind of applications can be easily implemented, such as a voice-and-gesture-controlled texture generation method based on Stable Diffusion 2.0, or an embodied conversational agent based on ChatGPT. With *Ubiq-Genie* we can reach the potential of integrating external frameworks into SVR for the creation of new types of collaborative experiences.

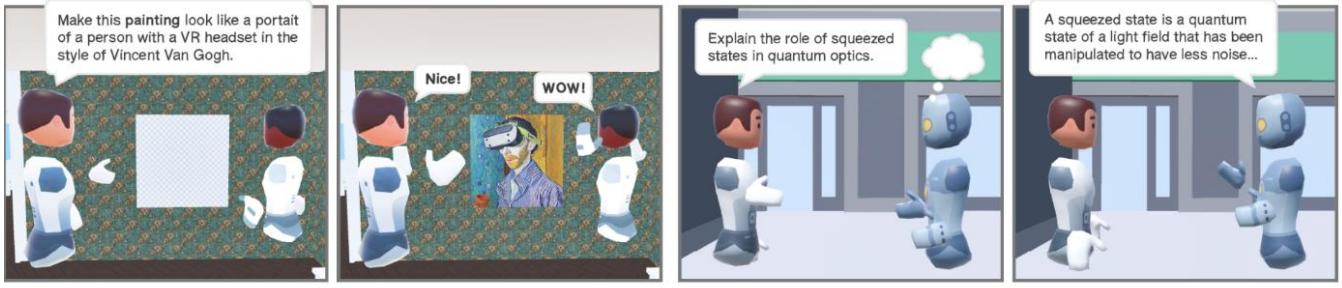


Figure 15. Example application using Ubiq.

5.2 Rec Room

https://rec.net/download

Rec Room is a place to build and play games with other people. You can party up with friends from all around the world to chat, hang out, explore player-created rooms, or even build something new to share with the world. *Rec Room* is free, and cross plays on different platforms, from phones to VR headsets. It's a social app you can play like a video game, where you can customize and dress up your cartoonish avatar, and use the *Maker Pen*, the tool used to build everything inside *Rec Room*.

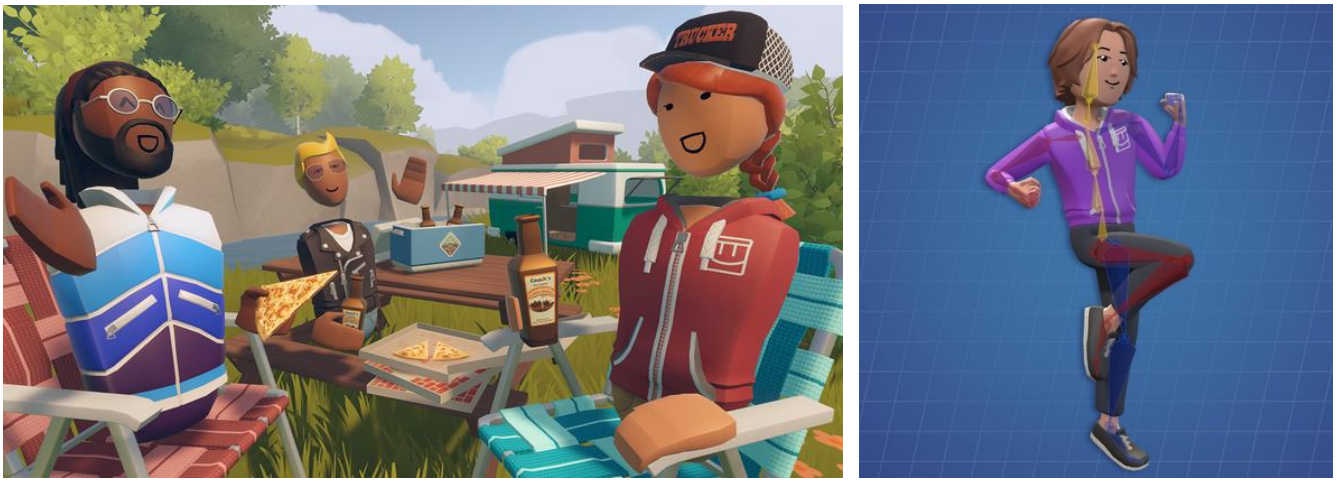


Figure 16. Rec Room for social VR (left) and full avatar (right)

Rec Room, in its *Junior Mode*, is certified by the *kidSAFE Seal Program* (https://kidsafeseal.com/aboutourprogram.html). This is an independent safety certification service and seal-of-approval program designed exclusively for children-friendly websites and technologies, including online game sites, educational services, virtual worlds, social networks, mobile apps, tablet devices, connected toys, and other similar online and interactive services.

In *Rec Room* there is a full-body avatar option. Their new avatar system sets up for full-body and finger tracking, for better movements in VR.

In *Rec Room* players can have custom rooms, meaning they can create their own rooms. These can then be used to play games, watch movies, or just hang out with friends online. The platform is a great way to socialize in VR and has a large and active community, so there are always people to play with.

5.3 Mozilla Hubs

https://hubs.mozilla.com/

Mozilla Hubs is a free, open-source, virtual reality (VR) platform that allows users to create and share 3D spaces. It is built on top of the *WebXR* standard, which means that it can be accessed from any VR headset or desktop computer. *Mozilla Hubs* can be used for a variety of purposes, including collaboration, socialization or education.

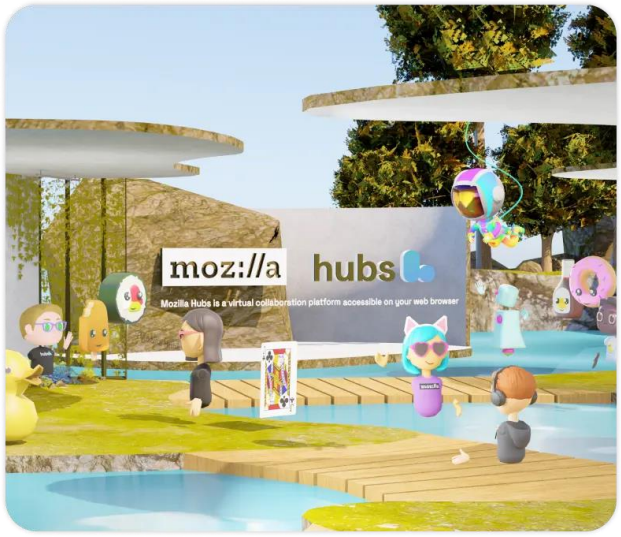


Figure 17. Mozilla Hubs VR world example

Mozilla Hubs can be used with VR. You can create a new room or join an existing room. Once in a room, you can start interacting with the environment and other users. You can use VR controllers to move around the environment, pick up objects, and interact with other users.

Mozilla Hubs has cross-platform compatibility, so you can use it with a variety of VR headsets and computers, it is free to try, open-source and has a large and active community. If you need space for more than 10 users and more than 500 MG of asset storage (for avatars and scenes), you need to subscribe and pay for monthly plans.

5.4 Spatial

https://www.spatial.io/

Spatial is a VR platform that allows users to create and share interactive 3D spaces. It is cross platform and built on top of the *WebXR* standard, which means that it can be accessed from any VR headset or desktop computer.

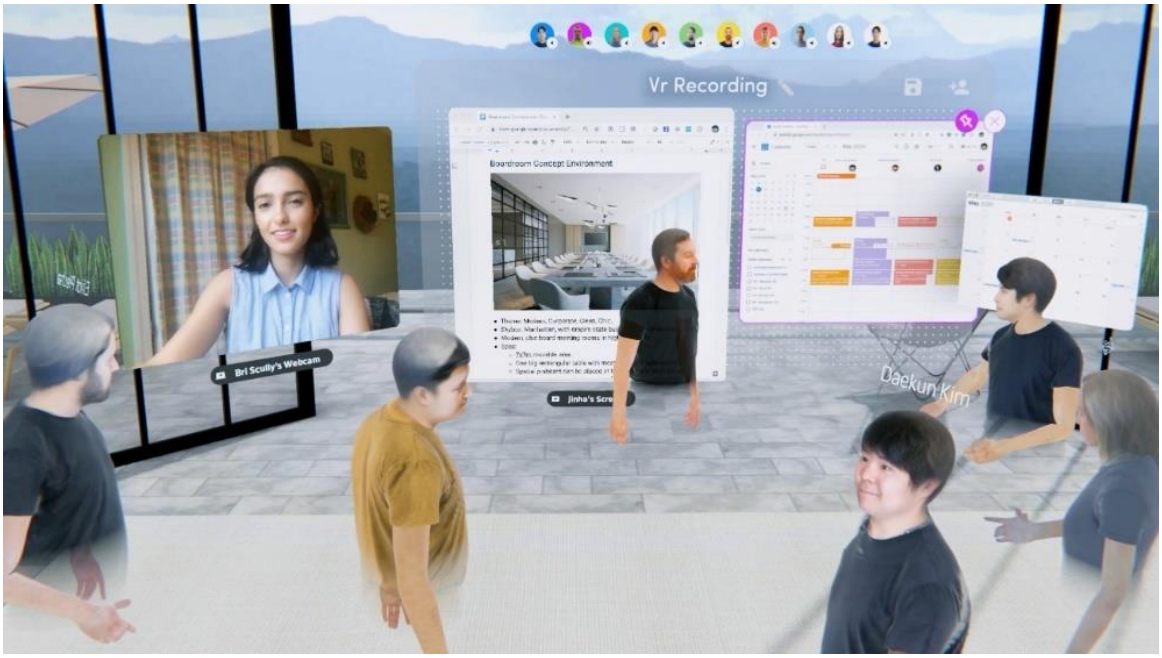


Figure 18. Spatial framework for collaborative VR

Spatial is built with *Unity*, so you can create your custom space and publish direct from *Unity* straight to a live multiplayer experience. It has an easy space creation through a drag and drop interface, with free templates, a *Sketchfab* integration, and the called *Spatial Creator Toolkit*. The *Spatial Creator Toolkit* is also powered by *Unity*, and anyone can use it, with no coding required (although it is highly recommended to be familiar with *Unity* first).

Spatial allows for avatar customization, so users can create their virtual avatars. These can also be created automatically from a frontal picture of the user. You can also use different dances and emotes (animations).

Spatial can be tried for free with a limit of 50 users in a room. For more users you need to pay a *Spatial+* subscription that allows up to 500 people in the same room.

5.5 VRChat

https://hello.vrchat.com/

VRChat is a virtual world platform where users can interact with each other using user-created avatars and 3D worlds. It can be used with virtual reality headsets or in a desktop mode. VRChat worlds are made up of thousands of connected worlds, in which players can interact with each other through virtual avatars. Avatars are created and uploaded by users using a software development kit for Unity. Avatars can be full-body, support lip syncing, eye tracking, and blinking, in addition to mimicking head and hand motion.

VRChat also has Udon, a visual programming language that uses a node graph system. A third-party compiler, UdonSharp, was developed to allow world scripts to be written in C#. A secondary application called *Creator Companion* appeared for managing projects and downloading community packages using a format compatible with the Unity Package Manager (UPM).

There is a *VRChat Plus* subscription service that allows users to display a custom avatar image on their nameplates, increases the number of avatars they can save in their favorites from 50 to 300, grants them an "increased trust rating", and allows them to attach an in-game photo to an invite request.

Figure 19. VR chat avatars

5.6 VR United

https://github.com/eventlab-projects/VRUnited_Builds

At the *EventLab*, at *Universitat de Barcelona*, directed by Professor Mel Slater., they came up with a cross platform online solution for VR: *VRUnited* is a platform that delivers any kind of shared virtual experience, which is commonly known as a Metaverse.

They offer a version compatible with the most common head-mounted display on the market (*Meta Quest*, *Pico*, *Oculus Rift*, and any *OpenXR* compatible device such as *HTC VIVE* or *Valve Index*) and *VRUnited* can also be used on a regular computer with no VR support. Regardless of the platform utilized, all attendees can share the same virtual experience.

The *VRUnited SDK* allows anyone to create a personal distribution or add new scenarios and avatars to the official *VRUnited* distribution (previous approval by the team is necessary). The *SDK* can be accessed from: https://github.com/eventlab-projects/VRUnited_SDK.

VR United has been used in a variety of remote applications such as (but not limited to) virtual meetings and conferences, concerts, interviewing a famous person as in the scope of paper, or two people playing chess remotely.

Photon Engine (https://www.photonengine.com/) is the network engine utilized by *VR United* to manage client synchronization, a strong and well-established tool used by thousands of commercial applications. When using *Photon*, all client communication is performed through the servers provided by *Photon*. This greatly simplifies the setup as we need only ensure that the clients have an Internet connection, so they can reach *Photon* servers, and that they are all connected to the same *Photon* server. The programmer can see all the networking low level information, such as firewall rules, reliability, load balancing, and other things, without any difficulty.

Upon completion of the server connection, participants must create a room or join an existing room. A room can be considered as a specific instance of the application and the client that creates the room is considered to be the Master Client. To share the same virtual experience, participants must decide beforehand which room they should all join. However, communication between different rooms is not possible by design, even if participants are connected on the same server.

An IEEE research paper demonstrating the capabilities of VR United has recently been accepted but still needs to be published.

VR United is currently a very powerful solution for embodiment, however it can only be used by experienced programmers or at least users that are familiar with the Unity 3D game engine.

Figure 20. VR united simulating a VR meeting from remote locations

6 Existing platforms for education in XR

In this section we list a large number of existing platforms that use XR for education. Besides describing the information which is publicly provided for each platform, we have also reviewed in total 12 of the listed platforms and provide our first-hand experience as testers of those platforms that are publicly available. To complete this work, we went through each of these platforms' official websites to check publicly available contents at this stage or contact them to get access to the applications. These contents range from abstract concepts to more solid single application software or hardware then to platforms that integrates multiple applications. Although some of them currently are not available to the public, however, based on the information, the development trend of XR platforms in education can still be identified to some extends. Table 1 shows a summary of these platforms.

Platform Names	Official Website	Brief Introduction
ClassVR	https://www.classvr.com	Hardware, VR headset by Avantis Education Ltd.
Eduvers	https://eduverse.com/	Educational content platform by Avantis Systems Ltd.
MEL Science VR	https://melscience.com/	Educational subscription that offers physical hands-on projects with digital experiences for guidance, some has XR technologies integrated
ARuVR	https://aruvr.com/	Content platform at concept stage
EON Reality	https://eonreality.com/	Learning and training platform with Immersive AI
GigXR	https://www.gigxr.com/	Platform integrated multiple applications for training healthcare related topics
ENGAGE	https://engagevr.io/	Platform planned to integrate XR social experiences in multiple aspects
VictoryXR	https://www.victoryxr.com/	Platform covers general XR topics such as virtual tour, VR labs, CTE training.
Unimersiv	https://unimersiv.com/	Single application previously available on Meta Unimersiv on Oculus Rift | Rift VR Games | Meta Store, but might be abandoned afterwards (No updates)

zSpace	https://zspace.com/	Integrate hardware and software together for special educational interactions with stylus.
Merge EDU	https://mergeedu.com/	Education platform allows students use physical identifier (e.g., a cube) to interact with pre-created 3D objects and simulations.
ThingLink	https://www.thinglink.com/	Education material authoring tool with some XR elements (e.g., 360 images)

Table 1. Summary of XR platforms in the market

This section includes two parts. In the first part we introduce the items based on the information we got either through trying the contents when it is available on the official websites, or by watching the demo videos that are publicly available. For those cases where the content is not available, we tried our best to extract the main concepts based on the existing information. At the end of this section, we provide a comprehensive conclusion part, where we analyzed development routes of XR education platforms based on our review, we describe the characteristics of the routes in detail with reviewed examples supported shown in Table 1.

For each of the platforms presented in this document, we first provide a brief description and then we focused our analysis based on two aspects:

What are the learning pattern(s)/case(s)/example(s) that are provided?

What interactions those platforms offer to educators?

6.1 ClassVR & Eduvers

https://www.classvr.com

ClassVR is a virtual reality (VR) platform designed specifically for educational settings. It offers a comprehensive solution that includes hardware, software, and a wide range of curriculum-aligned educational content. The platform aims to provide an immersive learning experience for students, allowing them to explore various subjects like history, science, and geography in a more interactive and engaging way.

One of the standout features of ClassVR is its user-friendly interface, which makes it easy for educators to integrate VR into their teaching methods. The platform comes with pre-loaded lesson plans and

activities, allowing teachers to hit the ground running without the need for extensive training. ClassVR also offers classroom management tools, enabling teachers to guide and monitor student interactions in the virtual environment, thus ensuring a safe and focused learning experience.

https://eduverse.com/

Avantis Education is a UK-based company that has built the "Eduverse". It is an innovative solution to bring the Metaverse to schools for immersive education. Students and teachers can interact through virtual classrooms, and access educational content in a secure and controlled environment. Eduverse is a cross-platform, web-based solution, so it works on VR headsets, tablets, phones, laptops, and computers. The platform supports remote and hybrid educational experiences.

Our analysis and experience as testers:

Class VR and Eduverse are both products produced by Avantis Ltd.. Class VR is available for use with the HMD and the Eduverse is the content platform. Eduverse expanded its compatibility with desktop and mobile devices, as well as other mainstream headsets such as Meta Quest, Vive. Eduverse has pre-created environment scenes based on specific topics, sometimes with simple animations embedded to illustrate the topic. Each pre-created scene has a corresponding learning document explaining the knowledge points shown in the scene. The document includes introduction to the topic, mission for the provided content, quiz and assignment.

Learning case example(s): For example, in "Generating Electricity" scene (Generating Electricity | Eduverse), as Figure 21shows, simple animations are embedded in the big wind fans and the generator to show how electricity are generated. The corresponding explanation provided for this topic can be turned on under the "Learn" button on the upper right side. Users should read the texts to understand the ideas behind. This explanation document could also be used by educators as a reference material on how to explain, teach or evaluate the specified content.

Figure 21 "Generating Electricity" scene

Interactions: Users can join the environment as a simple carton avatar to move around and teleport to observe objects. They can also invite others to join this room online by sharing a generated link and talk with each other. Figure 22 shows players meeting with each other in the environment. User can click the "Explore" button on the lower left to have access to all pre-created scenes and choose the topic they want to see. At current stage, no more content authoring functionalities are provided for educators.

Figure 22. Online players meet in the scene

6.2 MEL Science VR

https://melscience.com/

MEL Science is an educational platform that offers a variety of hands-on science kits and digital experiences to engage children in learning. The platform covers a range of subjects including STEM, Math, Space, Physics, and Chemistry for kids aged 5 to 16. Each kit is designed to be child-friendly and safe for home use.

In addition to physical kits, MEL Science also offers unique digital experiences through an interactive mobile app, virtual and augmented reality. These digital tools aim to make science more immersive and engaging for kids. The platform is recognized by experts and has received awards, making it a reputable choice for parents and educators looking to make science more accessible and fun for children.

Our analysis and experience as testers:

This platform provides hands-on kits with an interactive mobile app for guidance, virtual and augmented reality elements are integrated for immersive experiences to some extent. Those kits are usually physical parts that require kids to manually operate and observe to gain hands-on knowledge. The kits are designed based on topics covering STEM, Physics and Chemistry. All project demos can be found here: https://melscience.com/ES-en/sets/ . There is an application that users can install after subscription, then users can access instructions for each project. The instructions include video guidance and text explanations. Some of the hands-on projects also integrate XR elements (VR and AR).

Learning case example(s): Here we use cases which integrated XR elements for demonstration as examples. The “Hydraulic lift” project shown in Figure 23 aims to allow students to learn how and where hydraulics is used in real life by assembling a model of a real jack lift and build a simple hydraulic system. In addition to video and text guidance from the application, an augmented reality (AR) demo based on mobile phone is also created as Figure 24 shows, a virtual replica of the hydraulic lift and a virtual pig which is on the replica are generated when user turns the camera on, and the virtual replica can move with users’ hand gestures to show how the scissor mechanism works.

Figure 23. Components for "Hydraulic lift" project (The completed assembly is on the right side, the sub-parts are on the left side)

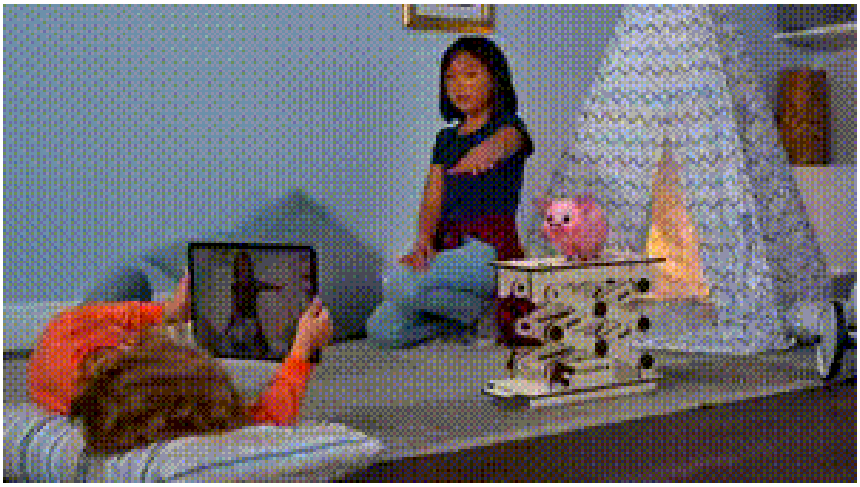


Figure 24. the AR demo for the "Hydraulic lift" project

Another VR demo shown on Mel Science's official website is exploring the virtual world in miniature scale to learn how molecules are structured by atoms (see Figure 25). However, we went through all the projects on the website and did not find one hands-on project that is related to this demo, so we assume that on one hand, VR is accepted by its immersive characteristics, and on the other hand, this VR demo is still in its initial stage.

Figure 25. VR demo for learning molecules

Interactions: the interactions are simple in this case, user just interact with the mobile phone to access the digital contents. The mobile device is used as an AR device as well to show more intuitive demo, no AR headset like Hololens are used at this stage. In VR aspect, user just observe the content with a VR headset. XR technologies are provided to visualize contents instead of authoring it, so educators cannot easily extend or incorporate new lessons.

6.3 ARuVR

https://aruvr.com/

ARuVR is a VR Education space. They provide users with the tools that are needed to build their own immersive training experiences in AR and VR, without being coding experts. It is an enterprise-grade, end-to-end platform for extended reality (XR) innovation, designed for people that do not necessarily have extensive XR knowledge. Within the ARuVR ecosystem, companies can find a comprehensive XR authoring system, real-time session controls, and live streaming tools, to provide immersive educational experiences.

Our analysis and experience as testers:

The official website of ARuVR does not contains any publicly available XR contents at this stage. Only with an invitation code from ARuVR can you try their contents (https://cloud.aruvr.com/webxr/).However, despite trying to contact them several times over a few months, we did not receive a reply. So, at this time cannot include ARuVR in our analysis and experience as testers. From their official website we infer that they are interested in developing a platform

that allows anyone without specialist XR skills to create and deliver immersive XR training experiences, which could be similar to ours but there is no information provided at the time of writing this report.

6.4 EON Reality

https://eonreality.com/

EON Reality is a company that focuses on bringing augmented reality and virtual reality to academic and industrial settings. It aims to make the technology accessible to educators, trainers, employers, and the general public without requiring advanced technical skills. The platform allows users to create interactive and immersive AR and VR lessons that can be distributed across various devices, from smartphones to laptops to publicly available headsets. Their XR platform, EON-XR, is designed to prepare millions of students, employees, and citizens for the present and future, replacing traditional training and teaching methods.

The platform is built with educators, trainers, and employers in mind, making it easy and accessible for anyone with a stable internet connection and a relatively modern smartphone or computer. It offers various features like voice-over recording, text-to-speech annotations, embedded videos, interactive activities, and multiple forms of assessments. EON-XR aims to make the transition from traditional training methods to AR and VR as seamless as possible, allowing subject matter experts to share their knowledge without having to learn complex coding or development tools.

Our analysis and experience as testers:

EON reality focus on developing a knowledge platform to support immersive learning and training with the help from a large AI language model. Educators can use the platform to easily generate contents based on AI and edit the contents according to their needs.

Learning case example(s): Eon reality just released a video demo showing the functionalities of their most recent version: (https://youtu.be/QKEM1gWAF9c?feature=shared). The demo shows their extended reality AI assistant avatar that takes information from large language models and embodies that information through the avatar by showing and guiding people in extended reality. The demo shows a specific case in the area of knowledge transfer.

Course Creator: User first select an AI avatar to shape the education level of the course and the tone and style of the AI assistant, if a university professor avatar is selected, the generated course content's knowledge level would be higher to match the target audience (university students). However, if primary school persona is selected, the generated content would be simpler to make it easier to understand for primary students. (overall, 5 catalog of courses samples are provided and curated: University, TVET/CTE, Community College, K-12 and Custom). All course topics are classified into 2 categories: Hard Skills and Soft Skills. Hard skills deal with more concrete practical skills such as construction training and nurse

training. Soft skills focus more on interpersonal social skills. Then, keywords combinations are provided under different topics for users to choose from to give a prompt to the AI system to generate contents. The system first provides a bunch of images based on users' previous selection for users to choose as the overview picture for the course. User then can give the choice on whether they want the AI assistant to explain the functionalities of specific parts as they explore or give an overall step-by-step explanation.

Their demo shows the Organic Chemistry Lab Techniques as in Figure 26. The system then generates the subtopics concepts explanations related to the topic of interest as shown in Figure 27. Each concept explanation includes text, images and videos. The AI assistant will then point to each of the concepts and start text-to-voice explanation. User can also choose which one they want to check. Users can edit the generated content by changing the text, image and video embedded, or by searching for related 3D models, they can also add more objects, voice annotations, 3D recordings, etc. Assessment templates like quizzes and assignments are also generated. If the user is satisfied with the course contents, they can save and publish the course to the platform or sell on marketplace, as Figure 28 shows. An AI report will be generated, which includes all the media materials (text, image, video, link, etc.) used in the course.

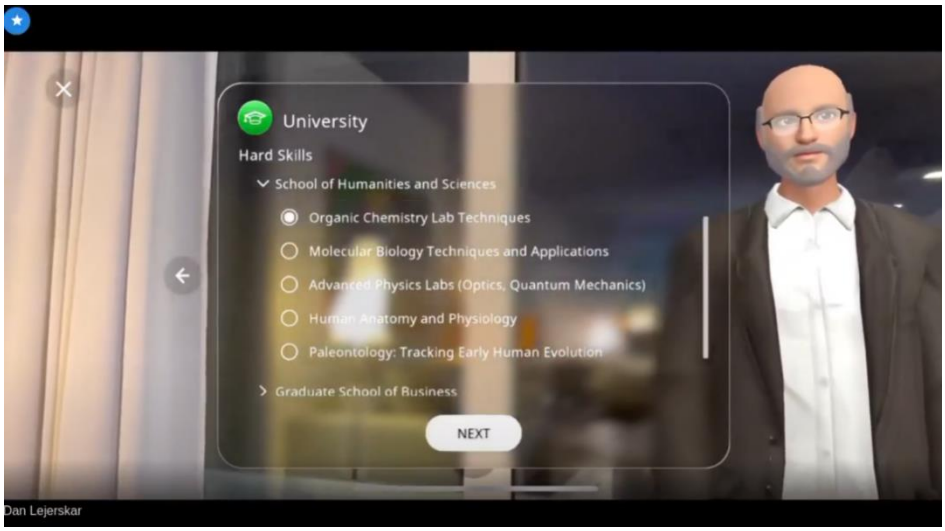


Figure 26. User select the topics to generate course contents.

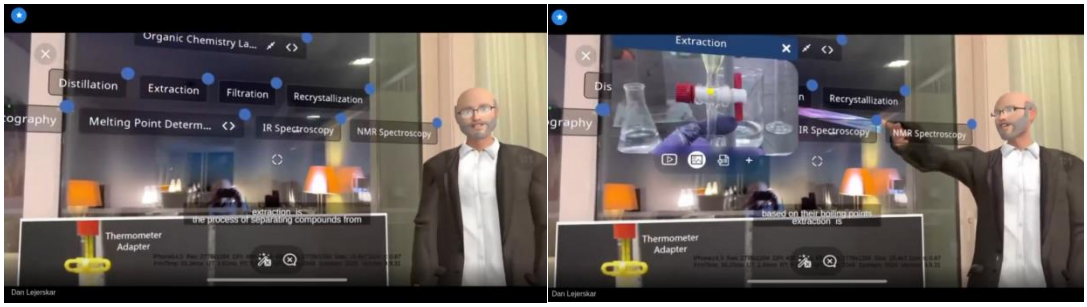


Figure 27. System generates concepts related to the selected topics.

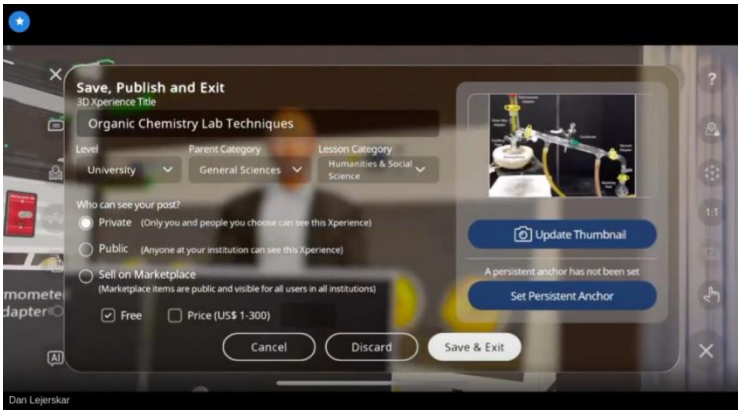


Figure 28. Save and publish the course contents.

Interactions: From the demo video we observe that user can access this app through mobile device and desktop. User can move around in the physical space holding the mobile device in their hands, and the system updates the users' position and rotation in the virtual space. Users get the generated course contents by inputting keywords related to the topic, either through the way of selecting provided keywords components, or customize the input by themselves. If they embed 3D models inside, depending on the name of sub-parts, the system generates explanations as well. By sharing a link, they can invite others to join the same room. They can also talk directly with the AI assistant in some cases for input answers to an assignment question. In addition, since the course contents are generated each time its used, then the contents will be a little different. They provide a large library for different topics (https://core.eon-xr.com/Library/Index_V2). Please note that all the content included in this report has been obtained from the company's Youtube presentation, but that we have not been able to get access to the platform to properly test it as educators trying to create new content for a lesson.

6.5 Prisms

https://www.prismsvr.com/

The Prisms of Reality platform is an e-learning environment with VR technology built-in. It provides an assistive VR teaching tool that aids students learning algebra, using intuitive visualizations displayed within an immersive VR environment.

Prisms of Reality leverages best-practice pedagogy with immersive tactile environments, to help students connect core concepts of Algebra and geometry. The virtual learning environments are customizable for the teacher, to observe real-time analytics and insights of students' progress. Current topics included are Geometry, Calculus, Physical Sciences, and Physics.

6.6 GigXR

https://www.gigxr.com/

The GigXR immersive learning platform, specializes on the healthcare industry and provides companies with access to a full library of holographic applications. With immersive applications, GigXR aims to eliminate the need for expensive cadavers, mannequins or simulated patients.

GigXR has created a host of different learning modules for various use cases. There is a "HoloPatient" module, which allows companies to train practitioners on how to interact with human patients. GigXR's learning hub also provides 3D anatomical models to explore larger-than-life holographic representations of human organs, like kidneys, hearts, and lungs.

Our analysis and experience as testers:

The demo cases provided by GigXR on the official website focus on holographic healthcare training topics. They also have collaboration with US government to offer military training.

Learning case example(s): Taking the Hololens respiratory training application as an example (https://www.gigxr.com/holoscenarios-respiratory/). A clinical asthmatic holographic patient is simulated. User could perform a series of actions to release and stabilize the patient's symptoms such as measuring oxygen by putting the probe on the patient's finger, then the simulated display will show the current oxygen level of the patient. Then, user should decide action to conduct next. (e.g., choose a non-breeze, listen to the patient's chest, checking on the blood pressure, etc.). If they performed correct procedures, the patient will get better.

Interactions: The simulated patient will react to user's actions to show whether they are correct or not. Collaborators can join online in another physical space to watch the user's operation, and they can also communicate verbally. The function of prescribing medication for the patient is also integrated in the virtual environment, professional can select the target medication for the patient. However, the application does not allow editing functionalities for the professional nurse or educator, the applications are created based on scenario cases under collaboration between XR developers and healthcare institutes.

6.7 ENGAGE

https://engagevr.io/

ENGAGE is a metaverse platform, for hosting large-scale events, group sessions, and learning experiences. Companies and educators can design custom metaverse worlds, which offer cross-platform support. Users can create their own simulations and immersive content and use avatars and animations to enhance communication and immersion. ENGAGE offers built-in tools for collaboration, whiteboarding, and presentations.

Our analysis and experience as testers:

ENGAGE focus more on the social experience aspects, it positions itself to be a specific computing platform for professionals, event organizers, educators and corporations to build their own virtual worlds. User can also create elements such as paintings and models, and save and sell them on the platform. However, when we tested their product, we found that this concept is currently in an initial stage. People can join in the same room together to talk about their ideas, teleport and move around with a headset. The virtual environment contains channels to other virtual environments, and when user come inside the channel, the virtual environment changes to a different 3D model. There are official virtual events organized by ENGAGE, however, not many audiences are involved at the moment. (Figure 29)

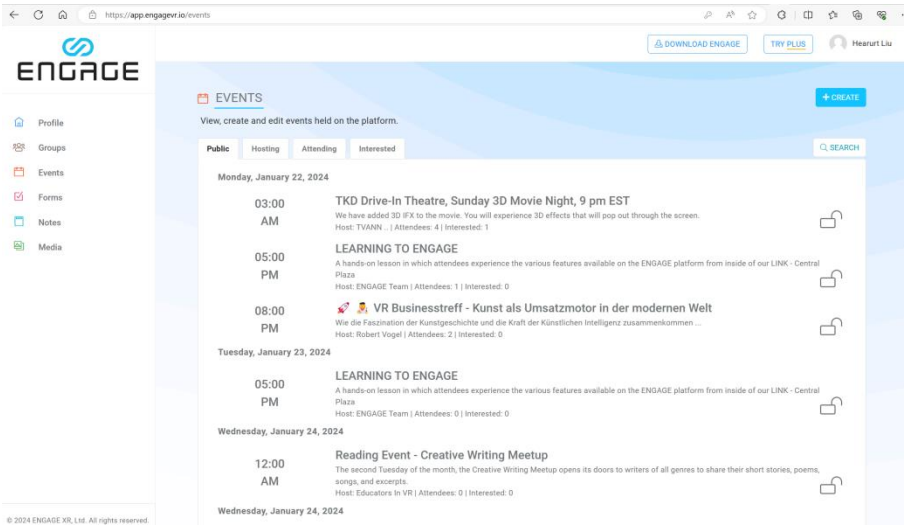


Figure 29. Virtual events organized by ENGAGE.

Learning case example(s):

We found a demo video related to education on ENGAGE official website, one is virtual classroom (https://engagevr.io/virtual-classroom-software-solutions/). In this video, the instructor is giving a virtual lecture. He can upload the prepared course content and put it in the room (e.g., images, slides, videos, etc.), then depending on the topic he talks, the virtual environment change to another 3D model to match the topic. Users can join either by mobile phone, desktop, or by VR headset. At last, 360 videos can be displayed for all the audience to see.

Interactions: All users can move around, teleport, communicate, create contents and share with others in the same room. The contents include video links, images, 3D models, text documents, etc. They can also record their lecture. However, since this platform focuses more on the social aspect, not enough educational reference materials are found at the moment for educators to use, they simply need to bring in their own contents from scratch. In addition, the marketplace is still in developing process.

6.8 VictoryXR

https://www.victoryxr.com/

VictoryXR provides schools and companies with a comprehensive platform providing access to classrooms, 3D VR objects, and professional development services. The VictoryXR ecosystem allows students and teachers to interact in spatial 3D. Users can navigate around immersive classrooms and

learn as if they were present in a real sense. It allows students to engage in collaborative sessions and immersive discussions. The VictoryXR technology works on mobile phones, laptops, and VR headsets. In 2021, VictoryXR partnered with Meta Platforms on the creation of digital university campuses.

Our analysis and experience as testers:

VictoryXR covers topics like animal dissections, safe chemistry experiments, and virtual trips. A teacher support page is created to give instructions to all the implemented virtual labs (https://www.victoryxr.com/teacher-support-pages/).

Learning case example(s): All the labs have step-by-step procedures; users need to go through all the steps to finish the training. We take "Frog Dissections" as an example. The application starts at displaying a pre-recorded video in front of the user to give a general introduction and safety rules for the lab (Figure 30). Then, the user needs to conduct the dissections step by step according to the guidance, they need to use different tools to do different steps, and learn the different parts of a frog. After they finish all the steps, a quiz is generated to collect the response from user.

Figure 30. The virtual instructor is giving the introduction for the lab.

Interactions: user can skip or replay the guidance during the process, they can also explore the virtual environment as they like. Different tools are offered for users to grab, operate on the frog model. They can observe the sub-models of internal organs closely. Similar to other immersive XR experiences, educators do not have much editing flexibility on the pre-created contents.

6.9 Unimersiv

https://unimersiv.com/

Unimersiv is an educational platform that specializes in extended reality (XR) experiences, offering both virtual reality (VR) and augmented reality (AR) content. The platform aims to enhance traditional learning methods by providing immersive educational experiences in subjects like history, science, and anatomy. Unimersiv offers a wide range of interactive courses and simulations that allow students to explore complex topics in a hands-on manner, thereby improving retention and engagement.

One of the unique aspects of Unimersiv is its focus on professional training as well as traditional education. The platform offers specialized courses aimed at industries like healthcare, engineering, and aviation, where XR can be particularly beneficial for training purposes. These courses are designed to simulate real-world scenarios, providing professionals with the opportunity to practice skills in a risk-free environment. This dual focus on both academic and professional education sets Unimersiv apart as a versatile XR educational platform.

The platform's primary objective is to leverage VR to allow students of all age groups to grasp concepts faster and in a more immersive manner. Additionally, Unimersiv emphasizes the importance of team performance and offers immersive VR training programs designed to save time, reduce costs, and mitigate risks.

Our analysis and experience as testers:

Unimersive is a single application on Meta store (https://www.meta.com/en-gb/experiences/pcvr/1045155438855839/?utm_source=unimersiv.com&utm_medium=oculusredirect), however, the content is no longer available. We assume this platform might have been abandoned afterwards. So, we will not include it in our analysis at this time.

6.10 zSpace

https://zspace.com/

zSpace is an educational technology platform that focuses on delivering immersive and interactive learning experiences in science, math, and career & technical education (CTE). The platform is designed to improve academic achievement and engagement by bringing learning to life through augmented and virtual reality. It offers solutions tailored for primary and middle education, career & technical education, and postsecondary & advanced sciences, aiming to prepare students for success in college and careers.

The platform utilizes three sensory characteristics—perception of depth, ability to look around, and kinesthetic realism—to create a natural and intuitive learning environment. zSpace also provides a range of applications designed for experiential learning, covering areas that would otherwise be too dangerous, expensive, or impossible to explore.

Our analysis and experience as testers:

The product by zSpace includes hardware and software. In the hardware aspect, zSpace provides a specially built laptop with stylus, stylus sensor module, display tracking, eye-tracking camera, and 3D glasses. In the software aspect, they have a pre-installed an app manager as a platform to access learning applications that come with the purchase of the hardware. User can access cross-curricular items based on the app manager platform. All their application demos are listed on https://zspace.com/apps.

Learning case example(s): Students can learn assembling knowledge about manufacturing hydraulics (https://zspace.com/edu/info/advanced-manufacturing-hydraulics). Students can separate the parts from the whole model and view and observe each sub-part. By assembling the sub-parts together, they get hands-on knowledge.

Interactions: With the hardware support on the laptop, users can interact with a 3D model using the stylus without wearing an HMD. Instead, Users need to wear polarizer glasses to observe the objects "virtually". They can move the 3D models around with the stylus, assemble and disassemble sub-parts, and check the corresponding instruction media information that is embedded with the 3D model for learning purposes (Figure 31). They can also switch between 2D view and 3D view, change the visualisation method to observe and learn the model on the 2D display or "on the air" with polarizer glasses. Figure 32 shows the rendering difference between the 2D view and 3D view as it shows on the display. Again, there is no position role for educators during the process, this tool is more like a self-learning tool.

Figure 31. User interact with the 3D model with the stylus and view it with polarizer glasses.

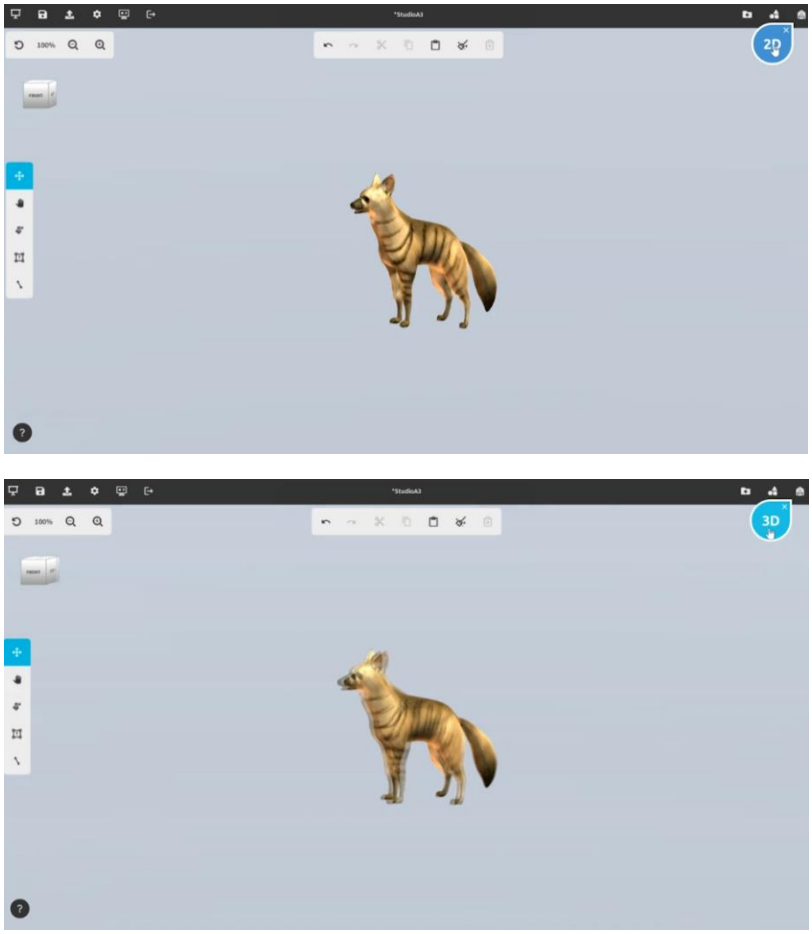


Figure 32. Rendering difference between 2D view and 3D view shown on display.

6.11 Merge EDU

https://mergeedu.com/

Merge EDU is an educational platform that specializes in engaging students in science and STEM subjects through augmented and virtual reality. The platform offers 3D objects and simulations that students can touch, hold, and interact with, aiming to make complex science and STEM concepts more understandable. It provides multi-sensory instruction, spatial development, and focused engagement, making it suitable for both home and school settings.

The platform offers a range of digital teaching aids and interactive simulations designed for primary school activities. It also provides tools for STEM education, including projects that use mixed reality technology.

Our analysis and experience as testers:

Merge EDU provides an identifier (e.g., cube) to visualize 3D simulations in mobile device to create an AR experience. The 3D simulation will attach to the position of the identifier, so when user move and hold the identifier on hands, a sense of interacting with the 3D simulations would be created. The sets include the cube identifier and a VR box (Figure 33). User can put their mobile device inside the box and view it in 3D.

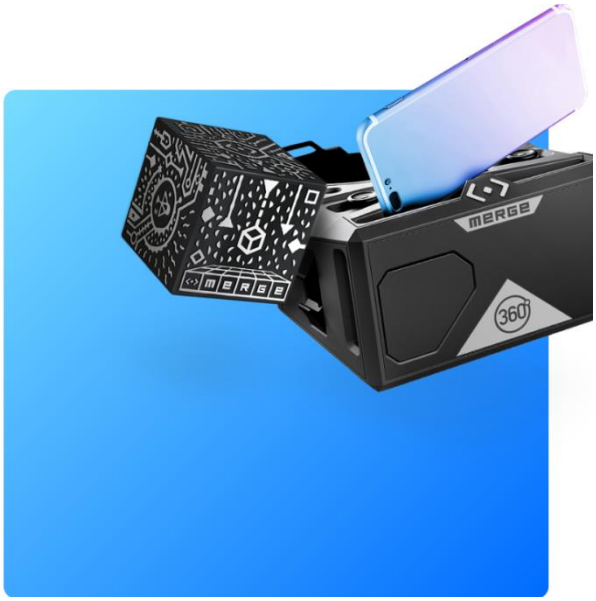


Figure 33. Merge EDU sets.

Learning case example(s): As Figure 34 shows, users can use the identifier to visualize animals. In this mode, the model is animated with sub-texts to provide more information about the animal. When users move the cube identifier in the physical space, the animal will move accordingly (so basically the cube serves as a marker that facilitates an interaction tool to rotate the model).

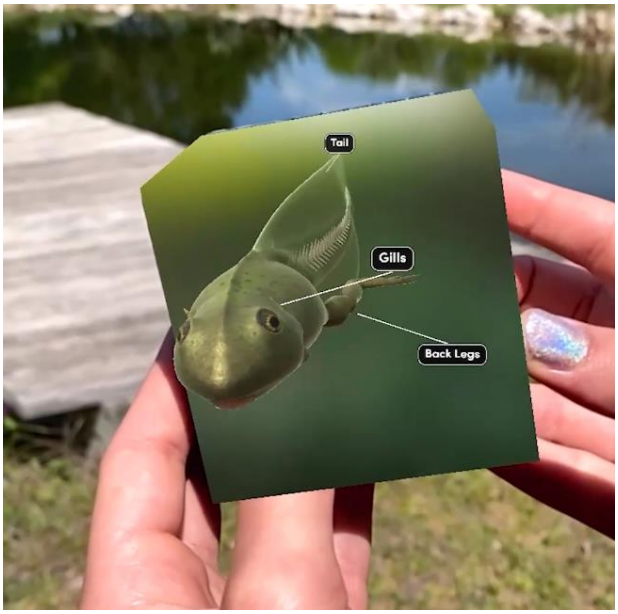


Figure 34. Newt demo by Merge EDU.

Interactions: User can zoom in and zoom out to observe, change the scale of the model, move and rotate to see it in different directions. No further interaction modes are provided, this limiting the tool to applying rotations to a 3D model in AR.

6.12 ThingLink

https://www.thinglink.com/

ThingLink is an interactive media creation platform that aims to make online learning more engaging and real. The platform allows users to create unique experiences with interactive images, videos, and 360° media. It offers various applications, including virtual tours, simulations, and interactive course modules.

ThingLink offers an intuitive editor that makes it easy to add hotspots to images, videos, and 3D models. It also provides analytics to track engagement and learning performance. The platform is scalable and offers enterprise-level support and security, making it suitable for both educational and corporate settings.

Our analysis and experience as testers:

ThingLink includes multimedia editor, scenario builder and guided tour. Originated from traditional online slides editor, it integrates XR elements such as 3D models and 360 image or videos. For 3D model

demo function, users can upload a low poly 3D model or choose one from the provided examples. Regarding the 360 contents, Thinglink provides access to an external 360 library, so that users can easily integrate the 360 multimedia inside the slide to give a virtual tour demo in class. Another key functionality is adding hot-spot on the multimedia to direct the target audience's attention to the points the user wants to emphasize. User can then add text or image explanations to the hot-spot to convey ideas. When the target audience interact with the hot-spot, text explanation will show up. In the desktop mode, the hot-points appear as blinking dots, while in the VR mode, the hot-spots turn to rotating cubes. (Figure 35). The scenario builder simply provides templates to rearrange all the created multimedia contents. Figure 36 shows all the templates offered to organize, user can also customize templates. Figure 37 shows more details about the template. By clicking on each of the rectangle areas, the user can edit the embedded content. After all the editing, the scenario can be previewed.

Figure 35. Difference between the hot-spots under desktop mode and VR mode.

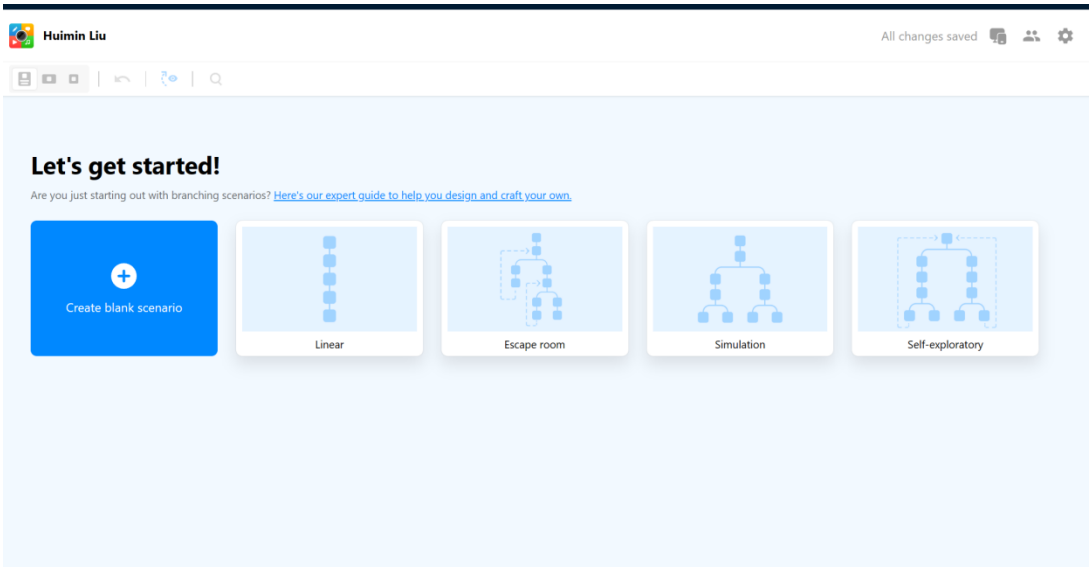


Figure 36. Scenario templates provided by ThingLink.

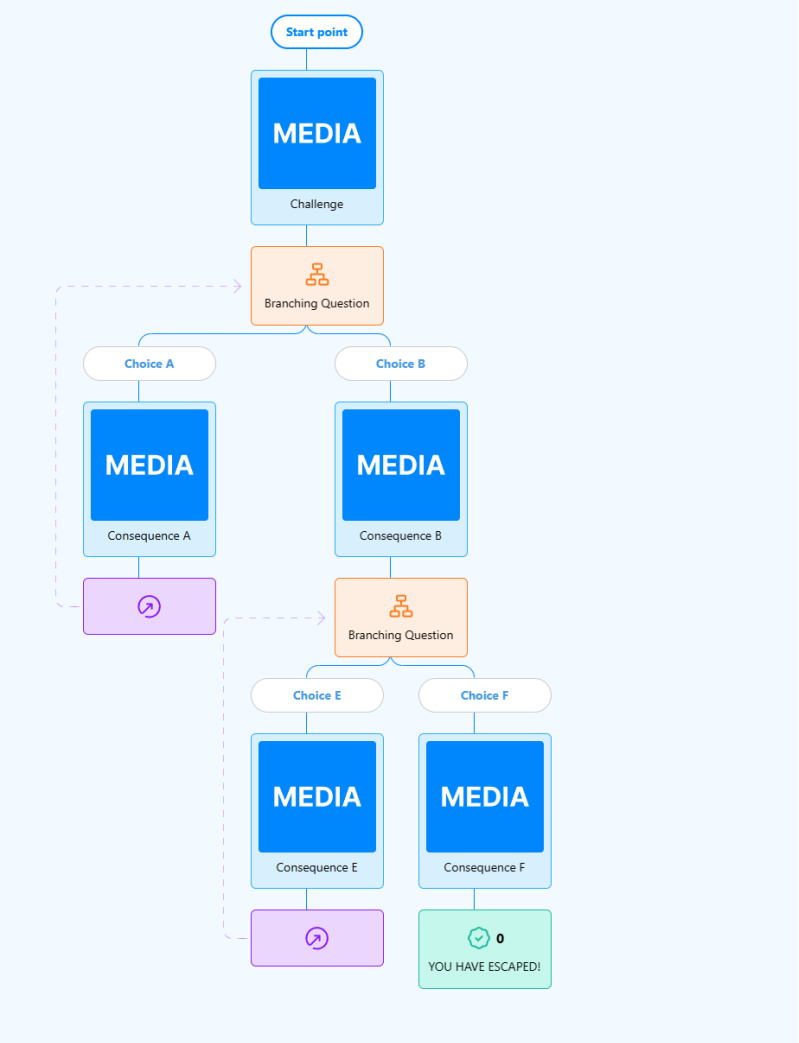


Figure 37. The Escape Room template details.

Learning case example(s): not applicable in this case.

Interactions: This tool offers high level of editing flexibility for the media part, so it seems to be the most flexible one and easier to create new content of all the platforms tested. However, the XR elements are very simple, since the user simply incorporate and view 3D models or 360 contents with hot-spot explanation. When incorporating 3D models, there is really no XR application available, but simply a 3D graphics model shown in the 2D screen and the user can apply rotations with direct interaction with

gestures when having a touch screen. The 360 contents can be displayed and visualized with google cardboard, however in this mode the interaction is limited to rotating the head to see all the 360 content without the possibility of changing the position of the user in the 360 world, and by staring at the rotating cubes, information appears in the form of text, videos or images. So even thought this appears to be the most usable platform for educators to create new content, the XR features are still very limited.

6.13 Edmersiv

http://www.edmersiv.com/

Edmersiv is an educational platform that leverages the power of virtual reality (VR) and augmented reality (AR) to create immersive learning experiences. The platform is designed to cater to both K-12 and higher education institutions, offering a range of interactive lessons and simulations across various subjects such as science, history, and engineering. Edmersiv aims to make learning more engaging and effective by allowing students to interact with educational content in a 3D environment, thereby enhancing comprehension and retention.

One of the notable features of Edmersiv is its adaptability to different educational settings. The platform offers a variety of customization options, allowing educators to tailor the content to fit their specific curriculum needs. Additionally, Edmersiv provides analytics and tracking tools to help teachers monitor student progress and engagement levels. This data-driven approach enables educators to make informed decisions about how to best utilize the platform's capabilities to enhance the learning experience.

6.14 Coursera VR

https://www.coursera.org/

Coursera has introduced VR-enabled courses in collaboration with Duke University, Peking University, and the University of Washington to make learning more engaging. These courses cover subjects like human physiology, Chinese language, and public speaking, and feature VR experiences that complement traditional lecture videos, readings, and assessments. The VR components are designed for learners of all educational backgrounds and can be accessed via desktop or most VR headsets in both paid and audited versions.

In addition to university courses, Coursera has also launched a new AR Professional Certificate and Specialization from Meta to help learners develop job-relevant AR skills. These programs are designed to teach learners how to build AR applications for various sectors like marketing, education, and

entertainment. Upon completion, learners gain access to the Meta Career Programs Job Board, which includes opportunities from over 200 employers.

6.15 Nearpod VR

https://nearpod.com/nearpod-vr

Nearpod is an educational technology platform that incorporates virtual reality (VR) experiences into its suite of interactive lessons and assessments. The VR component aims to make learning more engaging by offering immersive experiences that complement traditional teaching methods. Students can virtually explore historical sites, scientific phenomena, and more, all while teachers maintain control over the classroom experience through real-time assessments and feedback.

The platform is versatile, catering to various educational levels from K-12 to higher education. Nearpod VR allows educators to either select from a library of pre-made VR lessons or create their own, offering a customizable and interactive approach to education. This makes it a useful tool for educators looking to integrate more technology into their teaching methods while keeping students engaged.

6.16 KlipVR

https://klipvr.com/

Klip VR is an educational technology platform that focuses on providing immersive Virtual Reality (VR) experiences to enhance learning. The platform offers Virtual Educational Field Trips & Expeditions, allowing students to explore environments like the moon, the depths of the ocean, or the human body, which would otherwise be impossible to visit in person. Klip VR aims to amplify students' understanding of the world, focusing on building curiosity, fact retention, and visual learning to make learners future-ready. The platform is designed to act as an aid to the curriculum, enabling students to explore and grow in ways they couldn't have imagined before.

The platform offers a range of features to cater to different learning styles, including visual, hands-on, and verbal learning. Klip VR enhances the educational experience by providing a better sense of place, scaled learning experiences, and opportunities for active learning. It also aims to invoke emotional reactions, making the learning experience memorable. The platform promotes creativity and curiosity, allowing students to make decisions and adjustments in a virtual world, thereby fostering critical thinking and increased retention. Overall, Klip VR seeks to elevate the learning experience to a new level of understanding and knowledge.

6.17 Review of limitations of current platforms

Based on all information we gathered for this review, we can conclude that there is an increasing interest in using XR for education purposes as it offers many advantages over traditional 2D lessons. However, we found that most of the platforms are still in an initial stage, and that they have so far focused their efforts in providing a handful of lessons for students to test their potential and educators to evaluate how these tools could improve students' engagement and learning. From our in-depth analysis and test, we found that they are still very limited when it comes to educators creating new content of adapting the existing one to their lessons.

Some of these platforms are presented as an abstract concept with no concrete demo yet, such as ARuVR. Some have done implementations for single application like Unimersiv. Some have done more experiments and begin to show more concrete demos like VictoryVR and GigXR. In general, we divide all the reviewed items into 3 development routes: 1) originated from traditional educational content with simple XR elements embedded, 2) XR immersive route for specific pre-created cases and 3) AI based route. MEL Science VR, Thinglink are classified under the first development route. MEL Science previously focuses on producing physical hands-on learning kits which requires manual assembling operation. As the concept of immersive XR starts becoming popular, MEL Science also developed VR and AR applications to align with their project kits. Thinglink originated from a slide authoring tool like Powerpoint, and now integrates XR elements such as simple 3D models and 360 media inside the slides to better show up the content in mobile devices. ClassVR & Eduverse, GigXR, ENGAGE, VictoryVR, Unimersiv, zSpace, Merge EDU can be categorized as the second development route. All the applications are designed based on the immersive characteristics of XR technology, Usually the applications developed changes from case to case. The role of educators in this development route is usually the customer or consultant to give advice to professional XR developers to create specific application for their courses. Not much editing flexibility are given to educators. None of the platforms reviewed incorporated an easy way for educators to include XR content and experience. Those that offer some easy-to-use features for educators are limited to including 3D models (which can be viewed on the phone as 3D graphics with rotations driven by gestures, or else with AR and markers that can be rotated), alternatively they may allow to incorporate a 360 image or video but with no navigation capabilities for the user. So, the full potential of XR cannot be exploited through this limited editing tools. EON Reality is categorized as the third development route. It directly generates contents based on keywords input (either by selection or by voice communication). Educators are served as the supervisor for the generated contents, they have the ability to edit and make final decision on the course content. AI is a tool for educators to search on corresponding materials more quickly. Immersive technologies can also be combined with the AI to create an virtual AI assistant.

In addition, we also found that neither of these platforms have considered the gazing effect and precise body animations that the virtual avatar can provide as non-verbal communication to the learning

experience. At current stage, all avatars (if included in the reviewed items) we observed are carton avatars with no much animation capabilities.

To sum up, despite the large variety of XR application that are currently announced, there is still not a uniform solution easy to use and expand by teachers that are not computer science experts. More specifically we can list the following limitations:

- Training and Support: Teachers and educators may require training to effectively use XR platforms for teaching. The learning curve associated with new technologies could lead to uneven implementation if proper training and ongoing support are not provided.
- Classroom Integration: Integrating XR experiences into existing curricula and classroom activities can be challenging. Teachers need to find ways to align XR content with educational objectives and ensure that the technology enhances the learning experience rather than becoming a distraction.
- Content Customization: Some XR platforms might not offer easy ways for educators to create or customize content to suit their specific teaching needs. This can limit the adaptability of the platform to different classroom contexts.
- Limited Subject Coverage: Some XR platforms might focus more on certain subjects, such as science and technology, and have limited content available for other subjects.

Therefore, the main limitations of the existing platforms are that each platform has a limited content developed by themselves or partner companies. With XR4ED, we plan to create a platform which can allow anyone with basic knowledge about content creation, to create experiences without worrying about the integrability, since we provide an SDK which will handle that. Furthermore, XR4ED platform will run on a more distributed backend for the experiences and will act more as a browser for VR experiences in education rather than a single server hosted application. Finally, XR4ED marketplace creates a community of developers for the experiences and a sub-economy for the avatar creators, plugin developers etc. which the exhaustive list of platforms presented in this document do not provide.

Our vision for XR4ED, is a platform that will be easy to use by educators, and that will facilitate creating lessons and publishing their work in XR, thus making it available to the educational sector. Currently the content for educators is pre-defined, and it does not allow for changes, which limits the educators task of creating their own lesson plan. XR4ED will be open to educators to alter the current lesson template to their own needs, and adjust it to different curriculums.

7 Existing repositories for XR avatars

The creation of avatars requires: capturing, modeling and simulation. Simulation includes many aspects such as Lip synchronization for believable communication through speech, eye gaze capture for attention, and motion capture to replicate the user movements that are a key part of non-verbal communication and allow teachers to better explain complex concepts.

Immersive VR wearing HMDs requires having avatars that provide us with a self-representation, but also avatars that represent the other users in collaborative VR, and thus, allow us to interact with them in a natural way. In the following subsections we list several solutions that can facilitate the inclusion and animation of avatars in XR applications:

- QuickVR
- AvatarGo
- Final IK
- Oculus Lipsync

7.1 QuickVR

QuickVR is the result of the technical research and development in VR at the *EventLab*, at *Universitat de Barcelona*, directed by Professor Mel Slater. It is an open-source library for *Unity* that offers embodiment in a virtual character with out of the box support for almost any VR device that implements the *Unity XR Framework*. While the *Unity XR Framework* is focused on giving low level functionality such as stereo rendering, device tracking or input management, *QuickVR* focuses on higher level features like embodiment, body tracking, stereo planar reflections (meaning a mirror), a methodology that simplifies the logic coding for your experiments or user studies, locomotion and interaction with the environment. All this allows you to quickly prototype any new VR application in just a few hours or days and to reduce drastically production times. Moreover, *QuickVR* is very easy to use by coding novices, and it is also very easy to extend and customize if you are a more experienced programmer.

Since *QuickVR* is built on top of the *Unity XR Framework*, it doesn't need to know about each specific implementation of a specific provider, but it acts directly on the common framework. This way, we only need to install the corresponding plugin for the desired device, and it will be recognized by *Unity* and, by extension, by *QuickVR*. If your device is not yet supported through the *Unity XR Framework*, *QuickVR* is designed so that it can be easily extended to support it.

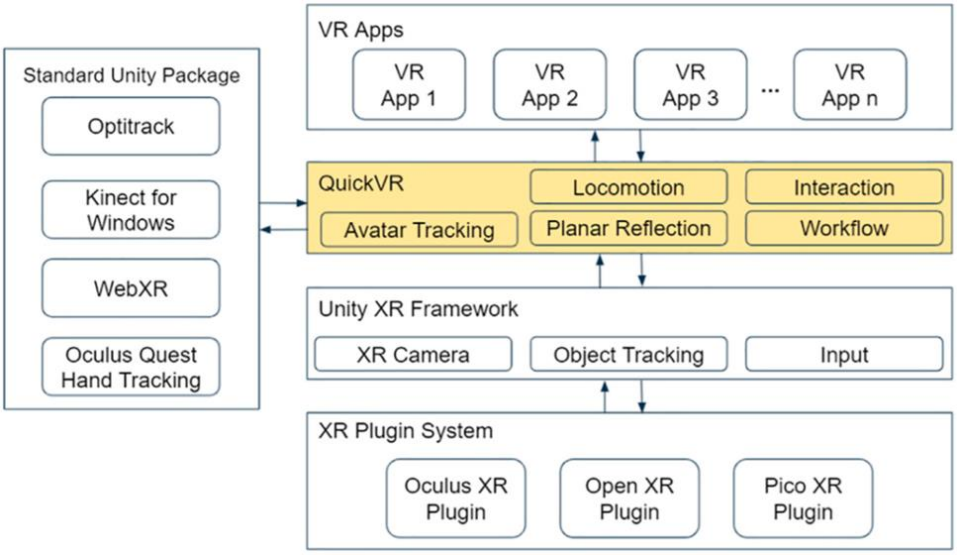


Figure 38. QuickVR platform

But the main feature of *QuickVR* is embodiment. And to achieve it, you only need to add one component called *QuickUnityVR* to any *Humanoid Avatar* within *Unity* and click on play. At start, *QuickVR* will recognize which device you are wearing and run an almost negligible calibration process, which only requires the participant to look forward. The assumption made here is that the avatar must have similar height and proportions than the participant.

At runtime, a basic *IK* solver computes the poses with a fine control of the *IK* step. Which means that we can easily modify the update mode of each *IK* chain depending on what we want to do. We can select to update different body parts using data from the tracking, or using data or code from the application, or even using an animation, thus achieving any configuration we could need, like for example combining the upper body part of a character controlled using tracking data with the lower body part using some predefine animation controller.

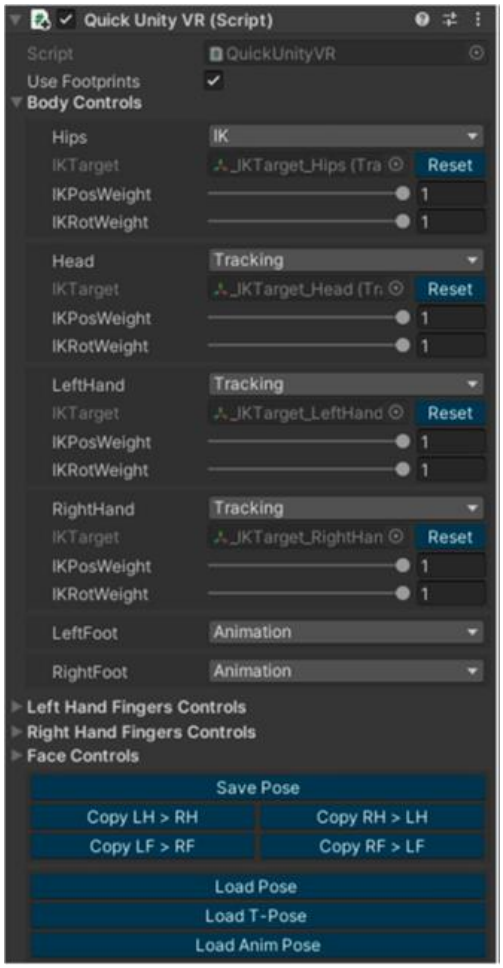


Figure 39. Including IK in QuickVR though Unity UI

Another nice feature that *QuickVR* offers is the ability to be embodied in different avatars throughout the same virtual experience by seamlessly switching from one to another, without the need of recalibrating. For that you can define a master avatar that will have the *QuickUnityVR* component and make all the *IK* computations. We then copy the pose of that master avatar to the final target avatar, no matter its size or proportions, where *QuickVR* also places the final camera.

As mentioned before, one important feature of *QuickVR* is its workflow system and its simplified logic coding. When you design many experiments, you realize how many parts of it are repeated or very similar within the same or different experiments. The idea of *QuickVR* is that you can divide the workflow of an experiment into small different logic pieces or stages, for which we can define *QuickStages*. Therefore, for each one of the pieces of our workflow we can have a corresponding *QuickStage*, and in *Unity*, these will appear as components of *GameObjects* within the scene hierarchy. That will allow you to easily

enable, disable or reorder the stages at your convenience. *QuickVR* offers some predefined stages, such as having the camera to fade in or fade out, managing and loading different scenes, giving calibration instructions to the participant, etc... But this workflow can also be highly customizable by extending or creating your own *QuickStages*. For that you only need to reimplement 3 main functions that are executed for each stage, corresponding to what happens at the beginning, during and at the end of the stage. And of course, we can have conditional blocks and loops with nested stages in them.

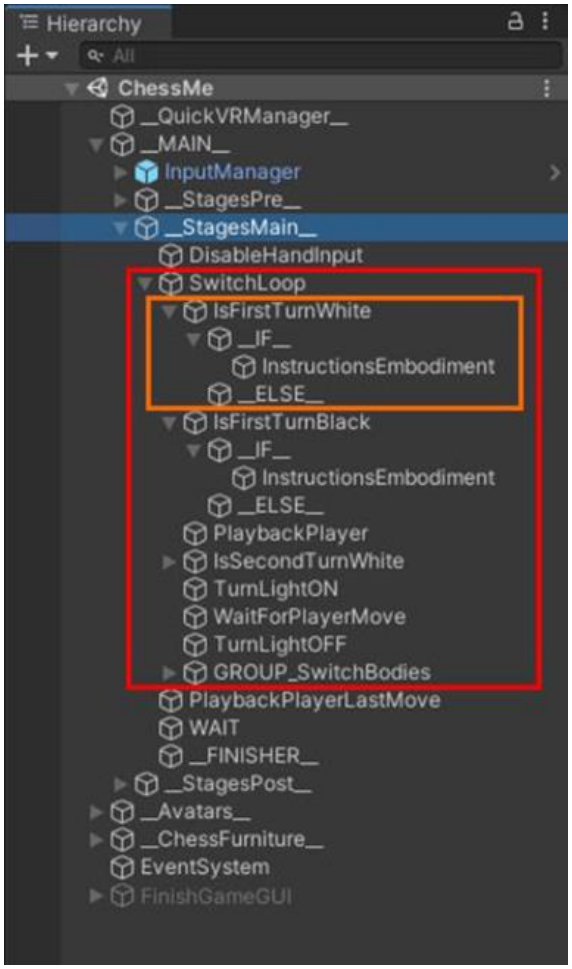


Figure 40. QuickVR Unity UI to set up an embodiment experience

There is a *GitLab* repository of *QuickVR*. Along with the source code you will find instructions to install it in your *Unity* projects, which is as easy as installing any other *Unity* package. You will also find tutorials and examples to start using the library, and some in-depth descriptions and explanations on how to use some advanced features.

https://gitlab.com/eventlabprojects/quickvr.packages/com.quickvr.quickbase

Finally, there is also a publication that describes most of the *QuickVR* library: [6].

7.2 AvatarGo

AvatarGo is a *Unity* package for incorporating self-avatars in any Virtual Reality application with a low-cost set-up consisting of a *SteamVR*-based *HMD*, 2 Controllers and 3 *HTC VIVE Trackers*. It incorporates a custom calibration step in which users need to walk inside a virtual avatar. Using a custom Fingers *Inverse Kinematics* solution, the hands can automatically adjust to the controllers.

Figure 41. Avatar set up and collaboration with AvatarGo

AvatarGo takes the user through a simple and quick set up that scales an avatar and computes the exact offsets between the trackers and the avatar's joints to provide high fidelity movements. It simplifies the set up and initiation of trackers, the pairing between trackers and end effectors of the avatar, and it naturally adapts the avatars' hands to the controllers. The user can easily walk into his/her own avatar and with just a few steps, have the avatar accurately following his/her movements.

There is a publication related to AvatarGo: [7]

They present a user study showing that the *Sense of Embodiment* increased significantly when using exact offsets as opposed to fixed ones. They also allowed the users to see a semitransparent avatar overlaid with their real body to objectively evaluate the quality of the avatar movement with *AvatarGo*.

The code of *AvatarGO* is available and ready to be used at *GitHub*:

https://github.com/UPC-ViRVIG/AvatarGo

AvatarGo is currently limited to the HTC VIVE HMD with three additional HTC trackers. Unfortunately, this is still a pricey solution, thus not affordable for all educational purposes.

Figure 42. AvatarGo provides a framework to easily calibrate and animate avatars for HTC VIVE. It offers collaborative features so that several users can be co-located in the same virtual space.

To overcome this limitation and further democratize the use of VR, UPC has been working on extending the animation capabilities to more cost-effective HMDs such as Meta Quest. The aim is to provide natural animations without the need for additional trackers. When using only three trackers (HMD and hand-held controllers), the main challenge becomes providing the user with natural locomotion animations.

For this purpose, the initial solution developed by UPC extends the concept of Motion Matching by inputting a different set of features available in a VR setup (data coming exclusively from the HMD and controllers) (see Figure 43). In addition, we also included a neural network that learns to predict body orientation from the HMD and controllers so that the avatar orientation is not simply defined by the HMD. Thus, the resulting self-avatar can perform side steps when detecting lateral movement or keep the correct body orientation while the user is looking around by moving the head. Since it has precise tracking coming from the hand-held controllers, the avatar hands are still controlled by IK as in AvatarGo to guarantee accurate positioning of the avatar hands. This provides a mixed animation model which combines predicted motion for the legs with IK for the head and hands.

There is a publication related to this research: [8]

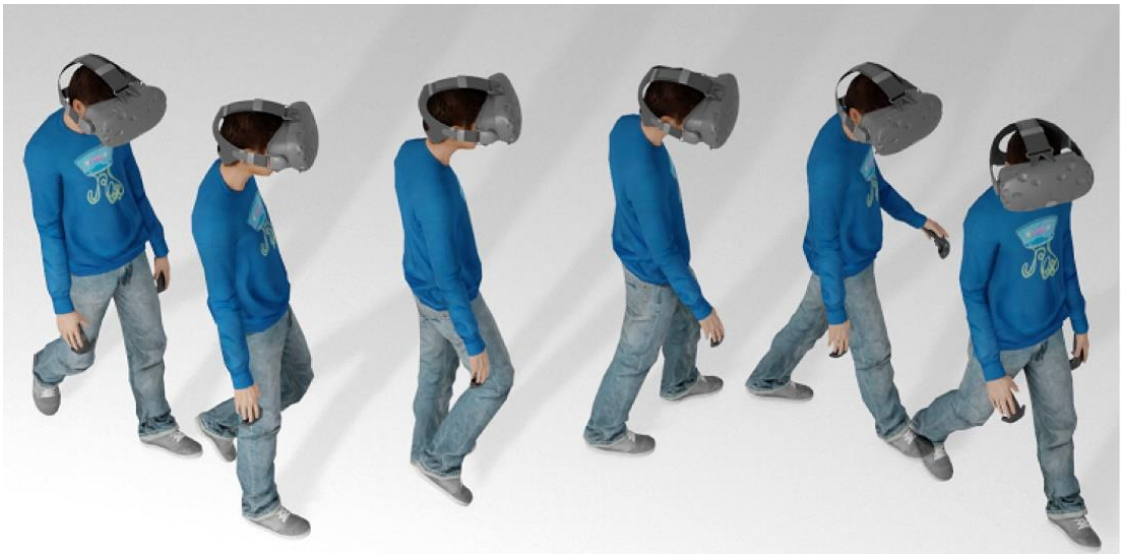


Figure 43. Motion matching for self-avatar animation in VR with three trackers.

7.3 Final IK

Final IK is a powerful set of inverse kinematics (IK) solvers and tools for *Unity*. It can be used to create realistic and believable animations in a variety of contexts, including foot placement correction, interactions with the dynamic game environment, aiming correction, and mapping VR avatars to the HMD and hand controllers.

Final IK's *Full Body IK* solver is specifically designed for VR and supports up to 6 tracked points for the head, hands, feet, and body. It also includes elbow and knee bend goals and built-in procedural locomotion. This allows *Final IK* to map VR avatars to the HMD and hand controllers, so that the movements of the user are reflected in the movements of the avatar.

In addition to mapping VR avatars, *Final IK* can also be used to create realistic interactions with objects in VR. For example, *Final IK* can be used to make a character grab an object, or to make a character's hand follow the movement of an object.

Final IK is a popular choice among game developers and animators because it is a powerful and versatile tool that can be used to create a wide range of realistic and believable animations.

The commercial asset for Unity can be found in the Unity Asset Store:

https://assetstore.unity.com/packages/tools/animation/final-ik-14290#description

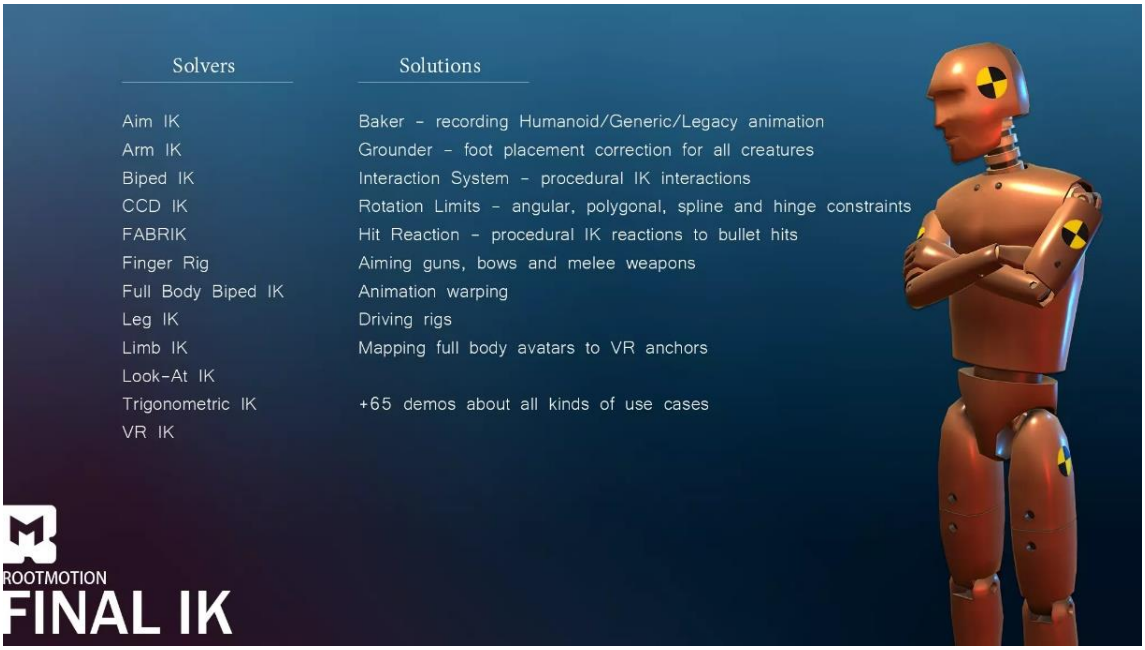


Figure 44. Final IK offers an efficient and robust Inverse Kinematics solution for avatar animation

7.4 Oculus Lipsync

Oculus Lipsync is a Unity plugin for use on *Windows* or *macOS* that can be used to sync avatar lip movements to speech sounds and laughter. *Lipsync* analyzes the audio input stream from microphone input or an audio file and predicts a set of values called visemes, which are gestures or expressions of the lips and face that correspond to a particular speech sound. Viseme is a visual unit of intelligibility that is used when discussing lip reading and is a basic visual unit of intelligibility. In computer animation, visemes may be used to animate avatars so that they look like they are speaking.

Lipsync employs a range of visemes to modify avatars based on a specific audio input stream. Each viseme targets a specified geometry morph target in an avatar to influence the amount that target will be expressed on the model. With Lipsync, we can generate a realistic lip movement in sync with what is said or heard. This enhances the visual cues that one can use when populating an application with avatars, whether the character is controlled by the user or is a non-playable character (NPC).

The *Lipsync* system maps to 15 separate viseme targets: sil, PP, FF, TH, DD, kk, CH, SS, nn, RR, aa, E, ih, oh, and ou. Visemes describe the facial expression produced when uttering a speech sound that corresponds with that sound. For example, the viseme sil corresponds to a silent/neutral expression, PP corresponds to pronouncing the first syllable in “popcorn” and FF the first syllable of “fish”. The 15

visemes have been chosen to offer the most comprehensive range of lip movement without language influence.

Oculus Lipsync can be downloaded from here:

https://developer.oculus.com/downloads/package/oculus-lipsync-unity/

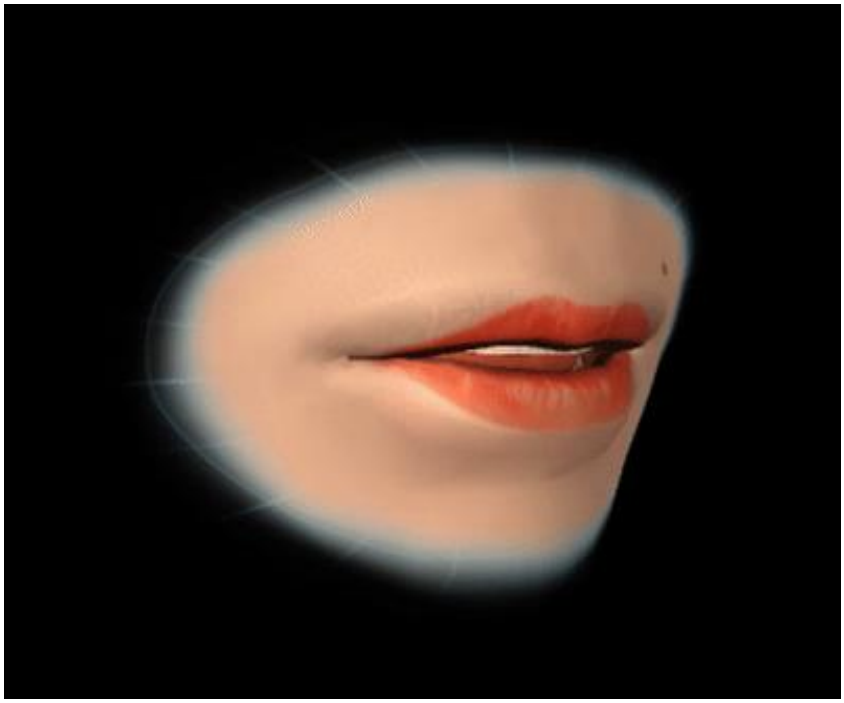


Figure 45. Oculus Lipsink to animate the avatar's mouth following the user speach

7.5 Content Creation Software for Avatars

- Adobe Fuse: https://www.adobe.com/es/products/fuse.htmlln
- Make Human: http://www.makehumancommunity.org/
- AvatarSDK: https://avatarsdk.com/
- Didimo: https://www.didimo.co/
- Reallusion Character Creator: https://www.reallusion.com/character-creator/

- Autodesk Character generator: https://charactergenerator.autodesk.com/
- MetaHuman Creator: https://metahuman.unrealengine.com/
- Mixamo: https://www.mixamo.com
- Reallusion ActorCore AccuRIG: https://actorcore.reallusion.com/auto-rig
- Faceform Wrap: https://faceform.com/download-wrap/
- Simplygon**:** https://www.simplygon.com/

7.5.1 Adobe Fuse

Created by *Mixamo* which was acquired by *Adobe*, *Fuse* is an avatar creator software with many options to build your own avatar. Unfortunately, it never came out officially and there is only a discontinued beta version out there. You can select and blend from different kind of body parts, and then add hair and clothes to your characters. Although the available clothes are quite limited, you can customize it and even follow a pipeline to add to the software your own meshes. Characters created with Fuse had the advantage of having a predefined set of facial blendshapes, very useful to make your created characters able to speak or have facial expressions.

Fuse can be downloaded from here: https://www.adobe.com/es/products/fuse.htmlIn Characters can be exported easily to obj (without rig), fbx, unity, or unreal.

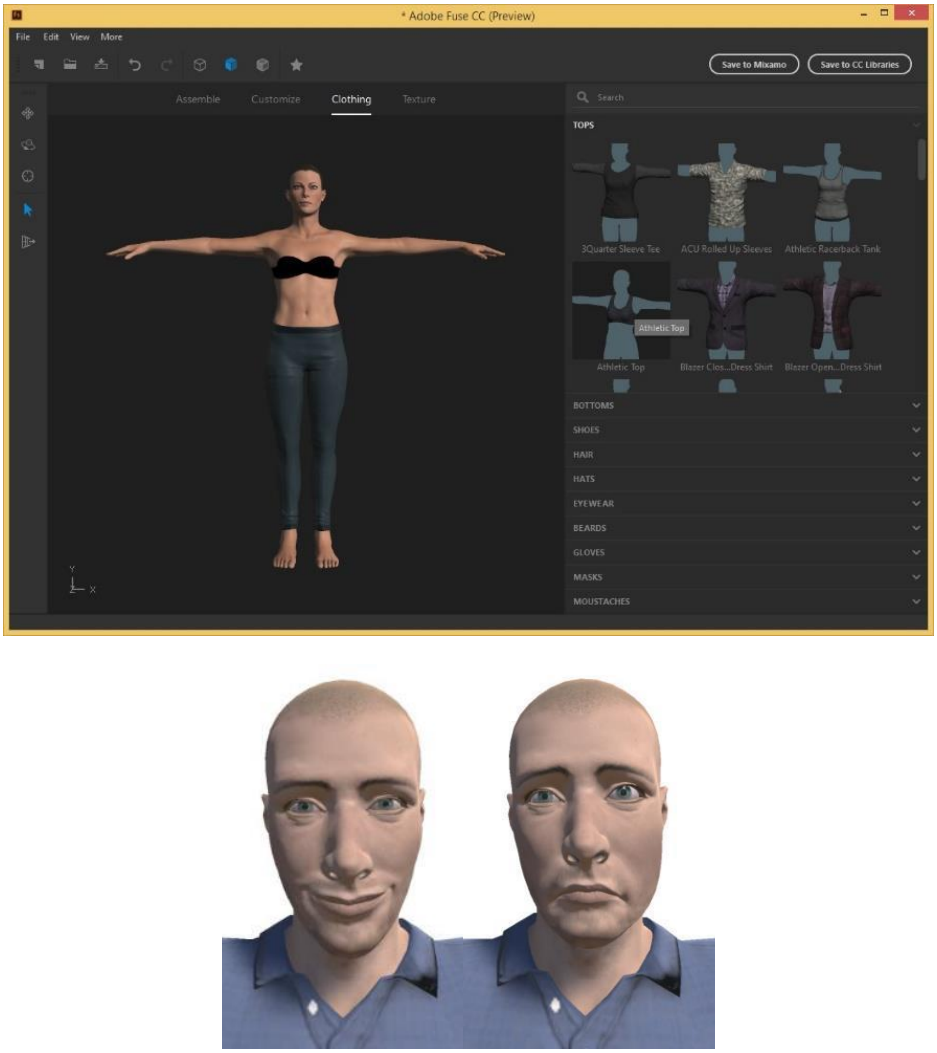


Figure 46. Adobe Fuse UI to create avatars

7.5.2 Make Human

Make Human is an open-source tool for making 3D characters. With a huge community who keeps maintaining it and developing it (they are currently upgrading its implementation to *Python 3*), *Make Human* has many options to offer and is completely open to customization. It has even an integration with *Blender*, adding all its scripting potential to it.

The main problem of *Make Human* as opposed to other commercial solutions is precisely its main advantage. There are not many high or good quality cloth assets to work with, and the ones there are, do

not all have the same quality. There is no professional maintenance behind it and the user interface is not very usable. Once you get a character, getting it to your final product can be a little bit difficult, especially if you want to get a highly realistic result.

Make Human can be downloaded from: http://www.makehumancommunity.org/

Overall, *Make Human* is a very powerful tool for expert users and programmers. It could be used or integrated in complex pipelines with some development effort. But it is not a tool that should be recommended for casual or novice users.

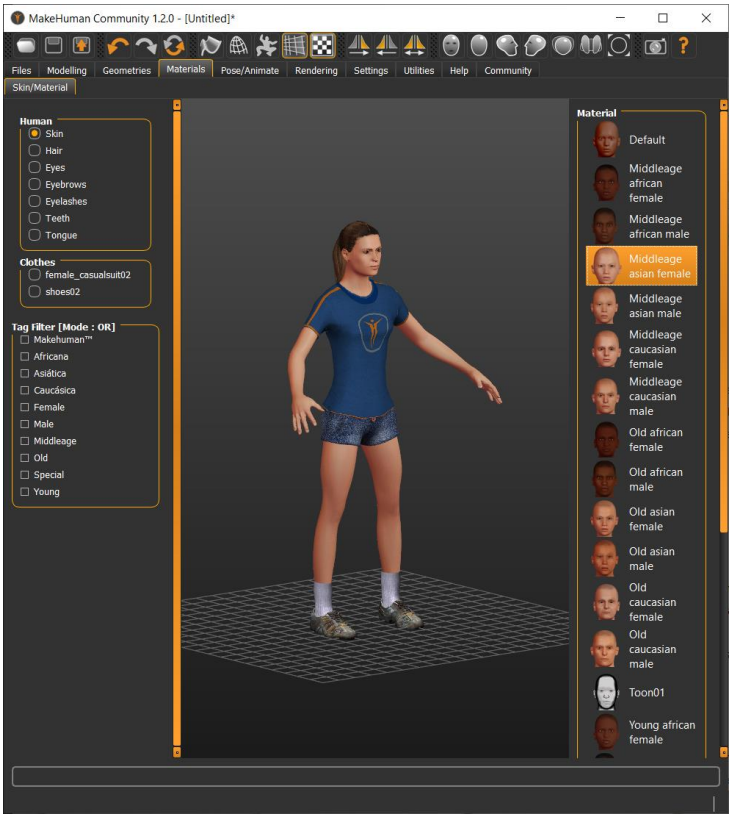


Figure 47. MakeHuman UI to customize avatars

7.5.3 AvatarSDK

AvatarSDK offers a cloud service to generate avatars just from one selfie of a person. They achieve this using deep learning and computer vision techniques they have developed and trained throughout the years. Before they just offered the generation of a head or a bust, but they now attach it to one body to select from a few types, offering a complete avatar generation. The body can be customized with a very

limited number of different clothes and colors, and the outcome avatars have also a complete set of blendshapes to properly give them facial animation.

Along with their cloud service, they have a complete *API* that can be integrated into almost any service, and a *Unity* specific plugin. You can try for free their services at https://avatarsdk.com/. After trial, you need to pay for a subscription plan that lets you generate a limited number of avatars per month (and pay extra if you need more of them). There is also the option to pay for a local model of their software that would not need connection to the Internet.

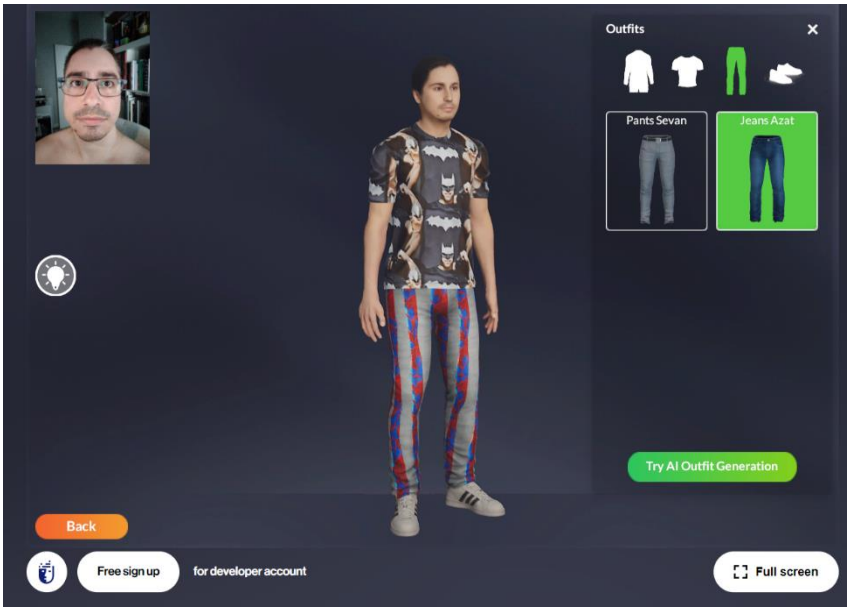


Figure 48. Example of AvatarSDK to generate avatars from a selfie

A very recent feature integrates generation of textures for the outfits through an AI generative diffusion model. But it still does not affect the generation of meshes which are quite limited.

7.5.4 Didimo

Didimo (https://www.didimo.co/) is a Portuguese company led by Veronica Orvalho that creates digital humans from photographic inputs. Their technology can be used to create realistic and lifelike digital humans that can be customized to look like any person. These digital humans can be animated to express

a wide range of emotions and can be used in a variety of applications, such as virtual reality, augmented reality, and video games.

Didimo's mission is to "bring the richness of human engagement to every digital interaction, making them as authentic as our physical ones." They believe that digital humans have the potential to revolutionize the way we interact with the digital world, and they are committed to making their technology accessible to everyone.

Figure 49. Didimo generates human-like avatars from pictures

Didimo has recently launched *Popul8*, an AI character-generation tool that will empower designers to do more. It is a new generative tool for creators designed to accelerate the process of adding unique characters to your projects. *Popul8* relies over years of academic research and builds on *Didimo*'s existing avatar creation pipeline, leaving creative control to the artists. It uses *Didimo*'s own fully-licensed data sources and does not rely on external tools or content.

Figure 50. Crowd of Didimos avatars

The time it would typically take to generate NPCs and other types of characters is drastically reduced with *Popul8*. Just in seconds, artists can create new random characters using text input or other characters to guide style.

7.5.5 Reallusion Character Creator

Character Creator (CC), whose last iteration is *Character Creator 4*, is a full character creation solution for designers (and not programmers) to easily generate, import and customize stylized or realistic characters. These can easily be exported to any other 3D tools, such as *Maya*, *Blender*, *Unity* or *Unreal*. *CC* offers high quality standards and is widely used in the industry.

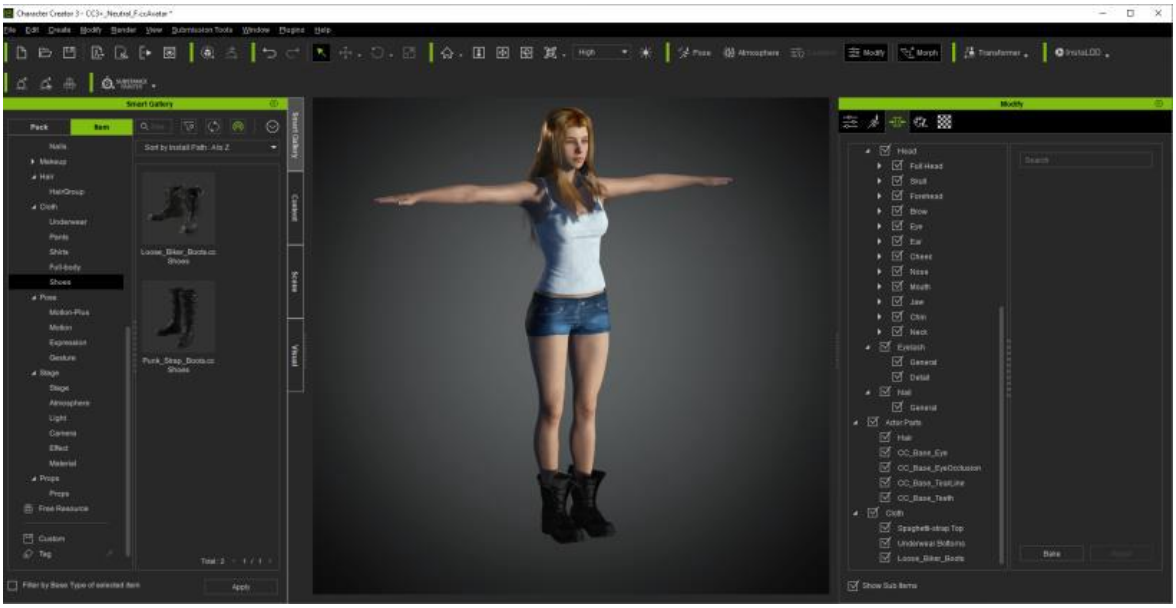


Figure 51. Reallusion Character Creator UI

You can import any rigged biped model to characterize it, add it clothes or a facial rig. You can also generate heads from a selfie picture with a specific plug-in (based on *AvatarSDK* technology). Or you can optimize your characters for low-poly, high-performance crowd simulation, AR, VR, etc.

Its user interface allows you to design characters, by easily adjusting character shapes, defining skin looks, changing hairstyles, or dressing them. The main issue with *CC* is their business model. You must pay a license for every seat (computer) where you install de software. You must pay for every additional plugin (such as the headshot one that generates an avatar from a picture). And you must pay for every new topology you want to use, any hairstyle, clothes or accessories. The available for free set is very limited.

You can try or buy *Character Creator* at: https://www.reallusion.com/character-creator/.

7.5.6 Autodesk Character Generator

Autodesk Character Generator is an online tool available at:

https://charactergenerator.autodesk.com/

But to gain access to Character Generator you need to have a subscription to a Maya, Maya LT, 3ds Max, MotionBuilder, Mudbox software, or Media & Entertainment Collection from Autodesk (a free student subscription is valid too).

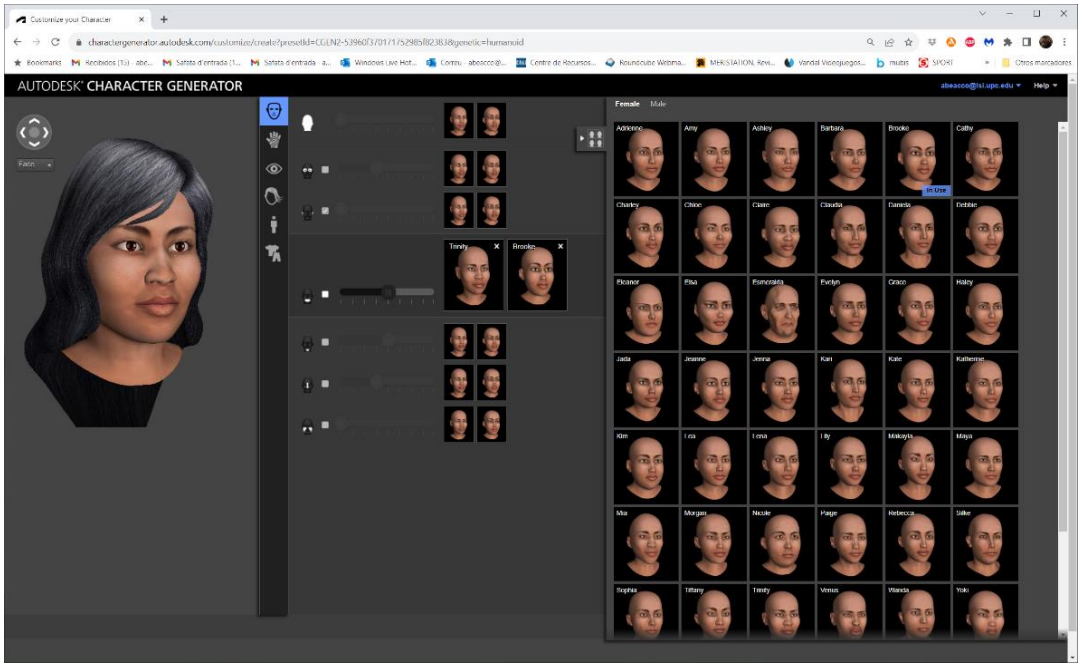


Figure 52. Autodesk Character Generator UI to edit avatars' appearance

Character Generator lets you create, customize, and download your rigged 3D characters from a catalog of over 100 body types, outfits, hairstyles, and physical attributes in a few simple steps. Your characters will be ready to animate, in popular animation packages and game engines.

Again, the main limitation is the number of outfits and hairstyles available, but characters have good enough quality, with the possibility of exporting them with different levels of detail, and with facial animation blendshapes.

7.5.7 MetaHuman Creator

The new *MetaHuman* avatars from *Epic* seem to be the new state of the art characters in terms of quality and speed of production. Although free to use for anyone with an *Epic* account, they are limited to be used (at least for now) with the *Unreal Engine* also from *Epic*. So, there is no option to use them in Unity for example, at least not in a straightforward and optimal way.

MetaHuman Creator works as an online tool that you can find at:

https://metahuman.unrealengine.com/mhc.

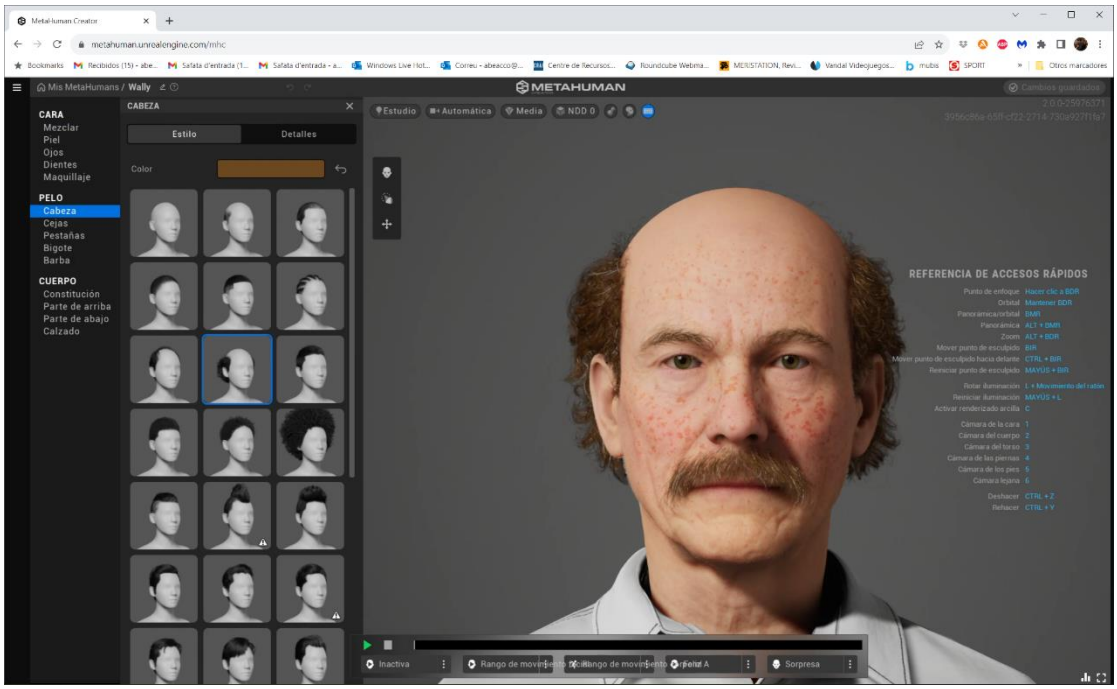


Figure 53. MetaHuman Creator allows the user to customize photorealistic avatars

After loading (which can take a few minutes), an easy-to-use interface allows the user to blend between different predefined characters and shapes, to obtain your desired character. Results have a very realistic aspect, but are still far away from perfect, as the tool is difficult to use for fine tuning and requires a lot of ability and time if you want, for example, to recreate a real person.

The generated characters have many levels of detail ranging from very high poly to really low poly, so they can be used in a wide range of applications. They also have a high-quality rig and facial animation. Integrated with *Unreal Engine* there are several tools and plug-ins to use them, such as the option of animating their faces using a front face video.

7.5.8 Mixamo

You can try *Mixamo* services at https://www.mixamo.com.

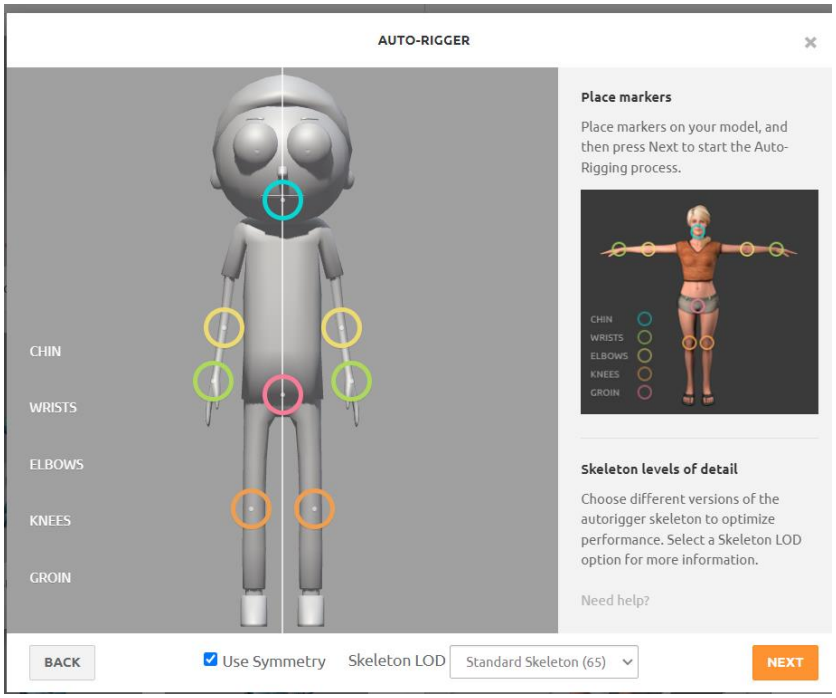


Figure 54. Mixamo platform to create avatars

In particular, you can be interested in use the free *Auto Rigger* tool, which allows you to upload a 3D mesh of any biped model and, in a very few steps, download it completely rigged and ready to be animated. Moreover, the obtained character is completely compatible with *Mixamo*'s outstanding library of animations.

7.5.9 Reallusion actorcore AccuRIG

Similar to *Mixamo*'s *Auto Rigger, AccuRIG* is a free application designed for fast and easy character rigging, aiming to reduce production effort for character artists by focusing on model design with automation and simplicity. With it you can achieve accurate and superior rigging results in 5 simple steps for models in *A/T/scan* poses, or with low/high/multiple meshes. You can direct export to all major 3D tools, or upload directly to *Reallusion ActorCore* and try tons of production-ready animations for game, film, archviz, digital twins and more.

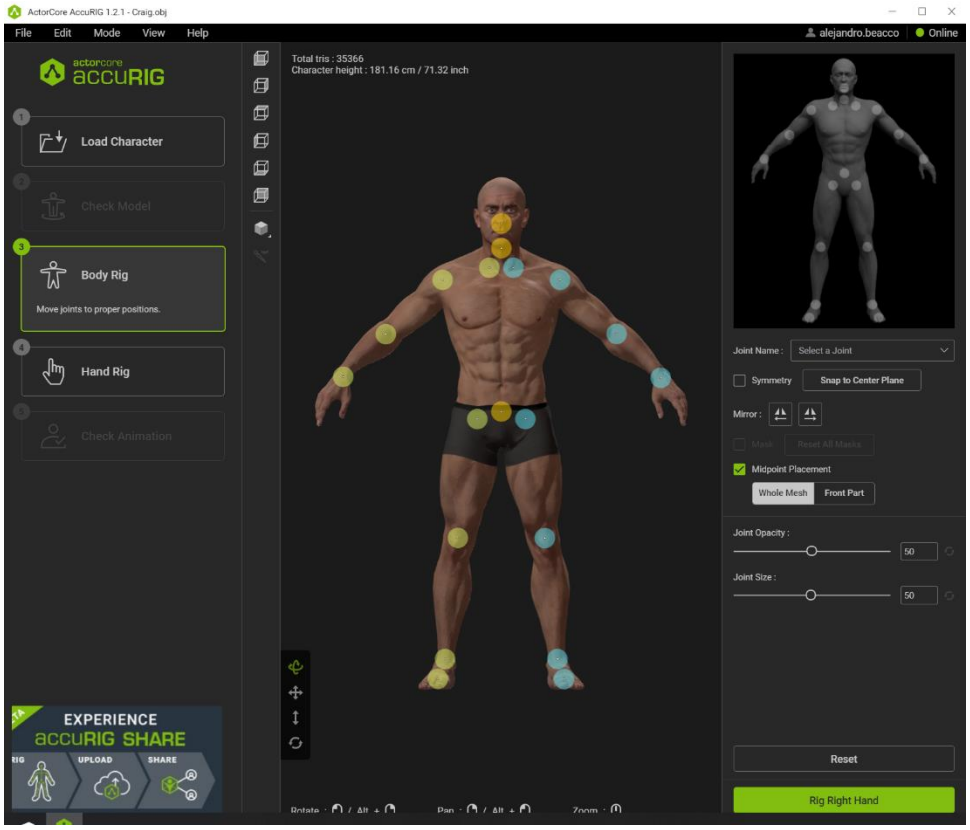


Figure 55. AccuRig

You can find and download AccuRig from: https://actorcore.reallusion.com/auto-rig.

7.5.10 Faceform Wrap

Wrap is an industry topology transfer tool that helps create digital characters based on 3D scans of real actors or sculpts. With *Wrap* you can convert 3D-scans of actor's facial expressions into a consistent topology. This is an integral part for facial rigging pipelines for games and movies. Wrap is also useful to transfer already existing expressions (blendshapes) from one model into another with the same topology. Or to change the shape of one topology into another one.

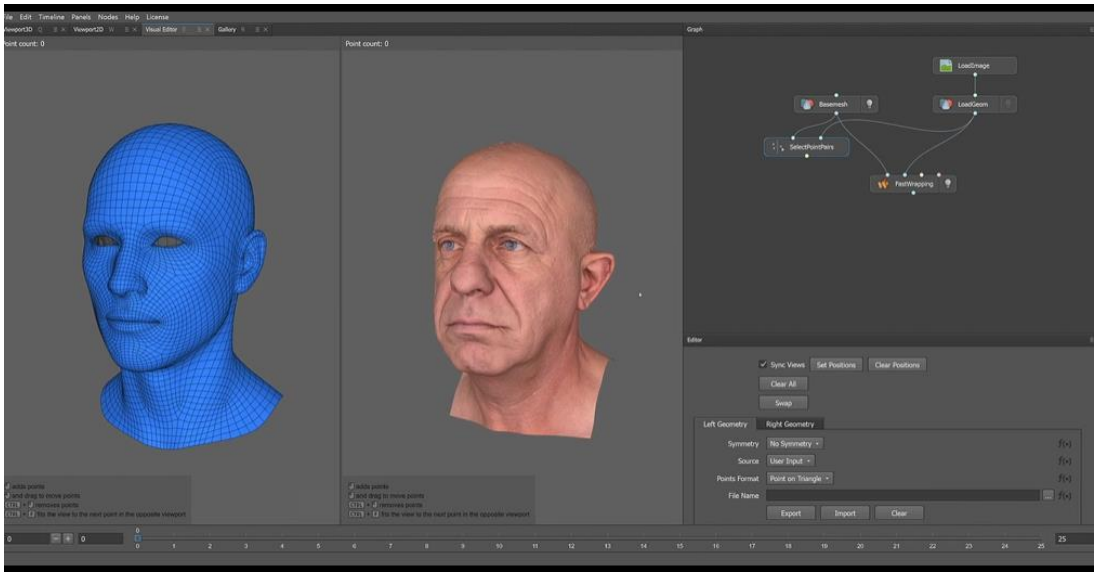


Figure 56. Faceform Wrap

This way, whenever you have a high-resolution mesh or scan that is not suitable for skinning, you can try changing its topology to a simpler one, and transfer the blendshapes of that one into your new mesh. *Wrap* has also features to easily adjust or adapt clothes and accessories from one avatar into another.

You can access *Wrap* from: https://faceform.com/download-wrap/

7.5.11 Simplygon

Microsoft's *Simplygon* is a software tool that optimizes 3D models for real-time rendering. It can be used to reduce the polygon count of 3D models, improve their performance, and make them more suitable for use in real-time applications.

Simplygon works by analyzing 3D models and identifying areas where they can be optimized. It then applies a number of different optimization techniques, such as polygon reduction, level of detail (LOD) generation, and texture compression. The result is a 3D model that is smaller, faster, and more efficient.

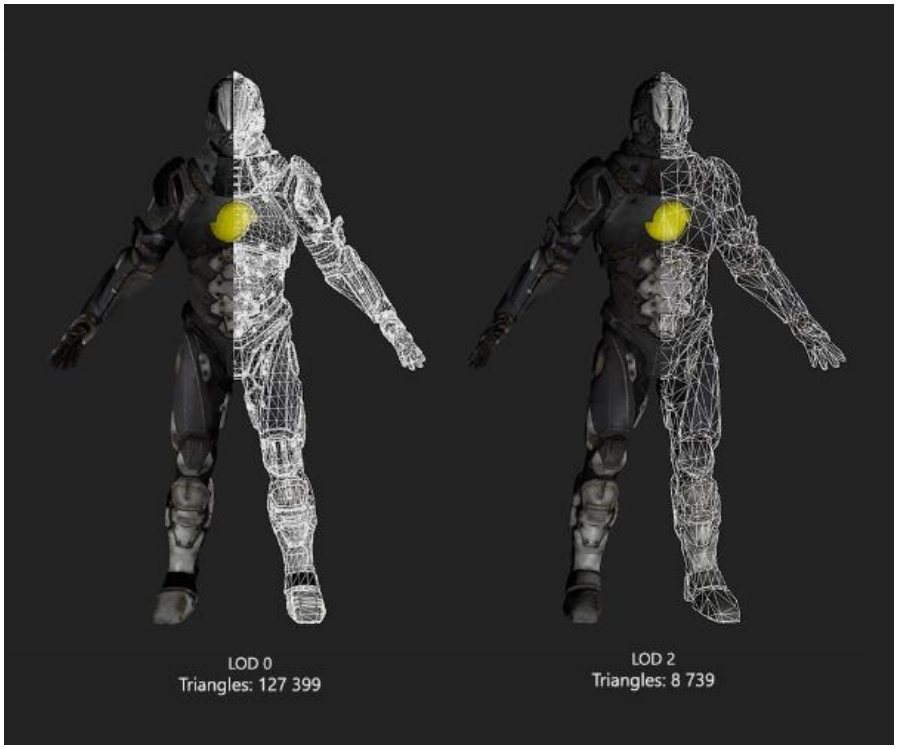


Figure 57. Simplygon

Simplygon is a powerful tool that can be used to improve the performance of 3D models in a variety of applications. It is used by game developers, CAD designers, and other professionals who need to create 3D models that can be rendered in real time.

In particular, *Simplygon* works very well with rigged characters, being able to transfer the skin weights from one level of detail to another. Therefore, *Simplygon* is a very interesting tool to consider whenever you need to optimize your 3D avatars for your applications that need to run on low-end devices. Moreover, *Simplygon* has a *Unity* plug-in that integrates its features into the engine user interface, accelerating the optimization pipelines of your production.

Simplygon has a limited free license and a payed one for projects and companies with lot of revenues. You can download the *SDK* at: https://www.simplygon.com/.

8 Repositories for 3D Assets

In this section we provide a large list of existing repositories for 3D assets. Making some of these repositories available through XR4ED market place will massively facilitate the access to 3D models for educators to create content for their classes. Unfortunately, it is not always easy to find the exact content that you need, and thus it is important to provide a unified platform where modelers could upload new content on demand. New content can be built with existing software for 3D modeling, such as Blender (https://www.blender.org/), Autodesk Maya (https://www.autodesk.es/products/maya/), SketchUp (https://www.sketchup.com/es) or Autodesk 3D studio max (https://www.autodesk.es/products/3ds-max/).

List of 3D assets repositories:

- Sketchfab: https://sketchfab.com
- 3D Warehouse: https://3dwarehouse.sketchup.com/
- Turbosquid: https://www.turbosquid.com
- Adobe Stock: https://stock.adobe.com/es/3d-assets
- Archive 3D: https://archive3d.net/
- Open3DModel: https://open3dmodel.com/
- Freepik: https://www.freepik.com/3d-models
- Free3D: https://free3d.com/
- 3DExport: https://3dexport.com/
- Quixel Megascans: https://quixel.com/megascans/home/
- FAB: https://fab.com/

8.1 Sketchfab:

https://sketchfab.com

Sketchfab makes it effortless for anyone to publish and locate 3D content online. The community of millions of creators who have published millions of models has made them one of the largest platforms for immersive and interactive 3D. Different models may have different usage rights. Therefore, double-check the license and usage rights before downloading any assets.

8.2 3D Warehouse:

https://3dwarehouse.sketchup.com/

SketchUp 3D models for architecture, design, construction, and entertainment can be shared and downloaded through *3D Warehouse,* an open library. *3D Warehouse* provides a free platform for anyone to create, modify, and re-upload content. Downloading files for use in any software is possible due to the fact that all models are free.

8.3 TurboSquid:

https://www.turbosquid.com

TurboSquid models are used by game developers, news agencies, architects, VFX studios, advertisers and creative professionals from all over the world. All major formats (MAX, FBX, OBJ, CAD, MAYA) are available for both paid and free 3D models files. Except where otherwise specified, free TurboSquid 3D Models are royalty-free.

8.4 Adobe Stock:

https://stock.adobe.com/es/3d-assets

Adobe Stock provides millions of royalty-free assets, which include thousands of 3D models, lights, and materials that are customizable and created by 3D specialists and world-class 3D artists. 3D scenes can be created using the assets for design, architecture, gaming, visual effects, and more. You can use Adobe Stock assets, except for the ones marked “editorial use only,” in any creative project, such as print ads, brochures, presentations, posters, book covers, commercials, websites, and annual reports. It's important to review the full terms of Adobe Stock licensing for anything else.

8.5 Archive 3D:

https://archive3d.net/

Archive 3D is a clean and huge 3D model download platform including equipment, appliances, people-related ware, structure, etc. You can easily find a specific 3D model according to its category in its vast 3D archives. The rights to use the assets may vary depending on the model, so check them before you download them all.

8.6 Open3DModel:

https://open3dmodel.com/

Open3DModel offers models in a variety of categories, including architecture, vehicles, and characters. This website is the place to find a 3D model of a building, car, or person. The website is easy to navigate, and you have the option to search for models by category or keyword.

8.7 Freepik:

https://www.freepik.com/3d-models

Freepik is a platform to find and download thousands of high-quality 3D modes. Designers and artists can quickly find the ideal solution for their projects. *Freepik* offers everything from vehicles and architecture to human anatomy and technology in formats like *FBX* and *OBJ*. All the 3D models can be downloaded for free, although it is required to give attribution to the authors. Otherwise, you must get a premium subscription.

8.8 Free3D:

https://free3d.com/

Free3D is a webpage consisting of more than 17,000 free 3d models in categories such as vehicles, plants, architecture, human anatomy, etc. The 3d files can be downloaded in formats like MAX, OBJ, FBX, 3DS, etc. For Stock Media Products, Free3D grants to you a non-exclusive, perpetual, worldwide right and license to copy, distribute, reproduce, adapt, publicly display, publicly perform, digitally perform, transmit, broadcast, telecast, advertise, create derivative works, and market Stock Media Products within Creations except for the ones marked with an “Editorial” notice on its Product Page.

8.9 3D Export:

https://3dexport.com/

3DExport is a marketplace where you can buy and sell 3D models, 3d print models and textures for using in computer graphics (CG) projects. It offers more than 15 different 3D formats for downloading such as *MAX*, *Cinema4D*, *Maya*, *Lightwave*, *Softimage*, *OBJ*, *FBX*, etc. But free downloads are only for personal and non-commercial use.

8.10 Quixel Megascans:

https://quixel.com/megascans/home/

Megascans from *Quixel* offers thousands of 3D assets, tileable surfaces, vegetation, imperfections, atlases, decals and much more, from urban to natural, with hundreds of new assets scanned weekly. Megascans allows for uncompromised quality and efficiency. It helps studios create beautiful scenery faster. All assets are consistently scanned, scaled and PBR calibrated, and every single 3D mesh comes with meticulously optimized topology, *UVs* and *LODs*, meaning less time doing boring work such as optimizing assets, and more time creating your experiences by using them.

Moreover, *Megascans* offers unlimited access to all assets for use with *Unreal Engine*. That means that if you have a Content License, you can simply sign in with your *Epic Games* account to get unlimited access to the *Megascans* library through another software called *Quixel Bridge* (https://quixel.com/bridge). But of course, *Megascans* assets can also be used in other tools and engines by acquiring the appropriate license.

8.11 FAB:

https://fab.com/

Fab is an upcoming new marketplace from *Epic Games* giving all digital content creators a single destination to discover, share, buy and sell digital assets. They are aggregating the contents of *Quixel*, *Sketchfab*, *Unreal Engine Marketplace* and *ArtStation Marketplace* into one new unified experience that will connect communities and make it easier to access a massive library of digital assets — 3D Models, Materials, Sound, VFX, Digital Humans, and more.

Fab will be an open marketplace, offering content for a broad set of content creation tools, game engines, open worlds, and metaverse platforms. Native integrations and *API* connectivity to leading content creation tools will bring speed and agility to world building. It is expected that *Fab* will launch later this year with an expansive library of digital assets for use across platforms.

8.12 Generative AIs for 3D models

Creating 3D models and assets by hand is very time-consuming and requires specific knowledge as well as having artistic skills. And finding the exact asset you are looking for is not always doable or easy in the large number of marketplaces. If you need to generate your game or application with hundreds of assets, the problem can rapidly scale.

To ease this content creation process and democratize it, there has been an increase in generative 3D networks that aim to produce 3D assets. This new active area of research has produced works such as:

[9] [10] [11] [12] [13] [14] [15] [16] [17] [18] [19] [20].

However, the obtained models on this kind of works are not always ready to be used for current commercial or practical applications. The 3D generated models should ideally be detailed and offer arbitrary topologies, as well as a textured mesh, which in the end is the primary representation used by standard computer graphics engines. Instead, most of the mentioned works still produce 3D point clouds, voxels, neural fields or implicit shapes. These would typically require some post-processing to convert them to a final textured mesh. And methods that directly output such meshes generally do it by working with pre-defined shape templates, and thus cannot generate new shapes or complex topologies. A recent method (GET3D) though has presented a generative model that directly outputs practical meshes using a differentiable explicit surface extraction method and a differentiable rendering technique.

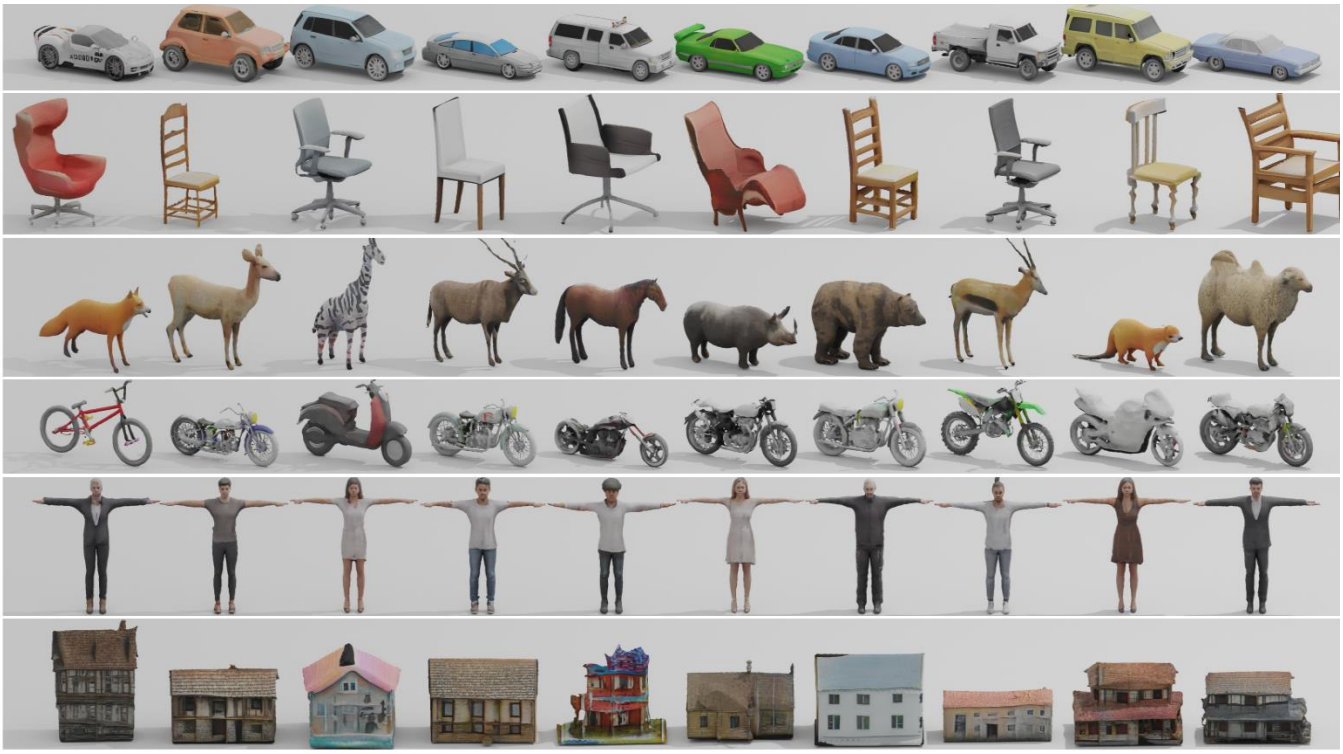


Figure 58. Generative AIs for 3D models generated with Nvidia GET3D.

In any case, as with any deep learning method, the main challenge and problem relies on the obtention of data, in this case databases of 3D models, that may need to be annotated, segmented and categorized.

You can train models using famous databases like ShapeNet or Renderpeople, but you will have to check the license of anything produced using that data. Essentially it is more challenging than 2D image generation due to the expensive 3D data collection and the complexity of 3D shapes.

As mentioned before, various 3D generators employ different shape representations. These generators are trained to model the distribution of shape geometry (and optionally, texture) from a collection of 3D shapes. Some methods attempt to learn a 3D generator using only 2D image supervision. These methods make use of explicit 3D representations, such as meshes and neural radiance fields, along with surface or volume-based differentiable rendering techniques, to enable the learning of 3D awareness from images.

9 Conclusions

In this document we have presented a large number of repositories, libraries, and APIs that are currently available and could be used for some of the building blocks of the XR4ED platform. Currently, the creation of virtual reality (VR) environments and games requires a substantial grasp of technical expertise, predominantly accessible to developer's adept in game engines that facilitate such endeavors. These presents a barrier for educators to embrace this technology and bring XR to their classrooms.

Besides having programing experience and being knowledgeable with game engines, in order to build a VR experience, the developer often needs to access many different tools. For example, we have presented in this document many repositories for 3D models. So, the user needs to access those repositories, and understand about formats to import/export between platforms in order to bring them to the final application. Similarly, if the educator needs avatars, he/she will need to access a different set of repositories, be able to get the right quality for the performance needed in the application (which also depends on the final hardware that will be used), and have knowledge about compatibility between skeletons and animation formats. Therefore, there is a need to simplify this process and make the class preparation transparent to the technology so that any educator can use it.

Current applications for XR in education are still limited to a specific number of lessons developed by experts (requiring knowledge in programing, game engines, VR and AR). As a student it is possible to access these lessons and experience them with an HMD or even just a smart phone for many AR applications or google cardboard. However, the content is fixed and educators would struggle to even make a few adjustments to better fit their teaching content. This makes the entering point for educators still extremely difficult and challenging. Large organization can pay for experts to develop their content, but looking towards the future and also at how educational tools have evolved in the past, we need platforms that are as simple to use as PowerPoint or google slides, but for XR content. Some applications have started moving in this direction, by allowing the educator to build content simply dragging and dropping 3D models or 360 images/videos into a format similar to the slides in a traditional presentation. This offers an easy-to-use framework but XR should go beyond observing a 3D model or 360 image/videos. We should move away from the presentation style consisting on one item or slide at a time, to fully immersive VR experiences where the user can navigate and interact, or even smoothly move from fully immersive VR to AR using mixed reality headsets. Very important as well is to have access to a marketplace where XR content and lessons can be shared and edited. This will push the future of XR for education tools as it will facilitate accessing content. We will be able to buy a VR scene or objects just like we buy books. But similarly, to current online books, it will be easier to modify or extend the content and also to keep track of students' progress. It is well known that students learn better when they get to experience things by themselves, as opposed to sitting in a classroom listening to the teacher. XR will open the door to building such experiences where students can discover and learn concepts at their own pace and experience them as if they were real.

Thus, the core goal of XR4ED is to provide a new platform that facilitates the process of building immersive learning experiences within a unified system. The XR Authoring tool will allow users to be inside a VR space and dynamically download 3D models from the Marketplace to create a VR Environment and content for their lectures. All within a single platform with all the assets available without having to access external programs or repositories. The game authoring tool connects with the backend and the database to get 3D assets and metadata associated. The VR tool allows to importing 3D assets in real time by an editor and can be saved for the viewer application to view. This will help in the development and modification of VR environments. XR4ED aspires to become one of the leading platforms for XR systems for education, learning and training in EU.

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