European Media and Immersion Lab

D3.10 – Report on HMDs and content creation engines for LBE

Work Package 3 – Lighthouse Projects at Laboratory Nodes

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Abstract

This document, “Report on HMDs and content creation engines for LBE” (D3.10) provides an overview of available HMDs, content creation engines and tracking solutions and their potential in use for LBEs. It will also highlight special characteristics of the respective systems and give advice which technologies have the greatest potential for the implementation in the context of the project.

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1 Introduction

This document provides an overview of available Head Mounted Displays (HMDs), content creation engines and tracking solutions for single and multi user experiences and their potential in use for Location Based Experiences (LBX). It will also highlight special characteristics of the respective systems and give advice on which technologies have the greatest potential for the implementation in the context of Filmakademie Baden-Württemberg and the other partners' Lighthouse projects. The document can also serve as a valuable resource for potential FSTP projects.

Notice that we have transitioned the abbreviation for Location Based Experience to LBX instead of LBE as the latter is often associated with Location Based Entertainment which does not need to involve immersive aspects per se.

The document is divided into the following main chapters, providing an overview of technologies with the potential for use in WP3.4:

HMDs: An overview of available HMDs, their characteristics, special features and potential uses within the project.

Tracking Solutions: A collection of available tracking solutions and their potential to be used in the project.

Content Creation Engines: A side-by-side comparison of content creation engines and their feature sets and workflows with the aim of determining the best possible development environment in the context of workpackage 3 task 4.

2 Head Mounted Displays (HMDs)

This chapter will present a selection of the most influential headsets in the current market and what sets them apart from each other. The market for HMDs has become very diverse with consumer, prosumer, enterprise and professional market segments. Different targets are addressed ranging from fully self-contained, mobile solutions to tethered high-quality headsets reaching towards the physical limit of what a human eye is able to perceive.

As of 2022, there are around 80 tethered VR glasses available, accompanied by around 60 mobile VR HMDs. On top, around 40 AR glasses like the HoloLens manufactured by Microsoft are available. The pace of releasing new devices has increased significantly with new companies and start-ups also jumping into the business. At least 10 new major VR HMD releases can be expected every year.[1]

[1] https://en.wikipedia.org/wiki/List_of_virtual_reality_headsets

Aside from these all-in-one solutions, smartphone-based VR headsets in which the smartphone's display and processors are used to drive head-mounted experiences are also available. This appears to be the best value option to jump into VR, given that a compatible smartphone is most often already available. The Google Cardboard project paved the way for this approach, Samsung's Gear VR is another example.

2.1 Tethered VR Headsets

Tethered VR headsets have been the standard for many years. They are connected through a cable or a WIFI connection to a workstation. These headsets deliver the best visual quality but tend to be heavier than stand-alone headsets and can restrict the movement of the users due to the attached cables. When used in location-based experiences these headsets are often connected to a backpack PC which adds additional weight to the user. Using a backpack system comes with an additional on-boarding and off-boarding effort for immersants and accordingly necessitates further staff operating the systems.

2.1.1 Pimax 8KX[2]

Image 1 Pimax 8KX headset

The Pimax headsets deliver a very wide field of view and high resolution. While delivering a high visual quality, some reports claim that they tend to be bulky.

[2] https://pimax.com/de/pimax-8k-x/

2.1.2 Valve Index[3]

Image 2 Valve Index headset with hand controllers/trackers and lighthouses

The Valve Index is still considered one of the best tethered consumer headsets due to its wide field of view and unique Index controllers that support finger tracking. A third-party solution for streaming VR content has been developed as a Kickstarter project but is yet to be released. The Valve Index provides access to dedicated content such as Half-Life: Alyx, a VR game in the Half-Life story universe. The game was highly acclaimed and received positive response. However, it did not trigger a VR gaming hype as many sources expected. While specifically designed for the Valve Index hardware, the game can also be played on other systems.

2.1.3 HTC Vive Pro[4]

Image 3 HTC Vive Pro headset

[3] https://www.valvesoftware.com/de/index
[4] https://www.vive.com/en/product/vive-pro/

The HTC Vive Pro used to be the best-in-class VR headset. Its use of lighthouse tracking and the option for streaming VR content made it appealing for many LBX use-cases. Yet, the system is not state of the art anymore in terms of visual fidelity.

2.2 Stand-alone VR Headsets

Stand-alone headsets got a big push through the development of Meta's Quest consumer headsets which currently rule the market for consumer VR HMDs. These headsets track themselves via internal infrared cameras (inside-out-tracking) and are therefore very simple to set up and use indoors. Stand-alone HMDs offer limited graphics performance via their internal mobile processor but can be connected to a workstation via cable or WIFI for experiences and games that require higher graphics performance. Thus, these headsets are very versatile to use and more affordable compared to tethered systems.

2.2.1 Meta Quest 2[5]

Image 4 Meta Quest 2 headset

Meta's consumer headset combines ease of use, acceptable tracking and visuals for an affordable price with a lot of entertaining apps and other high-quality content. Meta continuously added more and more innovative features to the headset with software updates, like for example hand-tracking or streaming via WiFi. Their latest announced feature called shared spatial anchors allows local multiplayer at home or for VR arcades by sharing point cloud information between the headsets over Meta's servers - which may require ongoing evaluation on data privacy.

[5] https://www.meta.com/de/quest/products/quest-2/

2.2.2 Pico 4[6]

Image 5 Pico 4 headset

The Pico 4 is currently in release. The Chinese headset has already become Meta's biggest potential rival, since the Pico 4 is sold even cheaper than the older Quest 2 and comes with so-called pancake lenses that are lighter, thinner and clearer than the fresnel lenses of older headsets. Pico is allowed to sell their headsets in Germany, though it is unclear if the mother company ByteDance, who also owns Tiktok, protects user data in line with the European GDPR. Frequently changing Terms and Conditions might require constant evaluation to guarantee GDPR conformity.

2.2.3 HTC Vive Focus 3[7]

Image 6 HTC Vive Focus 3 headset with hand controllers/trackers

Vive Focus 3 is HTC's answer to Meta's Quest 2. The headset has a more robust head strap than the Quest, which makes on- and offboarding faster and easier in LBX use-cases. It has exchangeable components, which makes this the most sustainable headset on the market. HTC continues to

[6] https://www.picoxr.com/de/products/pico4
[7] https://www.vive.com/de/product/vive-focus3/overview/

develop additional hardware components, for example for face tracking and tracking of props, which increases the versatility of these headsets. The combination of exchangeable components with reliable data privacy makes this headset attractive for business use cases like location-based experiences and is used in Europa-Park's Yullbe Go experiences and the VR park Zero Latency[8].

2.3 Mixed Reality Headsets with RGB-Video Pass Through

Mixed reality headsets with video pass through are the newest addition to the market. They offer a high quality stereoscopic coloured video pass-through mode. Therefore, virtual elements can be projected into the user's field of view instead of blocking the user's real environment. Being very new or expensive, none of these Headsets seem to be currently used for Location Based Experiences. New use cases might yet be explored in the near future.

2.3.1 Varjo XR3[9]

Image 7 Varjo XR3 headset

The Finnish Varjo XR3 is currently considered the headset with the highest visual quality on the market. It requires a high-end graphics workstation and an additional paid subscription which makes this headset expensive. It is therefore targeting mostly the enterprise market.

[8] https://invest.zerolatencyvr.com/next-gen
[9] https://varjo.com/products/xr-3/

2.3.2 Xtal 3[10]

Image 8 Xtal 3 headset

The Xtal 3 is a competitor to the Varjo XR3 and developed in particular for professional flight simulators. It requires a connection to a workstation. The headset has a high per-eye resolution (3840x2160 pixels) and a high horizontal field of view (180°). It does not require external base stations. It has integrated eye tracking and includes gaze analysis and dynamic foveated rendering[11]. Since it is primarily made for professional flight simulators, it is sold without controllers.

2.3.3 Lynx R-1[12]

Image 9 Lynx R-1 headset

The French Lynx R-1 is a stand-alone mixed reality headset with a unique diamond shaped lens design. The peripheral view is by standard not blocked but can be blocked with an additional

[10] https://vrgineers.com/xtal-3-mixed-reality/
[11] https://en.wikipedia.org/wiki/Foveated_rendering
[12] https://www.lynx-r.com

hardware component. The headset is currently set to be released in February 2023 and is marketed as having a high data privacy.

2.3.4 Meta Quest Pro[13]

Image 10 Meta Quest Pro headset with controllers

The Quest Pro is marketed as Meta's headset for co-working in VR. The peripheral view is optionally blocked in a way similar to the above-mentioned Lynx R-1. The headset features light and clear pancake lenses and has integrated eye and face tracking. It is targeted towards business use cases and for tech enthusiasts.

2.4 Outlook

Every year many new HMDs get released. The pace of new XR technology being brought to customers has never been faster. The above-described HMDs represent a segment of the market as of end of 2022.

After this deliverable is released and throughout the project's timespan a multitude of HMDs is expected to surface. For a full list of currently available and yet to be released headsets and their hardware specifications we recommend the website https://vr-compare.com/

Throughout the project, FABW will continue to observe the market of newly released HMDs. Rumours already suggest a soon to be released successor[14] to the Vive Focus 3 which might add and improve interesting features especially for Location Based Experiences such as potentially full-body motion capturing. In general, a tendency towards adding location-aware features can be observed lately.

[13] https://www.meta.com/de/en/quest/quest-pro/
[14] https://mixed-news.com/en/new-htc-vive-headset-leaked-fast-slim-and-modular/

3 Tracking Solutions

Different tracking solutions for HMDs and XR in general are available. Each of these uses fundamentally different techniques for positional and rotation tracking. This chapter provides an overview of all available methods.

3.1 Optical Outside-In Tracking

Optical Tracking Solutions use retro-reflective or active illuminated markers on bodysuits and/or objects which bounce back infrared light that is emitted from an array of special tracking cameras or the markers themselves. Based on this information, the software recalculates the position of the markers in virtual space and with that the position of the limbs of the tracked people. The special cameras of these systems are very expensive, need to be rigged around the tracking volume and calibrated before use. Furthermore, they depend on a controlled lighting scenario to not disturb the infrared light from the cameras. When optical outside-in motion capturing is used in offline production, problems in the captured data (like lost markers etc.) are fixed in a manual and time-consuming process in post-production. This is not possible for live location-based experiences, any errors need to be accepted as is.

Usual scenarios are full-body motion capturing and object (so called rigid-body) tracking. The benefit of such optical outside-in tracking is that it provides sub-millimetre precise positional tracking to gain absolute positions within the tracking volume. It is not prone to drifting over time and multiple tracking targets (e.g. multiple persons and objects) can be tracked at the same time including their positional relation towards each other. Since tracking markers need to be seen by at least 3 cameras at any time, the occluded areas (e.g. physical walls or objects inside the tracking volume) should be prevented. As mentioned above, the set-up of the tracking system might be complex, but also adding persons to the tracking is time consuming as markers need to be placed all over the body in a very specific manner. Fine details like fingers or facial expressions are fairly hard to perceive by such a system due to the limited resolution of tracking cameras. Special gloves with active infrared LEDs can be added to enhance finger tracking. Special head rigs can be used to track facial expressions. The infrared markers can also be attached to any prop to connect it to virtual props. These systems have been ruling the motion-capture market for decades because they can offer precise tracking but are no option for consumers who need an affordable system with fast and easy setup. The volume size is basically only limited by the amount of tracking cameras being available. Key players in this market are Vicon and Optitrack.

3.2 Video and AI Based Tracking

Video based tracking offers real-time motion capture in any environment using off the shelf cameras, computer vision and deep learning. This makes it possible to capture any human movement

anywhere for use in any game engine. The system uses the human body to calibrate and to capture motion instead of using markers on a suit. These systems are very new on the market. They only require a set of consumer cameras set-up around the tracking volume. Video based tracking works well in external sunlight. Key players on this market are Move.ai and Captury. Captury is currently limited to up to 3 people tracked with 6 to 24 cameras. Move.ai is currently limited to capturing up to 5 people in a 35m x 25m volume with up to 16 cameras, which might be sufficient for some LBX use cases. It is currently in beta and has no official pricing model yet. Facial tracking and object tracking is currently not included. Compared to optical outside-in tracking (chapter 3.1), the setup phase for adding persons to the tracking is minimal as no trackers are required on the body. This potentially also benefits the overall user experience. While well suited for full-body motion capture, reliable object tracking is more difficult or impossible for such solutions.

3.3 Lighthouse Tracking

Lighthouse tracking is considered the best affordable tracking solution for HMDs and VR on the consumer market. Two so-called Lighthouses are set up in a room, facing each other in the tracking volume. The lighthouses emit an invisible grid into the room providing orientation for the headsets and controllers. The system was developed by Valve and HTC. Since this tracking does not support finger tracking the Valve Index has special controllers that recognise the individual finger positions. Face tracking is not a lighthouse tracking feature but HTC offers an optional mouth tracking module for the Vive Pro. Additional props can be tracked with external trackers which makes this system interesting for LBXs with moderate budgets.

Usually such systems are only used to track the position and rotation of the headset itself and (optionally) also the hands of the immersant holding a set of hand trackers. While some experiences also use additional trackers, e.g., on the feet to provide something similar to a full-body motion capture, the accuracy of capturing whole body movements is far inferior to optical outside-in or AI tracking. On top, the lighthouse trackers are way larger than the tiny reflective markers used for optical tracking. As in the image-based tracking solutions, also lighthouse tracking is capable of tracking multiple HMDs and additional trackers simultaneously within the same tracking volume. The volume is limited to 10 x10 meters.

3.4 Inside-Out Tracking

HMDs with inside-out-tracking do not require any external hardware and are therefore the most flexible and affordable solution for Tracking in VR. The user just turns on the HMD and defines the experience area by drawing a virtual line on the ground with a controller in a pass-through view of the player’s environment. Too much sunlight or changing lighting conditions can affect the quality of tracking. It also requires an environment with recognisable optical features like furniture or pictures on the walls. The controllers must be in the player’s field of view to be tracked correctly. Modern HMDs

with inside-out tracking like the Vive Focus 3, Pico 4 and Meta Quest 2 also support hand tracking based on the infrared cameras of the HMDs. Eye and face tracking are becoming more and more common features of stand-alone headsets with inside-out tracking. It is unique to the Vive Focus 3 to support external trackers for props via the Vive Wrist Trackers.

3.5 Inertial Measurement Unit (IMU) Exclusive Tracking

Usually used for full-body motion capture, IMU tracking provides another possibility for tracking without the need for an external (e.g. outside-in) setup. Only a suit with included IMUs (e.g. XSense[15], Rokoko[16]) or a set of tracker bands (e.g. Sony Mocobi[17]) are needed. While this is an easy to setup system, the tracking is prone to drifting as only the positional and rotational acceleration of the IMUs in addition to a digital compass are used for tracking. In combination, this technology is also used to stabilise optical motion capture, or in HMDs to capture head rotations. In addition, the IMUs are sensitive to any interfering magnetic energy, e.g. coming from larger speakers. Nevertheless, IMU tracking has proven to be a quick solution for full-body motion capture.

4 Content Creation Engines

This chapter introduces the most common content creation engines available for use in LBX's and illustrates the decision-making process to pick a suitable basis for FABW's lighthouse project. After a first pre-selection based on former projects, the available documentation and the software's feature lists, it was decided to further investigate the Unreal Engine and the Unity Game Engine. Small tasks were constructed, which were implemented within the engines, and we measured the progress and effort it took for the implementation. Furthermore, performance (framerate) in combination with achievable visual quality on the target hardware (HTC Vive Focus 3) have been tested. Next to this, also the quality of documentation was included, together with the existence of a community and the presence of engine related tools. The tasks contained setting up a working multiplayer environment, sharing player positions and replicating their appearance. For quality measurements we used an already existing scene and adapted it to address the requirements we anticipate for our lighthouse project. Since light and shadow play a major role, the main focus was on dynamic light, baked light and shadow effects in addition to the usual criteria such as resolution of geometries and textures.

[15] https://www.xsens.com
[16] https://www.rokoko.com
[17] https://www.engadget.com/sony-mocopi-movement-tracker-metaverse-avatars-131721036.html

4.1 Supported Platforms

Table 1 Supported Features of Unity and Unreal game engines

	Unity	Unreal
PC	macOS, Windows, Linux	
Console	PS4, PS5, XBox, Switch	
Mobile	tvOS, iOS, Android	
Web	WebGL	--
XR	ARKit, ARCore, Microsoft HoloLens, Windows Mixed Reality, Magic Leap, Oculus, OpenXR, Playstation VR	ARKit, ARCore, Microsoft HoloLens, Windows Mixed Reality, SteamVR, Oculus, OpenXR, Playstation VR

4.2 Developer Tools

4.2.1 VR SDKs

Both engines support external SDKs for VR development. It is possible to have a direct VR preview in both editors if the HMD is connected - though for the use in Unreal Engine, the device should be connected before the editor starts. Also, when considering building for mobile VR instead of PCVR (VR applications running on Desktop and streaming to the HMD), Unity simplifies the project setup. For example, the downloadable Android target package comes with a Java bundle, which includes all the necessary tools (SDK, NDK, JDK) and sets up the project automatically. In Unreal, the process is more manual, which increases the risk of downloading the wrong packages resulting in failing build attempts.

Although both engines support OpenXR[18], Unity package management appears to be more organized, which allows for changing the supported SDK for OpenXR on the fly (e.g. switching Vive's WaveVR support to OculusXR support) to build the same application for different devices with the

[18] https://www.khronos.org/openxr/

support of HMD specific features. Unreal lacks a dedicated XR management tool and plugin activation has to be handled manually through the plugin manager.

4.2.2 Engine Features

Unreal

Sequencer

The Unreal sequencer is a mighty tool to animate cinematic scenes in sync to audio/dialogue files as the sequences can be placed on a joined timeline. The ability to nest sequences into each other allows an organized workflow and lets multiple users work on a cinematic sequence at the same time (as the different users are working on different subsequences). Also, the sequencer allows the implementation of game logic out of the box via event tracks (namely triggers and repeaters) – which allows the user to branch the sequence dependent on the players input.

Unity's equivalent to sequencer is called timeline and is called through a playable director component. It is also possible to sync animation to audio. This feature is absolutely key when working with pre-captured or hand animated facial animation to achieve a cinematic look, as the on-runtime auto-lip sync tools available only come with basic functionality. Also, Unity timeline does not have the same functionality as the Unreal Sequencer, and game logic has to be realised via scripts.

Blueprints

Unreal projects can be set up as C++ or as blueprint projects. Blueprints are a way of visual coding and are a beginner friendly way to learn about the engine. Intermediate and advanced users can also benefit from blueprints as they are a great tool for straightforward prototyping, come with node-sensitive auto suggestion and memorable color-coding. Dependent on the overhead of the project, it is absolutely possible to develop an application with the use of blueprints only. However, when a project reaches a certain amount of scale, good and clean refactoring is needed to maintain clarity and organizational structure, as the blueprint graphs can grow very big very fast – and event calls or outdated branches can be placed all over the graph where they can be hard to find on the long run.

Though Unity also introduced their visual scripting graph feature (and also allows visual scripting tools from third parties), Unreal blueprints have been around for longer and are therefore better documented, have a bigger user base and have gone through more iterations to become user friendly.

Geometry Brushes

Another feature of Unreal engine which shines in the earlier stages of production are geometry brushes, as they give the user the chance to quickly grey-box a level without leaving the editor. In this

case, it is not only basic geometry somehow put together like it would be possible in any other engine, but the ability to e.g. extrude faces, boolean operations or UV editing and the conversion to a static mesh after blocking is done.

Unity

Scriptable Render Pipelines

As introduced in 2018, Unity allows the use of the Scriptable Render Pipelines, giving the developer more control about the visual fidelity and rendering features in the developed application. In fact, with the Scriptable Render Pipeline Unity also released the Universal Render Pipeline (URP) – mostly used in mobile (VR) and 2D projects – as well as the High Definition Render Pipeline (HDRP) – mostly for high visual fidelity with features like tessellation or physical lighting. HDRP for VR should be only considered for PCVR projects.

Shader Graph

The shader graph is a node based visual shading tool for writing custom shaders targeting the specific render pipeline in use. The basic functionalities are similar to the built-in shader editor in Unreal, but provide additional possibilities to custom functions which can be shared globally between shaders. As Unreal also supports material functions to be reused in different materials, Unity seems to generally be more versatile in customizing shaders, whereas Unreal is more restricted and is often referred to as having a specific 'unreal-look'.

4.2.3 Asset Pipeline

Unreal

Uasset

Unreal Engine is based on a FBX[19]-content-pipeline and provides several import options for how to handle the data, and converts it into the engines own .uasset files, which store the asset specific settings. Meshes, rigs and animation are separated into different .uasset files. The original file still exists in the project, but has to be reimported every time a change in the settings is needed. Therefore, the migration of assets between projects can be performed through the "asset migration" tool to ensure a lossless migration with all of the assets' dependencies. With plugins like DataSmith additional, more specific data formats can be imported. A USD-based asset workflow[20] also exists as a beta implementation for version 4 of the Unreal Engine.

[19] https://www.autodesk.com/products/fbx/overview

Quixel Bride

Unreal integrated the toolset of Quixel, known for photogrammetry assets and PBR-shaded materials, with the Quixel Bridge. With the activation of the plugin, an asset browser manages the download and import of quality photogrammetry content in different resolutions directly into the project, along with all textures and materials, which speeds up the work of environment artists rapidly – in case a photorealistic look is desired.

Live Link

Live Link is used to stream data into the Unreal project from different sources which are capable to use this interface. It is most commonly used to stream and record motion capture data in real-time.

Unity

In contrast to Unreal, Unity uses a non-destructive approach. Assets that are imported are also kept as originals in the project and are only ever converted to the optimal format for the current target platform and engine settings. This means that it is no longer necessary to re-import assets if the environmental conditions change. This way, changes in the settings of the asset can be made and applied without reimporting the source file. Replacing or updating the source file is as easy as replacing it in the source directory. Here, again, the established data exchange format is FBX, although more modern formats such as USD are also supported.

Custom Import Presets

Every import setting can also be saved as a preset asset and either reapplied manually per asset or set up in the preset manager with additional filters like file locations or matching characters to simplify batch importing for certain asset types. This can speed up interactions with many assets substantially.

Custom Packages

Data transfer between Unity projects is achieved via custom unity packages. Multiple assets can be exported into a package which automatically suggests packing all dependencies into that package. In fact, all plugins imported into the project from the asset store or other sources come in Unity packages. However, as Unity allows the use of different render pipelines one should be aware of possible shader mismatches (e.g. when importing a material asset created with a different render pipeline).

4.3 Documentation & Community

4.3.1 Engine & API Documentation

Unity

The Unity Application Programming Interface (API) as well as the Unity Editor Manual are both up-to-date since version 5.2 till now (2023.1) and provide well-documented explanations and example code snippets.

Unreal

The Unreal Engine Documentation is up-to-date from version 4.26 to now (5.1) and contains an editor manual, different feature overviews and API documentations for C++ coding as well as visual scripting with blueprints.

4.3.2 Asset Stores

Unity

The Unity Asset Store can be accessed via the editor or the Unity website. Also, already purchased or freely acquired assets (scenes, plugins, packages, shaders, …) can be accessed via the package manager, which is used to import all different kinds of additional packages into the project. It also allows to install packages from git, zip-files or even add custom registries, from which you can access the up-to-date versions of certain packages.

Unreal

The Unreal Marketplace is a web service, which can be accessed via browser or the Epic Launcher which is the hub application to manage different engine installs, projects, game libraries. Acquired assets can come in their own Unreal project or as packages – plugins may come as project or engine plugins. While a project plugin can be used for a specific project, an engine plugin needs to be installed into the engine source directory to ensure functionality. For plugins, which are not marketplace exclusive but can also be downloaded from third parties, the plugin needs to be manually copied into the designated directories of the engine.

4.3.3 Community

Although it is not easy to make a general assumption about the absolute numbers of usage of the different engines, it is possible to make valid arguments based on popular platforms and services

which share their data. If we look at the launches per year on Steam[20], which is the biggest online game distribution service, it becomes clear that Unity-based games were released almost three times more often than games based on Unreal Engine.

Another report released by Unity[21] themselves shows that about 45% of all mobile Apps have been developed with Unity already in 2015.

Taking the number of subscribers of the official subreddits into account (Unity 3D with 312k members, Unreal with 200k members) we can see a bigger user base on Unity's side. Also, having a look at the official forums and comparing the "showcases" we can see 20,757 topics for Unity and 10.8k topics for Unreal.

The information gathered from this data shows a bigger developer community of Unity, which results in more content, like assets, plugins, tutorials and community driven support.

While it is not a direct indicator for the absolute numbers of Unreal users, Unreal owns and supports communities like artstation.com.

4.3.4 Tutorials

Both Engines provide a wide range of examples for every core feature in their documentation including script/blueprint examples. In addition, both engines maintain their own learning platforms (Unity Learn[22]; Unreal Engine Learn[23]) containing example projects, courses and official tutorials. Also, both engines are represented online by their community members with how-to's and tutorials on all relevant sites like YouTube, 80.lv, etc.

4.4 Achievable Quality and Performance

Since the desired atmosphere in our LBX is strongly defined by lighting, light and shadow, the focus of the quality test for the rendering is on the features: Dynamic Light Sources, Dynamic Shadows as well as the baking (precalculation) of more complex lighting situations. Additionally, it was considered that the expected target platform will be a mobile (untethered) HMD. The Vive Focus 3 was used for this purpose. In conjunction with the official SDK[24] for the Focus, an Android application was built within each engine and transferred to the HMD for testing.

[20] https://www.gamedeveloper.com/business/game-engines-on-steam-the-definitive-breakdown
[21] https://unity.com/our-company/newsroom/unity-technologies-delivers-mobile-industry-report-analyzing-global-gaming
[22] https://unity.com/learn
[23] https://www.unrealengine.com/en-US/learn
[24] https://hub.vive.com/storage/docs/en-us/index.html

4.4.1 Target Platform

The HTC Vive Focus 3 was chosen for testing purposes, as it was state of the art at the time of writing. The HMD runs Android 10 (API Level 29) and uses the Qualcomm Snapdragon XR2[25], an SOC with an octa-core Kryo 585 (1 x 2.84 GHz, 3 x 2.42 GHz, 4 x 1.8 GHz) CPU and an Adreno 650 GPU. The System provides 8GB of RAM. The two RGB stripe displays have a resolution of 2448x2448 pixels and a horizontal Field of View of 116 degree.

4.4.2 Test Scene

A relatively complex scene has been used to push the engine and hardware to its limits. The scene contains 442 objects with a total of 230k triangles and 148 textures with a maximum resolution of 2k for the shading components Albedo, Normal, Metallic and Ambient Occlusion combined in 35 materials. The lighting addresses the requirements of our LBX and consists of a static directional light with shadow casting as a global light source, two static point lights building the room lighting in conjunction with 4 baked light sources to simulate a chain of lights and an animated point light that casts dynamic shadows.

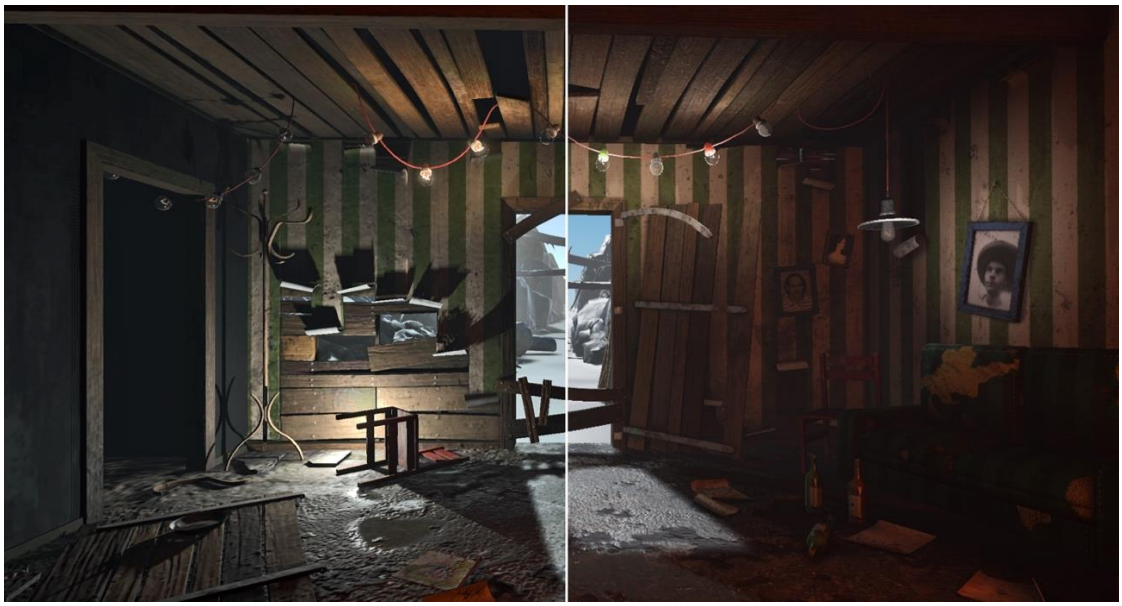

Image 11 Visual appearance of the scene. Left Unity, right Unreal.

In order to generate a smooth experience and avoid motion sickness, the highest possible frame rates should be aimed for, especially in virtual experiences. Typically, more than 60 frames per second are

[25] https://www.qualcomm.com/products/application/xr-vr-ar/snapdragon-xr2-5g-platform

required in this case. This is particularly difficult to achieve on mobile VR devices if the graphics being displayed exceeds a certain level of complexity. Specialised rendering techniques, which render the environment into an image buffer beforehand, are used to create a smoother experience on mobile devices. This enables head rotations to be displayed with a higher frame rate, as the time-consuming updating of the environment can also be carried out with slower update rates. It is assumed that frame rates from 30 fps are sufficient.

4.4.3 Test Results and Conclusion

Visually and technically identical scenes were adapted for the respective engines and tested for their performance. There was no significant difference in the measured frame rate. Unreal fluctuated between 50 and 27 fps, depending on the content displayed, and Unity has been measured between 50 and 30 fps.

Both engines can process the scene and basically render with all its geometry and material details. However, differences occur in the available rendering techniques and features. While Unity can render all light sources as required, Unreal has some issues. On mobile devices in Unreal it is only possible to display moving light sources, casting shadows to a very limited extent. Only so-called "modulated shadows[26]" are possible, which are limited in quality and are only available for light sources that are position independent (directional lights). Therefore, there would be no way for a moving light source such as a torch to cast a shadow.

4.5 Network Communication

4.5.1 Unity

Among the different types of network topologies Unity supports, there are two considerable options for LBX namely called Listen Server and Dedicated server. The other options (Local MP, LAN Game or P2P) do not fit the requirements and will not be mentioned any further.

Listen Server

Game Sessions hosted on Listen Servers have the advantage of not needing an external server for communication between the clients, as the Host Player becomes server and player, while the other players join this host players session, which may impact the performance on the host players device (depending on the application's performance needs). Also, if the host player ends the game (on purpose or through hard- or software malfunction), the game ends for all players in this session.

[26] https://docs.unrealengine.com/4.27/en-US/SharingAndReleasing/Mobile/Lighting/

Dedicated Server

A dedicated game server fixes the problem of abrupt interruption by the host by hosting the persistent world or level the other players join on an external device. In the scope of an LBX, where the maximum amount of players, levels and interactions is predictable, this server can be a portable computer connected to a local network, where the players can join via WiFi.

Native Solutions (Netcode for GameObjects)

Netcode for GameObjects (Netcode) is a high-level networking API integrated into Unity. It can handle network communication and abstraction of networking logic. It enables sending scene changes and events across a networking session to multiple clients. Focus of the API is a seamless integration into Unity and its development environment, instead of handling low-level protocols and networking frameworks. Netcode supports Listen and dedicated network configurations.

Third-Party Solutions

Photon is a popular and widely used multiplayer server solution which also offers a web hosting solution as well as the ability for self-hosting. The setup process is very beginner friendly as every supported replicable functionality hast its own component in the package (e.g. Transform View, Animation View). Photon Voice is a module made for voice chat and can be installed additionally to the main plugin.

FABW Developments

At FABW the Virtual Production Editing Tools (VPET)[27] have been developed on top of Unity for many years. Lately a refactoring and reimplementation of open-source VPET has resulted in a separation of its core functionalities and virtual production specific implementations. The core has been made modular and is now called TRACER (Toolset for Realtime Animation, Collaboration & Extended Reality). It provides a variety of network communication functionality. These range from a lightweight and fast 3D scene transfer protocol, to real-time and time synchronized scene update communication between many clients. LBX developments could also benefit from this open-source software base. Many if not all network communication challenges can be represented and solved within TRACER, which internally relies on netMQ[28] as communication layer. As TRACER is specifically developed for 3D assets, animation and live update exchange, it has the potential to reduce the overall development demand in this regard for the LBX lighthouse developed by FABW as well as XR projects in general.

[27] https://animationsinstitut.de/de/forschung/tools/vpet
[28] https://github.com/zeromq/netmq/

4.5.2 Unreal

Unreal engine comes natively with a built-in multiplayer framework as the engine itself developed from an Engine for multiplayer first-person-shooter games. In fact, every game based on Unreal has multiplayer features built-in even if it is using only one player. However, there are two separate ways to lay a foundation for the project depending on the architectural approach for the desired multiplayer experience.

Listen Server

The listen server approach is part of every Unreal version acquired from the Epic Launcher and can be used without any special effort. In this case, one player serves as host and runs a game instance on this player's device so other players can connect to this game session. If the host cancels the game instance, the game also stops for all other players connected. Therefore, a bad network connection of the host player has a direct influence on the other clients' experience.

Dedicated Server

For a dedicated server it is necessary to build Unreal Engine from source, which requires basic knowledge of a complex build system. In addition, a building target for the dedicated server has to be created manually in code for the dedicated server to gain the ability of packaging the server build to run it outside the editor. In this architectural approach, every player is a client connecting to the server which handles all player inputs on a dedicated device.

Native Solutions

As mentioned before, Unreal comes with a robust multiplayer framework that can be used without third-party software or plug-ins. The built-in event system can be used for client server communication as every custom event with a custom property can be used as RPC (Remote Procedural Call) and can be replicated as Multicast, Run On Server or Run On Owning Client.

Third Party Solutions

Photon as mentioned in the Unity segment is also available for Unreal.

5 Conclusions

Within the current status quo of hardware development - though other HMDs offer higher visual fidelity, or features for mixed reality - the Vive Focus 3 hits a sweet spot within quality, weight, ease of use, data privacy, sustainability, versatility and pricing for its intended use-case of FABW's lighthouse experience. Furthermore, HTC proved to be enhancing the possibilities of these headsets with

additional hardware components. The Focus 3 headsets already proved themselves on the market for Location Based Experiences use cases like Europa-Park's Yullbe Go and VR parks from Zero Lantency. The Focus 3 uses inside-out-tracking, which is acceptable in most LBX setups. It has yet to be tested if the tracking could be substantially improved by video-based tracking solutions like Move.ai that are just about to be officially released.

As new technologies in the field of VR/XR are evolving quickly and are being released quite frequently, it is hard to foresee the future which HMD will dominate the field of LBX in the next 2-3 years. However, it should be considered to develop within the OpenXR standard which was established in 2017 by the Khronos group. OpenXR works as a layer between the chosen engine and the HMD specific development tools, which allow you to develop for more than one type of VR gear at a time and enable the possibility to switch the target platform mid-development with smaller adjustments and without restructuring the whole project to the dependencies of the targeted HMD.

The question of the engine depends very much on the need. Unreal is aimed at two types of content creators. On the one hand, there are those who want to get started at a very high level without having to deal with the underlying technical aspects. On the other hand, there are large, professional development teams that are able to adapt or further develop a complex game engine to their needs. If, however, more complex or highly optimised projects need to be realised with a compact team size and effort, Unity's strengths come into play. Furthermore, the tests carried out that these advantages come into play especially in projects for mobile devices such as a stand-alone HMD. The visual advantages that an Unreal Engine offers on high-performance workstations cannot be used on weaker and less feature rich hardware. Here, a high degree of optimisation and flexibility in the render pipeline, as offered by Unity, is more important.