Philipp Schnitzhofer BSc

Virtual Reality

as a new way to
visualize architecture

MASTER'S THESIS

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Supervisor

Univ.-Prof. Dipl.-Arch. Dr.sc.ETH,
Urs Leonhard Hirschberg

IAM

Institute of Architecture and Media

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Exposé

The architectural design process traditionally starts with sketches and models to figure out the basics of a design and to show ideas to have a discussion about it. But most of these methods are abstract and often and are often difficult to communicate by the creator. It can be difficult to get a clear understanding of the project because of complicated geometries or a big scale. Especially for people who are outside of the architectural mindset it is hard to understand plans and spatial perception.

To develop a deeper understanding of architectural projects, it is necessary to go to the location of the building, but great architecture is all over the globe. The idea to explore and learn from exceptional architecture by experiencing the entirety of a building in the comfort of your home or office is fascinating. What is virtual reality and to explore this new possibility of communicating architecture and to show the potential it has to offer for design, workflow and education in architecture is the goal of this thesis.

The chosen way to test this is in the form of a virtual reality visualization project of the Farnsworth House by Ludwig Mies van der Rohe to show how usable and accessible it is today.

Thanking words

My parents were the biggest and best support for the entirety of my education. Thanks mom and dad for the extraordinary positive encouragement through my years of studying. Next to them are my grandmother and my aunt, who always supported my choices.

Thanks to my brother for motivating me in showing interest and giving feedback. Thanks to my girlfriend Astrid and to the best friends to life and study with Fabian, David, Laura, Joseph, Johannes, Stefan.

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Chapter 1 - Virtual Reality

1 Introduction

My first personal contact with virtual reality was with the release of the Oculus Rift development kit 1 in March 2013. A friend of mine was an early kickstarter backer and this was the first time I tried virtual reality. After the success of Oculus and their release of the Oculus Rift, the company set the foundation for the development of modern virtual reality headsets. The quality, setup and use of these development kits were not really exceptional at the time but it was a great first experience and eye-opener. Since then I followed almost every step of the development of this technology and after I tried the oculus development kit 2 in early 2016, I knew it was just a matter of time and money until I needed to get one to satisfy my interest.

The improvements of virtual reality headsets in recent years is due to the interest of the gaming industry in this new form of entertainment. Virtual reality has become immensely popular in the gaming and technology community and it has started to attract the attention of the general public. Today, many people have tried virtual reality at exhibitions or other events because of the interesting appearance and the 'I want to try this' -effect of virtual reality headsets. Entertainment is a big part of the progression, but it will become important in education, communication, research and many other fields as well.

Architectural visualizations of projects in form of stylized or photorealistic renderings are the absolute standard today. Less common are pre- or real-time-rendered animated walkthroughs that make it possible to experience the project from a first person perspective. These 3D geometries are presented on 2D surfaces like a monitor or on paper whereas virtual reality is a completely new medium to present and communicate architecture.

2 Definition

´virtual reality´

noun

The computer-generated simulation of a three-dimensional image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment, such as a helmet with a screen inside or gloves fitted with sensors.

-Oxford dictionary

A computer system that creates an environment that looks real on the screen and in which the person operating the computer can take part.
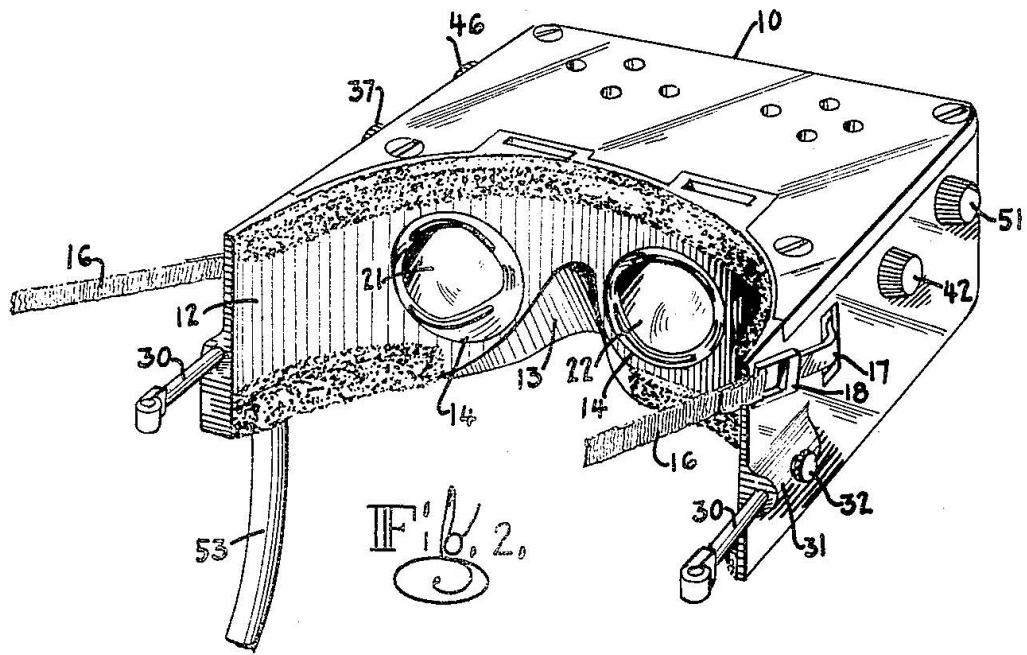
-Cambridge dictionary

Fig. 2 Telesphere Mask - 1960

Fig. 3 The Sword of Damocles - 1968

3 History

The origin of modern virtual headsets is controversial because of the general definition of the concept and the amount of technical progress over the years. Around the year 1950 the demand for new technological entertainment innovations like stereoscopic 3D for movies like ´It Came from Outer Space - 1953´ presumably led to the invention of the first virtual reality concepts. Two often mentioned inventors namely, Morton Heilig and Ivan Sutherland, are considered the fathers of virtual reality.

3.1 Morton Heilig

As a philosopher, inventor and filmmaker, he saw great potential in 3D technologies at the time. Heilig invented a 3D camera and projector in addition to his viewing machine and produced five films to demonstrate the Sensorama's capabilities. The Sensorama Machine was invented in 1957 and patented in 1962. Morton's first patent, the Telesphere Mask (Fig. 2) was patented in 1960. It was in every way a 3D video headset we are used to, except that Heilig used miniaturized TV tubes.[1]

3.2 Ivan Sutherland

In 1963 Ivan Sutherland, computer scientist and Harvard associate professor, demonstrated the Sketchpad, a system to allow interactive, computer generated visual imagery displayed on a cathode ray tube. In 1965, he described a vision for an immersive, computer based, synthetic world display system. His paper ´The Ultimate display´ included his vision of the presentation of visual, aural, and haptic feedback in response to the actions of the user. By 1968, Sutherland and his student Bob Sproull had realized a system called ´The Sword of Damocles´ (Fig. 3) that accomplished the visual component of his vision. Sutherlands system included a head mounted display, mechanical head tracking and a computer program that rendered a cyclo hexane molecule in three dimensions.[2]

1   Vgl. Brockwell 2016, 1-2.
2   Vgl. Graig 2009, 4-5.

Fig. 4 Oculus Rift

Fig. 5 HTC Vive

4 Current virtual reality headsets

To fully understand virtual reality, it is necessary to understand the different modern devices of this technology as well as its restrictions.

4.1 HTC Vive and Oculus Rift

Today there are two leading manufacturers of commercial head mounted displays for virtual reality. On the one side there is the Oculus Rift (Fig. 4), developed and manufactured by Oculus VR, a division of Facebook Inc, on the other side there is the HTC Vive (Fig. 5), developed by HTC and Valve Corporation. The main difference between these two headsets, besides the visual presentation of headset and controller, is the tracking system. Oculus usage is to sit or stand in front of your desk with a smaller area to move in.[3] The concept of the HTC Vive always had a full roomscale tracking system in mind and this is why this master thesis focuses on the Vive.

To give the user a compelling experience the controllers are a big part to achieve intuitive interaction with the environment. The controllers of the Oculus and the Vive are both near 1 to 1 representation in the virtual space and have a lot of benefits. Without the interaction with objects or only to point at something with your hands it feels limiting in options what you can do with virtual reality. The design of the Oculus Rift controllers follows a traditional button and joystick arrangement which is comparable to the split classic game controller. While these controllers are very good they are generally more intuitive for people who play games with normal controllers. The HTC Vive controllers are a new controller design especially for virtual reality. Build quality and battery time are arguments for this controller, while size and weight could be better. The minimalist yet useful amount of buttons, triggers and touch pads are not overwhelming at the beginning but make a lot of sense when getting used to them.

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3   Vgl. Nite 2014, 2.

Fig. 6 Playstation VR

Fig. 7 Google Daydream

Fig. 8 Samsung Gear VR

For the sake of completeness the following sections provide a brief overview of further virtual reality headsets and their characteristics. The previous head mounted displays were tested to an extent to compare them to each other. The following headsets are important to mention for current advancements of this technology but were not tested for this thesis.

4.2 Playstation VR

The most comparable headset is the PS VR (Fig. 6) from Sony. With a high resolution display and a good visual tracking system it is similar to the Oculus and Vive. Because of the limited processing power of the Playstation 4 Pro and development restrictions, the PS VR headset is unsuitable for private and non commercial development. To achieve the necessary frame-rate Sony uses a frame interpolation system called 'reprojection'. A connect box between the Playstation and the headset increases the low frame-rate of 60fps to 120fps, but not without a visual decrease of quality and latency which shows the importance of a powerful computer.[4]

4.3 Daydream, Gear VR

An easy approach to get into virtual reality is a head mounted device for smartphones. Examples of this concept are Google Daydream (Fig. 7) and Samsung Gear VR (Fig. 8). The fact that those devices do not require cables, are light as well as portable are the main benefits of this virtual reality design. It is necessary to have a very powerful smartphone to achieve an acceptable frame-rate which can be as expensive as the Oculus or Vive. But the main shortfall is that these headsets provide rotational tracking only and are therefore unsuitable for applications that require tracking the users position in the room.[5]

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4   Vgl. Nite 2014, 6.
5   Vgl. Nite 2014, 6-8.

Fig. 9 Windows mixed reality lineup

Fig. 10 Windows mixed reality motion controller

Fig. 11 Acer OJO 500

4.4 Windows mixed reality headsets

In 2016 Microsoft announced the development of different virtual reality headsets in cooperation with technology companys like Samsung, Asus, HP, Acer, Lenovo and Dell. Since then a competitive lineup of headsets has been released for consumers and professionals.

The general idea is to offer a sitting or standing virtual reality experience without external sensors or components with a visual tracking system similar to the Microsoft Hololens. The cameras of the headsets are necessary to track the motion controllers, that means using the controllers is only possible by looking at them. The plug and play aspect of these headsets is a big feature, because all of the drivers and software are included and maintained with Windows 10 updates. The easy to setup and use nature of these headsets and the lower cost compared to the Oculus Rift or HTC Vive makes them a good alternative for starting with virtual reality.

The Acer OJO 500 is the latest mixed reality headset which will be released in November 2018 and will include a more modular design with detachable parts. It is designed for businesses like museums or tourist attractions that might have customers using the headset multiple times per day.

Fig. 12 Oculus Go

Fig. 13 HTC Vive Pro

4.5 Latest headsets

In recent years the development of virtual reality headsets could be categorized in tethered headsets that are connected with a computer and mobile ones. The Oculus Go (Fig. 12) which was released in May 2018 is the latest all in one headset without the need of a smartphone. The main flaw of this headset is the lack of positional tracking. While visual quality of the screen is not that different to other mobile headsets, the lenses are higher in quality and comparable to the ones the Oculus Rift uses.[6]

The HTC Vive Pro (Fig. 13) was released in April 2018 and can be seen as an incremental update of the HTC Vive. The main improvement is the higher display resolution than the standard Vive which is a crucial hardware aspect of today's virtual headsets. The addition of dual front facing cameras, integrated headphones and the doubling of the movement area to 10x10m makes the Vive Pro the most powerful headset to date.[7]

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6   Vgl. Robertson 1.
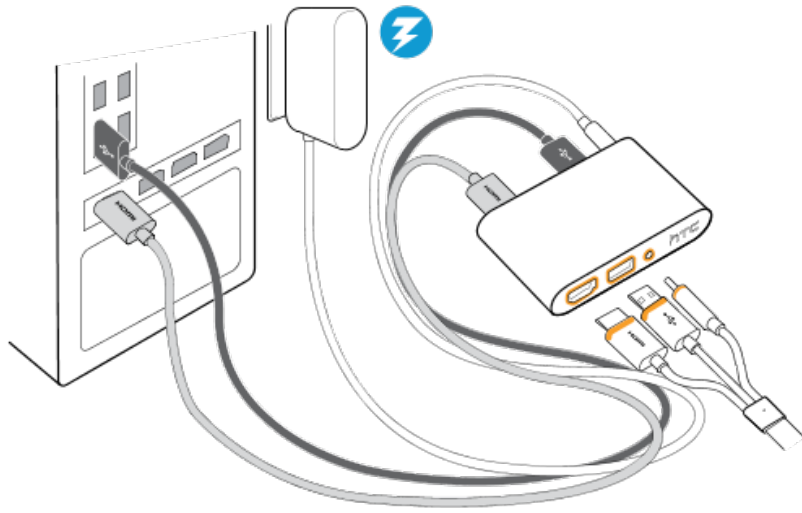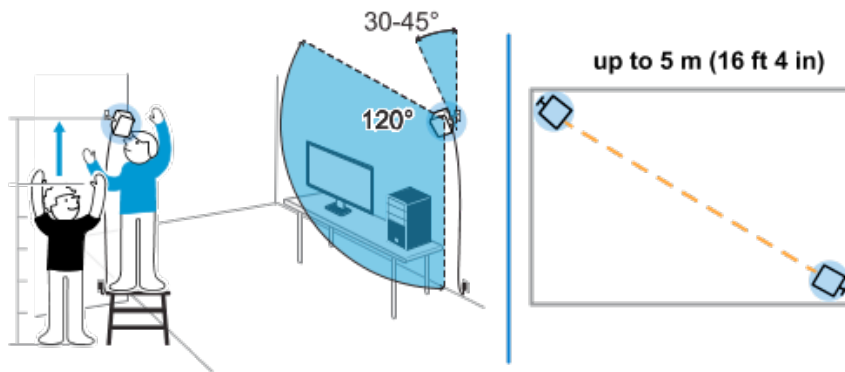7   Vgl. Pino 1.

Fig. 14 Linkbox
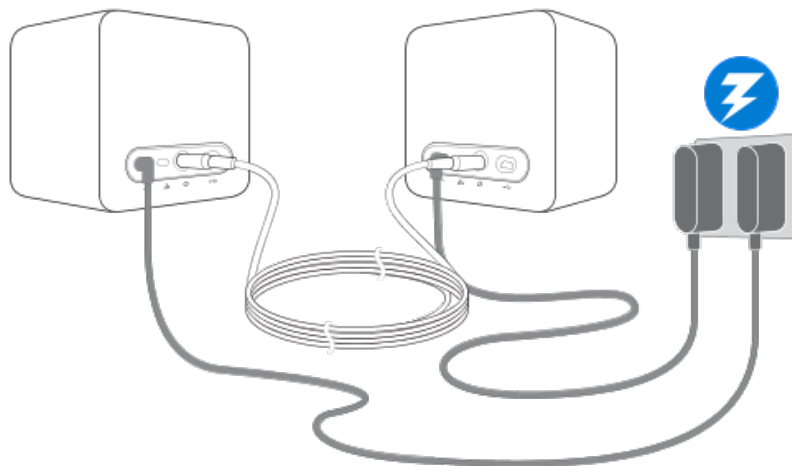

Fig. 15 Base station mount

Fig. 16 Base station connection

5 Setup

The HTC Vive provides the most features and best quality today, but there are other aspects for a good virtual reality experience besides the headset itself. Virtual reality users tend to focus on represented information and the task to evaluate the project and tend to become aware of the technology only when it does not function in the expected way. A professional setup of your digital and physical space for a architectural use case is essential for a comfortable and useful experience. In using the HTC Vive a lot of important setup details can be found to be improved and are explained in the following pages.

5.1 Connection

To connect the computer and the headset it is necessary to have an HDMI 1.4 outlet on the graphics card and a USB 2.0 port on the motherboard. These two cables are plugged into the link box (Fig. 14), which also needs power. The cables, HDMI and USB of the headmount display are plugged into the connect box. To extend the distance between the computer and the headset, longer cables between the connect box and the computer are needed. Audio is sent through the HDMI cable and a headphone port is situated on the headset. It is also possible to acquire the 'Vive Deluxe Audio Strap' which has integrated headphones on the head strap.

The 'Lighthouse' sensors should be mounted as high as possible in opposite corners and face in the direction of the bottom center point of the playing area (Fig. 15). If there is no place for a wall or ceiling mount, it is possible to use two tripods, but every vibration or touch of the sensors results in a motion sickness inducing movement in the virtual space. Reflective surfaces can also negatively affect the tracking of the Vive. A direct connection with the computer is not necessary because the sensors are passive, but each sensor needs a power outlet (Fig. 16).
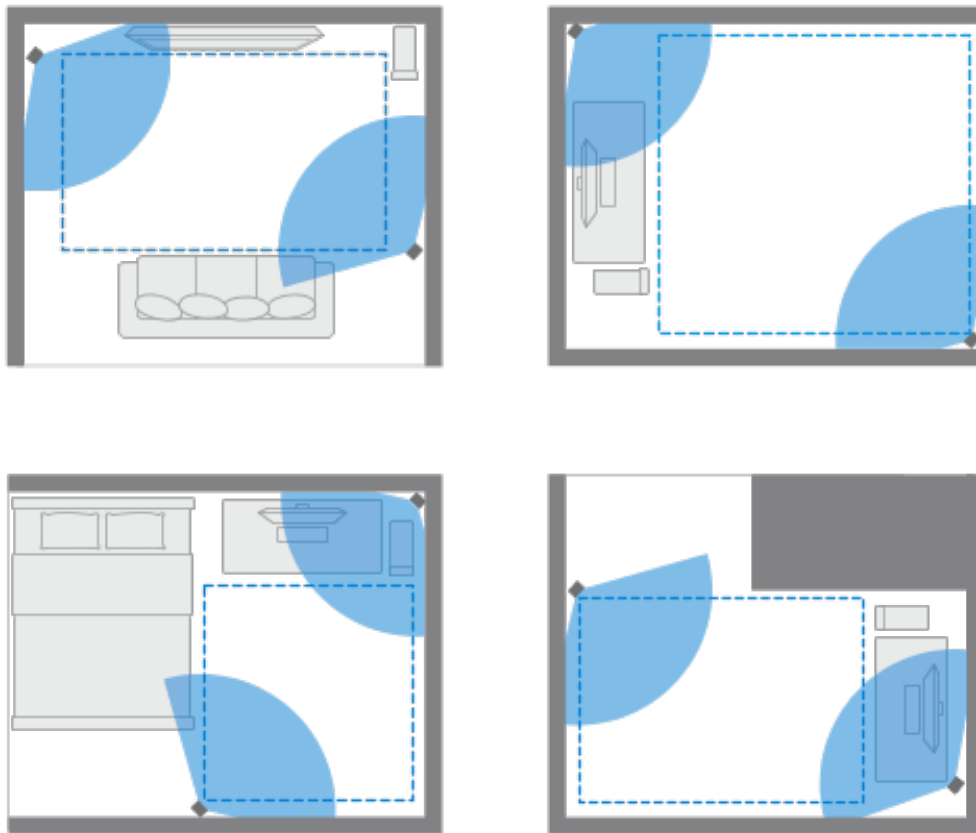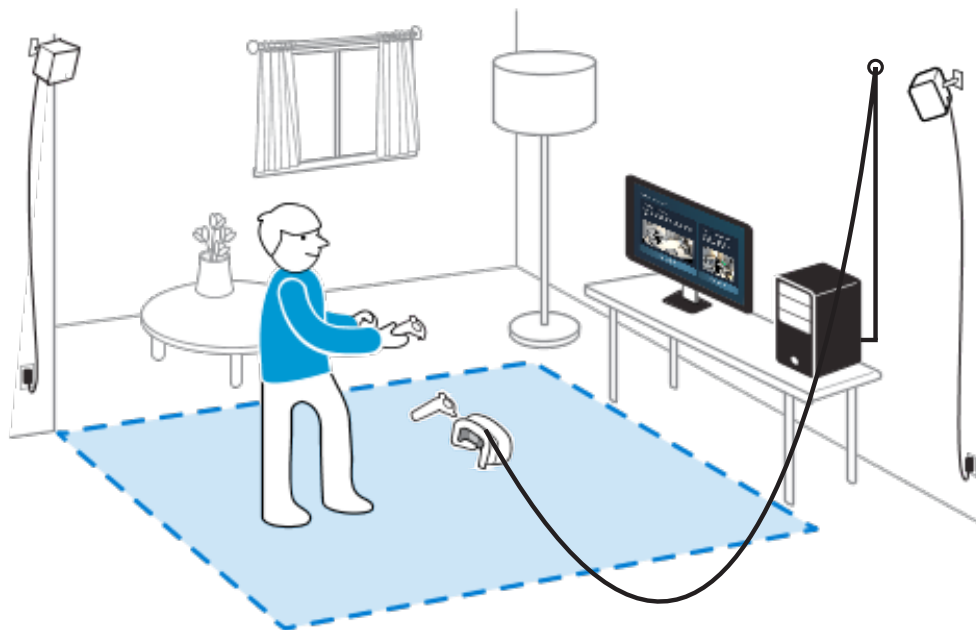
Fig. 17 play area planning

Fig. 18 room-scale play area

Spectators can watch on the monitor of the computer, but using a Steam Link to transmit the monitor output to a separate television can further improve the experience. The Steam Link is a small box which is plugged into a television and is connected to the computer through an ethernet cable or Wifi. The sound can be played simultaneously in the headphones of the headset and the TV.

5.2 Movement area

An important aspect of a safe and useful setup is to plan out the room and connection from and to your dedicated VR area and computer. The sensors of the Vive are able to track an area of 5,0 x 5,0m, which is not always possible in every building with furniture and other obstacles in the way (Fig. 17). In my experience 2,5 x 2,5m is the minimum requirement for a useful roomscale setup.

Two essential aspects are to make sure not to run into things and not to step on the cable. This can be achieved by laying down a thick carpet to hapticly sense the playing area. It is also possible to set the boundary to visible in the Vive software, but in most cases this is not visible enough to ensure the safety of the user. The best way to solve the cable problem is to mount a hook or a snap link to the wall at head height from where the cable is able to hang freely (Fig. 18). In my opinion these two additions to the setup improve the experience substantially.

The right room temperature is also an easily forgotten aspect when trying to provide a good VR experience. Because of the high brightness and refresh rate of the display inside the headset, a cool room temperature is necessary to avoid face sweat.
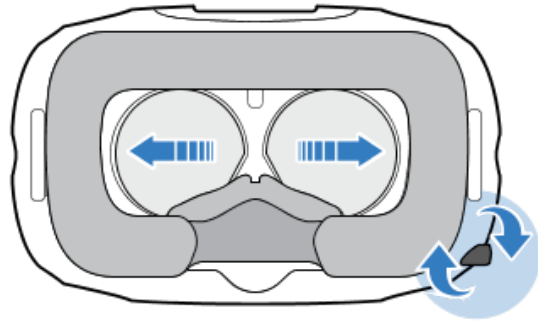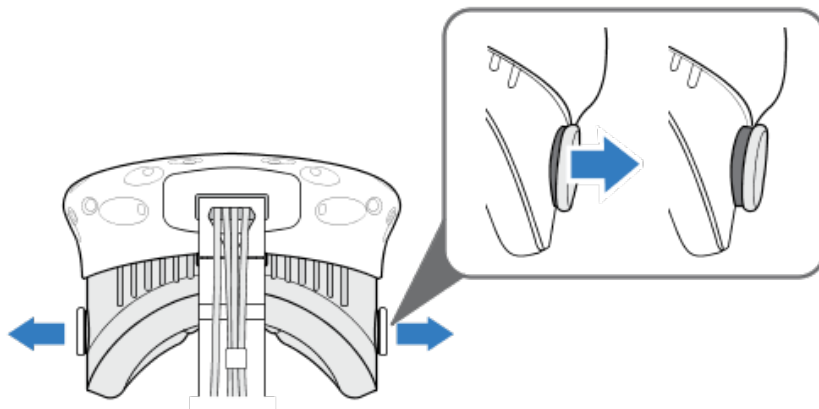
Fig. 19 pupillary distance

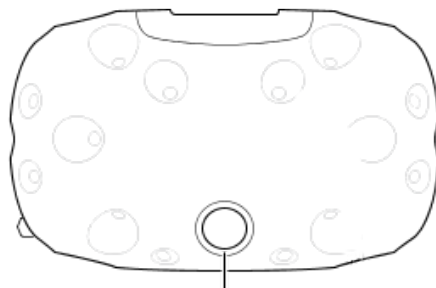Fig. 20 adjustment wheel for glasses

Fig. 21 front facing camera

5.3 Headset adjustments

For the least eyestrain possible and the optimal viewing experience it is necessary to adjust the Vive's lenses to match your pupillary distance (Fig. 19) which is measured in millimeters. An easy way to find this distance is to use a mirrored ruler in front of a mirror.

Wearing glasses is generally not a problem but it is favorable to have narrow side glasses. If the glasses are too close to the lenses of the headset, it is possible to increase this distance by pulling out the side adjustment wheels and turning them to increase the distance (Fig. 20). This results in a small decrease of the field of view and should be readjusted afterwards.

5.4 Camera

A special feature of the HTC is the camera on the front of the headset (Fig. 21). This camera can be used to view the real surrounding environment by double tapping the home button on the controller or on the left side of the headset. This can be used to orientate yourself or to pick up things without taking the headset off. Another usage of the camera is the chaperon overlay, which shows the outlines of the environment when the player gets too close to the edge of the movement area. This is a good way to avoid colliding with objects in the real world.
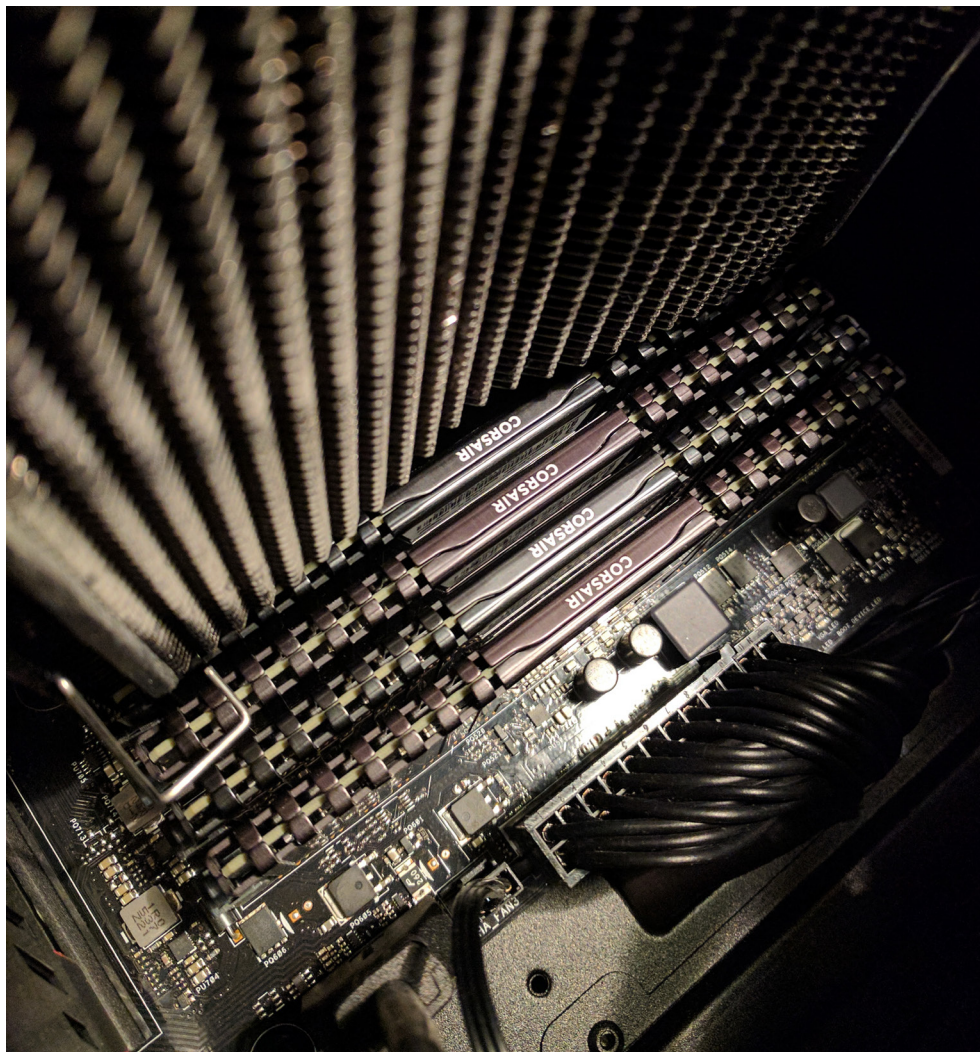
Fig. 22 Computer specifications

5.5 PC specifications

To drive a virtual reality headset a high performance computer is essential to achieve optimal results. The most common causes of motion sickness in virtual reality are low frame-rate, under 90 frames per second, skipped frames, freezing of the screen for short time and latency over 20 milliseconds and those should always be avoided.

Recommended computer specifications

Graphics:	NVIDIA GeForce GTX 1060 or AMD Radeon RX 480, or better
Processor:	Intel Core i5-4590 or AMD FX 8350, equivalent or better
Memory:	4 GB RAM or more
Video out:	HDMI 1.4, DisplayPort 1.2 or newer
USB ports:	1 x USB 2.0 or better port
Operating system:	Windows 7 SP1, Windows 8.1 or later, Windows 10[8]

Personal test computer specifications

Graphics:	Nvidia Geforce 980TI OC
Processor:	Intel i5 6600k OC at 4,4GHz
Memory:	32GB RAM
Video out:	HDMI 1.4 and DisplayPort 1.2
USB ports:	USB 3.0
Operating system:	Windows 10

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8   o.A.: SPECS & DETAILS 2018, 1.

Fig. 23 Mission ISS

Fig. 24 Everest VR

Fig. 25 Rec Room

Fig. 26 The Lab

6 VR applications showcase

This chapter compiles a list of VR applications which were influential in the way I understand and appreciate virtual reality. With a huge library of applications to choose from these games are a great way to explore and understand the tremendous possibilities of virtual reality. There are 3 main platforms to find software on: Steam Store, Vive Viveport and Oculus Store.

Mission ISS: This highly detailed model of the international space station shows the station in its entirety. This application contains information from astronauts in every module and it is possible to dock a space capsule and go on a spacewalk. Learning how to move in zero gravity, as well as how nauseating and motion sickness inducing it can be to have no point of reference is an informative and educational experience. (Fig. 23)

Everest VR: This application shows the achievable sense of scale with virtual reality. The visuals are very close to reality because of the precise geographical and photographic data of Mount Everest. It makes it possible to look at the route climbers take to reach the top of the largest mountain of the earth in an educative way. (Fig. 24)

Rec Room: Games like dodgeball, paintball and discgolf are designed to be played with other people. These games shows the concept of a virtual space where it is possible to talk and interact with other people. (Fig. 25)

The Lab: From trying to shoot with bow and arrow to being inside of an arcade game to realistic environments to looking at an anatomical 3D visualization of the human body, this application shows the amount of possibilities of virtual reality. (Fig. 26)
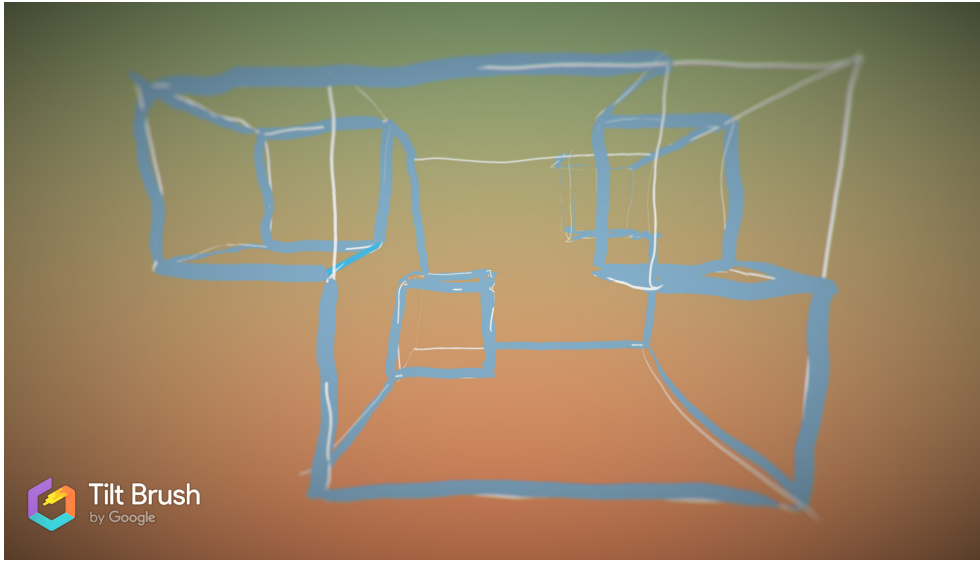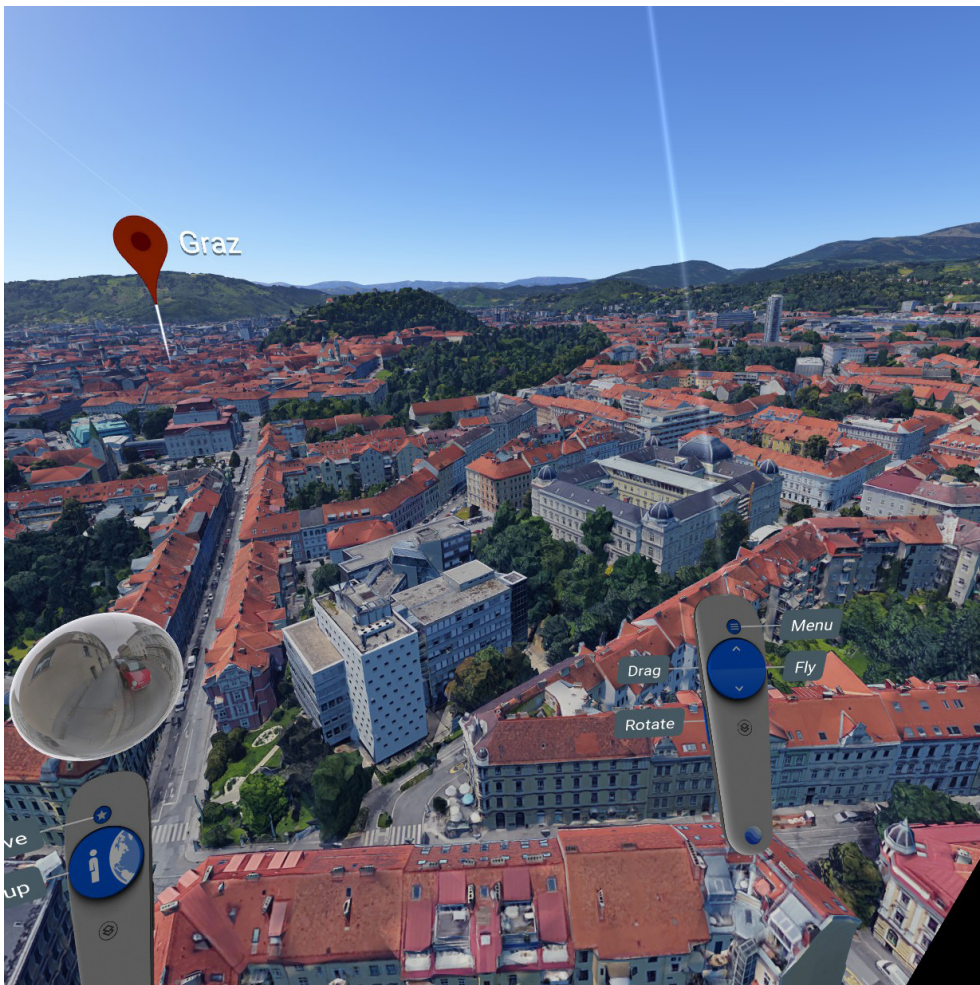
Fig. 27 Google Tilt Brush

Fig. 28 Google Earth VR

Google Tilt Brush: Painting in 3D on a computer is not possible because of the 2D input as well as the 2D representation on the computer screen. With virtual reality it is possible to track the controller in 3D space as well as the visual representation of lines and surfaces in space. Google tilt brush is an example that shows this aspect of virtual reality. Drawing a cube in VR demonstrates this in a simple but meaningful way. (Fig. 27)

Google Earth VR: Google Earth and Google Maps have been powerful tools for architecture for a long time and enable the user to look at the whole globe from any distance. The concept started by photographing the world with satellites and creating extremely accurate maps of geography, street plans and buildings. In recent years the resolution of this scanning and photographing the earth has gotten a lot better with methods like plane photography and with triangulation algorithms to create a nearly perfect 3D representation of the world. To use this tremendous data set in VR with stereoscopic 3D and the sense of scale provides big value for architecture. (Fig. 28)
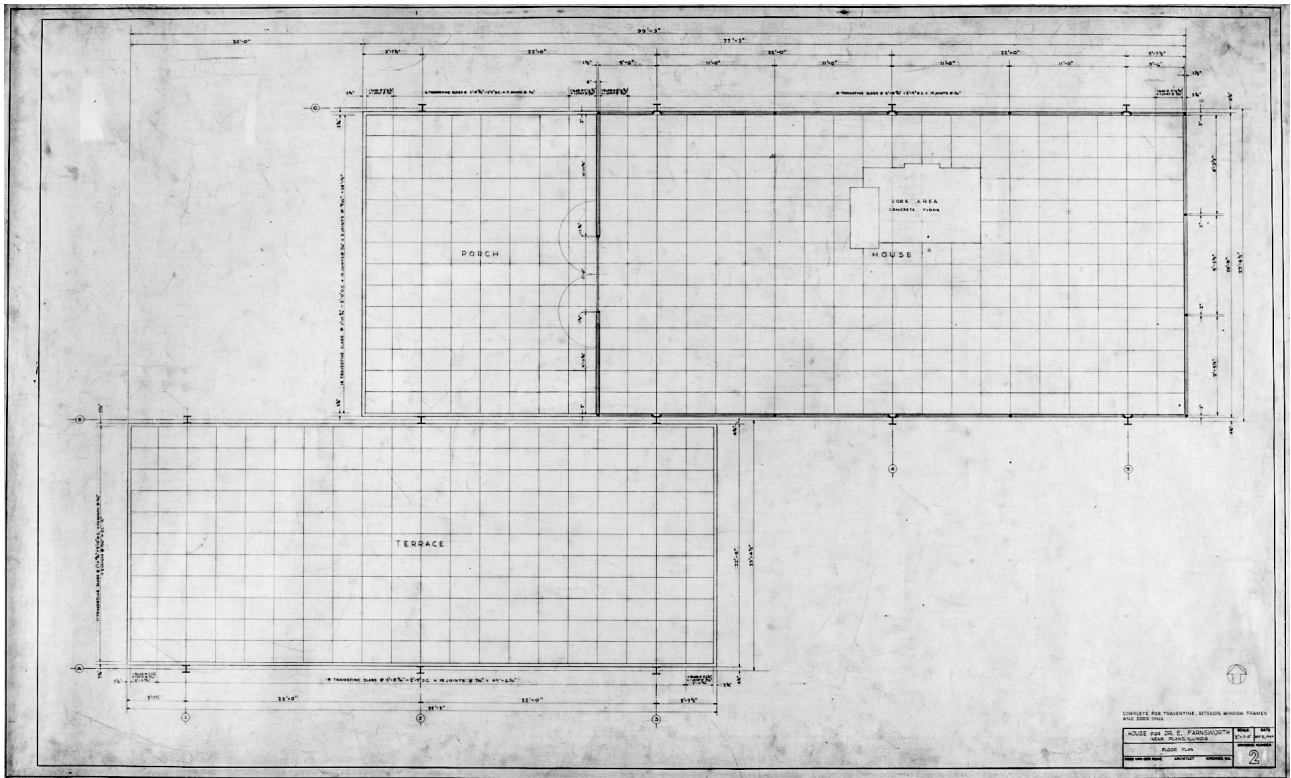
Chapter 2

Virtual reality in architecture

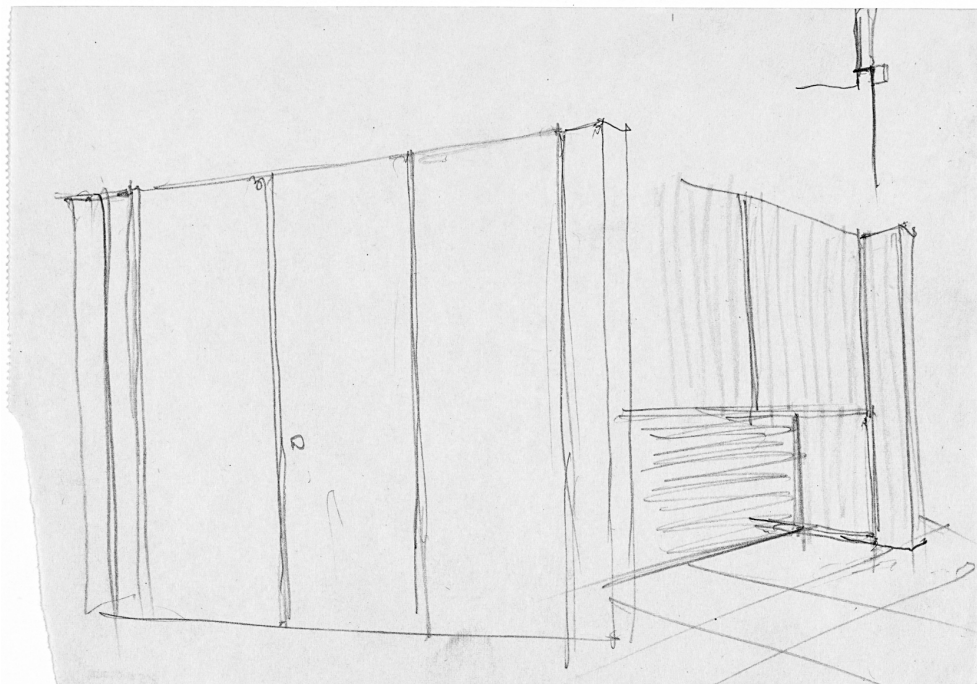Fig. 29 original floor plan, Farnsworth House, 1949

Fig. 30 original interior perspective, Farnsworth House, Plano,1945-1951

VR introduces new visualization approaches into practices that are already digital and how to obtain real value for architecture with this fast evolving technology is an important question to answer.

1 Architectural representations

The first part of this chapter shows the differences between 2D and 3D representations and what new aspects virtual reality has to offer for architecture.

1.1 2D representation

Two-dimensional representations, such as maps and blueprints, are often used to simplify three-dimensional structures. Translating these geometries into two dimensions allows us to represent environments that are too large and complex to be viewed directly. 2D representations can present entire environments from a single vantage point. The ability to look at the world at different scales allows the structures that are most prominent at these scales to be prioritized, and movement between these scales can help shift our attention to specific aspects of the built environment.

Such representations are symbolic in nature, and can be used as a relatively easy way of communicating knowledge about the layout of an environment. A 2D representation provides an interpretation or description rather than direct access to it. Maps and blueprints provide a means to rapidly assimilate knowledge about the relationships between different building areas, however they provide less explicit information about directions and route distances.
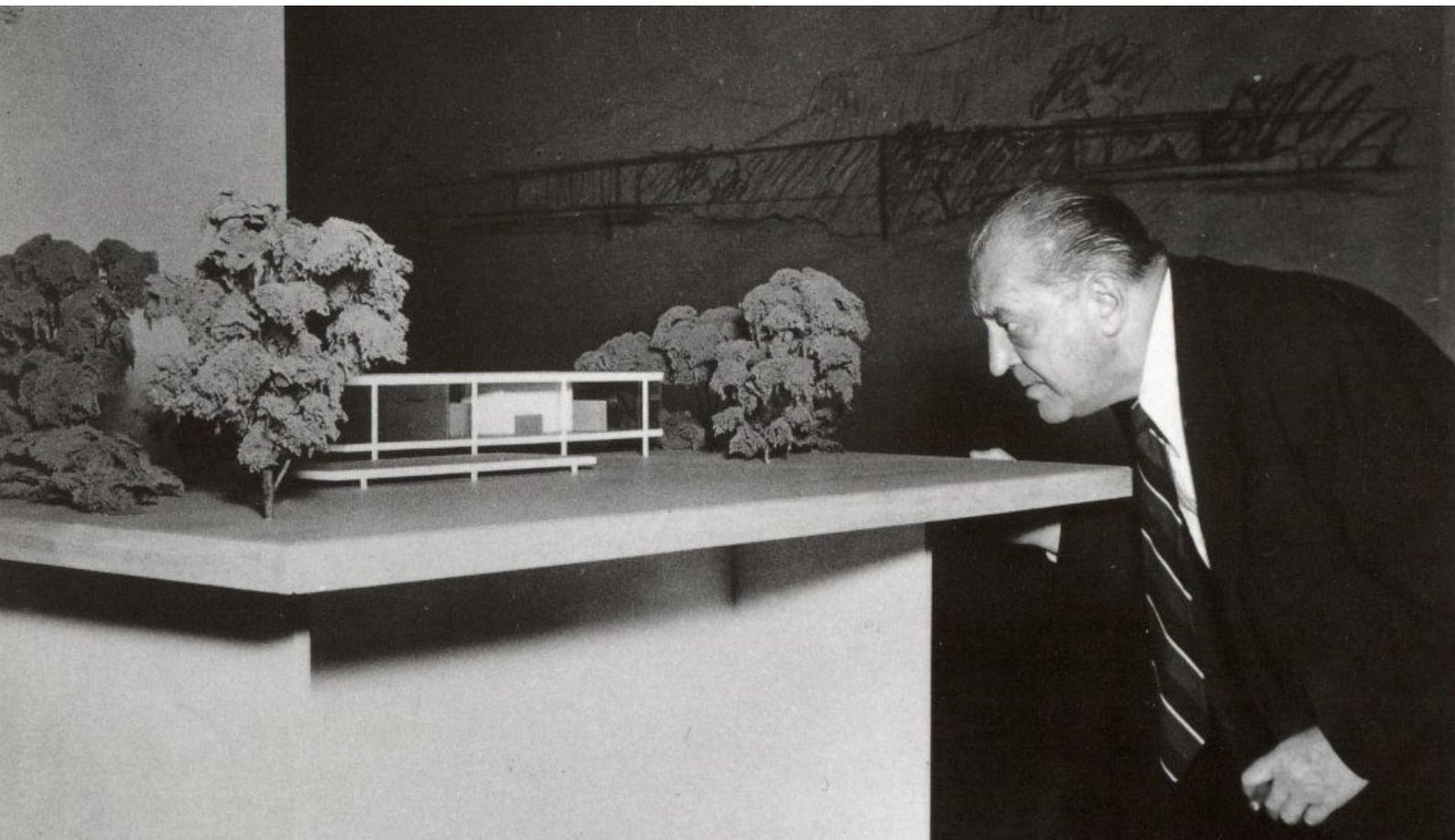
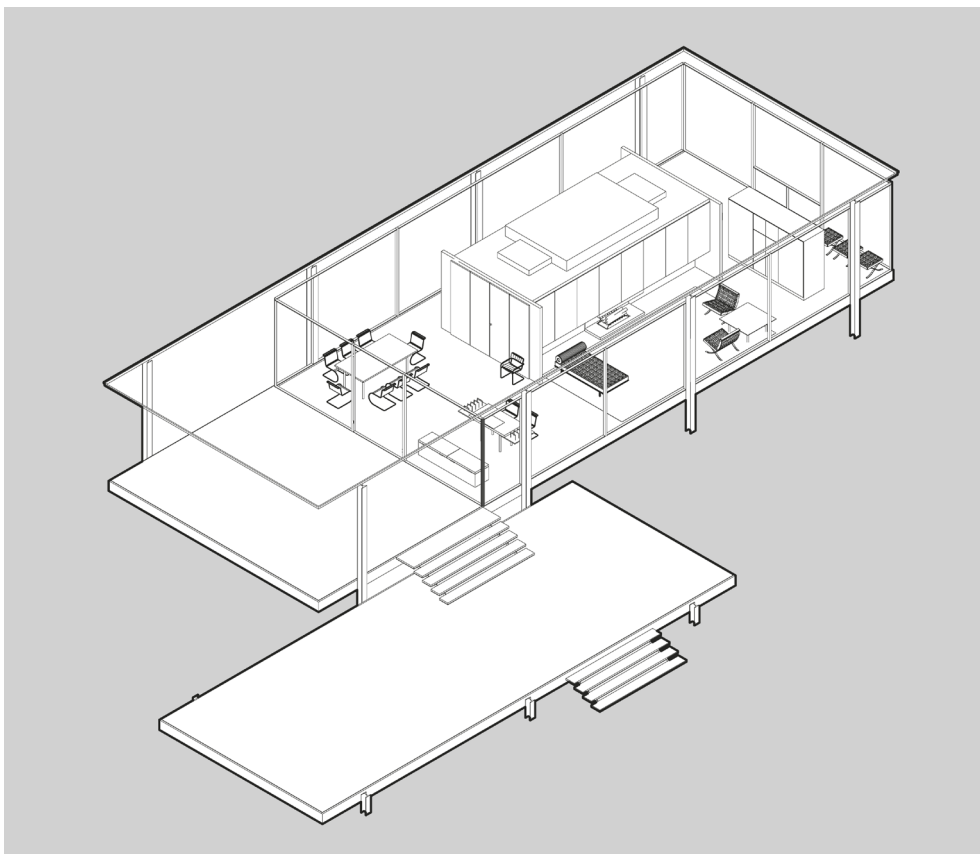Fig. 31 3D model of Farnsworth House with Mies Van Der Rohe

Fig. 32 Isometric view of 3D model

Chapter 2 - Virtual reality in architecture

1.2 3D models

Three-dimensional representations, or models, allow design and construction professionals and non-professionals to more easily understand spatial aspects of existing and proposed built environment projects. Building models has often been seen as a necessary accompaniment to architectural drawings. The desire to increase public participation in the design process has also prompted the use of 3D models to support collaborative design projects, rather than simply presenting final designs for review.

Models can be physical scale models or digital. The use of digital models in designing built environment projects is becoming a standard industry practice. In contrast to longstanding design processes, when using 3D models and other project information are typically created first, and 2D drawings are generated from these models. However, due to the characteristics of screen technologies, digital models viewed on 2D screen systems are seen as perspective, axonometric or isometric representations on single or multiple 2D viewing planes. Although these models are created in 3D environments users typically interact with and view them on 2D screens.

Representations such as the 2D drawings and 3D models are reformulated within the brain as mental representations. In contrast, a interactive, spatial and social VR environment has some distinguishing characteristics against 2D and 3D representations.
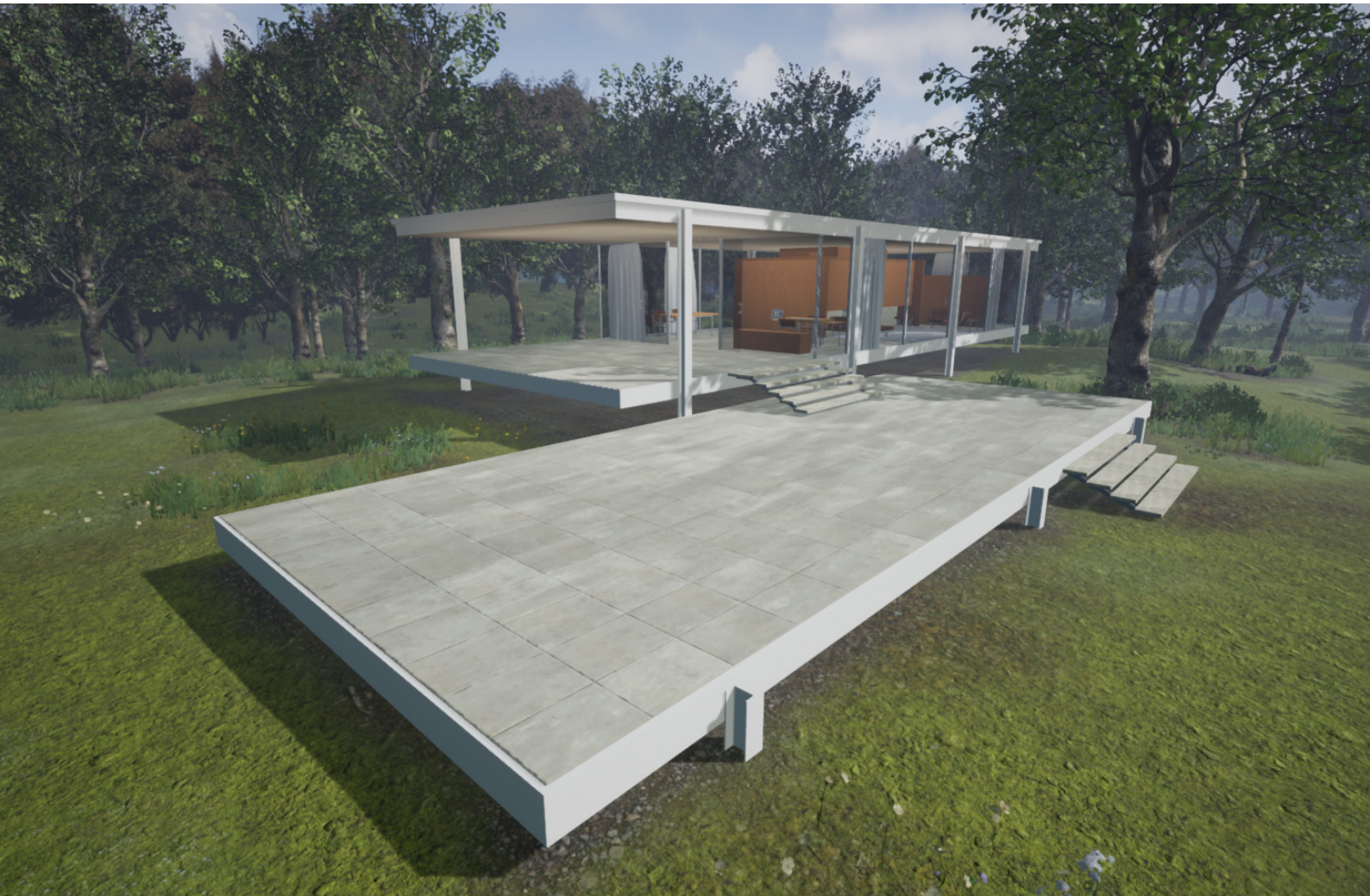
Fig. 33 Farnsworth House rendered in Unreal Engine for VR

Fig. 34 free explorable environment in virtual reality

Chapter 2 - Virtual reality in architecture

1.3 Virtual reality environment

In VR, users are not constrained to predetermined viewpoints and can choose how to navigate and what to see within an environment. Furthermore, in a VR environment, users not only typically have navigation capabilities, but they may also have the ability to use devices or gestures to change the environment or change objects within it.

As with the actual world, people tend to be able to intuitively interact with virtual environments, and often understand the effects of their actions. However, interaction with a virtual environment is usually not the same as interaction with a physical environment. For example, our perceptions of time and distance in a VR model often differ from our real-world experiences, as navigating a virtual environment is not typically bound to transportation modes we experience moving through the real world. A realistic walking speed may seem slow in VR, and unlike in the real world, users may be able to fly, teleport and speed through the environment. Moving between two points in a virtual model is often much faster than would be possible in the real world.

Unconstrained movement through a VR environment, depth perception and peripheral vision also support a VR experience. VR experiences generally attempt to follow the logic of the physical world and users can typically navigate freely through virtual environments and decide what to interact with and observe. Stereoscopic views and a greater field of vision within the environment are among a range of techniques that VR designers use to provide the illusion of an unmediated spatial experience. Rather than manipulating a 3D representation or virtual model, in an immersive experience, a user should feel as if they were within the reality that is represented. The success of any given VR model depends on the given task, the model itself, its users and the context in which it is experienced.
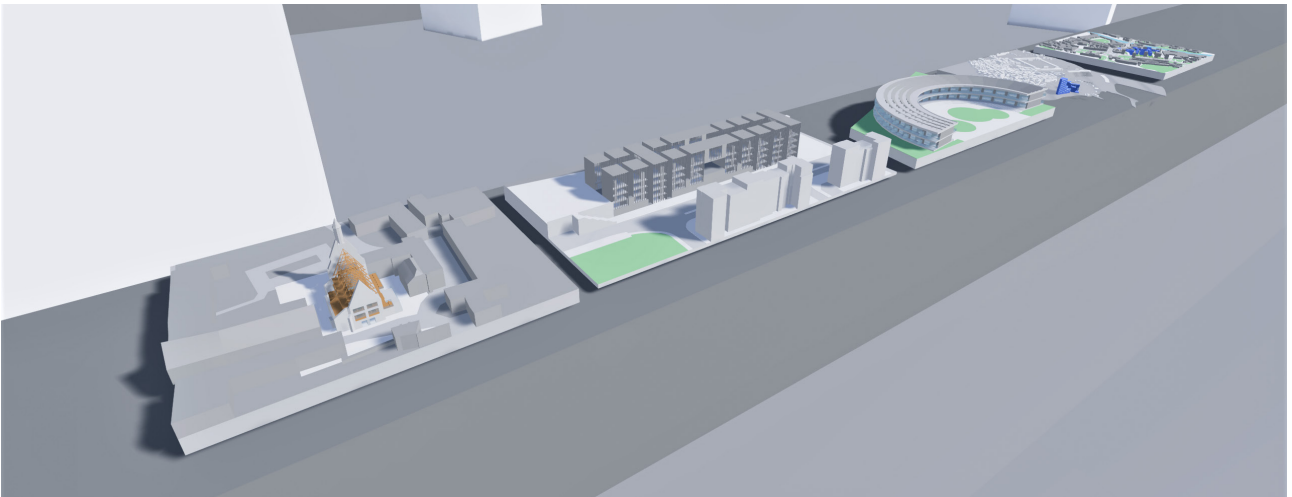
Fig. 35 reviewing the design of different models

Fig. 36 interaction with models

Fig. 37 1 to1 scale of project

2 Architectural applications of virtual reality

To digitally model and simulate a physical structure VR systems provide professionals with additional digital information about this environment. The fast development of new hardware and software will open a lot of new possible uses for virtual reality in architecture. Today VR is often used for design reviews, design practice, marketing and city visualizing operations and this chapter shows these applications.

2.1 Design reviews

Participatory design and virtual reality applications have shaped the dialogue around virtual design representations. Virtual or full-scale digital representations that are similar to physical objects demonstrate the potential of virtual reality approaches. These approaches might help project teams visualize information more easily, thus better understanding the design and engaging in fruitful dialogues. Comparing how immersive virtual reality displays, Vive and Oculus, and non immersive displays, such as monitors or paper, support various phases in the architectural process and enable more intuitive design reviews in terms of how users perceive and understand space. The quality of team engagement in collaborative design review processes seems to be affected not only by model content, but also by the medium used to convey information and the extent to which it enables users to interactively explore designs. The ability to annotate the design during the review can contribute to its effectiveness. It is important to ask project occupants at any given stage about how a design meets their needs, as users tend to evaluate the built environment differently from designers. Involving clients, practitioners from other project disciplines and end-users with diverse knowledge backgrounds in the design review process relies on their ability to accurately visualize and understand information and provide meaningful feedback.[9]

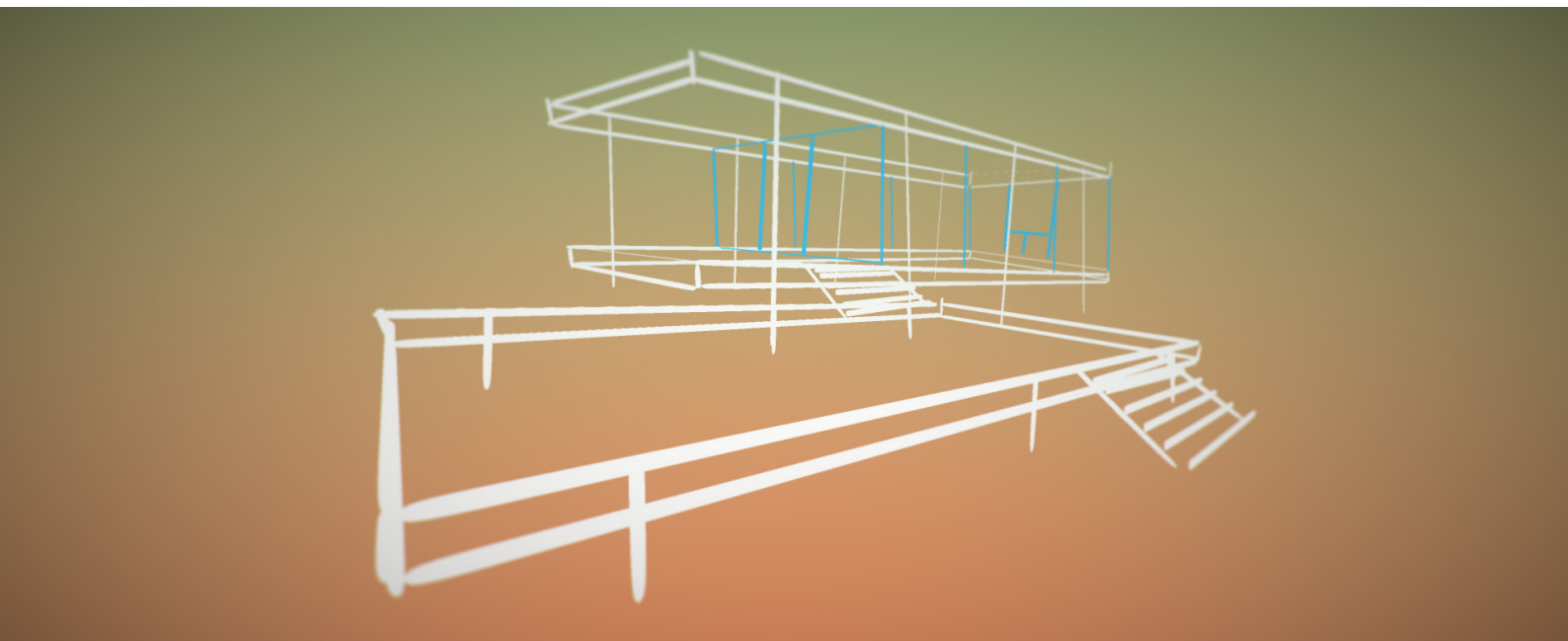9   Vgl. Whyte, Nikolic 2018, 81-85.

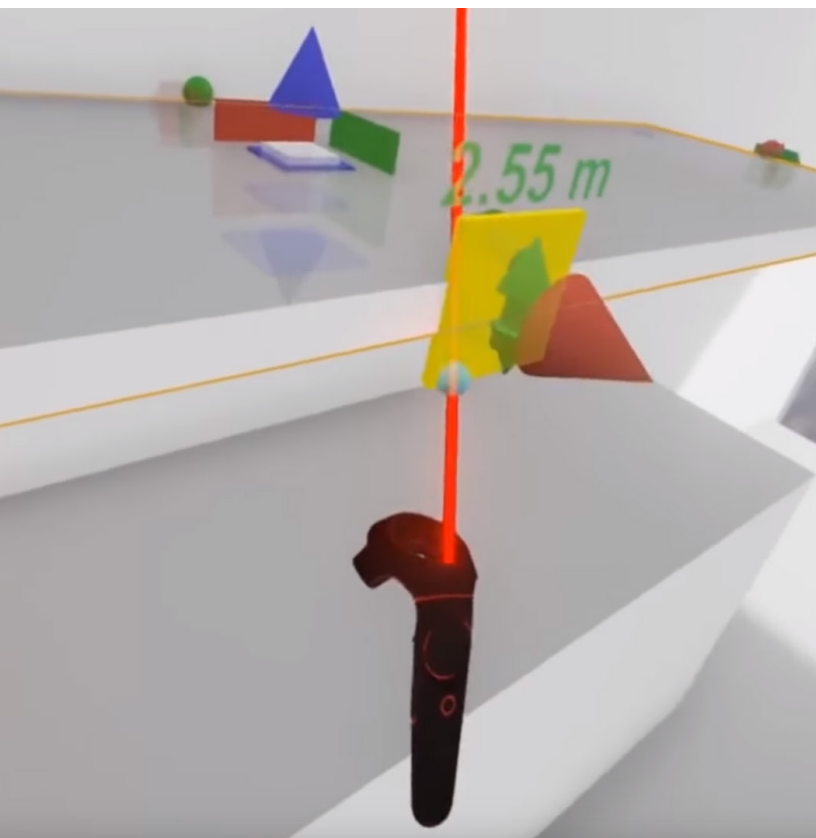Fig. 38 3D sketching with Google Tilt Brush

Fig. 39 creating geometry in Unreal Engine 4 VR editor

2.2 Design practice

Recently, there have been significant developments in the computing and gaming industry that opened immense possibilities to more easily design rich interactive environments using VR. Realtime engines can be found as a common platform for developing virtual reality applications on devices ranging from mobile phones to high-end immersive VR systems. This integration increasingly allows the use of VR systems for realtime rendering of aesthetic features of the design, such as texture or lighting. Developing software beyond the traditional gaming environments that combine architectural, structural, engineering and interior information is essential to enable users to experience the volume, space and lighting of designs in virtual environments. At the moment, realtime engines are attracting much attention in the built environment community because of its ability to integrate model data from different sources with its own functions and objects library that allows physical, environmental and other properties of the design to be realistically simulated. Coupled with virtual reality systems such as head-mounted displays, different forms of interactivity, such as tracking user movements through the virtual space or dynamically switching between design options, can engage a broader range of users in the design process. However, in the design process, virtual reality continues to be used most widely for design review in later phases. The extent to which virtual reality applications are useful in design review depends in part on project characteristics such as the complexity of a project and its level of component reuse.[10]

10   Vgl. Whyte, Nikolic 2018, 88-95.

Fig. 40 realtime rendered living room, REinVR

Fig. 41 realtime rendered office space, REinVR

Chapter 2 - Virtual reality in architecture

Trade-offs often emerge between the expected benefits and the time required to create virtual reality models. This is slowly changing and we can expect collaborative design to become a more important use for VR as the link between design applications and VR becomes more direct, reliable and flexible, allowing for a bidirectional flow of information. This can open new avenues for achieving value in early design as well, and not only late in the design when VR models get a greater reuse value through design marketing.[11]

2.3 Marketing

A motive for using VR in many design firms was for marketing purposes. Organizations that work on smaller projects, such as housing developments, are using virtual reality to promote sales to potential customers. Housing developers operate speculatively and face considerable risks, as they often have no known buyers at the start of the process. The ability to sell unbuilt projects using virtual reality is a major advantage, as it reduces the risk of development. Virtual reality allows an architect to show their housing types to clients on a VR headset at any office or show room. For many virtual reality users, some marketing advantages also come from its novelty. Current approaches to marketing built environment projects focus on glossy images, but virtual reality offers greater opportunity to show clients the spatial layout of new unbuilt buildings and structures in a way that was not possible before.[12]

For example, REinVR, Real Estate in Virtual Reality, is a Canadian company that uses advanced video game technology to create photo-realistic visuals and animation (Fig. 40, fig. 41) to beautifully showcase real estate projects that have not yet been built.

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11 Vgl. Whyte, Nikolic 2018, 88-95.
12 Vgl. Whyte, Nikolic 2018, 86-88.

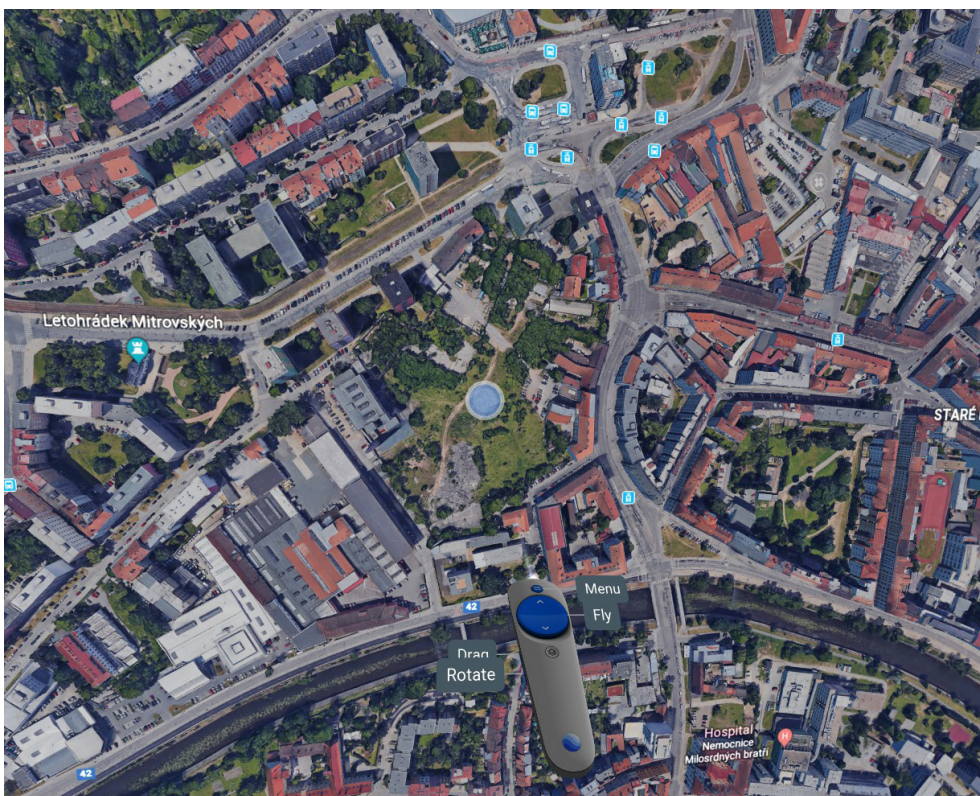Fig. 42 Google Earth VR view of a building site in Brno, Czech Republic

Fig. 43 top down view in Google Earth VR

2.4 Visualizing city operations

Most people globally live in urban areas and rapid population growth in cities presents built environment professionals with the challenge of responding to growing demands for housing, transportation and resources. Interventions to build new buildings and infrastructure are made in the context of the continually inhabited places within the existing built environment. Across scales, from buildings and neighborhoods to infrastructure and cities, virtual models can be used to democratize planning and test a range of future scenarios, or to understand operations of the built environment. Over the last decades, professionals have been experimenting with VR uses for operating, using, maintaining and planning the built environment. This rich set of applications and how VR systems are used to present information about urban regions, cities and neighborhoods to both improve the operation of existing buildings and infrastructure and to plan new interventions. Models used in planning may have quite different information content from the models used to understand instances of the built environment operation. [13]
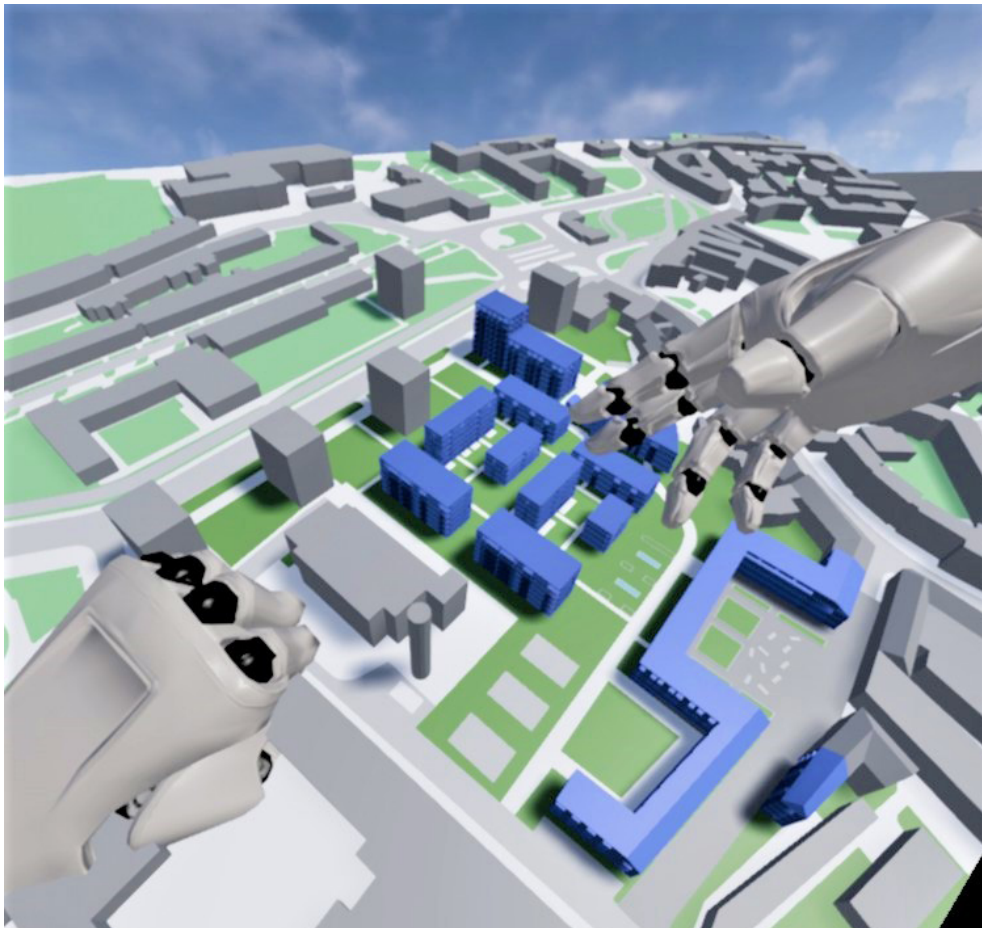
13   Vgl. Whyte, Nikolic 2018, 43.

Fig. 44 reviewing the model of the planned buildings

Fig. 45 VR walk-trough in 1 to 1 scale

For planning, a distinguishing characteristic of VR systems is that they enable one to experience the city both at the street-level view and an interactive bird's-eye view. The desire for participatory planning processes motivated a search for new forms of representation beyond maps, models and plans to enable a street-level view. By focusing the attention on urban areas viewed at the street level using a range of viewpoints, rather than the view from above, VR systems allows greater participation and better decision-making in the planning process. Before the introduction of Google Earth and Google Street View, a number of firms explored the use of VR systems with interfaces similar to 3D games to enhance navigation in the built environment. Google Earth and Google Street View overcame the limitations experienced by such early experiments for many applications. Modeling urban environments in VR can also enable us to walk through models of buildings and environments that no longer exist. The relationship and correspondence between the digital and real environments is important for understanding historical environments.[14]

14   Vgl. Whyte, Nikolic 2018, 54-55.

Chapter 3

Farnsworth House VR project

Fig. 46 front side

Fig. 47 back side

Chapter 3 - Farnsworth House VR project

The Farnsworth House is one of the most significant buildings of Mies van der Rohe and is widely recognized as an icon of the International Style of architecture. Because of the importance for architecture and its connection with the surrounding area, the Farnsworth House was chosen for this project to demonstrate the capabilities of virtual reality for architecture.

1 Farnsworth House introduction

"In a low-lying meadow beside the Fox River at Piano, Illinois, stands a serene pavilion of glass, steel and travertine. [...] The Farnsworth House consists of three horizontal planes: a terrace, a floor, and a roof. Welded to the leading edge of each plane are steel columns which keep them all suspended in mid-air. Because they do not rest on the columns, but merely touch them in passing, these horizontal elements seem to be held to their supports by magnetism. Floor and roof appear as opaque planes defining the top and bottom of a volume whose sides are simply large panels of glass. The Farnsworth House is, indeed, a quantity of air caught between a floor and a roof. In spring the pavilion stands on a carpet of daffodils, in summer upon a green meadow, in autumn amid the glow of golden foliage; and when the adjacent river overflows the house resembles a boat floating on the great expanse of water. It is in effect a raised stage from which an entranced viewer may not merely observe ever-changing nature, but almost experience the sensation of being within it. It is Mies van der Rohe's last realized house, built to provide a cultivated and well-to-do urbanite with a quiet retreat where she could enjoy nature and recover from the cares of work."[15] "His most fundamental decision involved the relationship between the building and the landscape - a relationship that aimed at bringing nature, the house and human beings together into 'a higher unity', as Mies van der Rohe put it."

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15   Vandenberg 2005, 2.
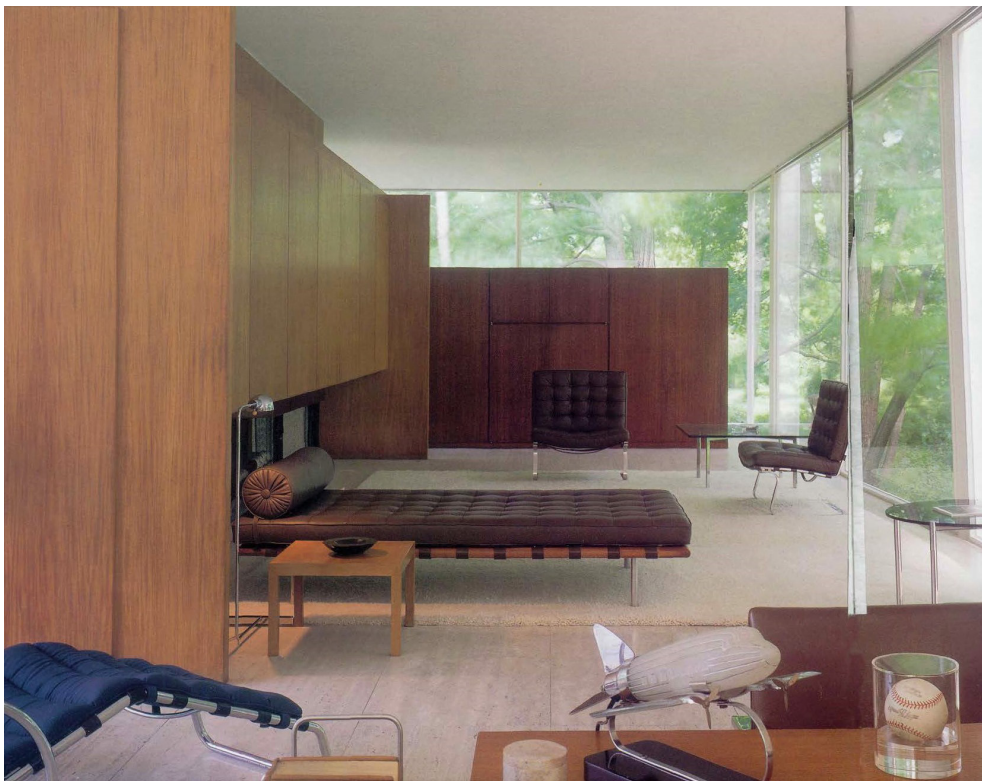16   Vandenberg 2005, 13.

Fig. 48 staircase

Fig. 49 living room

2 Documentation

Recreating the Farnsworth House for virtual reality is a task which requires floor plans, sections and photographic material. Bad documentation is a common problem for important architectural structures in form of wrong or incomplete plans and manipulated photographs. In many pictures the position of the furniture is different because architectural photographers like to change things for the composition. Because of severe flood damage in 1956 and 1996, important furniture and structural parts were damaged and had to be rebuilt. Different owners had different ideas and solutions for problems of this weekend house. Insect screens on the porch and roller shades are some of many changes over the years.

Comparing many plans and photographs is necessary to figure out the correct version of the Farnsworth House. Recreating the original state with the ideas of Mies Van Der Rohe is important for the architectural message of this building and this project.
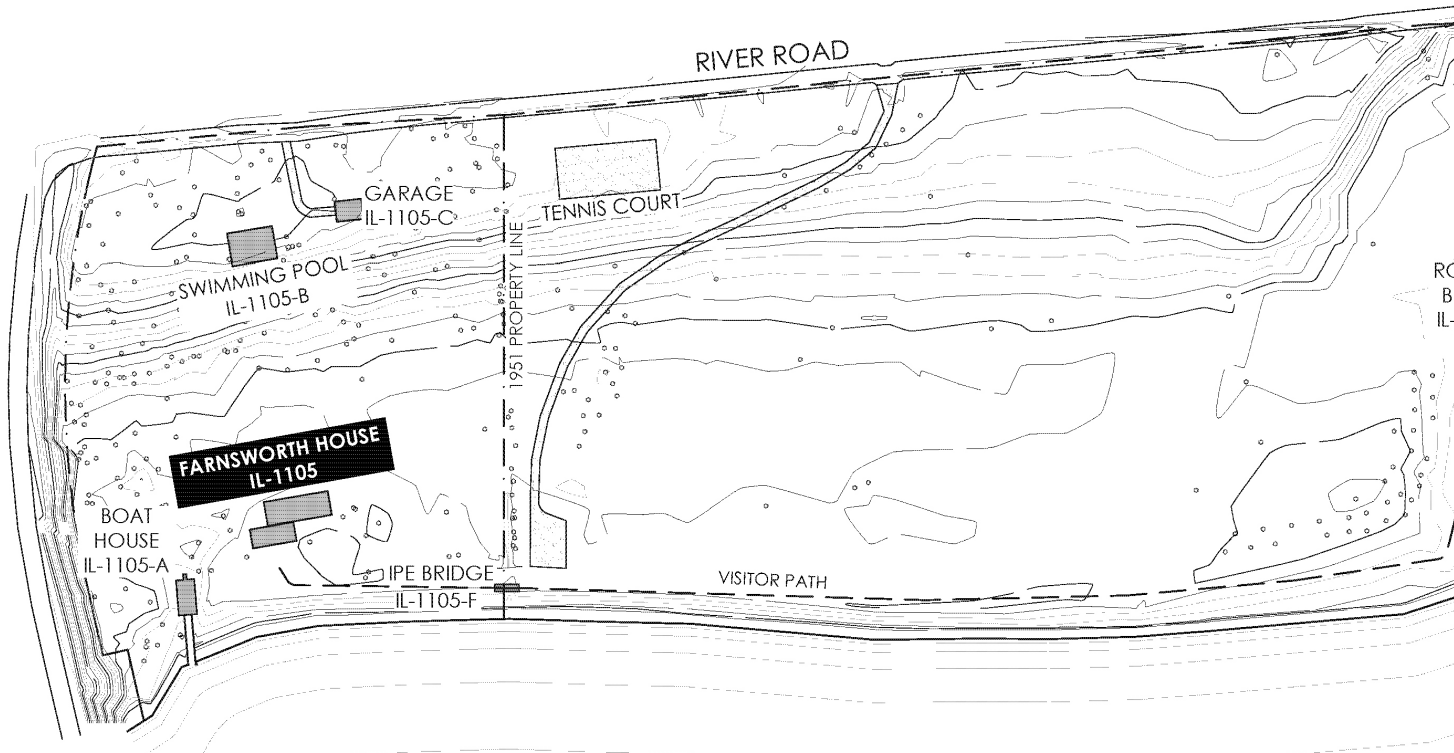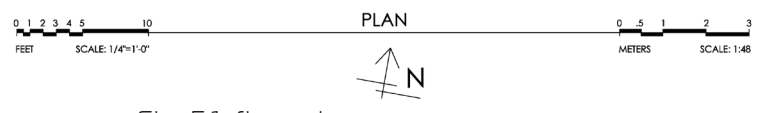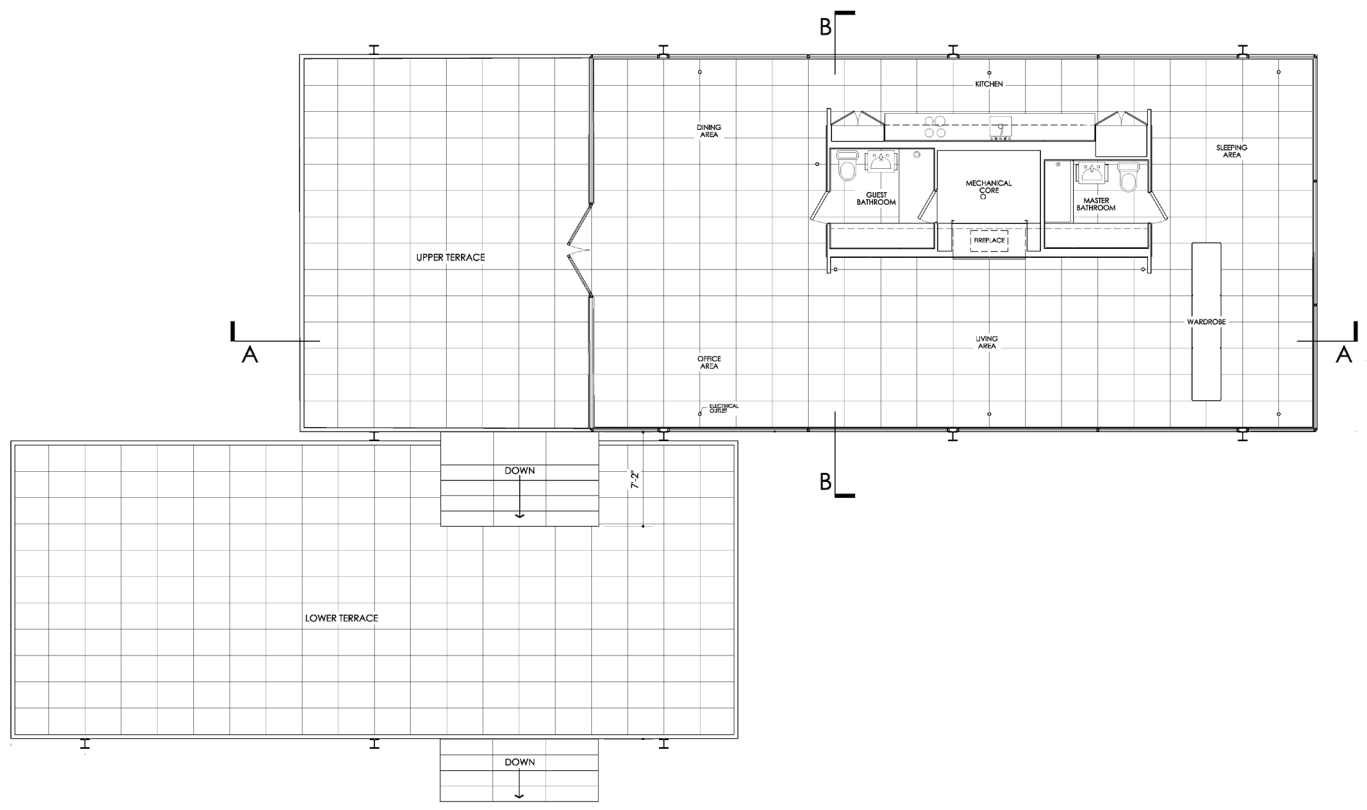
Fig. 50 building site

RIVER ROAD

GARAGE
IL-1105-C

TENNIS COURT

SWIMMING POOL
IL-1105-B

1951 PROPERTY LINE

FARNSWORTH HOUSE
IL-1105

BOAT
HOUSE
IL-1105-A

IPE BRIDGE
IL-1105-F

VISITOR PATH

RO
B
IL-

0   125   250   375   500

Fig. 51 floor plan

B

KITCHEN

DINING
AREA

SLEEPING
AREA

UPPER TERRACE

GUEST
BATHROOM

MECHANICAL
CORE

MASTER
BATHROOM

FIREPLACE

WARDROBE

A   A

OFFICE
AREA

LIVING
AREA

ELECTRICAL
OUTLET

B

DOWN

7'-2"

LOWER TERRACE

DOWN

0 1 2 3 4 5   10   PLAN   0 .5 1   2   3

FEET   SCALE: 1/4"=1'-0"   METERS   SCALE: 1:48

N

VISITORS
CENTER
IL-1105-D

OB ROY
RIDGE
1105-E

FOX RIVER

1961 PROPERTY LINE

N

0   15   30   60   90   120
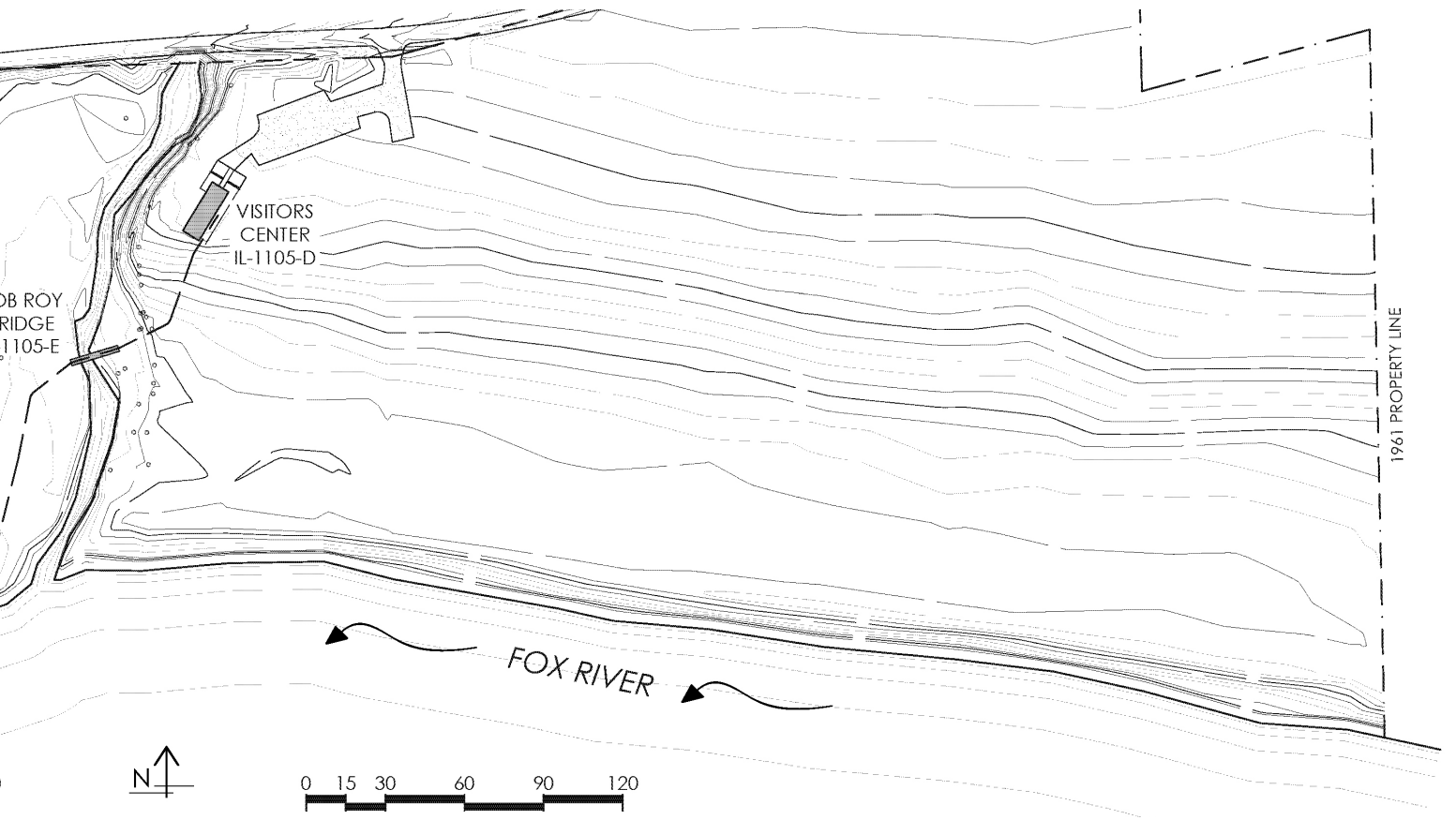
Farnsworth House recording project plans
Cellini, Jenna/Milnarik, Elizabeth/Roeder,Brad
USA 2009

SOUTH ELEVATION

LOWER TERRACE

UPPER TERRACE

0 1 2 3 4 5   10
FEET   SCALE: 1/4"=1'-0"

0 .5 1   2   3
METERS   SCALE: 1:48

Fig. 52 south elevation

CENTRAL UTILITY SHAFT

UPPER TERRACE

LOWER TERRACE

NORTH ELEVATION

0 1 2 3 4 5   10
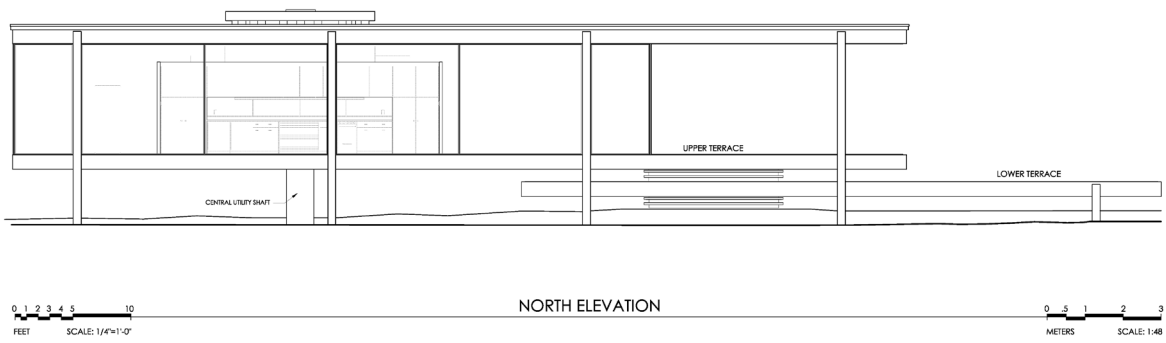FEET   SCALE: 1/4"=1'-0"

0 .5 1   2   3
METERS   SCALE: 1:48
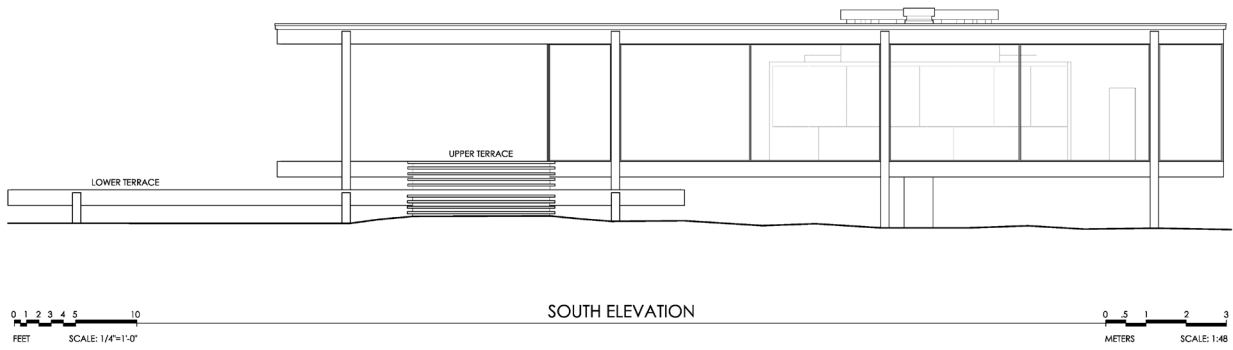
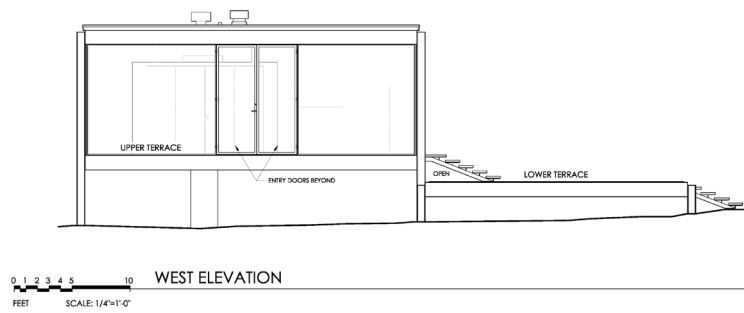Fig. 53 north elevation

EAST ELEVATION
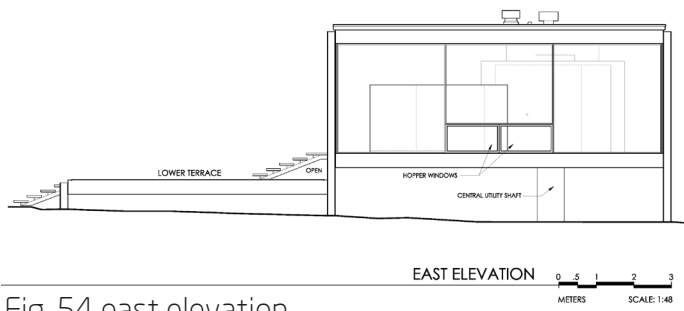
Fig. 54 east elevation

WEST ELEVATION
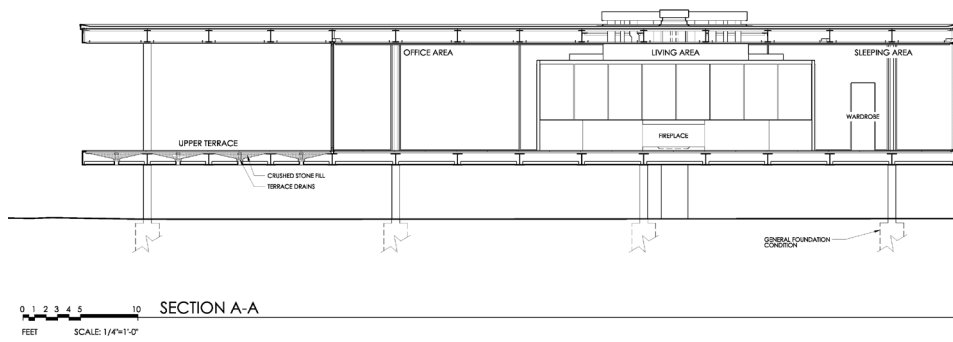
Fig. 55 west elevation

SECTION A-A
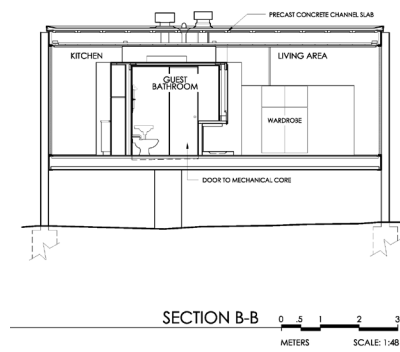
Fig. 56 section A-A

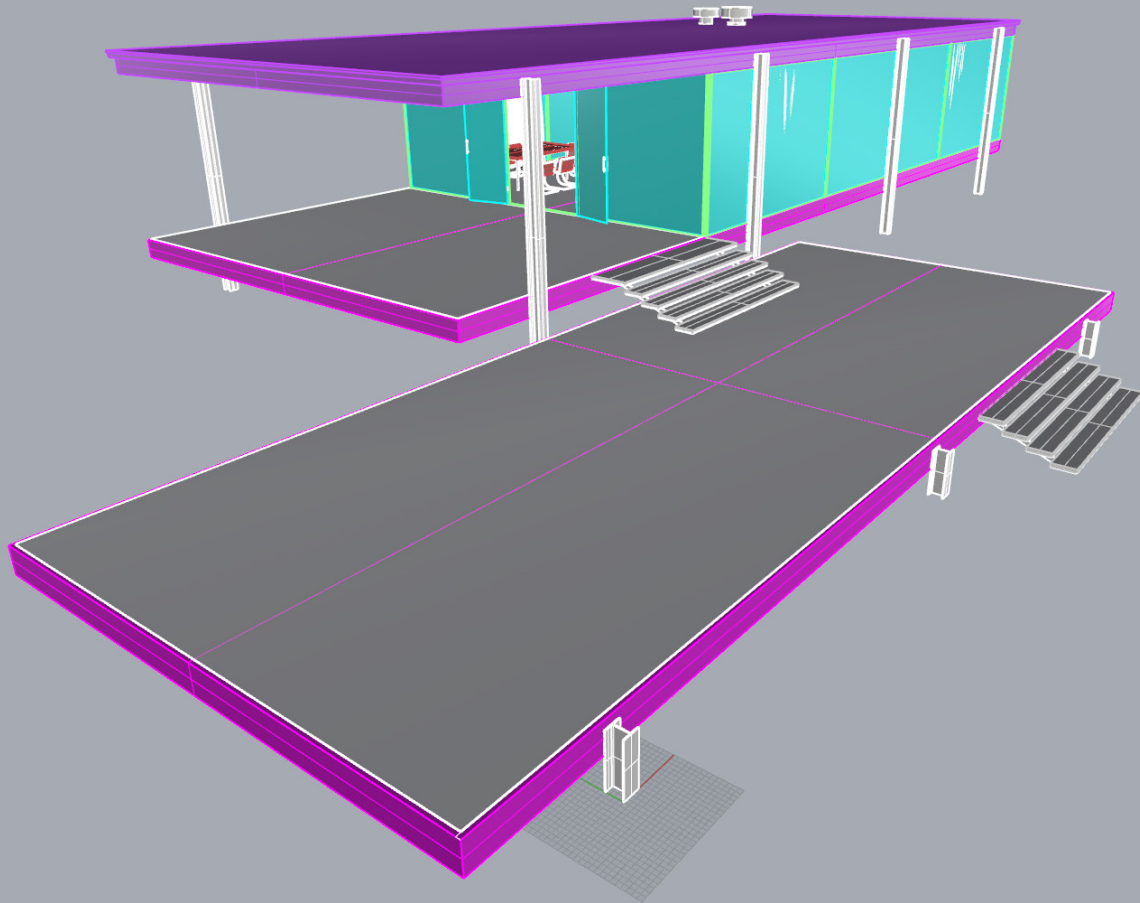SECTION B-B

Fig. 57 section B-B
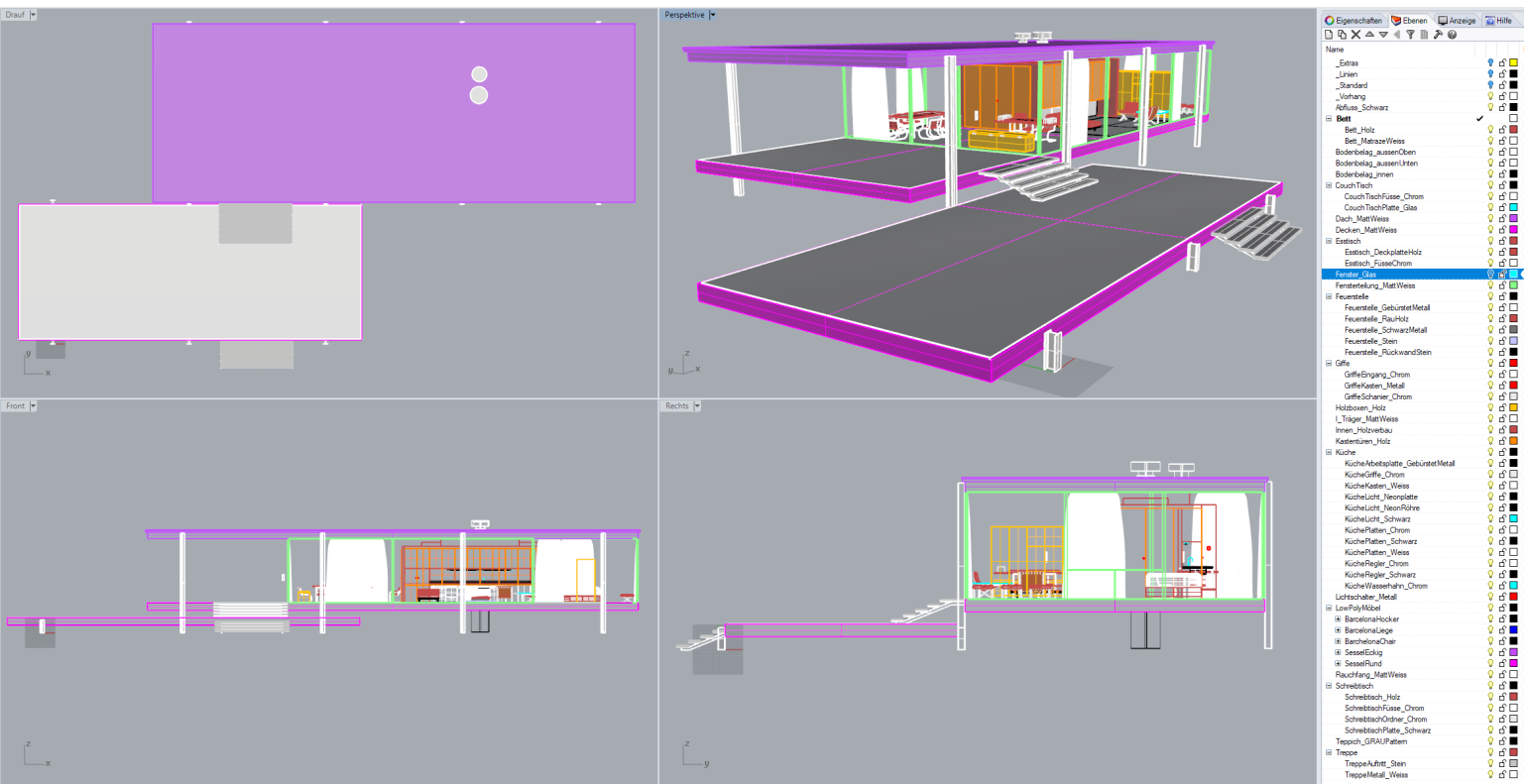
Fig. 58 Farnsworth House model in Rhinoceros

Fig. 59 Rhinoceros viewports and layer structure

3 Rhinoceros modeling

After finding the necessary plan and photo documentation for the Farnsworth House, the next step is to model the structure in 3D. Most architectural drawing programs like Google Sketchup, Archicad, Autocad, Allplan or Rhinoceros can export 3D data in usable file formats. Rhinoceros 5 is a widely professionally used program to create 3D structures and was therefore chosen for this project.

Importing plans, scaling them to the right proportions and tracing the lines is a good way to start modeling. With the information of 2D floor plans and sections, the next step is to create 3D geometry. It is helpful to use good photo documentation while modeling important details of the building and furniture. A good layer structure is important from start to finish (Fig. 59). Object layers can be grouped by different materials and should be named accordingly for easier texturing. After finishing an object, checking if the surfaces are facing the right direction is good practice.

While Rhinoceros is widely used for architectural modeling, it is not the best in converting nurbs to polygon meshes. This aspect can result in a decreased performance in real-time rendering because of a bigger polycount due to a non efficient nurbs to mesh conversion. Converting the nurbs into a polymesh before exporting gives more control over the complexity scale of the final mesh. Making sure the whole geometry is centered around the 0,0,0 point is important for later reexporting edited meshes in order to correctly replacing them. Exporting as an OBJ file is generally advised since OBJ is a useable 3D model format for later use in a real-time render engine.

Fig. 60 Unreal Engine 4 - Nature

Fig. 61 Unreal Engine 4 - Lighting

Fig. 62 Unreal Engine 4 - realtime rendered short film - `A Boy and his Kite`

4 Engine consideration

Engines are comparable to other rendering programs but are optimized for real-time rendering. The most used engines for real-time rendering are Unity 5 and Unreal Engine 4. After developing a virtual reality master course project with Unity 5 I realized that my lack of coding experience was a problem. While I learned a lot in this course I was limited in my possibilities with Unity.

What sparked my interest in the Unreal Engine were many interesting projects of nature environments with green grass which moves in the wind and realistic trees rendered in real-time. In my opinion the recreation of the natural environment is important for a believable architectural visualization. Projects of interior scenes of rooms with photorealistic furniture and realistic lighting are astonishingly good in visual fidelity and performance. The nature environment of the real-time rendered short film „A boy and his kite" is a fantastic demonstration of the capabilities of this render engine.

The main factors for choosing Unreal Engine 4 are documentation and the availability of tutorials, assets, VR integration, interface, graphical fidelity and optimization. It is possible to use the engine node system called Blueprint, as well as coding languages for programming. Unreal Engine 4 was used for this project due to these advantages.

Fig. 63 Farnsworth house in Unreal engine 4

5 Farnsworth House VR project introduction

After putting the headset on and grabbing the controllers the user is placed at the start of the gravel road connecting the parking space and the Farnsworth house. The controls for movement and interaction with objects are shown on easy to read panels at the starting point. A table with simple cubes is situated right in front of the user to test the grabbing of objects. In this action, the user recognizes the ability to walk in physical space, but also sees its space limitation. This should motivate the user to try and teleport to move the physical playarea to a new place in the digital environment and thus understanding the virtual reality movement of teleportation. With these basic controls the player can explore the environment freely and by this becoming more familiar with them. The Farnsworth House is visible from every point of the environment and the user can choose to explore the environment first or go directly to building on the indicating gravel road. This is important to show the user freedom in virtual reality to look at the house from every angle.

At the Farnsworth House the player is able to go inside and get a spatial understanding of the building. Exploring all areas of the house can be done in both directions because of the half open design of the different rooms. Interaction with light switches, furniture and other objects is possible to create a more immersive experience. An obvious sheet of paper on the desk shows the additional controls of the project. The option to remotely turn the lights off and on is the right menu button and to blend in additional information about the building on the left one. Original pictures of the house and owners should motivate the user to take another look at the interior. Important to show is the grabable 1:50 model of the Farnsworth House on the long table to show this interesting aspect of virtual reality. After this the user should have a good idea of the spatial layout and dimensions and should have acquired additional knowledge about the Farnsworth House, which is the goal for this educational architectural virtual reality project.
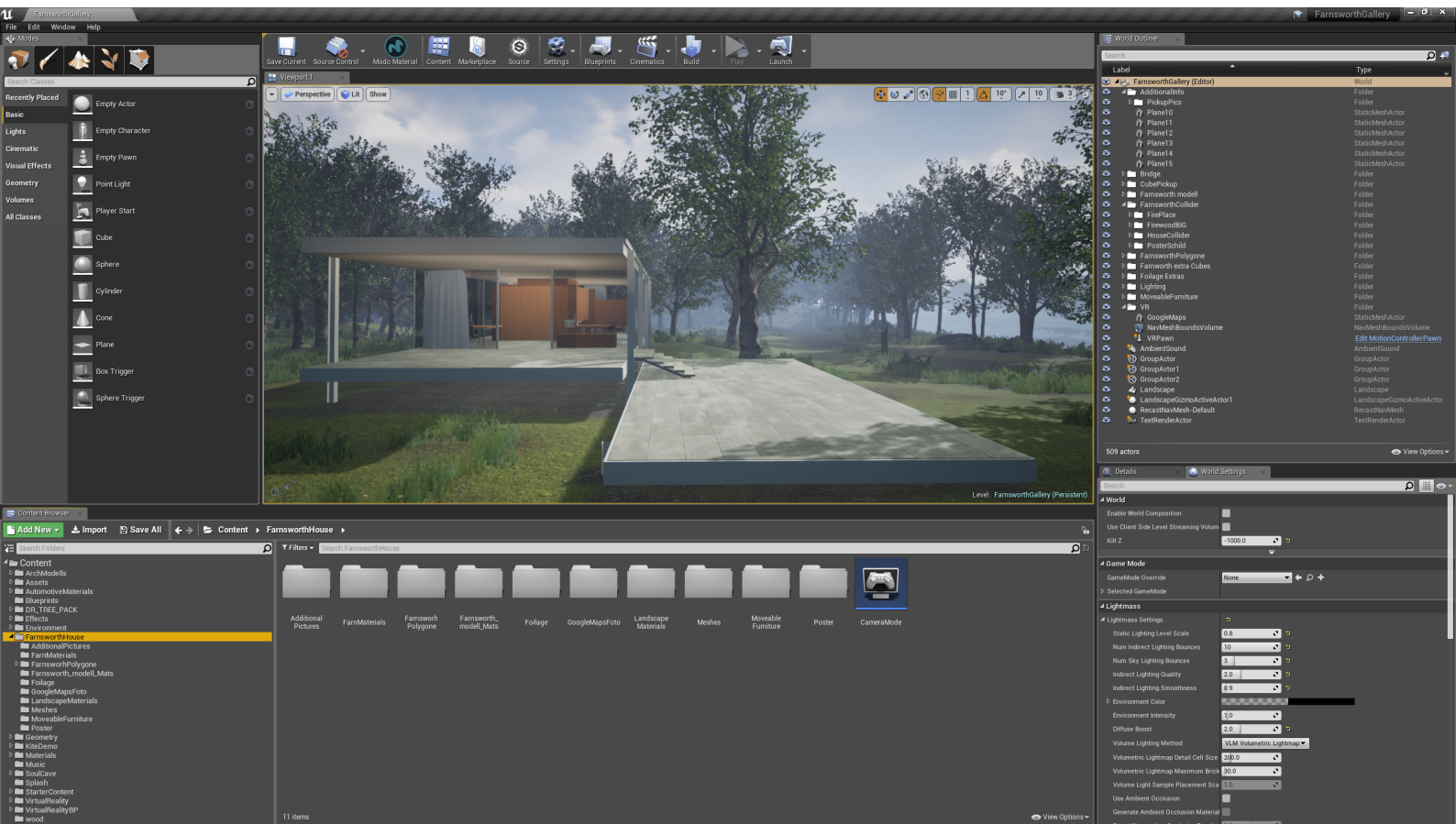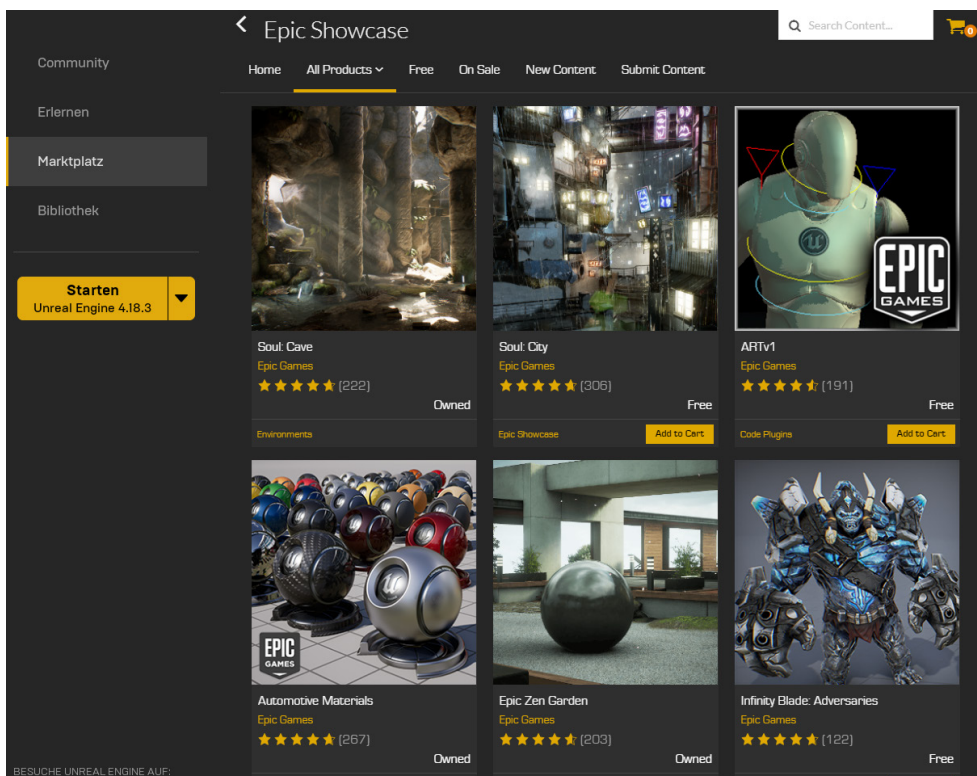
Fig. 64 Unreal Engine 4 Interface

Fig. 65 Asset marketplace

Chapter 3 - Farnsworth House VR project

6 Project development in UE 4

The following pages show the development of the Farnsworth House VR project and explain the acquired knowledge about the Unreal Engine 4.

6.1 Basics

The first thing to learn is how to navigate a scene and how to organize content in the content browser and world outliner (Fig. 64). This is important because of the many different file types like meshes, textures, materials, blueprints and many more. Importing assets into your project is dependent on the file type and it is crucial to check the import information. A systematic folder structure is essential in a big project to find assets in an efficient way.

6.2 Assets

To start with the starter content is a good way to get used to handling different types of files in your project. Implementing and editing assets correctly is crucial for understanding and learning in the beginning. For an efficient workflow it is necessary to constantly expand your asset library. Asset packs can be found on the Epic market place (Fig. 65) and Online. Only free assets were used for this project.
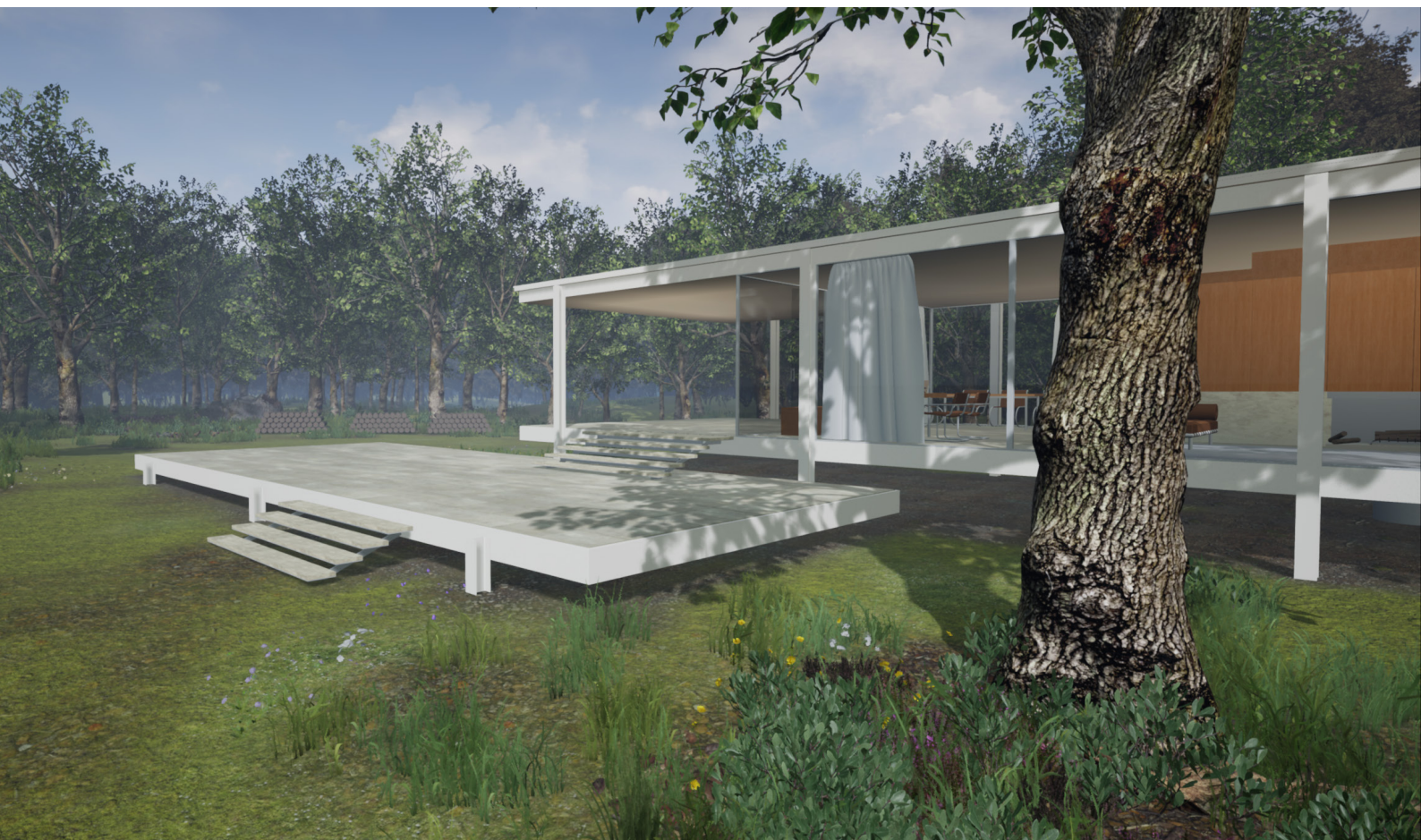
Fig. 66 inside materials

Fig. 67 outside materials, landscape material blending

6.3 Materials

Textures contain image data but can not be applied to a mesh directly. A material has to be created first. After creating a new material in the content browser, the texture node can be connected in the material editor. The material editor is a node system which allows to set many important attributes for the material like base color, metallic value, specular value, roughness, emissivity color, opacity, normal maps and others. A basic way to create a material is to select the desired texture and connecting this node with the base color pin. Light reactivity is achieved with the addition of a normal map texture and needs to be connected with the normal pin. A simple color is made with a 'constant3vector' converted into a parameter. Additional textures can be added, blended or masked out. To control just the value of a pin, a scalar parameter is needed. This makes it possible to set values for the material and see the result in real-time.

Landscape materials are made by creating a material, which blends up to twelve textures together with the layer blend node. This material can then be used as a landscape painting material (Fig. 67) by adding the according textures into the target layers.
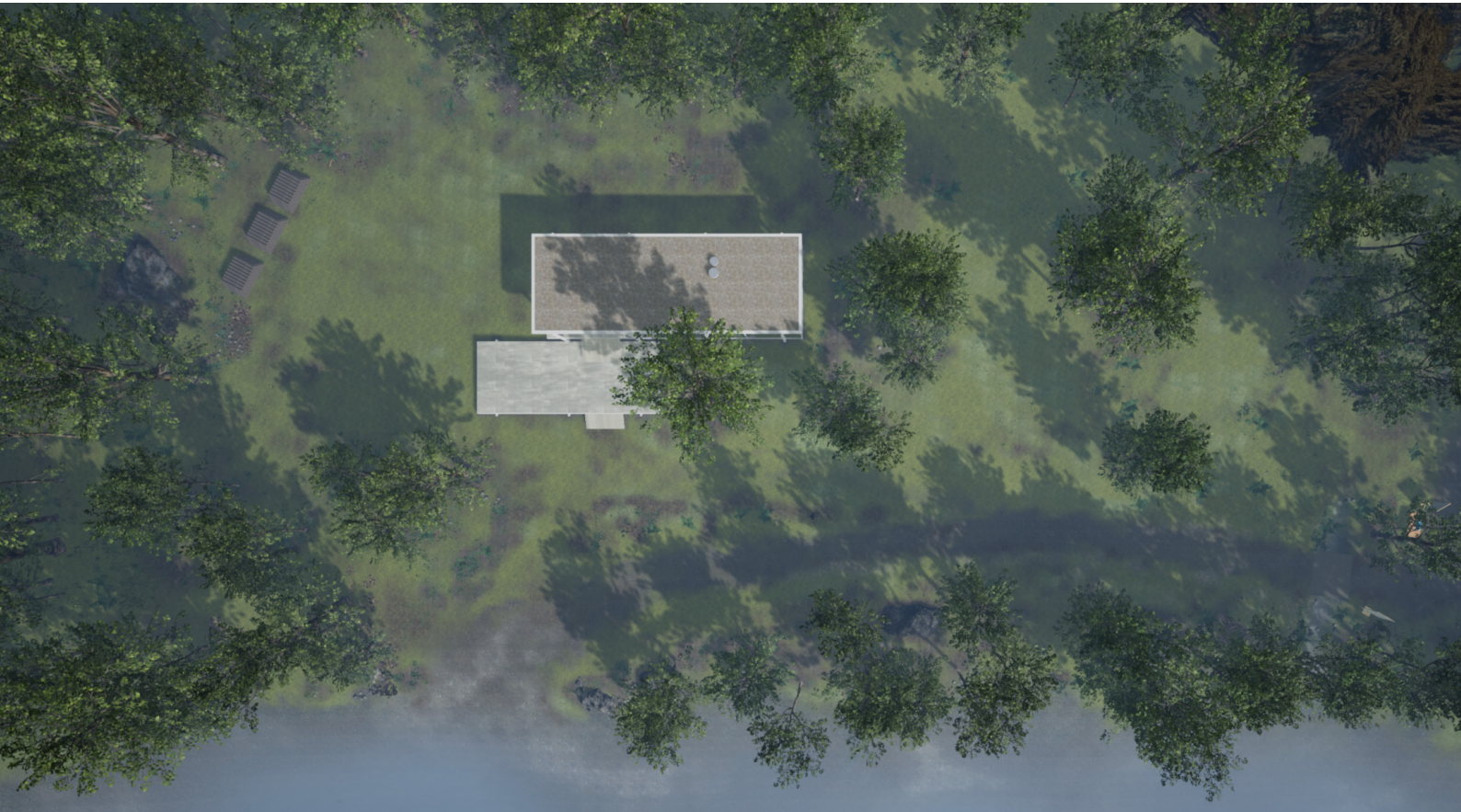
Fig. 68 nature environment

Fig. 69 surrounding area

6.4 Nature environment

Because of the relevance of the building site of the Farnsworth House it is necessary to create a convincing landscape. Reference photos are important to get a general understanding of the environment. In this case topography is not very important because of the flat nature of the site. Not many pictures can be found of the distance between the Fox river and the house due to the direction of the building and dense vegetation. Since the Farnsworth House was built in 1951, trees and foliage were constantly changing which can be seen in photographic documentations.

Pictures, plans and appropriately scaled Google satellite maps of the surrounding area are essential to create a correct building site. This technique can be used to find the correct place for trees, open green spaces and the width of the river. Right proportions of open and woodland areas, pathway and river and are important. Different kinds of rocks, grass and plants like flowers and bushes are added to achieve a more natural look. Especially important for this project are the path leading to the house, the shoreline and width of the river.
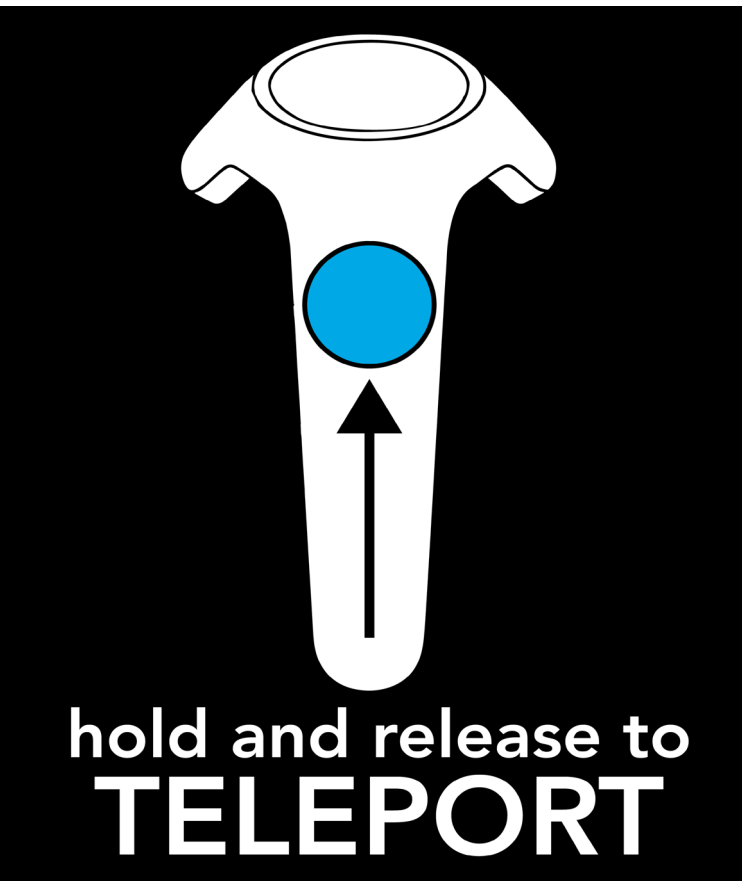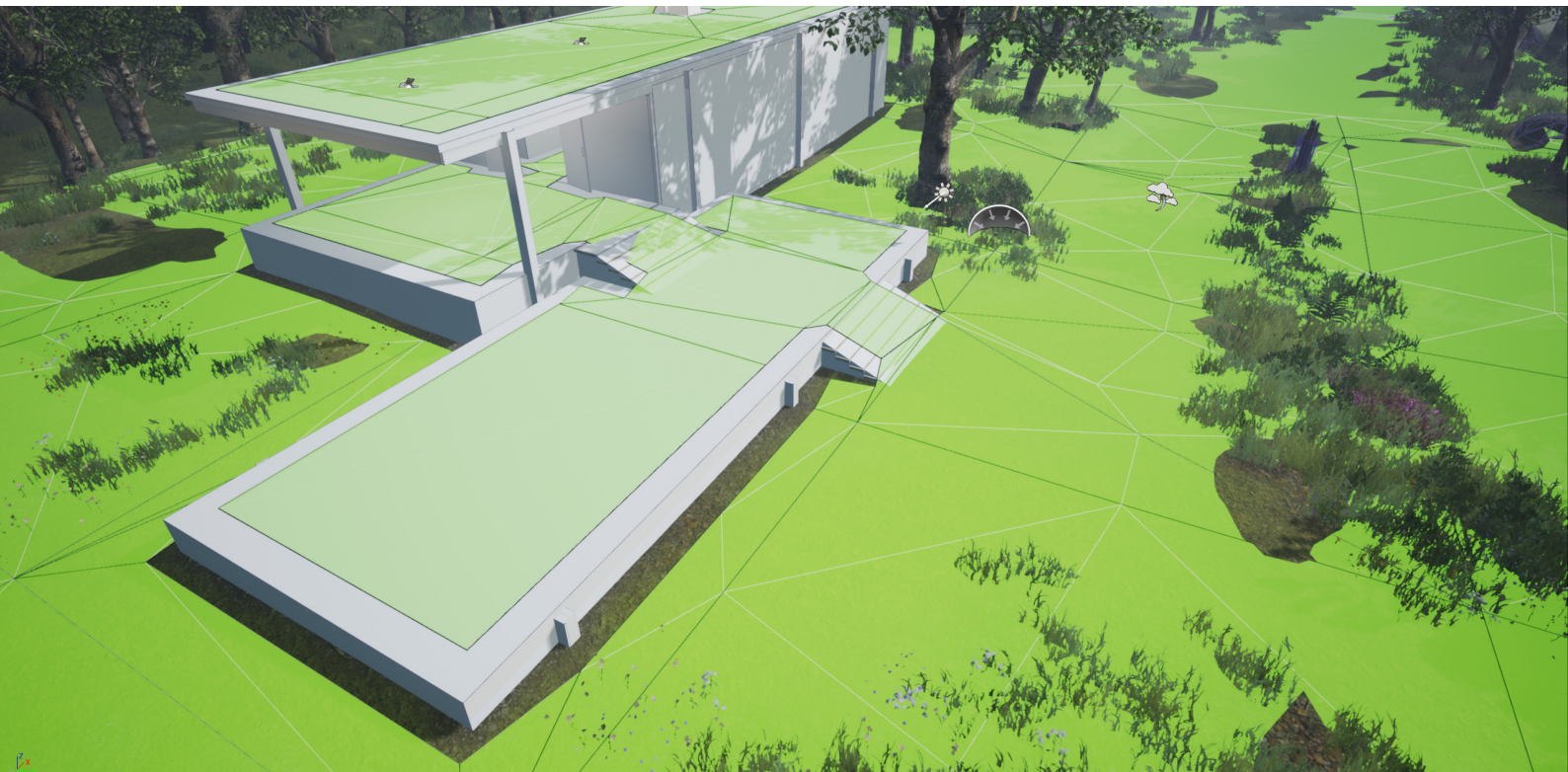
Fig. 70 teleportation system

Fig. 71 visible collision and navigation system

6.5 Movement

Unless the goal is to make a specific room which does not exceed the size of the movement area, it is necessary to think about how to expand these limitations. There are many ways to achieve this and the best way to understand the problems is to try applications with different ways of character movement.

One of the worst choices to make is to take the camera out of the control of the user. A perfect example to explain the things to avoid is a virtual reality roller coaster simulation. Linear camera travel can work if done right, but acceleration, deceleration and rotation are severely motion sickness inducing. A popular but not perfect way of movement is to grab and pull with the controller. This technique uses the position of the controller and allows the user to pull the world on a plan. While mildly motion sickness inducing, this way of movement is acceptable but not the best option.

Teleportation is the most beginner friendly and most comfortable way of achieving a walk around experience. The most used way of teleportation is by holding a button on the controller and pointing it in the direction the user wants to go (Fig. 70). By releasing it, the view fades to black and the position of the move area is changed to the desired position. The goal for this project is to make the scene as freely explorable as possible to allow the user to look at the Farnsworth House from any distance and angle. The teleportation system of the virtual reality template is acceptable, but in order for it to work properly some changes are important. By enabling the vertical movement of the playing area as well as to teleport onto objects, a useful teleportation experience can be ensured. A simplified and non visible collision structure was created to achieve good navigation (Fig. 71). To set the outer and upper limits of the scene a navigation bound volume is needed.
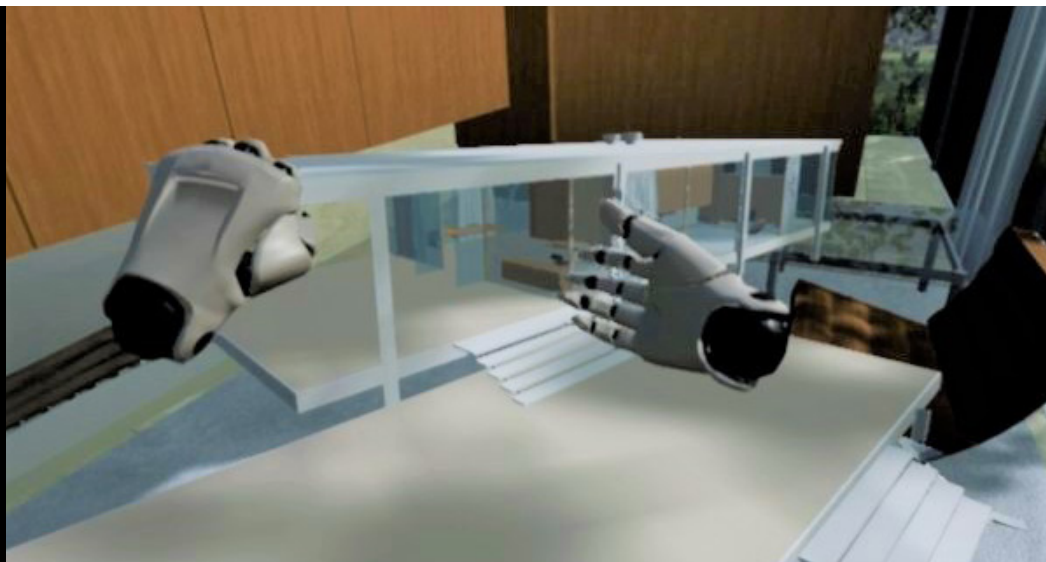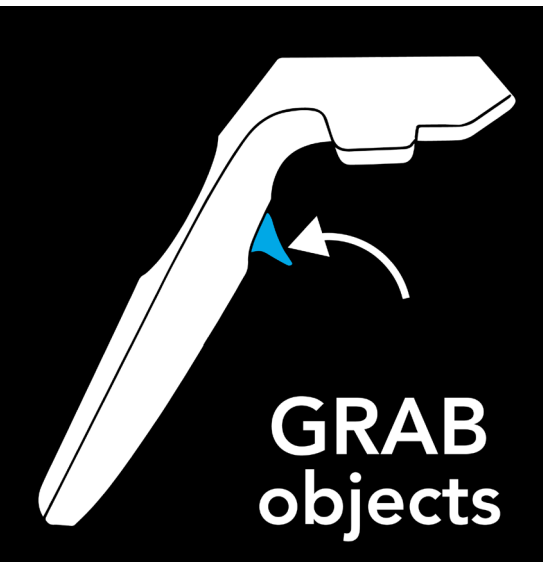
Fig. 72 touchable scaled model

Fig. 73 additional information on button press

Fig. 74 1:50 scale model of the Farnsworth House

6.6 Interactivity

The amount of interactivity ranges from a free-fly camera with no collision to a walk through with a completely detailed kitchen where you can open any drawer and interact with everything. Finding a good balance is important to create a believable scene in a usable timescale. There were a lot of ideas for interactivity at the beginning of this project, but not everything made sense for time and performance reasons.

The first and most significant feature in my opinion is to make touchable physical objects for furniture and other elements in the scene. Using the template is a good way of creating touchable objects by defining them with the blueprint as such. To help with physical performance it is good to simplify the collision geometry with invisible boxes.

Two kinds of lighting, one being a natural setting with only sunlight and the other a lit interior with house lights were added. There are two ways of choosing these settings, one is to touch the light switches in the house and the other by a button press on the controller.

Additional information about the Farnsworth House and a scaled model were created to show the educational possibilities. An ignitable fireplace and physically rendered wood logs were added to engage the curiosity of the user.
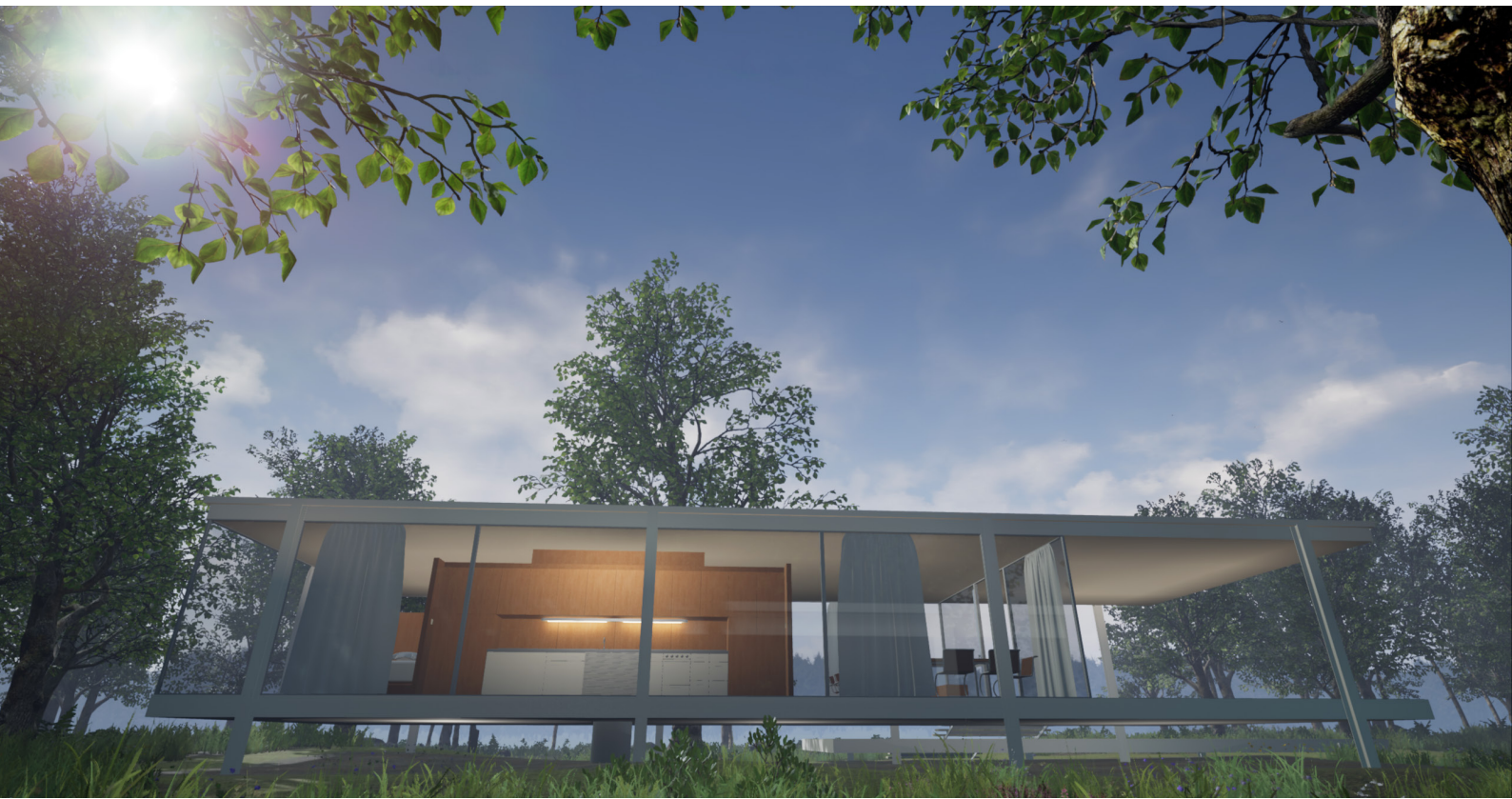
Fig. 75 lighting outside

Fig. 76 lighting inside

Chapter 3 - Farnsworth House VR project

6.7 Lighting

To create a natural look for the scene the main light source is the directional sunlight and a skylight to fill in the shadow areas. A good way to create a believable sun is by enabling bloom and setting it to convolution. The sun as well as the skybox have options to edit them for the desired result. It is important to set them to static and not dynamic to bake shadows in order to save processing power, especially for virtual reality.

On the inside of the house the goal is to create a convincing artificial lighting setup to simulate the real lights of the Farnsworth House. For this, many different light sources are needed and performance issues can emerge. While building interior lighting it is always necessary to test the performance, which differs immensely between rendering it on a monitor versus in a virtual reality headset. Reducing the light quality without decreasing the optical quality enhances the performance substantially.

Fig. 77 natural lighting temperature

Fig. 78 exponential height fog- Fox river depth

6.8 Post-processing

A post-processing volume enables the creator to make a lot of chances for the overall scene. Setting the white balance is a useful option for adjusting the overall cool or warm scene, which can be changed as well by changing the color of the light source (Fig. 77). An exponential height fog is used to create depth and a realistic atmosphere at a farther distance (Fig. 78).

Post-processing options like image effects, lens flares, depth of field, ambient occlusion and motion blur can be used to enhance the visual quality of a scene. These were tested for this project and are not recommended for virtual reality. These options are generally used for rendering on a monitor, where performance of frames per second and response time is not an issue.
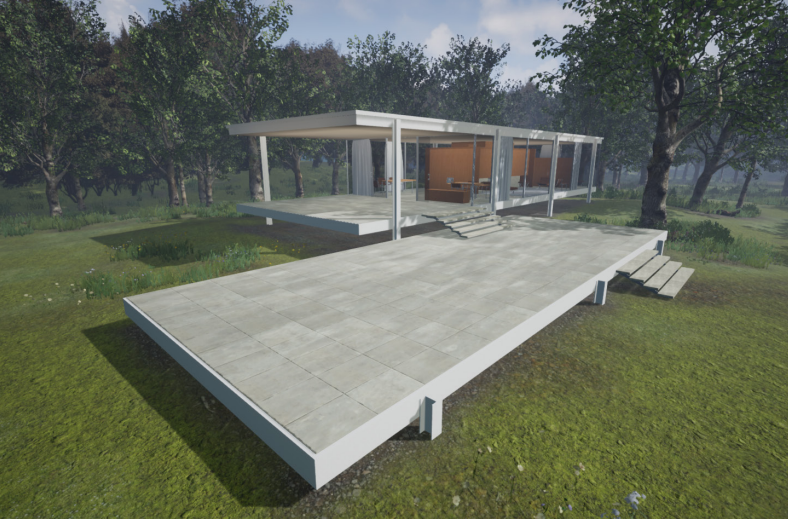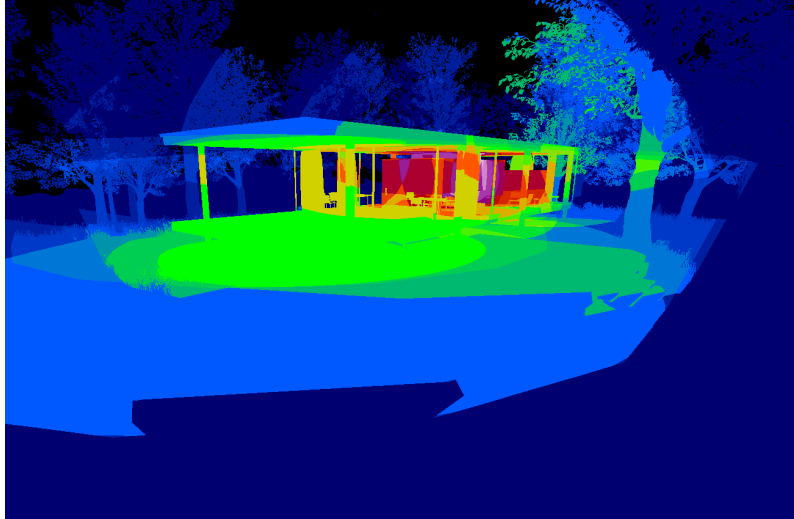
Fig. 79 normal view mode

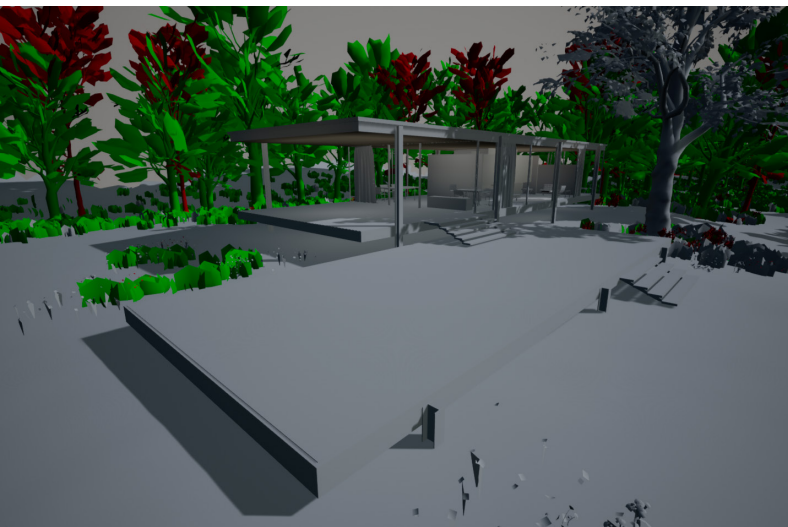Fig. 80 light complexity view mode

Fig. 81 level of detail view mode
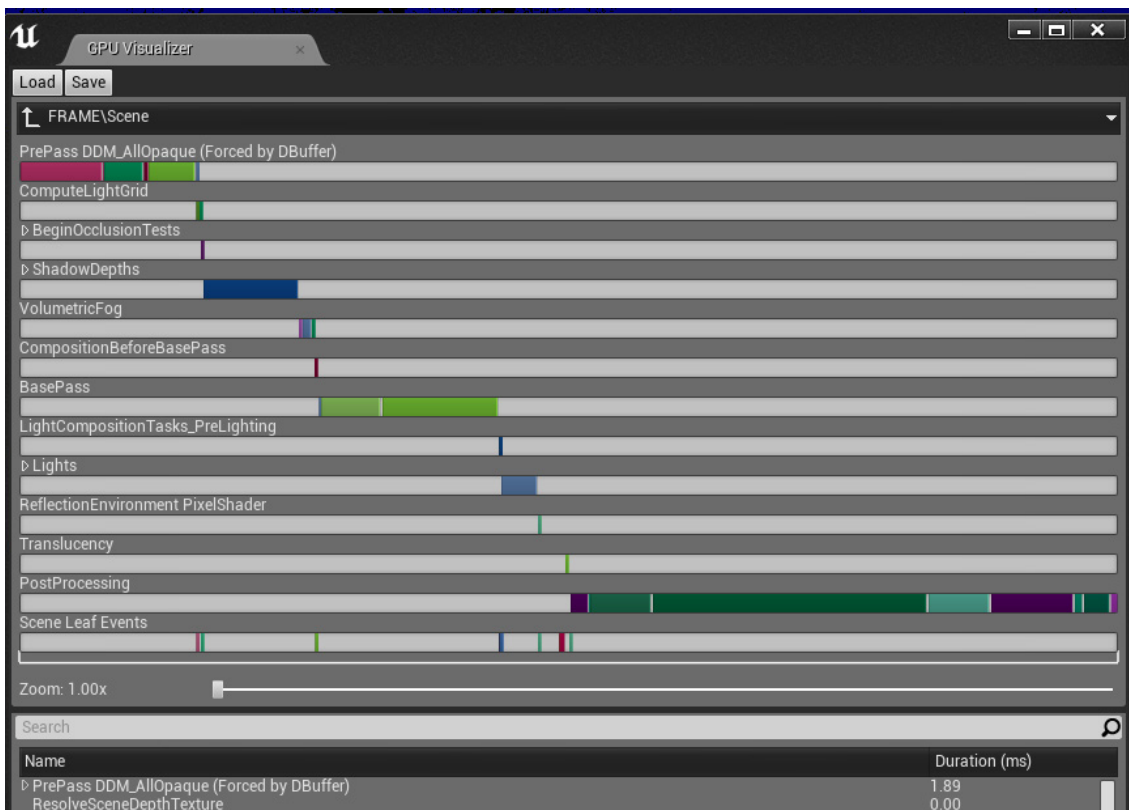

Fig. 82 reflections view mode

Fig. 83 GPU visualizer

6.9 Graphic settings and performance optimization

Unreal engine 4 is known for its scalability and performance options and a fast way to set these is in the level blueprint. The level blueprint can execute commands for the engine at the start and changing them can be set to different keys on the keyboard.

The options for a level reset and quit, a frames per second counter and different graphic settings were set to different buttons in this blueprint.

The Unreal Editor viewports (Fig. 79-82) have various visualization modes. Optimization viewmodes are useful for visually checking the type of data being processed, as well as to diagnose any problems or unexpected results. The GPU visualizer window (Fig. 83) is a good first way to see which elements of a scene are impacting performance the most in relation to others.

Rendering for virtual reality is different than rendering on a normal monitor, so it is always necessary to test with the headset. It is possible to test in editor with the VR preview and enable a frames per second counter. Decreases in performance can be seen by exploring the scene and watching the fps counter. For the most accurate way of testing the scene needs to be exported. A good way is to do this every so often to ensure to not over-populate the scene.

Frame-rate and frame times are extremely important for a good virtual reality project. The frame-rate should always be at a constant 90 frames per second and the frame times below 20 milliseconds to ensure an enjoyable and motion sickness free experience.

Chapter 4

Summary

1 Results

Room scale virtual reality is a new revolutionary tool where the user movement in reality is translated into a virtual environment in real-time. This property brings huge advantages to the visualization of architecture because it enables the user to get a real sense of scale of a building or structure. Virtual reality is a tool to present ideas in a new way which is accessible for everyone. It is also a new appliance in architecture which has the power to change the traditional workflow of creating and understanding architecture.

As of now, virtual reality headsets and graphical computing power are at a point where it is not necessary to invest an enormous initial amount of resources to have a usable experience. While modern headsets are definitely still in the early stages of this technology, it has great potential to revolutionize the way we use it to communicate three dimensional ideas in the near future.

There are questions about how abstract the representation should be: the more aesthetically polished a model is, the more likely it is to be used simply as a vehicle for persuasion. Clients and end users generally will feel more comfortable making design changes if it does not appear that decisions have already been made and designs have been finalized, which tends to occur more often when they are presented with highly detailed or photo realistic models.

In design presentation and review, a general lack of an inherent narrative structure in virtual reality applications has been a recurring issue. One concern is that virtual reality models may not provide designers and users with an appropriate balance of participation and control.

2 Conclusion

This thesis started with my general interest in virtual reality and the possibilities it can offer for architecture. During the time period of creating the Farnsworth House for virtual reality and writing this thesis I had a lot of thoughts and ideas about this technology. I tried to compile those in a comprehensive way for people who are interested in virtual reality and want to know how this project was created.

Learning to use Unreal Engine 4 was a challenging task because of the amount of functionality modern real-time engines have to offer. It definitely showed me why more than one person is working on such projects to achieve results in a reasonable timescale. The goal was to show my understanding and appreciation of virtual reality and test its usability for architecture. In retrospect it was the amount of new acquired skills and knowledge that made this thesis worth the effort.

3 Outlook

Many negative aspects and problems have been resolved since the release of the first Oculus headset five years ago. A lot of companies have invested greatly in virtual reality in the last years, but it still has not completely reached the general public. Looking back to the early smart phones, displays, computers and many other examples of technology, shows that time and multiple iterations are required for it to reach its full potential.

Processing power, resolution, frame-rate and comfort will increase as well as other aspects in the development of future virtual reality. The movement area is still very limiting and the end goal will be to achieve a free moving experience where the user is able to interact with the virtual world in the same way as they interact in reality.

The next big step is wireless technology for virtual reality. Some advances have been made in this regard but the importance of low input lag paired with the necessity of transferring very large amounts of data still makes this a challenge. Some manufactures have developed VR backpacks - powerful laptops without a screen with fast changeable battery packs, but with a weight of about 4kg and a battery time of around an hour it is not the best alternative yet.

Input devices will continue to become more accurate and more intuitive to use. Haptic feedback will likely be an area worth developing for virtual reality. Research and development in this field could potentially lead to gloves or suits that apply pressure on how we interact with the virtual world. Texture, temperature, taste and smell will eventually follow. This will take this technology to a point at which it will be difficult to distinguish reality from the virtual world.

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University of Technology

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