

Bachelor's thesis

Information and Communications Technology

2019

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DESIGN AND DEVELOPMENT OF VIRTUAL REALITY APPLICATION



BACHELOR'S THESIS | ABSTRACT

TURKU UNIVERSITY OF APPLIED SCIENCES

Information and Communications Technology

2019 | 37 pages

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DESIGN AND DEVELOPMENT OF VIRTUAL REALITY APPLICATION

Virtual reality technology and solutions have evolved greatly over recent years. Virtual reality has become a valuable part of technology, like in training and due to its versatility, it can be applied in many different industries.

This research was commissioned by Morrow Games Oy and this work aimed to research the theory and practices of virtual reality, its design and development process, create a basic virtual reality project that can be tested and define some of the best practices for creating a virtual reality experience.

The work deals with the basics of virtual reality, its key elements, its different forms, technology, concerns, and challenges. The work also deals with the virtual reality application design and development process, recommended development tools, testing, and determining user experience. In this work was used material related to virtual reality, like articles, documents, literature and Unreal Engine was used for development.

The result of the research was an overview of virtual reality, the best design, and development practices, and important considerations when creating virtual reality applications.

KEYWORDS:

technology, three-dimensional, Unreal Engine, virtual reality

OPINNÄYTETYÖ (AMK) | TIIVISTELMÄ

TURUN AMMATTIKORKEAKOULU

Tieto- ja viestintätekniikka

2019 | 37 sivua

Ohjaaja: Yliopettaja Mika Luimula, dos.

Henri Vuorio

VIRTUAALITODELLISUUS-SOVELLUKSEN SUUNNITTELU JA TOTEUTUS

Virtuaalitodellisuuteen liittyvät teknologiaratkaisut ovat kehittyneet huomattavassa määrin viimeisten vuosien aikana. Virtuaalitodellisuus on tullut merkittäväksi välineeksi teknologiaan, kuten koulutukseen ja sen monipuolisuuden vuoksi sitä voidaan soveltaa monilla eri toimialoilla.

Tämän tutkimuksen toimeksiantajana oli Morrow Games Oy ja työn tavoite oli tutkia virtuaalitodellisuuden suunnittelun ja toteutuksen teoriaa sekä eri käytäntöjä ja luoda virtuaalitodellisuus projekti, jolla pystytään testaamaan ja määrittelemään virtuaalitodellisuuden parhaita käytäntöjä.

Työ käsittelee virtuaalitodellisuuden perusteita, sen avainelementtejä, sen eri muotoja, teknologiaa sekä huolia ja haasteita. Työ käsittelee myös virtuaalitodellisuus-sovelluksen suunnitteluprosessia, työkaluja, testausta, käyttökokemusta sekä sen toteuttamisprosessia. Työn toteutuksessa hyödynnettiin virtuaalitodellisuuteen liittyvää materiaalia, kuten artikkeleita, asiakirjoja, kirjallisuutta ja Unreal Engine -pelimoottoria käytettiin toteutusvaiheessa.

Työn tuloksena saatiin yleiskuva virtuaalitodellisuudesta, suunnittelun ja toteutuksen parhaista käytännöistä ja siitä, mitä on tärkeää ottaa huomioon, kun toteutetaan sovelluksia virtuaalitodellisuuteen.

ASIASANAT:

kolmiulotteisuus, teknologia, Unreal Engine, virtuaalitodellisuus

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LIST OF ABBREVIATIONS (OR) SYMBOLS

3D	Three-dimensional.
Actor	Actor is an object that is placed into a level. Actors support 3D transformations like rotation, scale, and translation.
Blueprint	Blueprint is a visual scripting system used in the Unreal Engine.
CPU	Central processing unit.
FOV	Field of view
GPU	Graphics processing unit.
HMD	Head-mounted display. An HMD has a small monitor in front of each eye, and it can be a full helmet or a pair of goggles and is used with virtual reality systems.
HUD	A heads-up display.
Immersion	Immersion refers to the user's experience so that his concentration is fully in virtual reality.
PC	Personal Computer.
Plug-in	(or plugin, or add-on) is a software component that can be used to add a specific feature to the desired program.
UI	User Interface.
UMG	Unreal Motion Graphics UI Designer.
VR	Virtual reality is an immersive computer-simulated reality or multimedia, that creates an environment that simulates a feeling of presence in an imagined world or in the real world and gives the ability to the user to interact with the world.

1 INTRODUCTION

Virtual reality can convince the user that they are somewhere where they aren't. That is the reason virtual reality is becoming more common and due to its versatility, it is used in many different industries. Especially the game industry and entertainment have pushed the development of virtual reality in the right direction.

The subject of this thesis is focused on virtual reality and its design and development process and the purpose is to learn more about the different virtual reality practices. My perspective on the subject is mainly what I have studied, learned, and researched. There is a lot of research material for the design and development process for virtual reality, and this thesis answers common questions about the virtual reality, its design, and the development process as well what to consider and why when designing and developing applications for virtual reality. In this work was used much-related material, literature and Unreal Engine. I also aim to make the information more accessible to others interested in virtual reality.

The thesis begins with the definition of virtual reality. I research what virtual reality is, its key elements, information about the technology and concerns and challenges. In Chapter 3, I focus on the design process, what tools to use and what to consider, when designing applications for virtual reality. Also, this chapter focuses on different testing methods and user experience. In Chapter 4, I will go through the overall level developing process and some of the best practices, when I created and tested a basic virtual reality application with Unreal Engine. After that, I will consider my research and work to determine what are the most important parts and best practices for the development of virtual reality applications. There is much more to learn about virtual reality, but this thesis answers the questions about virtual reality and its design and development process.

2 VIRTUAL REALITY

Virtual reality (VR) can create and simulate an experience so that the users forget that they are in an artificial environment and they can interact with the virtual world. This can be achieved with a technology that provides a realistic artificial environment or three-dimensional image. It is created with a mix of interactive software and hardware, and it is then presented to the user so that the environment feels real and where they can interact with it in a physical or seemingly real way. To get a fully immersive experience an input devices and headset are being used. The virtual reality environment can be almost anything, it can break the bounds of physical reality or it could be a normal setting. The largest technology companies (like Google, Facebook, and Microsoft) are currently investing in virtual reality and the development of virtual reality has just begun to grow. (Reality Technologies, n.d.)

Virtual reality is being used in many different industries and it will eventually involve more industries. Here are some of those industries that use virtual reality technology:

- Gaming
- Education
- Healthcare
- Marketing
- Technology

(AltexSoft, 2018.)

2.1 Key components of a virtual reality

For next it's time to focus on the key components that are used and needed in virtual reality experience.

2.1.1 Virtual world

In the three-dimensional virtual world, users can interact with the virtual world and with the other users. A virtual world shows visually any changes in interactions and movements in the real world. (Reality Technologies, n.d.)

2.1.2 Immersion

When the user has the feeling of being physically in a non-physical virtual reality world, that is called immersion. The immersion can be created with the stimulation of the many human senses. When enough human senses are stimulated the total immersion can be achieved. There are two types of immersion in virtual reality:

- Mental immersion – Is a deep mental state, where user disbelieves they are in a virtual environment.
- Physical immersion – Is a physical engagement and the user has a suspension of disbelief that they are in a virtual environment.

(Electricalfundablog, n.d.)

2.1.3 Sensory feedback

As many human senses as possible are needed to be simulated for virtual reality to work. These include many senses like vision (visual), hearing (aural), and touch (haptic). Sensory feedback is mandatory to properly simulate all these senses. With the use of integrated software and hardware, also known as inputs, sensory feedback can be achieved. (Reality Technologies, n.d.) I will later focus more on hardware and inputs in a Technology chapter.

2.1.4 Interactivity

The virtual reality experience to feel natural the interaction is mandatory. The interaction gives users comfortability to engage with the virtual reality environment. The interaction includes changes in their viewpoint, like movements of their heads or the overall movement of the user. The human brain can easily sense if the virtual environment fails to respond and that breaks the immersion. To remain the immersion the virtual reality environment needs to respond naturally to the user's actions. (Reality Technologies, n.d.)

2.2 Different types of virtual reality

There are many types of technologies in virtual reality and more to come when technology progresses. The different virtual reality types separate with the cases of use, different applications and different levels of immersion. Virtual reality has three basic types: Non-immersive, semi-immersive, and fully immersive. (Electricalfundablog, n.d.)

2.2.1 Non-immersive simulations

The least immersive experience is the non-immersive simulations. Non-immersive simulations only stimulate some of the user's senses and therefore the user is aware of the outside world. This non-immersive three-dimensional environment can be accessed with monitors like desktop workstations. (Electricalfundablog, n.d.)

2.2.2 Semi-immersive simulations

If the user is not fully immersed in the virtual environment, it is called semi-immersive simulation. These semi-immersive simulations are used in a flying simulation and many other different simulations. Semi-immersive simulations are used with multiple projection systems or large screen projectors and these stimulate the visuals. (Electricalfundablog, n.d.)

2.2.3 Fully immersive simulations

In fully immersive simulations the hardware is used to stimulate all the user's senses and it provides the most immersive experience of the simulations. These simulations can create a very realistic experience. (Electricalfundablog, n.d.)

2.3 The technology of virtual reality

The right kind of technology is used to fool the human brain to feel the artificial environment as real. With the use of a headset and handheld input devices, the virtual reality experience feels and looks real. Like in the televisions and computer screens the

three-dimensional virtual environment is displayed to the user without the boundaries. The use of handheld input devices like motion trackers, makes the experiment to feel real as they make the base of interactivity and react to the user's movements. With the stimulation of the real-world senses, the virtual environment feels a lot like the natural world. (Reality Technologies, n.d.)

2.3.1 Virtual reality systems



Picture 1. Computer with virtual reality compatibility. (Virtual Living, 2017)

Virtual reality systems and high computing power are needed when producing virtual reality content. Using the personal computer (PC), smartphones, or consoles these three-dimensional interactive environments can be created and viewed with the virtual reality headset. (Virtual Reality, 2017a)

2.3.2 Head-mounted displays



Picture 2. Sony's PlayStation virtual reality headset. (Savov, 2017)

A head-mounted display (HMD) or sometimes called as goggles, or headset is a device that puts a display in front of the user's eyes. The display covers the user's view and displays virtual reality content to the user. There are virtual reality headsets, that can use smartphone displays to provide virtual reality content, like the Google Cardboard or the Samsung Gear VR. Some of the head-mounted displays come with a headset and these can also provide audio stimulation. In the market, there is also a wireless virtual reality headset, and these give a much more user-friendly experience. (Reality Technologies, n.d.) In this work, I refer to head-mounted displays as headsets.

Examples of virtual reality headset devices:

- HTC Vive
- Oculus Rift
- PlayStation VR
- Samsung Gear VR
- VR-1 – Human-eye resolution headset, manufactured by Varjo.

2.3.3 Input devices for virtual reality



Picture 3. Vive and Oculus input devices. (Virtual Reality, 2017b)

The input devices are used to give users a sense of immersion. With the input devices, the user can use navigation and interact in the virtual reality.

Examples of virtual reality input devices:

- Joysticks
- Wand Controllers
- Trackpads

(Virtual Reality, n.d.)

2.3.4 Accessories and peripherals

Virtual reality has many accessories and more being in development. These accessories provide new ways of using virtual reality and they expand the overall immersion and experience. In the future, these accessories are being used for VR training, entertainment, fitness, sports, games, wellness, and healthcare. Here are a couple of types of accessories listed down below:

- Haptic gloves – Oculus VR is working on haptic gloves, that provide the feeling of touch. The gloves offer resistance and control the amount of movement.
- Full body haptic suits – These suits give user feedback and stimulate nerves using electricity.

- Virtuix Omni – Virtuix Omni is a multi-directional treadmill, where the user is stationary, but lets users to move at full speed, freely and in 360 degrees.

(Dormehl, 2018.)

2.4 Concerns and challenges

Virtual reality has many challenges and concerns that are needed to be addressed when working with virtual reality. These include user experience issues, small mainstream presence, and technology issues. (Sappington, 2018.) Some of the main issues include injury, price, cybersickness, eye strain, seizures, and aftereffects.

2.4.1 Injury

When the user is immersed in virtual reality, they become blind and deaf to the real world, and the risk with multiple types of injuries is increased. It is safer to use virtual reality seated because while standing the user can collide with cables or walls that are in the real world and almost always the user will need supervision. Also, any touch from the real-world can break the immersion. When implementing sounds for virtual reality experience the hearing loss should also be considered. (Jerald, 2016, pp. 178-179.)

2.4.2 Price

One of the challenges virtual reality has is the price. Virtual reality devices are needed to experience a high-quality virtual reality. These can cost a lot, but there are much lower cost solutions to get a good virtual reality experience. Google pursues the consumers to virtual reality with its Daydream VR platform. The Daydream VR gives mobile users access to content like apps and virtual reality videos. Also, Sony has its virtual reality games, headset, and controllers that can be used with the PlayStation 4. Sony offers a Sony's VR Bundle, which includes all mentioned before, or the headset can be bought separately. (Neiger, 2016.)

2.4.3 Cybersickness

People that are affected by virtual reality can get cybersickness (a form of motion sickness). When affected with cybersickness, headache, nausea, and vomiting may occur. The reason these occur is not fully identified, but many factors have concluded that field of view, lag, and vection are causing the problems. Vection happens when movement in the real-world conflicts with the visuals and the body because the motion is just an illusion in virtual reality. Lag happens when there is a delay between the user and the change in the display. (Virtual Reality, 2017c.)

2.4.4 Eye strain, seizures, and aftereffects

Eye strain, seizures, and different aftereffects may occur when affected by virtual reality. If there are flashing lights in virtual reality environment, it can cause flicker that is distracting and it can cause symptoms like fatigue, dizziness, nausea, headache, confusion, panic and in worse case even seizures and loss of consciousness. Anyone with epilepsy should not use virtual reality and any kind of flashing or flickering lights should not be implemented, because they can cause a photic seizure. After using the virtual reality and returning to the real-world aftereffects may still occur, like perceptual instability of the world, disorientation, or flashbacks. (Jerald, 2016, pp. 173-175.)

Now the work has answered what virtual reality is, its technology and concerns and challenges that come with it. Next, the work focuses on the design of a virtual reality application.

3 DESIGN OF VIRTUAL REALITY APPLICATION

When designing the virtual reality experience, it is important that the created world needs to convince the user that they are part of it. Knowing design and environment principles help a lot when designing virtual reality experience. The designed virtual world needs to feel and look consistent. Wherever the user is located, they need to feel comfortable, but to feel immersed the user doesn't need to be in a realistic virtual world. (The CGVR Lab, 2017.)

3.1 The design process of virtual reality application

In this part, the work focuses on the environment and design principles and what to consider when they are built in virtual reality experience. When designing the virtual reality experience, the user must be at the center of the focus. The world needs to be consistent and it's mandatory that the user feels being part of the virtual world. Also, the overall experience needs to be versatile and immersive. The virtual world needs to provide information to the user so that they know all the time where to look and what to do. The virtual world needs to guide the user in the right direction so that the user doesn't lose interest, and this can be achieved by drawing the user's attention with the use of visuals and sounds. (The CGVR Lab, 2017.)

Some core experience elements should be considered when designing virtual reality experience. Here are some of them:

- Constant improvement of the core experience is required, try different methods, and learn from user feedback.
- The experience has more priority than technology.
- Provide information to the users that they know what they need to do.
- Users need a goal.
- Forget photorealism, believability is a better option.
- Don't make the experience too complicated, because there are new users not used to virtual reality.
- Breaks in immersion are needed to avoid.
- Remember the target audience.

(Jerald, 2016, pp. 267-268.)

3.1.1 Traditional gaming and virtual reality

Traditional games can be useful when designing virtual reality experiences because of their similarities. Overall game design has many similarities that can be used in virtual reality, but the virtual reality also has many differences that are needed to consider. Traditional gaming wins on many facets compared to virtual reality. Traditional games have gone through a long development time, and therefore the games are longer and much more detailed. Traditional games can have more quality in them, but virtual reality can give the best kind of immersion, where the users are part of the virtual world and interact with it. So, overall the traditional games include more content, but the virtual reality provides creativity and immersion that has never seen before. (VRrOOM Ltd., 2017.)

Designing virtual reality experience has many similarities, like when designing traditional games. In Unite 2016 session Curtiss Murphy described Flow and Simplicity, which are two effective game design concepts.

Flow includes four points:

- Goals – Players need goals, and that keeps them to come back.
- Feedback – Players need to always progress.
- No distractions – Design needs to be simple.
- Just-Right – Difficulty needs to be perfectly balanced with time/skill.

Simplicity includes four points:

- Core – The design should be kept in the essentials.
- Limited choice – Users don't need too many choices.
- Intuitive – Try to make the experience awesome.
- Player's perspective – Remember the target audience.

(Curtiss, 2016.)

3.1.2 Physiological comfort

The experience of virtual reality to feel comfortable is important. If virtual reality is used for long times users can get the feeling of fatigue and nausea. This can happen if the user is stationary, but the virtual environment is moving. The feeling of nausea can be prevented with the use of different methods. Some ways to prevent nausea is to use a dashboard that moves the same time as the user or a fixed reference point. One way to prevent the nausea is to give the user the ability to control the movement, like accelerating. Teleportation is one of the most recommended movement methods for virtual reality because the movement can't be seen, it helps to prevent nausea. (Hudelson, 2018.)

3.1.3 Environmental comfort

Getting environmental comfort right is a big part of the virtual reality experience. Virtual reality environment includes everything that happens in virtual reality experience. In the real-world people can feel uncomfortable in large, small, or high spaces, so when designing the virtual reality environment, the scale of the world is needed to be considered. There are many useful techniques to guide the user like audio, and light that can be used in virtual reality experiments. (Hudelson, 2018.)

There are multiple ways to make the experience more comfortable to the user. Here are some of these ways:

Environmental wayfinding aids:

- Help users to know their goals, sense of position and direction with the use of environmental wayfinding aids like markers, maps, compass, trails, and objectives.
- Wayfinding aids should be used in both a subtle and explicit way.
- Place landmarks strategically.
- Navigation can be guided with visual handrails.

(Jerald, 2016, pp. 269-270)

3.1.4 Human perception

Human perception is one of the many problems in virtual reality technology. The optical illusions and physiology of the human body are needed to understand to achieve full human perceptual without the side effect. Most of the user's senses are needed to be fooled because the virtual reality tries to simulate the real world. The most important sense is human vision, which provides information about distance, speed, and space perception. Next, the most important senses are hearing, touch, and then the other senses. (Virtual Reality, 2017a.)

Designers can use the advantage of virtual reality camera settings, like a field of view with numerous different techniques. One method is to set the field of view smaller for some parts and wider in other parts. Another method is to make the frame of a field of view -rounded because the shape feels better than rectilinear shape. (Jerald, 2016, p. 255.)

User interface:

Virtual reality application needs a visual interactive communication layer from the machine to the user. Any kind of interactive element in the virtual reality environment is called the user interface (UI), and these can come in many forms. User interfaces are needed and used for display, and the interaction inputs. One way for the user interface in virtual reality is a basic menu that is presented in a HUD. With the user interface, the user can select items, trigger actions, and much more. Simple HUD can work, but it is not the best solution for virtual reality as it may cause issues that make the HUD impractical or uncomfortable. Instead, the navigational elements can be implemented into the environment, and therefore the interface is intuitive to the actions. (The VRAR Stories and Audience Committee, 2017, pp.14-15.)

Use of audio:

- Audio can provide situational awareness and attention from all directions.
- Users become deaf if there's no audio.
- Using too many sounds will overwhelm the user.

- Providing audio when using the interfaces gives feedback to the user.

Use of color and lighting:

- Colors can bring out emotions.
- Bright colors that stand out can get the attention of the users.
- Highlighting and ghosting of objects can be used to signify usability.

(Jerald, 2016, pp. 269-270.)

Giving feedback to the user:

Providing feedback to the user is a good way to give reactions based on what is happening in virtual reality. One way to give feedback to the user is to use hand inputs sound and rumble features. Using this rumble feature can make the experience much more effective and increasing the immersion. (Jerald, 2016, p. 306)

3.2 Tools

A game engine is needed to develop an interactive virtual reality experience. These game engines and VR engines are programs, that are specifically aimed to create immersive, and realistic virtual reality worlds. There are also many free and good software available for virtual reality development and this is a good opportunity for new developers to start creating virtual reality experiences. Many of these tools also offer an online marketplace where users can find 2D, 3D models, templates, as well as different virtual reality related tools. (AltexSoft, 2018.) Next, the work focuses on some of the common tools that are recommended when creating a virtual reality experience.

3.2.1 Unity 3D

One of the tools to consider for virtual reality development is Unity 3D. Unity 3D has a framework that is extremely easy to learn. This allows inexperienced users to create good quality projects. The only thing the user needs to know is programming languages JavaScript and C# to get started. Unity 3D is free, but there is also a paid premium

version. The free version of Unity 3D is still enough to learn the basic of the program. (SoftMediaLab, 2018)

3.2.2 Unreal Engine

The Unreal Engine is a high-end game engine. Unreal Engine is free, even for professional use, but once a product ships Epic Games only asks for 5% of the gross revenue of the product. Unreal Engine is easy to use, VR-ready and it has the heavily optimized code. (Robinson, 2018)

3.2.3 CryEngine

CryEngine has an excellent toolset for the 3D visualization and with that, it has gained a lot of fans. Users must be familiar to C++ or C# to start using CryEngine. These are built-in 3D rendering optimization tools, visualization, and business logic execution. CryEngine isn't free, but almost all its features can be tested without any payments. (SoftMediaLab, 2018)

3.2.4 Modeling software

Objects that are in virtual reality application are needed to be modeled and built. To build these things, they are needed to be modeled using 3D modeling software. There is much different software available, but here is some recommended:

- Autodesk 3ds Max is a 3D computer graphics program used by professionals. 3ds Max has a very large toolset for 3D modeling. It has many different modifiers, and therefore it can make the modeling process a little easier.
- Blender is a free, open-source, cross-platform, modeling, animation, and rendering tool.
- Houdini by SideFX is used to create visual effects, 3D art, and it has good flexibility and control. It also has a plugin for the Unreal Engine for automatic level design generation.

(Creative Bloq Staff, 2019.)

3.3 Testing and user experience

While making a virtual reality experience, it is very useful to test it with the target audience. Testing and getting user experience is a very effective way to learn what is needed to reach the desired virtual reality experience. Communication with team members and users is essential for learning. Getting feedback, criticism, and failures is a learning process to figure out the problems and ensure it will not happen again. (Jerald, 2016, p. 428.)

3.3.1 Testing methods

Testing and getting user experience to have many techniques, forms, and definitions. I will not include all the many different methods, but here are some of these testing methods and approaches.

- Demos are the most common method to acquire feedback from users. Demos give communication with the target audience, understanding, fresh ideas, and the same time market the project.
- Interviews are a series of questions that are asked by an interviewer and are much easier and flexible for the user than questionnaires. The best data from the interview comes after the person is experienced the VR application.
- Questionnaires are questions that are asked from participants, where they respond to the questions provided to them. Questionnaires provide for more private responses and are easier to administer. Surveys are typically not the appropriate way for the evaluation of VR applications.
- Focus groups are like interviews that occur in a group. Groups are more efficient than individual interviews and participants build off each other's ideas. Participants typically use a prototype and base their feedback on that experience. Focus groups are very useful at the beginning of the VR design.

- Expert evaluations are systematic approaches that identify usability problems from the user's perspective. Expert evaluations are the most efficient method of improving usability.

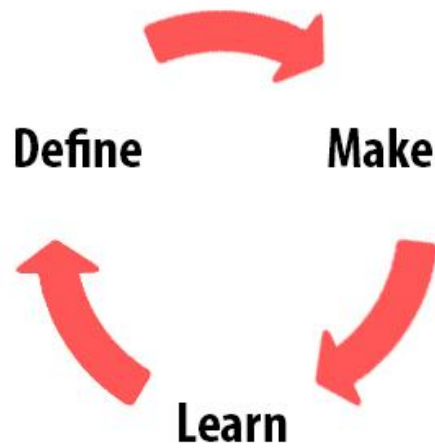
(Jerald, 2016, pp. 436-440.)

3.3.2 The define-make-learn cycle

Virtual reality experience must be created based on prototyping, redesign and getting useful feedback from the users. Nowadays virtual reality experiences can be created quickly, easily and without any programming experience. Because of this prototyping and testing is a big part when designing virtual reality experience. General iterative design is a good way when designing a comfortable virtual reality experience. The iterative design has three iterative stages, and these need careful consideration and are critical to optimizing the user experience and comfortable virtual reality experience.

- The define stage. In this stage, the question that is tried to be solved is: "What do we make?"
- The make stage. In this stage, the question that is tried to be solved is: "How do we make it?"
- The learn stage. In this stage, the question that is tried to be solved is: "What works and what doesn't?" After that, the answers are used once again in the define stage to start the cycle again.

These stages are conceptually performed in sequence, but they are often interwoven and occur in parallel. (Jerald, 2016, pp. 369-371.)



Picture 4. Process of virtual reality development. (Jerald, 2016, p. 370)

There are many different things to be considered when designing virtual reality experience, but with proper design, testing and learning the desired outcome can be achieved and overcome the challenges.

4 DEVELOPMENT OF VIRTUAL REALITY APPLICATION

Virtual reality applications can be developed in many ways and to many different platforms. Many powerful tools can be utilized to create these virtual reality worlds and new tools come often, so it's good to research these occasionally. Sketching, coding, modeling, and testing with these different tools will help to complete the desired virtual reality application. Next, I take a closer look at one of the developing methods that I used to create a small and very basic virtual reality project, using the Unreal Engine.

4.1 Development of basic virtual reality project with Unreal Engine

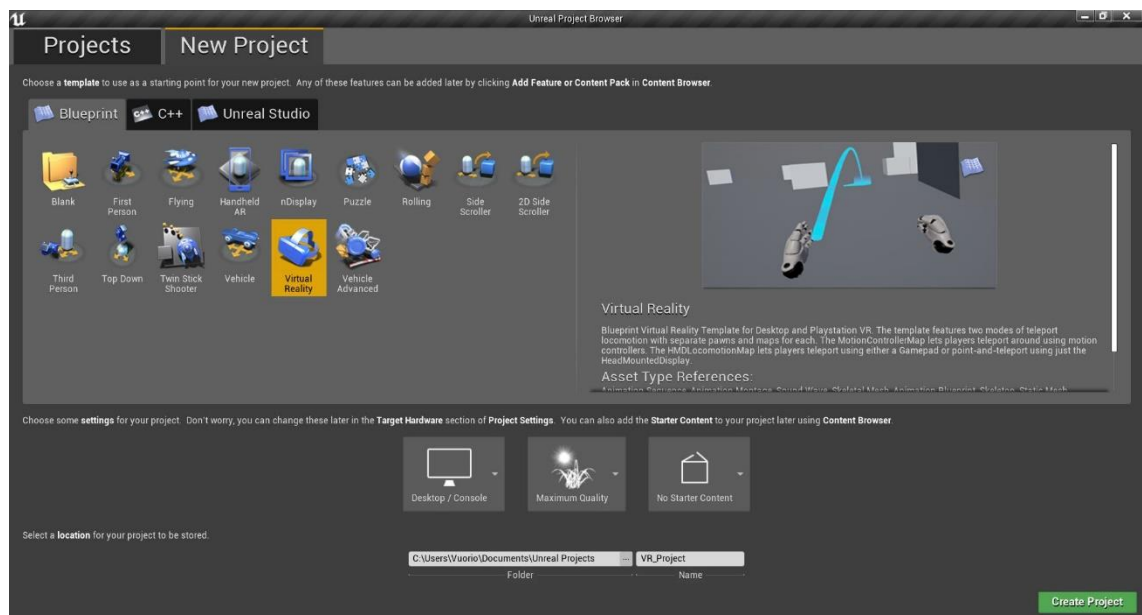
For this work, I created a small and very basic virtual reality project using the Unreal Engine. The objective of the project was to create a small basic virtual reality application, apply some of the best virtual reality practices and workflow adjustments to it, and look at the basic process of virtual reality project creation and test it. I chose the Unreal Engine to develop this project, because I have some experience with it, and I have used it in the past in multiple different virtual reality projects. My focus was on the overall use of Unreal Engine, virtual reality components, and solutions when making a virtual reality project. The project was developed for and tested with HTC Vive. Testing was done after all the big changes in the project to analyse the changes and determine the better options for virtual reality experience.

4.1.1 HTC Vive setup

First is needed to install the HTC Base Stations and make sure that the VR compatible PC and HTC Vive is connected and are ready to be used. After that Steam and SteamVR is needed to be installed to the system and make sure that all controllers and headset are updated. When the Steam app is open, clicking the VR button in the upper right corner of the Steam app will open the SteamVR. Then the Room setup and Tutorial is needed to be accomplished, to set up room scale and test that everything is working as intended. These can be accessed from the SteamVR menu and selecting Room setup or Tutorial. When setup is ready, and everything is working, the HTC Vive is ready to be used.

4.1.2 Creating a virtual reality project

When the Unreal Engine is installed and opened, start with the New Project tab. For virtual reality projects choose Virtual Reality Blueprint, which can be accessed by selecting New Project > Blueprint > Virtual Reality. After that select the wanted settings for the project. This virtual reality project was created for desktop, with Maximum Quality, and with No Starter Content. The location and name of the project can also be changed. After that, the project can be created.



Picture 5. Starting a virtual reality project in the Unreal Engine.

After the project was created, it also created the DefaultEngine.INI file to the project's Config folder. I edited this DefaultEngine.INI file under SystemSettings to preferred settings for virtual reality applications. The settings were edited to look like this:

```
[SystemSettings]
vr.PixelDensity=1
r.SeparateTranslucency=0
r.HZBOcclusion=0
r.MotionBlurQuality=0
r.PostProcessAAQuality=3
r.BloomQuality=1
r.EyeAdaptationQuality=0
```

```

r.AmbientOcclusionLevels=0
r.SSR.Quality=1
r.DepthOfFieldQuality=0
r.SceneColorFormat=2
r.TranslucencyVolumeBlur=0
r.TranslucencyLightingVolumeDim=4
r.MaxAnisotropy=8
r.LensFlareQuality=0
r.SceneColorFringeQuality=0
r.FastBlurThreshold=0
r.SSR.MaxRoughness=0.1
r.rhcmdbypass=0
sg.EffectsQuality=2
sg.PostProcessQuality=0

```

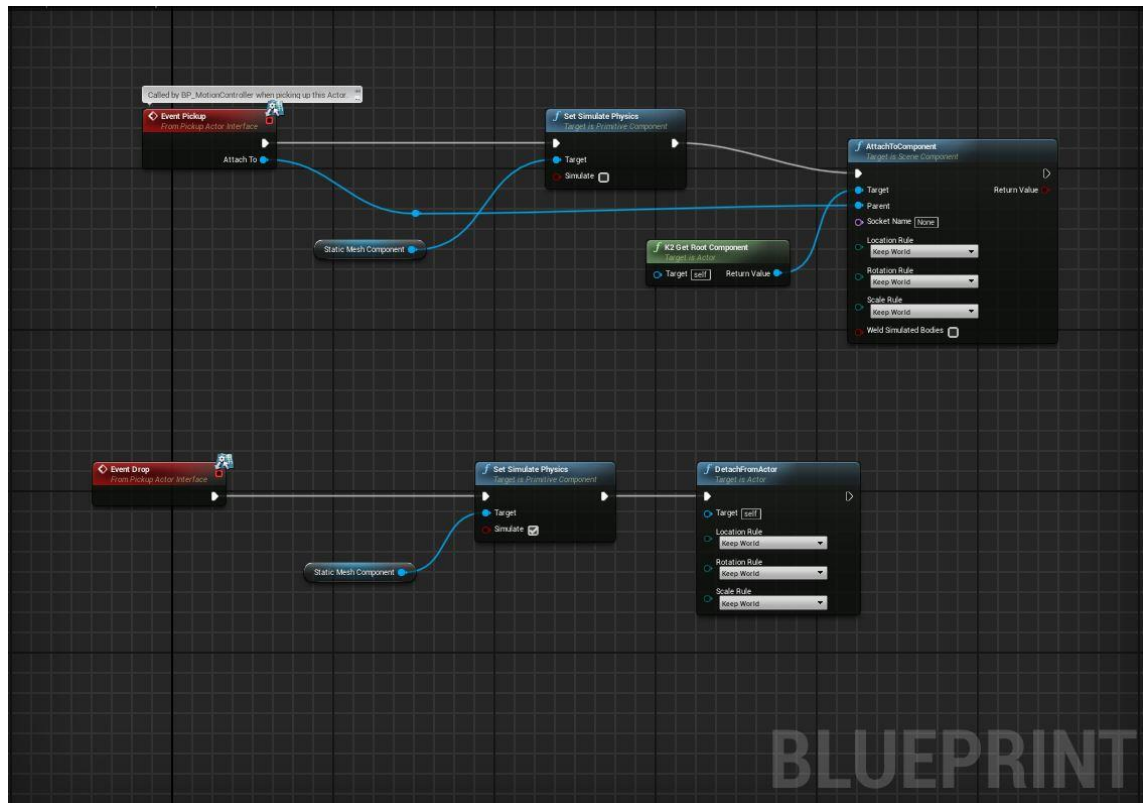
When starting the project, it is also good to confirm that the SteamVR plugin is enabled. In the Plugins menu wanted virtual reality plugins can be enabled and added to the project. The Unreal Engine also has many subsystems that can be extended using plugins. With plugins, user can add entirely new features and modify built-in functionality without editing Unreal Engines code. Plugins can add many additional features like the user can create new file types, add to the Editor new menu items and toolbar commands, or create entirely new features and Editor sub-modes. There are many useful plugins for development of virtual reality application.

There is also a pre-built level that has already many virtual reality functions like grapping an object and teleportation for the movement. The level is in the content browser in a folder VirtualRealityBP/maps and there is a level called: MotionControllerMap. To try this level in VR, click the Play button on top and select VR Preview. This level and all that it contains can also be modified or used in an empty new level. In this project I worked with this pre-build level, where I added, edited and tested the content to get to the wanted result.

4.1.3 Creating a virtual reality environment

In the Unreal Engine, the environment is made using a collection of Meshes, Lights, Blueprints, and more and these are called Actors. Developing the environment includes

placing Actors, selecting Actors, positioning Actors, and modifying Actors. So, to create a level that looks and behave as needed these Actors are needed to place into the scene, moved around to create an environment, and modify their properties as needed. The Blueprints are a visual scripting system and with the use of code, these Actors can be modified to needed way, like picking up objects. Using these different Actors, I made the desired small and simple basic environment to test the results of best practices for virtual reality.



Picture 6. Blueprint for dropping and picking up objects.

4.1.4 Virtual reality settings

How the VR camera is set up in the Unreal Engine depends if the experience is used seated or in a standing position. In a seated experience, it's needed to raise the camera for the character to be standing. However, for a standing experience, it's needed to make sure that the camera origin is on the ground. Different camera locations were tested and position a little lower than the eye height had the best result.

Table 1. Recommended camera location. (Unreal Engine, 2019)

Property	UE4 Default	Recommended VR
Base Eye Height:	180 cm	160 cm

When I created the virtual reality character, I needed to change settings of the character to recommended settings to work as wanted in virtual reality. If character size is too big or too small, it can ruin the immersion, so character Height and Width was needed to replicate the real-life measurements as much as possible. Different Height and Width settings were tested, and the recommended settings worked much better than the default settings. The next table shows recommended Height and Width for virtual reality.

Table 2. Recommended character Height and Width. (Unreal Engine, 2019)

Property	UE4 Default	Recommended VR
Height:	192 cm	176 cm
Width:	84 cm	68 cm

Different kind of speed and movement types are used by the need of experience, so it is difficult to recommend a setting for. Usually, the movement speed should be slower much slower than the default speed. In this project, the movement speed was dismissed and recommended virtual reality movement method teleportation was implemented.

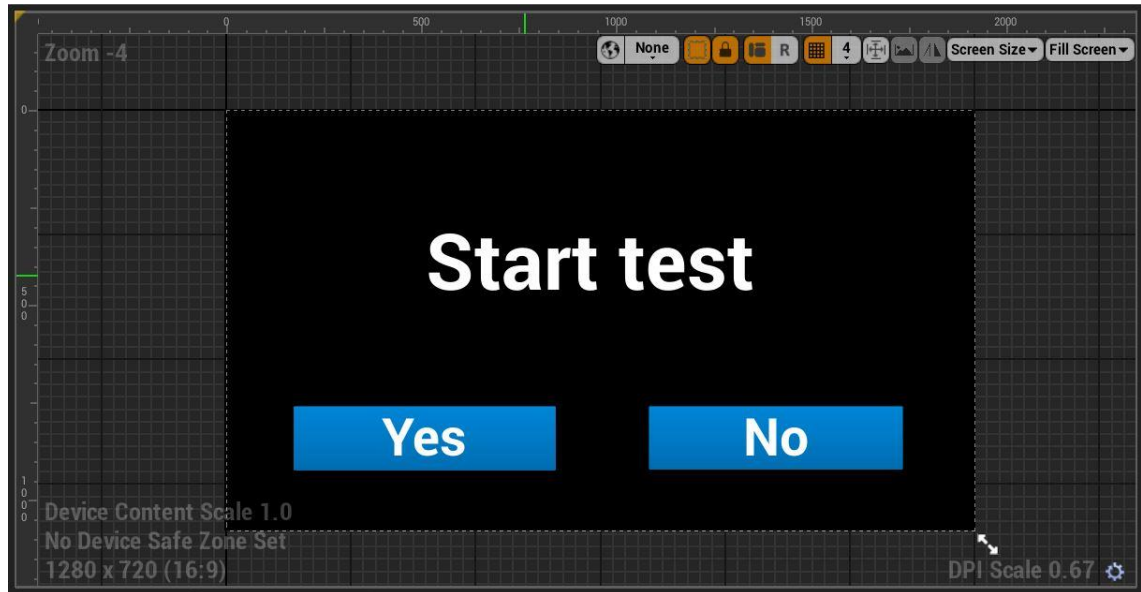
Table 3. Recommended movement speed. (Unreal Engine, 2019)

Property	UE4 Default	Recommended VR
Movement Speed:	60 m/s	24 m/s

4.1.5 Creating a user interface

Creating a user interface with the Unreal Engine is a simple task. The user interface is a big part of any application, but for virtual reality, it is recommended that an interface is a 3D object, or it is implemented inside the environment. Unreal Engine has a visual UI authoring tool called: Unreal Motion Graphics UI Designer (UMG). With these tool

elements like in-game HUDs, menus or other graphics related to the interface can be made. Within the UMG there are Widgets, that can be used to create things like buttons and checkboxes.



Picture 7. Basic user interface.

These Widgets can be constructed and edited in a Widget Blueprint. The Widget Blueprint has two different tabs: The Designer and the Graph tab. The basic functions and the visual layout can be constructed in the Designer tab. Widget functionality can be constructed in the Graph tab. For this small virtual reality project, I made a very basic user interface, with a couple of buttons and the interface was implemented in three ways: the traditional way, 3D object and into the environment. These different methods were tested and interface in the environment or 3D object worked much better than the traditional way.

4.1.6 Build process

In the scene, there are Preview labels in the shadows and the light leaks. This means that the lights in the scene have not yet been calculated. The scene and lights in the viewport are not looking the same in the final product, and to see how the result will look like, the project needs to be Build. To activate the build process, click a Build button on the top. Once the Build process has completed, it gives an indication of the result and

the project can be previewed with the Play feature. The Light Quality settings can also be changed inside of the Build Options to adjust the quality of the lighting when it is built.

4.2 Finalizing the virtual reality project

When the virtual reality project was almost at its final stage, it was optimized and packed for the desktop application. Next, the work focuses on some of the optimizing methods and packaging the project of virtual reality applications.

4.2.1 Optimizing

To get rid of possible performance problems, the virtual reality project is needed to optimize. The project should be optimized as much as possible because low framerates can also trigger simulation sickness. Here are some of the optimizing methods I used in my virtual reality project:

- Unreal Engine has a GPU Profiler that can track down assets that are too expensive for virtual reality. To activate the GPU profiler, press CTRL + SHIFT +, (Comma Key) together, while the project is running. A window will appear that shows what the project is doing on the CPU and GPU and the expensive assets can be tracked down.
- Virtual reality has demanding rendering requirements and many of the advanced Post Processing features can cause performance problems, so features that are enabled by default are needed to disable. First, in the (PP) volume, and the Post Process Volume section, enable the Unbound option. This makes the PP volume settings to apply to the entire level. After that, the settings of the Post Process Volume can be expanded, and each active PP settings can be disabled by enabling the property and setting the value from default to 0. The most important features to disable that are heavy and impact on performance are Lens Flares, Screen Space reflections, Temporal AA, SSAO, and Bloom.
- To help reduce the likelihood of users having an unpleasant virtual reality experience the frame rate needs to be changed. The framerate should be

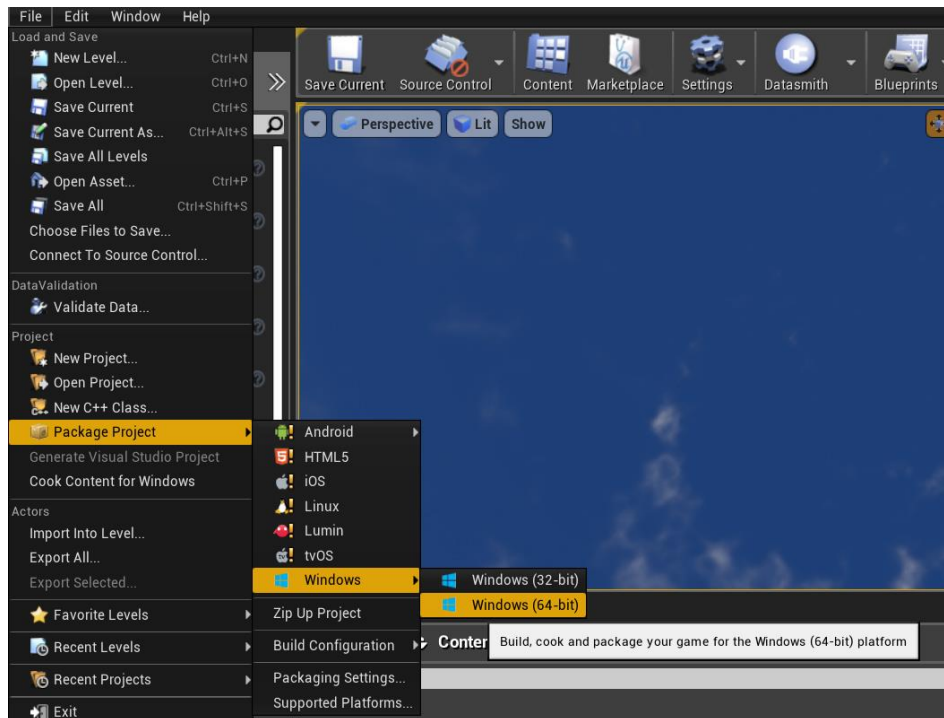
maintained so that it's always over the native framerate. The table below shows the various HDM's target frame rates to run on those devices.

Table 4. Various target frame rates. (Unreal Engine, 2019)

HMD Device	Target Frame Rate
DK1	60 FPS
DK2	75 FPS
Rift Retail	90 FPS
Vive	90 FPS
Gear VR	60 FPS
PSVR	Variable up to 120 FPS

4.2.2 Packaging the project

Now that the virtual reality project is as ready as wanted, and optimized it is needed to be packed to a wanted platform. First, the packaging settings are needed to configure and after the configuration, the packaging of the project can be started. The project of this work was needed to run on Windows, so it was packed to Windows (64-bit). After the packaging the project is done, a virtual reality project is an application form, that is easy to share and use, where needed.



Picture 8. Packaging the project.

Now the small virtual reality application is ready, and it can be used and developed further to a wanted direction. The work gave a lot of information about the basics of developing a virtual reality project with the Unreal Engine. Performing and testing these common actions will increase the skills to develop virtual reality experiences. The Unreal Engine offers a lot of content that makes the learning process much easier. The use of Blueprints is a useful way to make mechanics in just a couple of clicks and using them is easy to learn. After the basics of virtual reality development with the Unreal Engine, the complexity of environments and experience can be evolved to create something far more creative.

5 RESULTS AND CONCLUSION

This thesis was commissioned by Morrow Games Oy and the goal of the thesis was to research virtual reality, design, and development process of virtual reality application, make a small virtual reality application, test the application, and determine the best practices.

The research provided a basic knowledge of virtual reality, its key elements, virtual reality types and basic knowledge of its technology, concerns, and challenges. The research also provided basic information about the overall design and development process, which included tools, testing methods, user experience, and best practices. Testing the created project, also provided information about the best methods to use, when creating virtual reality applications and the project can also be developed further in a wanted direction.

The research provided a lot of new and useful information for Morrow Games and me. The topic of virtual reality is wide and there was a lot of material on the topic. The theory of this topic took most of my work time, and therefore the practice part of the work was done quickly, so that could have been improved. The research showed that there is much more information and learning to discover virtual reality, its design and development process. There is much more information related to this topic, that this work didn't include. The virtual reality, its design, and development are very big topics and it has many different methods and things to consider, but the research provided basic knowledge and best practices to the topic and that was the wanted result. The work included basic information about the virtual reality, design, and development, best practices and it's useful for anybody interested in virtual reality.

The virtual reality and its development are growing and more of different applications and technology has come forward. There are many things to consider, when working with virtual reality and when designing and developing applications for virtual reality. The development of virtual reality has just begun and there's much more to learn about it.

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