Evaluating Immersive Virtual Reality Environment for Facility Management Planning

Master thesis

International Master of Science in Construction and Real Estate Management

Joint Study Programme of Metropolia UAS and HTW Berlin

Submitted on 25.08.2017

from

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ACKNOWLEDGEMENT

First of all, I would thank my beloved parents, who gave immense support throughout my life and I would like to take this opportunity to express deepest gratitude to my thesis advisor Prof. Dr.-Ing. Markus Krämer for his sincere guidance and suggestions which enabled me the positive attitude and successfully completing my thesis work effectively.

I would also like to express my heart full gratitude and appreciation to my second adviser Principal Lecturer of Metropolia University of Applied Sciences, Päivi Jäväjä, firstly for accepting to be my supervisor, regardless of her busy schedule, and secondly for suggesting valuable ideas during coursework's and through all process of making it possible for me to complete my thesis work successfully.

Finally, I want to thank all my friends and family in HTW Berlin and Metropolia University and in my hometown who supported me and gave a broader thinking by making part of their diversified culture.

Metropolia

htw. Hochschule für Technik und Wirtschaft Berlin University of Applied Sciences

International Master of Science in Construction and Real Estate Management
Joint Study Programme of Metropolia Helsinki and HTW Berlin

Date:

Conceptual Formulation

Master Thesis for Mr. Syed Saqiful Hassan

Student number 552972

Topic: Evaluating Immersive Virtual Reality Environment for Facility Management Planning

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The thesis is part of HTW Berlin Master's program of Construction and Real Estate Management.

Immersive Virtual Reality (IVR) has gained widespread attention in the recent years. The use of IVR in the field of AEC is much of interest, as it could be very beneficial to the field. IVR allows computer generated models to simulate on a scale of 1:1 to the brain. It helps the owner, architect, engineer, facility manager and the contractor to visualize the whole project before the actual project starts building, this process allows to identify the problems and decide the best possible solution for the project beforehand.

The focus of the thesis would be study cases where IVR is already used in the AEC and Facility industry and evaluate the processes. The result of the thesis will be finding out how can IVR used in facility management planning and how could it be improved.

The study questions for these thesis is listed below:

1. Is Immersive Virtual Environment, a valuable tool for AEC and FM industry?
2. What are the available Immersive Virtual Environment platform, software and tools for the AEC and FM industry?
3. What is the most viable virtual reality system setup for viewing a model for FM Planning?

The Master's Thesis project will start on 01.03.2017 and will last on 19.07.2017. The thesis will be presented in the colloquium to be decided later.

Signature of the Supervisor

ABSTRACT

With the advancement in the field of Architecture, Engineering and Construction (AEC) and Facility Management (FM) industry, the projects are becoming more and more complex. The data involved in this project are very complex and informative. Building Information Modelling (BIM) deals with the complex data and translate all the information for the human being. According to Salman Azhar, “Building Information Modelling (BIM) is the process by which the computer-generated model could be used and developed to use in planning design, construction and operation of a facility (Azhar, 2011).”

With the advancement of technology 3D models the projects are becoming more complex. They contain a lot of information and data. Converting all this information into a 2D format, and making them understandable to the general population is very limiting. Using Immersive Virtual Reality System, it easily possible to change the outcomes of the information exchange. “Immersive Virtual Reality (IVR) is a technology which allows the participants to immerse themselves to artificial environment and be a part of the environment as they would have been in real life (KUNCHAM, 2013).” For the professional related AEC and FM industry, it will be better to understand the project they are building and operating.

The aim of this thesis paper is to understand how IVR could help facility planning process, how 3D models could be prepared for IVR environment and used in the facility planning. To make this thesis, materials are used are BIM software, game engine, IVR hardware and previous research, publications, AEC journals, articles, software vendor brochure, online magazines and the most important practical experience.

The finding of the thesis will help to develop the role of IVR technology in the AEC and FM industry using BIMs.

Key words: BIM, IVR, Facility Planning, Unity 3D, File format, HTC Vive

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LIST OF ABBREVIATIONS

AEC – Architecture, Engineering & Construction

AECO – Architecture, Engineering, Construction & Operation

AR – Augmented Reality

ARL – Applied Research Lab

BIM – Building Information Model

CAD – Computer Aided Design

CAFM – Computer Aided Facility Management

CAVE – Cave Automatic Virtual Environment

CMMS – Computerized Maintenance Management Systems

EAM – Enterprise Asset Management

ERP – Enterprise Resource Planning

FBX – Filmbox

FM – Facility Management

FOV – Field of View

GPS – Global Positioning System

HMD – Head Mounted Display

IFMA – International Facility Management Association

IFC – Industry Foundation Classes

IVE – Immersive Virtual Environment

IVR – Immersive Virtual Reality

IWMS – Integrated Workplace Management System

LOD – Level of Detail

OLED – Organic Light Emitting Diode

PC – Personal Computer

VE – Virtual Environment

VR – Virtual Reality

VRML – Virtual Reality Modeling Language

1 INTRODUCTION

In the recent year, the Architecture, Engineering and Construction (AEC) and Facility Management (FM) industry the projects have become complex. the industry has always labelled as a low-technology and inefficient industry with low productivity. One of the reasons to blame for this low productivity could be the inherent waste in the construction delivery process (Atul Khanzode, 2006). It is believed that the waste is the direct result of technological interoperability between the parties involved. Due to the technological deficiency, the information related to complex project get misinterpreted or lost. For this a much of research in the current time has been focusing on developing the visualization techniques that will improve the communication of the project information.

Building Information Modeling (BIM) is a developing technology, which process the complex data utilizing a 3-Dimensional graphical representation to improve communication, collaboration and data exchange. According to Salman Azhar, "Building Information Modelling (BIM) is the process by which the computer-generated model could be used and developed to use in planning design, construction and operation of a facility (Azhar, 2011)." BIM model allows the visualize, do engineering analysis, conflict analysis, code criteria checking, cost engineering, as-built product, budgeting and many other purposes. Several studies have proved that BIM is able to improve the interoperability of information, productivity and efficiency in the AEC and FM industry. BIM allows to reduce the errors in design and construction, increase the collaboration between the project teams and help to reduce the project time and cost. The information generated by BIM helps to form reliable decisions in every stages of facility life-cycle, starting from inception to operations of the facility.

Immersive Virtual Reality (IVR) is an advancement in technology which uses 3D graphical representation and the surrounding environment to enhance and achieve higher level of understanding. The environment that is experienced is created by computer granted model and through technological hardware. "Immersive Virtual Reality (IVR) is a technology which allows the participants to immerse themselves to artificial environment and be a part of the environment as they would have been in real life (KUNCHAM, 2013).” The enhanced understanding allows the user to get a better information and deeper understanding about the space and engineering equipment of the facility. The immersive virtual reality could be categorized into three categories: full immersive, semi-immersive or non-immersive. the category depends on the level of user impressiveness into the virtual world and the immersive could be controlled by computer software and hardware.

- Full – Immersive: Computer Automatic Virtual Environment (CAVE)s.
- Semi – Immersive: Head-mounted Display Unit.
- Non – Immersive: Computer Screens.

According to many research, the use of immersive visualization systems in the AEC industry to improve and communication and reduce error. The technology helps to benefits in facility design and construction management. One of most important benefit is improving the understanding and communications between the participants of the project. Immersive virtual environment allows the participant to immerse themselves in virtual facility prototype in human-scale and ability to interactive with the models.

With the improvement of technology, the researcher is examining the involvement of BIM technology in the immersive virtual environment. The AEC and FM industry, uses both the technology for the project participants to understand and gain better sense of presence with the 3D or 4D model. it will allow participant to understand the information related with the project and equipment’s and improve the design or input in the design or construction planning of the facility. Also, it will able to get training in the construction process of a facility, which will improve the safety of the construction.

The main aim of this research is focused the understanding and studying the process of preparing an Immersive Virtual Reality model created from BIM software’s like, Autodesk Revit, Realwork and Recap. This study will concentrate on the models that were converted through Revit, scanned building model using drone and 3D scanner. For this reason, a case study project was selected, which will provide with the data for the research. It will allow to understand benefits and limitation of the current workflow for IVE in the AEC and FM industry. Get an understanding on the available software and tools. And how it helps in the planning process.

1.1 Research Motivation

The main motivation of this research is to investigate the process to transfer BIM model into Immersive Virtual Reality Model.

HTW Berlin, is conducting research on developing BIM model from the perspective of Facility Management. The research project duration is from 2016 to 2018 and include two building in Berlin:

- Farbandu Haus
- St Hedwig Hosipital

As part of the research, scan technology is investigated to prepare BIM models of the buildings. Purpose of the research is to find a suitable workflow to transfer the models prepared by HTW Berlin research, into IVR environment. A case study, building in HTW Berlin campus, was used to test the scanning and modelling technology. That case study building is also used in this research.

Ultimately, this research will help to facilitate an immersive virtual reality environment for the two building of the HTW research and used as a useful tool in the facility management of the buildings.

1.2 Research Problem & Question

The Architecture, Engineering, Construction and Operation (AECO) companies uses different kind of commercial software packages like, ArchiCAD, Autodesk Revit, Naviswork, Sketchup or Autodesk AutoCAD to implement BIM. Typically, the file format of this kind of software packages also varies like, RVT, NWC, NWD, IFC or DWG, containing parametric digital models. On the other hand, immersive virtual reality systems use typically the game engines like Unity 3D or Unreal, among many other software and their formats are different like Virtual Reality Modeling Language (VRML), FBX or X3D. therefore, to represent the building information modelling into IVR environment it is necessary to convert the models into VRML, FBX or X3D format. It is not possible to store all the information developed by BIM application vendors into the building information model of IVR environment. The workflow for the conversion varies, as it is still a developing field. Normally it is a time-consuming process, which result in loss of information in the model. Normally we see only the geometry information surviving the process. This problem that has been indicated as limitation into the research and modernization of AECO industry.

Also, as stated before IVR is still a developing industry, a much research is needed in the field. It is still needed to research how this technology can help to modernize and develop the AECO industry. What are the tools that are needed to be used which could stream line the construction industry, minimize the cost and improve the safety.

The research questions for this thesis are listed below:

1. Is Immersive Virtual Reality Environment (IVR), a valuable tool for AEC and FM industry?
2. What are the available Immersive Virtual Environment platform, software and tools for the AEC and FM industry?
3. What is the most viable virtual reality system setup for viewing a BIM model for facility planning?

1.3 Thesis Methodology

This thesis contains 7 chapters. **Chapter 1**, provides the introduction to the research topic. It explains the problem faced using IVR environment in the AECO industry, research questions and the motivation for the research questions.

Chapter 2, contain review of BIM its use in the AEC and facility planning process. This chapter was focused to understand BIM development in AECO industry. How BIM data and 3D models are used in IVR technology

Chapter 3, provide information about the Immersive Virtual Reality Environment. The characteristic, how they could be used in the AEC and FM industry. Also, it provides information about the industry used software and hardware. It helped to understand and develop the workflow for preparing the field test.

Chapter 4, introduce the workflow used for the demonstration of the research. It provides in depth knowledge about the software used, and the file format supported by them. Also, introduce HTC Vive, the hardware used for the research, its characterises.

Chapter 5, explains the steps followed in the development of the suggested IVR model in detail.

Chapter 6, describe the limitation and problems faced while developing the model. And recommendation for future development of the process.

Chapter 7, discusses the summary made from the research. Provides the benefits of IVR environment model in the AEC and FM planning. Provide the answers for the research questions.

The Figure 1, shows the process mapping of the research and connection between the chapters and how the information from the chapters helped to derive the conclusion and recommendation of the research.

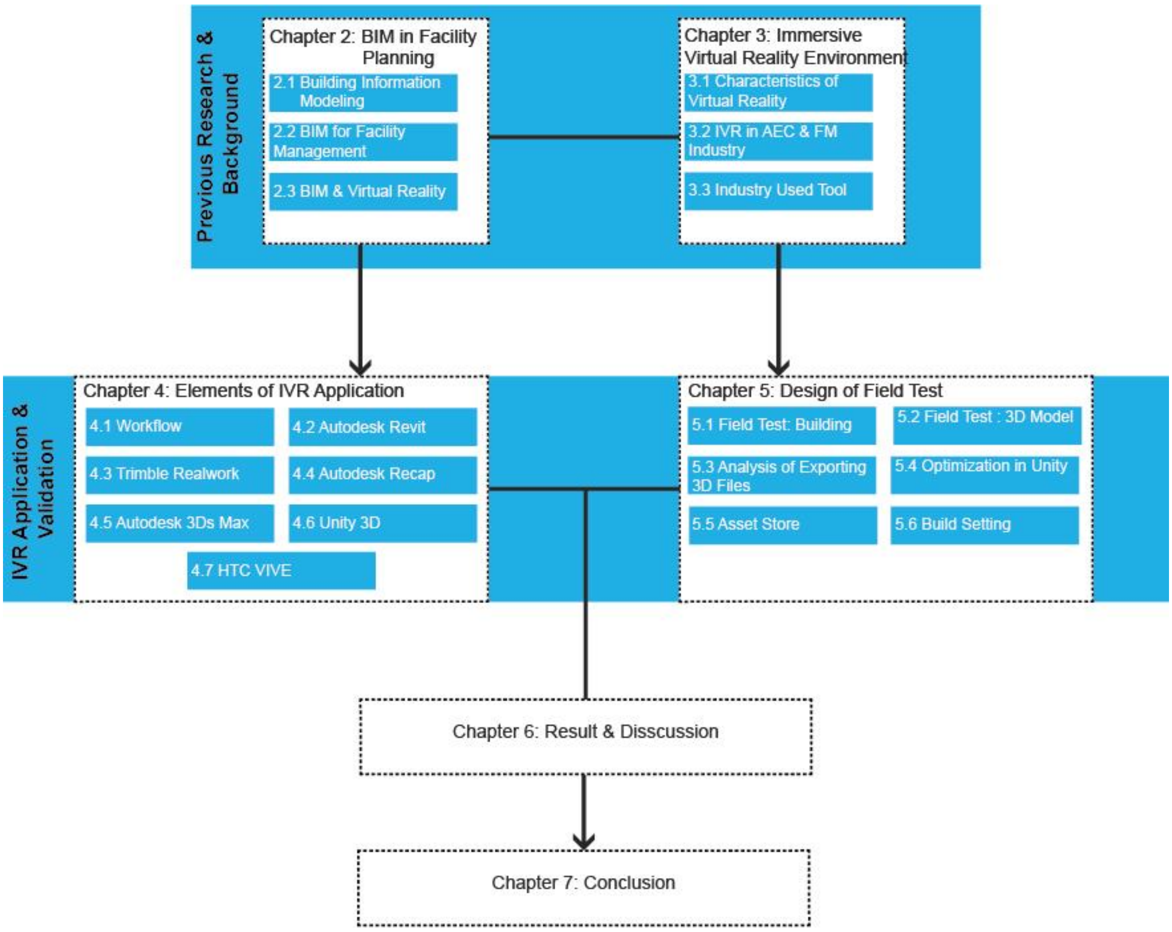


Figure 1: Process mapping of research method

2 BIM FOR FM PLANNING

BIM is important aspect of the AEC industry, it is used to prepare model which contain both geometric and alpha numeric data. To understand better about the use of IVR and prepare the IVR models specific to the industry, this chapter was used to understand BIM in the field and how IVR are used with BIM in the current industry.

2.1 Building Information Modeling (BIM)

Building information modeling is a technology, that has been gaining rapid acceptance in the architecture, engineering and construction (AEC) industry. It is a software technology that allows to represent the three-dimensional building, with database capabilities for the data of the building.

“BIM contain building geometry, with structured information base of nongraphic data which provide information about the building components (Paul Teicholz, 2013).” Benefits of using BIM all objects have life like identity and attributes, for example wall is identified as wall, boiler as boiler. computer-aided design (CAD), an industry software used for drawing and documenting, the difference is the unavailability of database of the information and attributes of the building.

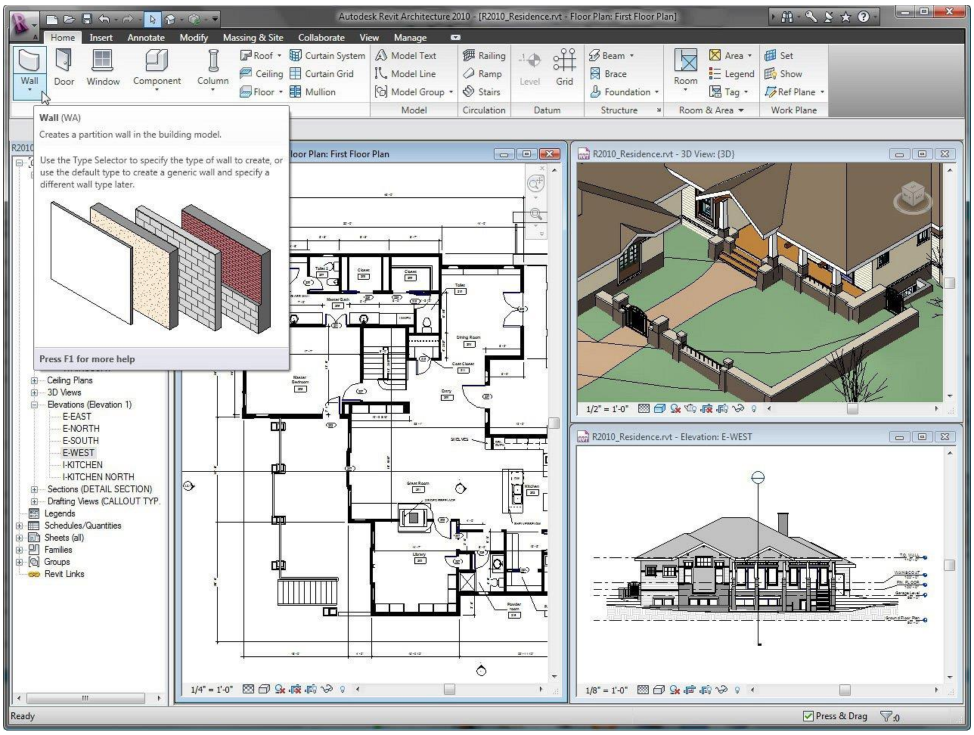


Figure 2: Building Information Model (BIM) - Autodesk REVIT

Compared to traditional applications BIM is a data application, which contain the ability to associate data with the objects in the model. Because of this ability, BIM can facilitate a wide range of capabilities, that include quantity take-off, cost estimation, space and assets management, energy analysis and many other activities.

As result of the abilities BIM is a powerful tool which can support the project delivery and make the process more integrated and efficient. It has been seen BIM as a data application has the capability to reduce cost and promote efficiencies in AEC projects. Below are given the ways, BIM promote efficiencies and cost reduction in projects (Paul Teicholz, 2013):

- **Early Decision:** BIM as an application allow to evaluate a building performance at an earlier stage, which allow to have a decisions and changes with less impact on the cost and time of the project.
- **Improved Accuracy:** BIM allows more effective communication between the parties involved in the project. This helps to reduce the errors and changes during the design and construction process.
- **Rapid Quantification:** BIM model can automatically generate quantities and data, which allows to produce estimate and workflow more efficiently and quickly than the traditional process.
- **Robust Analytics:** BIM software allows complex analysis, which include clash detection, scheduling and sequencing and energy analysis. Which helps in the prompt decision making and resolve issues and reduce delays in projects.
- **Improved Coordination:** BIM allows multiple parties involved in a project to virtually construct the building, identify clashes in the building system. This was not a possibility with CAD, as a result this reduce the costly changes in the projects.
- **Improved Project Delivery:** BIM allows to deliver a complete and structured data for the project.

2.2 BIM for Facility Management (FM)

BIM is a powerful tool for design and construction in the AEC industry and it has been used in the industry for a quite some time. Though the data used in design and construction phase is very important for FM sector, the use of BIM in the industry is still on the early phases. There is not much of “best practice” scenario for BIM in the FM sector. According to International Facility Management Association (IFMA) the use of BIM depends on the organization, their mission and requirement of the facility they are supporting (Paul Teicholz, 2013). The data required for the FM depends on the typology of the facility and the organizations. There is a wide variety of data system for FM and some of them are:

- Computer-Aided Facility Management (CAFM).
- Integrated Workplace Management System (IWMS).
- Computerized Maintenance Management Systems (CMMS).
- Enterprise Resource Planning (ERP).
- Enterprise Asset Management (EAM).

BIM can use the data for life-cycle management of a building and the physical assets involved in them. The technology allows the owner and the facility manager of the facility to retrieve accurate information through virtual model of the physical facility. This helps the individual involved in FM, who might not be typically trained in drawings and documentation of a projects. The advantages of BIM for FM include (Paul Teicholz, 2013):

- Centralized Information Base
- Support for Analysis
- Location Information for Equipment, Fixture and Furnishings
- Support for Emergency Response and Security Management and Planning.

BIM applications are not yet specifically developed to support FM industry but it can facilitate to support the building life cycle requirements. According to Paul, they might include (Paul Teicholz, 2013):

- **BIM templets for efficient project development:** with the help of well-developed industry standard, it is possible to insert project-specific data into the building information models, which will specify the specific space and assets requirements.

- **Regularized project delivery:** Systems could be developed with could incorporate organizational data, which in future will support facility management data needs after the projects would be completed.
- **Space Management:** BIM can allow space management requirements and space measurement rules. It could be automated to check the capacity of spaces. Also, it allows display of space, which support better management and communications of space for the FM team.
- **Visualization.** BIM allows power visualization of the model, with capabilities like showing potential changes over time. Which allows the user to communicate critical building issues. Also, it allows clash detection, rules checking and validation, change tracking over time and dynamic walkthroughs.
- **Energy and sustainability management:** energy and sustainability is a critical issue for the FM managers. It does not only allow the facility to have a cost effective operational, also allows to achieve certifications. BIM could support this process by in-operation simulations and help to analyse the effects of changes, renovations or retrofits.
- **Emergency management/security:** as stated before BIM allow a three-dimensional representation of a building, this could help to analyse and plan emergency requirements and security measures.
- **Display of real-time data:** with the help of modern technology it is possible to incorporate real-time data from the sensors into BIM (for example light level, temperature readings). This type of technology allows the analysis and feedback of the facility in a three-dimensional visual form.

The information for FM BIM is immense, it will need to integrate not only design and construction data, but also information on existing facility, geographic information system, building automation system and mode.

Recently there has been a great deal of study in the need for capturing information on existing facilities. Laser scanning is one of the developing technology in this field and very useful to the FM industry. It allows to capture the physical geometries of existing building as a data file called point clouds. With the help of software, the points generated from the laser scans can generate surface and objects. Which helps to generate a three-dimensional model very easily. With the help of this technology it is easily possible to capture complex geometries, piping system and mechanical equipment's and other as – built data. Though it is a complex and still in development process. For the research point cloud is a crucial step for generating 3D models, and transforming the model intso VR environment, which allow facility planners to work on the existing buildings. Detail description of point cloud and the process for generating the data into 3D model are given in the Chapter 5.2.

Figure 3: Laser Scanner

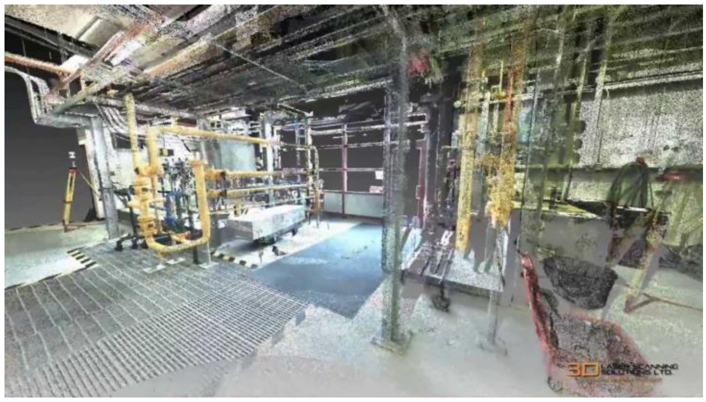


Figure 4: Point Cloud Data

2.3 BIM & Virtual Reality

Virtual Reality (VR) uses computer simulation to depict built real environment. With the help of headsets, BIM CAVEs and googles it allows to walk through the 3D virtual environment, also data from the real world could be imposed into the real-life scene.

With the rapid development in the VR and AR industry, the cost of the hardware has reduced and the uses of this technology has been introducing to the AEC and FM industry. Though, the technology is still in the development stage. This allows to view and understand the 3D data very easily and interactively.

Most of the majority of BIM authoring tools support Industry Foundation Classes (buildingSMART, 2007). IFC is the standard for representing BIM, it allows information sharing for the whole building life cycle. This format differs generally from the 3D file formats, such as 3D studio, FBX and others.

These kinds of technology allow to use the BIM data and review building related information, for instance energy use data, duct and piping work. It also allows to infrastructure information, which is very difficult to comprehend on a computer or printout format. It allows to inspect room to see the placement and condition of assets, with their generic information. As the technology is developing and the use of the technology is being introduced in the industry the possibilities and benefits is increasing.

BIM in the AEC field allows to use single source of data for 2D-drawings, offline renderings as well as real time renderings and VR. In theory, it should make easier to interacted VR visualization as a planning, design and communication tool during the design and planning process. But, this development has led to new sets of challenges. BIMs are normally too large and complex to be directly used as VR or real-time rendering (Dalton, 2013). For this normally there are optimization step to make the dataset more suitable for use in the IVR environment. But this is a step that is required every time the design changes, which affects the efficiency of the tool.

Gaming tools are used to produce immersive visualization from the BIMs, but they require a lot of manual work for the visualization to be realized. Couple of workflow for BIM to VR is described in chapter 4.1, with a streamline process, but still it requires a lot of time and that depends on the size and complexity of the BIM and visualization.

In the same time, we are seeing BIMs to become more details in terms of geometry and number of objects. Also, we are seeing in the IVR sector new hardware and software with higher performance. The interactivity and real-time performance in the planning and design process is important. With the development in the field a solution could be reached for this.

3 IMMERSIVE VIRTUAL REALITY ENVIRONMENT

Virtual Reality (VR) is a computer-generated environment. VR allows the user to immerse themselves inside an artificial world created by the computer, with the help of all the sensation and illusions (Fadi Castronovo, 2013). The history of VR starts in the World War II, VR was developed from the flight simulation during that time and computer graphics research during 1960s. but up until mid-1990s, VR was not researched in the field of AEC industry. with the development in the computer technology, it easy to create VR environment.

VR, allows to visualize substantial amounts of complex information, in a Virtual Environment (VE). In contrast to traditional 3D system, there is limitations in understanding the complex environment and information. As VR is a technology that gives the sensation of inside artificial environment, it is some time referred to immersive technology. According to Cummings, level of immersion with which could be also explained, with level of sensory fidelity, depends greatly on field of view (FOV), stereoscopy, display resolution, head-tracking or input device (James J. Cummings, 2012).

From the use of VR in flight simulators to train the pilots, different use of VR has been explored. For example, it is used the manufacturing industry for virtual prototyping, which allow to evaluate the products and the machinery, also it is used in the medicine for complex experiment and medical procedures.

This chapter allowed to understand IVR technology. The software and hardware part of the technology. The knowledge from the hardware and software industry were used to develop the IVR models.

3.1 Characteristics of Virtual Reality

VR Technology, utilize the user’s field of view and simulation of depth to represent the information and able to interact in an immersive environment at a human scale. According to Cummings, level of immersion with which could be also explained, with level of sensory fidelity, depends greatly on field of view (FOV), stereoscopy, display resolution, head-tracking or input device (James J. Cummings, 2012).

VR system could be categorized into different level, according to the level of immersion it provides. According to Nseir three categories include: non-immersive, semi-immersive and immersive (NSEIR, 2011).

- **Non-Immersive VR system**: it consists of three-dimensional environment, which could be views through graphics monitor and could be navigated and controlled by mouse. With the help of stereo glass and stereo projection, the environment could be viewed stereo. Low cost and portability are the biggest advantages against another VR system. Though there are lot of limitations in Desktop VR system, for example it lacks the total immersion in vertical spaces.
- **Semi-Immersive VR System**: Projection-based VR systems are usually referred to semi-immersive VR system. It provides partial immersive VR system. Semi-Immersive VR system consists of several projects and large screens. it provides wider field of view then Non-Immersive VR system and due to this the sense of immersion is greater than Desktop VR.
- **Fully Immersive VR System**: It provides the uses with a 360-full view of the virtual environment. With the help of Head-mounted system (HMD), it is possible to achieve the fully immersive VR system. Cave Automatic Virtual Environment (CAVE) is another way to achieve fully immersive VR system. The VR system provide full scale reproduction of the artificial three-dimensional work. as the perspective of the user changes wherever the user is looking, it gives a full sense of immersion.

3.2 Immersive Virtual Reality in AEC & FM Industry.

VR technology is a great benefit to the AEC and FM industry. “With the help of this technology it is possible to improve the efficiency and effectiveness of the industry (NSEIR, 2011).” It is possible to implement into all stages of construction project, from planning to detail design, preparation, construction completion to facility management. In the design and planning phase of project it is possible to review the design and get a better understanding of the design, check the constructability of the project, minimize changes and additional work prior to the construction and during the running of the facility.

Jennifer Whyte from Business School at Imperial College London, performed a research during 2002, on industrial application of VR in the AEC industry in USA and UK. The research was carried out into eleven companies, which were using virtual reality technology. The objective of the research was to identify the strategies, business idea behind the implementation. According to the research, the business objective was to display the technical information, design reive, simulating dynamic operation of the facility, coordination of detail design, scheduling of construction and marketing. Marketing is one of the driver behind the use of VR in the industry.

During 1994, a research was carried out by C. Bridgewater in implementation of virtual reality in collaborative scheduling process. The research developed list of fields were the VR for the construction projects could be used. The detailed list of VR use in the AEC, are given in the Table 1:

Area	**Potential Application**
Site Operation	• Rehearsing erection sequences • Planning lifting operation • Progress and monitoring • Communications • Inspection and maintenance • Safety training and skills
Office Automation	• Tele conference • Project review and evaluation • Project Documentation • Marketing
Design Phases	• Preliminary and detailed design • Lighting and ventilation simulations • Data exchange • File/safety/access assessment • Scheduling and progress reviews
Special Area	• Nuclear industry • Subsea inspections and work • Near space operations • Micro inspection and testing

Table 1: Potential Application of VR in Construction (Bridgewater, 1994)

VR in the field of education of the industry also has been proven to be of great benefit. Construction is very time consuming and visual based education. traditional education system of architecture and construction rely on 2-dimensional information, this type of information is difficult to understand. In 2002, Professor Kalisperis, carried out a research in the Department of Architecture at Pennsylvania State University, in the use of immersive virtual reality environment in architectural education. VR-Desktop was introduced in the second-year design studio. The student could work on immersive environment, validate conceptual details in the virtual space. According to the study, “the thirty-five-student showed more understanding to the designed spaces and process, there were less interpretation than the traditional techniques (KALISPERIS Loukas N., 2002).”

Technical Research Centre of Finland (VTT) and the National Research and Development Centre for Welfare and Health (STAKES), jointly carried out a project called ‘User-Oriented Hospital Space (HospiTool)’. HospiTool, is a project that developed tools which allowed the end-user to participate in the planning and evaluation of hospital spaces. This tool allowed the user to match the space with user requirements. the 3D model of the hospital was used in Computer Aided Virtual Environment (CAVE) and Lumeviewer developed by VTT. Selection of patients and nurses could view and have a walk through the model in the CAVE. The main idea of the walkthrough was for the user to express the user’s idea about the patient’s room and working area in the hospital. The important aspects of the experiments remained to concentrate on features like the room size, window placement, functionality in general. CAVE allowed the non-technical users a better understanding of the space, then in the traditional form of drawings. According to Porkka of VTT, “the project allowed the planner and designers a better understanding of the user experience (E. Nykänen, 2008).”

Applied Research Lab (ARL) of Pennsylvania State University, conducted one study to determine the use of full scale virtual model of a nuclear plant in IVE, to help in reducing the cost of the construction and maintenance of the facility. The experiment used the CAVE like environment, which generated 3D stereoscopic views on the four walls and floors and which allowed the user to immerse themselves in the model. the 3D model was generated from the 3D CAD and then converted into VRML format. The experiment allowed the user to develop a construction schedule, by using the IVE. The study found that 25% of the scheduled time could be reduced using the IVE over traditional methods, which in return reduce the cost of the construction (V. E. WHISKER, 2003).

3.3 Industry Used Tools

Virtual Reality technology is a large computer-generated environment, it uses high-tech information technology to create this environment. It uses both hardware and software technology to create the environment and involve the AEC and FM industry. The hardware normally contains Immersive Virtual Environment (IVE) display system and computer with high graphic processing power. The software normally uses three-dimensional technology from game design and development to develop IVE. The Figure 5 shows VR platforms according to The VRAR Association:

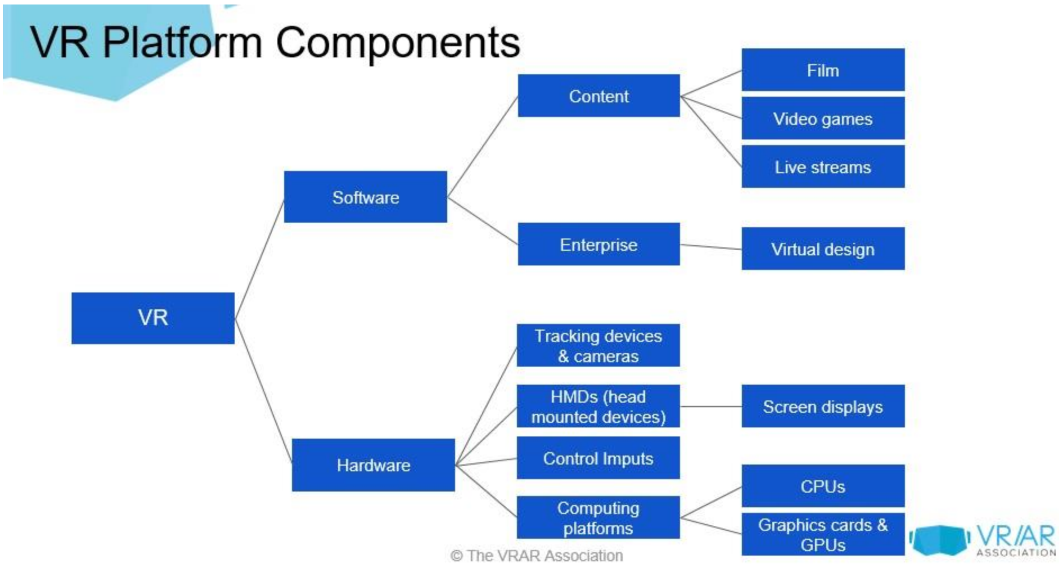


Figure 5: VR Platform Components (The VRAR Association, 2016)

This section will contain information about both hardware and software that are available in the market for Immersive Virtual Environment.

3.3.1 Hardware Platform

IVE, uses computer keyboard, mouse, special helmet, interactive display system and interactive sensing devices to interact into the environment. AEC and FM industry can use this technology to interact with the environment to understand the project or building. The technology for VR is though still at the development phase, it has not reached to its full potential. There are several core technologies, which is used by VR, they are:

Cave Automatic Virtual Environment (CAVE) – CAVE was first introduced in 1992 ACM SIGGRAPH convention, it was created by Electronic Visualization Laboratory at the University of Illinois in Chicago. It uses projection technology, it uses three vertical walls with rear-projected stereo displays (Cruz-Neira, 1992). Also, there is a fourth projector, projecting toward the floor, which allow improved environment.

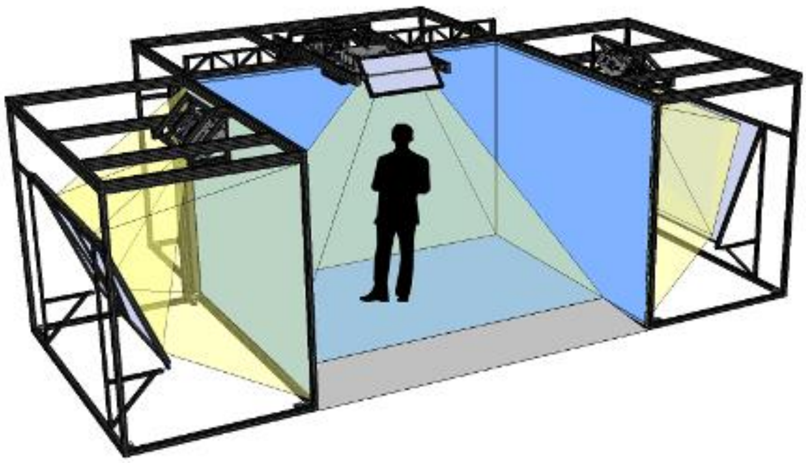


Figure 6: Cave Automatic Virtual Environment

A typical CAVE set up includes (Virtual Reality Society, 2017):

- Rear projection wall
- Down projection floor
- Speakers at different angles
- Tracking sensors in the walls
- Sound/music
- Video

According to Robert, CAVE has few characteristics (Kenyon, 1995):

- Multi-person Virtual Environment

- Wide field-of-view
- Inside-out surround 3-D video presentation
- Off axis stereo projection
- Head and hand-tracked user interaction
- 3-D Audio
- Expensive

Head Mounted Display (HMD) – Head Mounted Display, was first developed during 1968. HMD is an interactive device that allow to navigate through the virtual environment. Also, HMD could be used for Augmented Environment. HMD uses tracking to track the movement of the user and centre the perspective of the environment to the user (Tara Nees, n.d.). one of the problem with HMD is person without the tracking sensor can only see the image in distorted view, therefor HMD allow to experience the IVE for one person at a time. With the advance of mobile and HMD technology, it is also possible to view models or IVE using the mobile instead of high-power computer system.

Figure 7: VR HMD with Mobile

Initially HMD, was used by the military and aerospace industry, but with the introduction in the game industry, the consumer market has picked up the technology. The market share of HMD has been increasing in an exponential level, an analysis shows that is the Figure 8 below. The rapid adaptation of HMD by the technology, shows the use also has been increasing in the AEC and FM industry. It is very economical way to experience the three-dimensional system in a Virtual Environment compared to CAVE system.

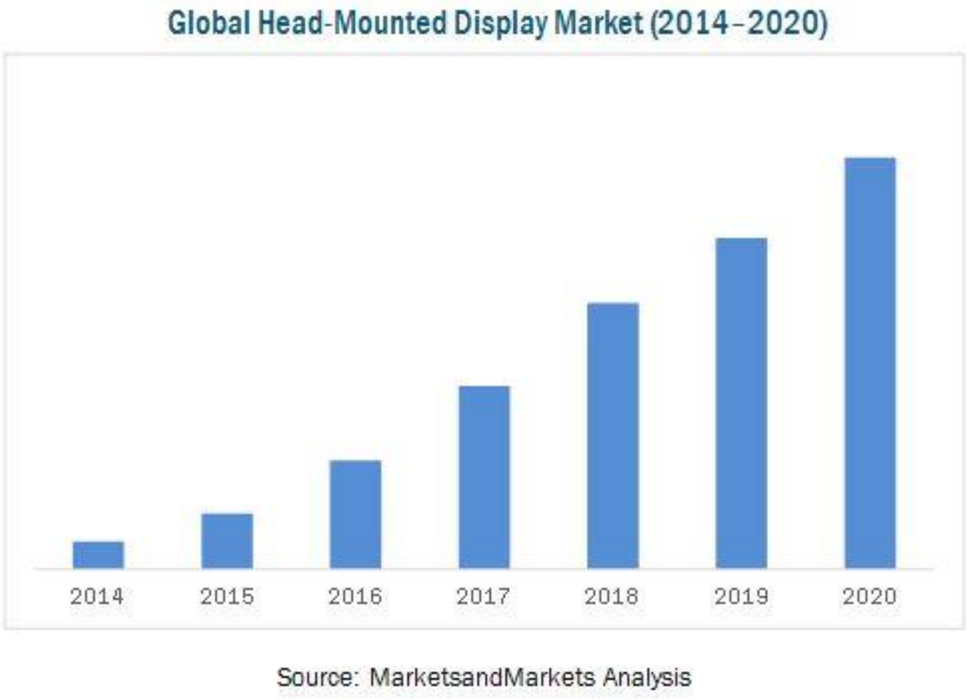


Figure 8: Market Share Analysis

3.3.2 Software Platform

Immersive Virtual Environment is created by three-dimensional modelling software, e.g. 3D Studio Max, Navisworks, AutoCAD etc. Also, gaming technology plays a significant role in developing software for 3D modelling technology with the capability of VR reality. For example, Unity 3D and Unreal Engine is a very common platform in the gaming industry, that support the VR technologies natively. Also, this software allows to buy already built asset for the IV environment.

4 ELEMENTS OF IMMERSIVE VIRTUAL REALITY APPLICATIONS

3D model in the construction industry is created using BIM software like Autodesk Revit©, ArchiCAD and many other software like it or 3D graphical software like Autodesk 3Ds Max. once the model has been created different game engines like Unity or Unreal is used to convert the models into 3D environments. This chapter allows us to study the workflow and the tools used for the development of the models.

4.1 Workflow

One of the objective of the research is to conduct research to determine process needed for BIM model to be converted into virtual world for the facility planning and construction purposes, identify the challenges and recommend defining a more efficient work flow. The research included examining the effects of model sizes, formats and its granularity on time efficiency for the BIM to virtual world process.

Due to large amount of information contained within BIM it is an excellent candidate for importing into game engines to construct realistic virtual environments. However, it is not always a straightforward process, requiring several steps and can vary depending on the use, format and size of the native files.

For this research, a BIM model of a service building of HTW Wilhelminenhof Campus used. The BIM model were created in three different method:

- 3D Scan
- Drone Photogrammetry
- BIM model

Unity 3D software was used for creating VR environment and eventually viewing it via HTC Vive.

After reviewing current literature, three different workflows for converting BIM model into virtual environment was identified (Sutenee Nopachinda, 2016). The three workflows are shown and described below:

Workflow 01: Converting rendered BIM to gaming engine and VR environment.

Workflow 1 shown in Figure 9 consists of importing a BIM model into rendering software before exporting into a game engine and VR software. This is a popular workflow for the BIM model created by many popular software like, Autodesk Revit, Graphisoft ArchiCAD etc.

Figure 9: Workflow 01 - Converting rendered BIM to gaming engine and VR environment

Workflow 02: Directly importing BIM into VR environment via plug-in.

Figure 10, shows workflow 2, which import the BIM model directly into a VR software through commercial plug-ins. The commercial plug-ins are not native of the BIM software. The plug-in takes the BIM model and the view in the software and convert it to a 3D model. Plug-in usually allows navigation in first person or third person perspective.

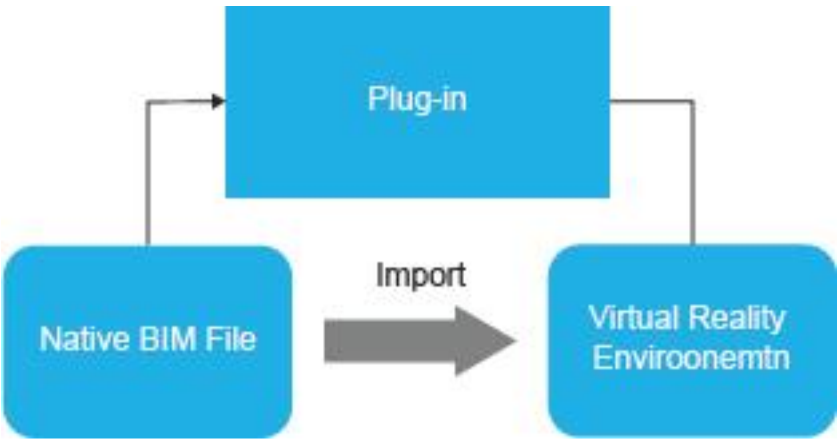


Figure 10: Workflow 02 - Directly importing BIM into VR environment via plug-in

Workflow 03: Importing BIM into gaming engine and VR environment.

Figure 11**,** shows workflow 03, which uses same procedure as workflow 01 but bypassing the rendering step. In this step, the BIM is directly imported into the game engine and to the VR environment.

Figure 11: Workflow 03 - Importing BIM into gaming engine and VR environment

The research, will explore workflow 01 as it is the most popular and most widely used in the industry. As, the research will be conducted with different format of data sources, workflow 01 was further developed with the help of HTW Berlin research shown in Appendix A, which will support all the format sources. The developed workflow is shown in Figure 12:

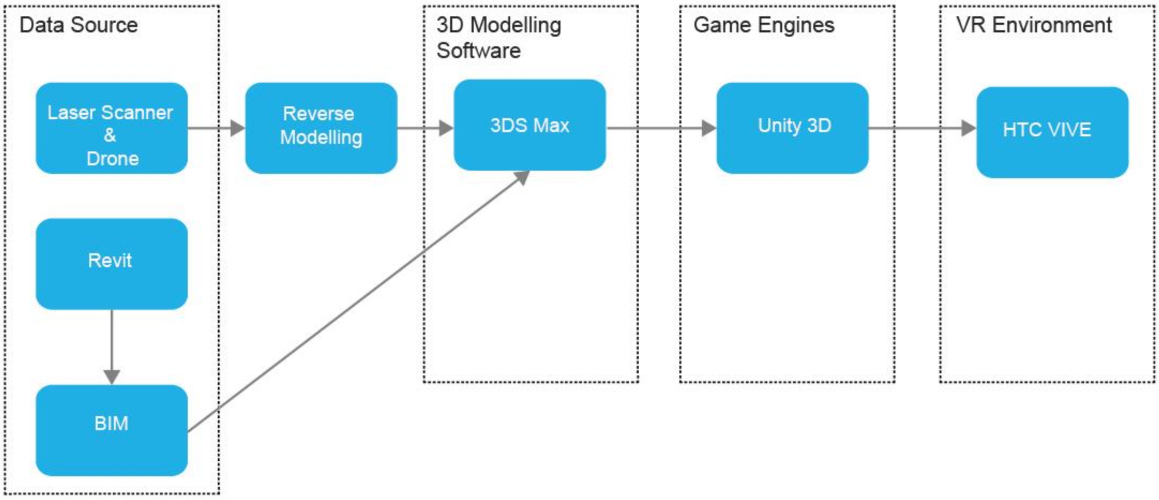


Figure 12: Developed Workflow

The software and tools used for the research following the workflow is described in later part of Chapter 4. Also, the process of workflow in the research is described in Chapter 5.

4.2 Autodesk Revit©

According to Autodesk, Revit© is a platform developed by Autodesk Inc. for building information modelling which is a tool for design and documentation and it support the design, drawings and schedule requirement of the projects (Autodesk, 2010). Revit uses information from a central model database for wall, floor and other elements of a building to represent information in the for the 2D information and 3D information of the project. Benefit of using Revit is the parametric engine, that allow when one information is changed to be represented in all – model views, drawing sheets, schedules, sections, and plans (Autodesk, 2010).

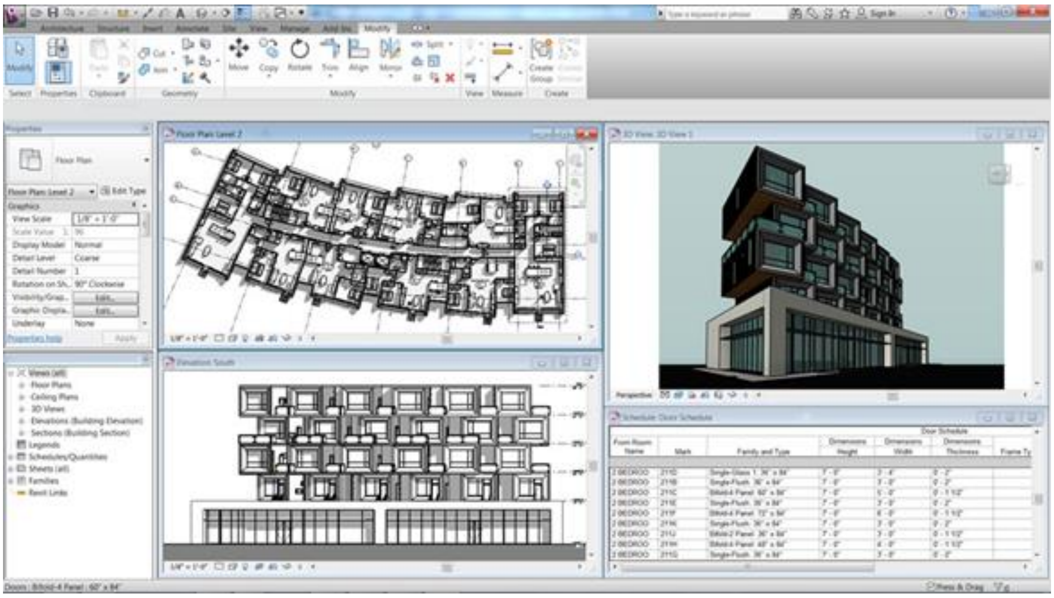


Figure 13: Autodesk Revit

Julia Zolotova of St. Petersburg State Political University, stated in a publication the benefits of using Autodesk Revit©. The benefit list was created, studying the results of tanning of Civil Engineers of St. Petersburg State Political University. The main benefits include (Julia Zolotova, 2015):

- Parametric Ability – Edit one view and automatically change all the views and central database.
- Building Elements database, such as walls, foundation, columns, roofs etc.
- Compatibility with other products.
- Built-in collaboration ability. IFC capability.

The workflow creating a BIM model using Autodesk Revit is shown in Figure 14. Later the process for developing the case study building is shown in sub-chapter 5.2.1.

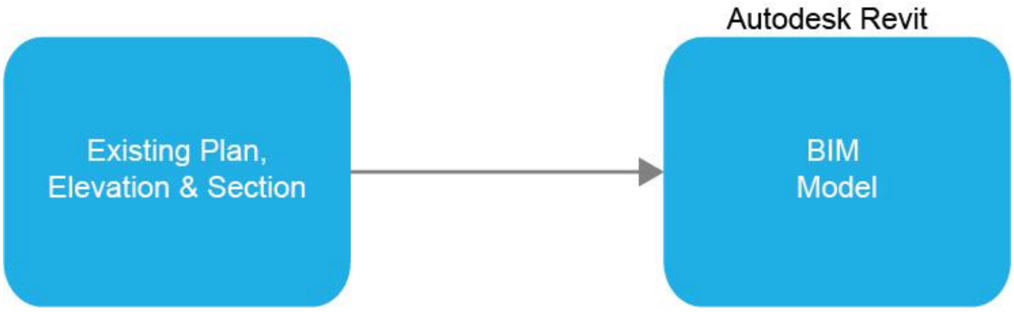


Figure 14: Autodesk Revit Workflow

To prepare BIM of existing building, the information is needed to be collected from the existing plan and elevation and section. Also, during the modelling site picture and information is needed. Depending on the level of model information it is possible to prepare the model. It is possible to also input equipment information into the model which could be used for facility planning and management. This kind of product is called 6D BIM model.

Revit© is a powerful design program, with compatibilities between other similar design program. It allows data to be import/export into different format by saving the model into different formats. For the benefits of the research, the export format of the data in Revit is studied. The default file extension used by Revit© with detail are mentioned in the Table 2:

Format	Data Contained	File Type Specification
.rvt	Revit Project.	3d graphics, CAD-CAM-CAE file type
.rte	Revit Project Templet.	3d graphics, CAD-CAM-CAE file type
.rfa	Revit family data.	3d graphics, CAD-CAM-CAE file type

Table 2: Revit default file extension (Autodesk Inc, 2017)

Revit can work with these files and recognised by this software. Different industry standard of files is also supported by Revit for both export and import, which allow other industry standard software can use. these are show in the Table 3:

Format	Import	Export
DGN	×	×
DWF™	×	×
DWG™	×	×
DXF™	×	×
IFC	×	×
ACIS SAT	×	×
SKP		×
BMP	×	×
PNG	×	×
JPG	×	×
AVI	×	×
PAN	×	
IVR	×	
TGA	×	×
TIFF	×	×
TARGA	×	×
ODBC	×	×
HTML	×	
.TXT	×	×
MBD	×	
XLS	×	
gbXML	×	×
FBX		×
NWC		×
Microsoft® Access		×
Microsoft® Excel		×
Microsoft® SQL Server		×

Table 3: Import/Export REVIT Formats (Autodesk Inc, 2017)

For our research, we focus on the exportation from Revit to Unity, therefore, it is essential to review which formats could be exported. Most generic format that could be exported are:

ACIS (.sat), DXF/DWG (.dxf, .dwg) files, Tif (.tif), FBX (.fbx). detail of the file formats are given below (SANTAMARÍA, 2015):

- ACIS – ACIS allows import or export of body and face colours, curves and wireframe geometry. It is possible to export the entity attribute information of faces and edges to ACIS files. Wireframe is used, while doing geometric modelling system. It allows to understand the shape of the solid objects, with the help of its characteristics lines and points.

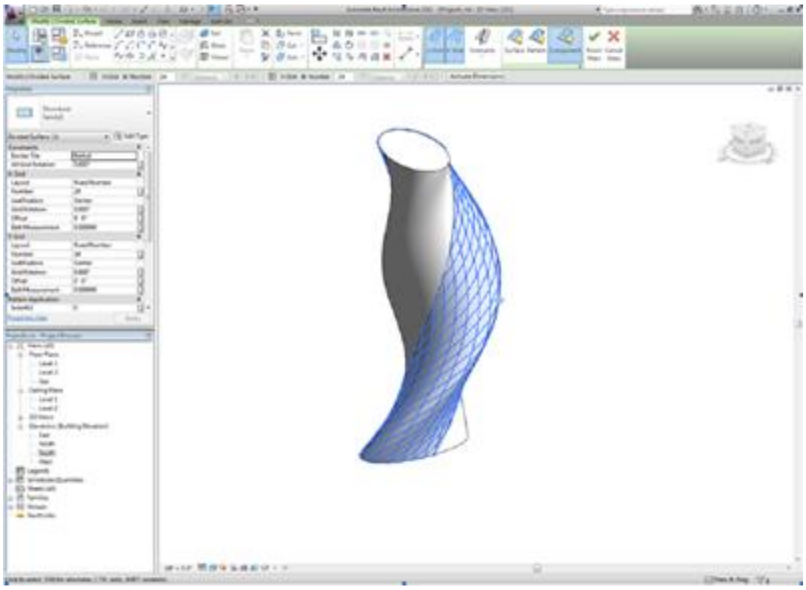


Figure 15: ACIS (.sat) format

- DXF/DWG – Autodesk developed DXF/DWG, which is a Drawing Interchange Format. It is a CAD data file format. It enables data interoperability between AutoCAD native file format.

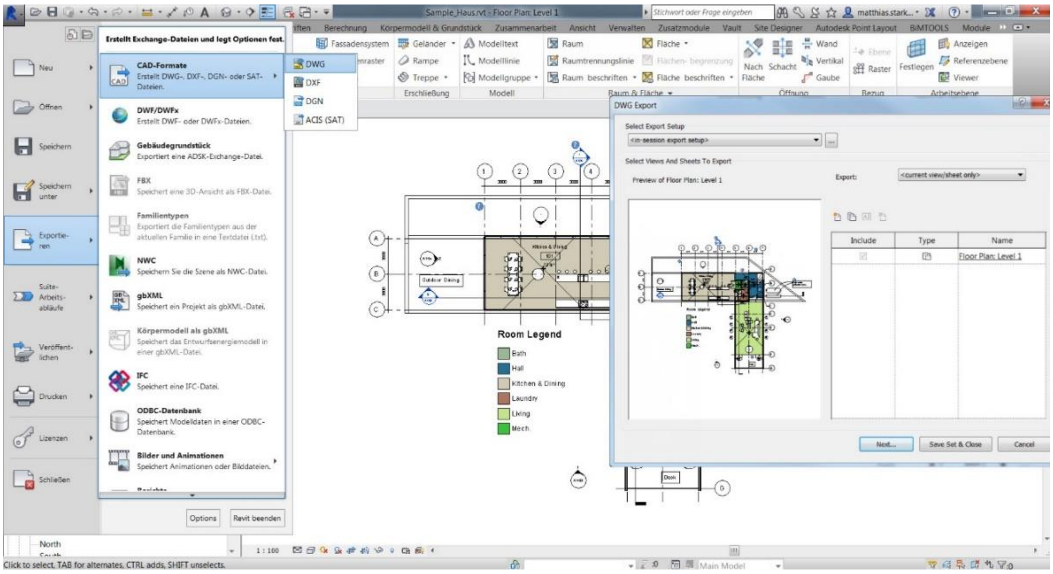


Figure 16: DXF/DWG Format

- Tif – TIFF is computer file format for images, abbreviation: Tagged Image File Format.

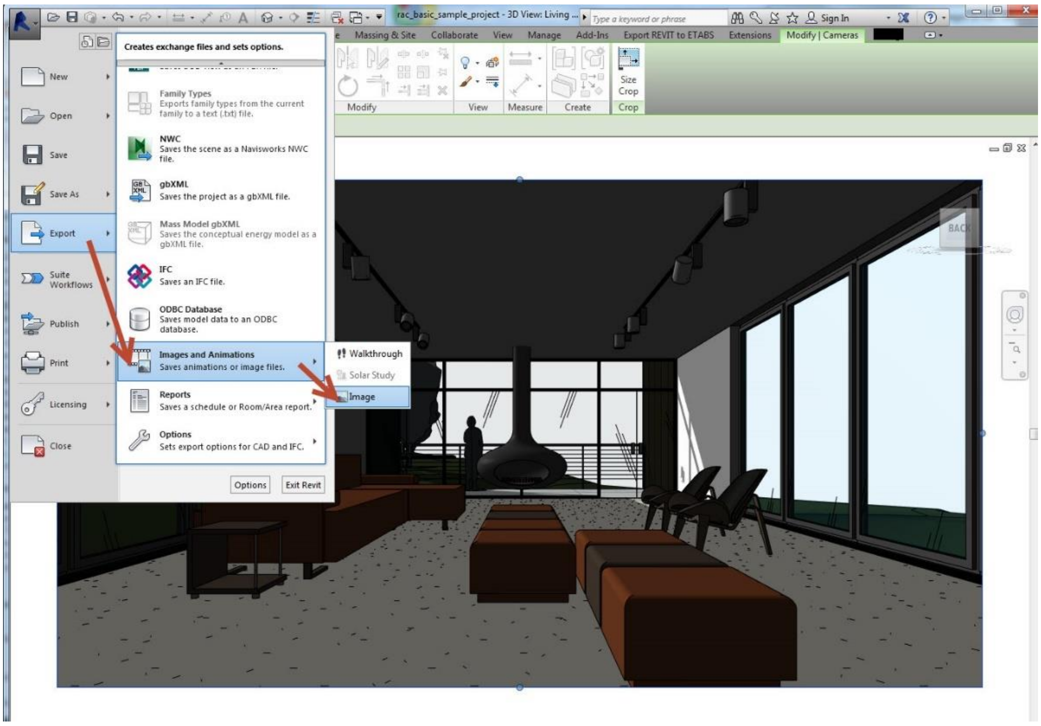


Figure 17: Tif Format

- FBX (.fbx) – is a 3D asset exchange format compatible with many 3D tools.

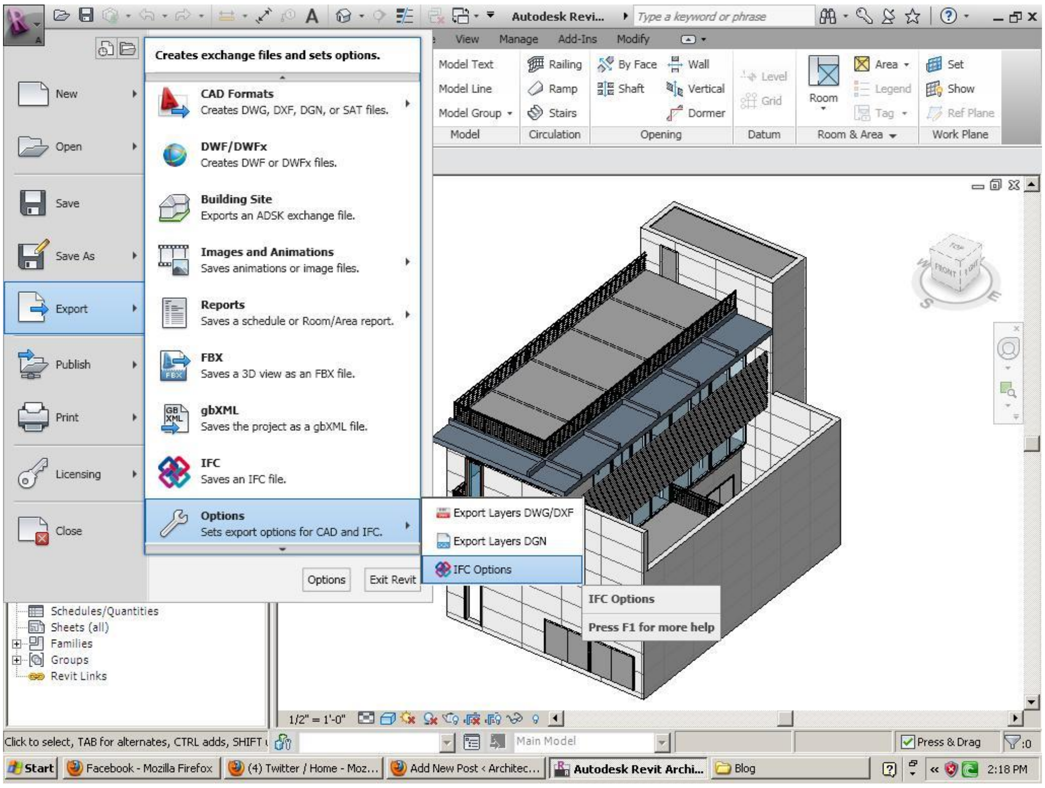


Figure 18: FBX file format

4.3 Trimble Realworks

Part of the research was to convert Building data collected by Trimble 3D Scanner into VR environment. Trimble Realworks were used to develop the point cloud from the 3D scanner into a useable BIM model.

According to Trimble, Realworks is designed and used for point cloud processing and analysis. The software provide solution to efficiently register, analyse, model and create data (Trimble, 2017).

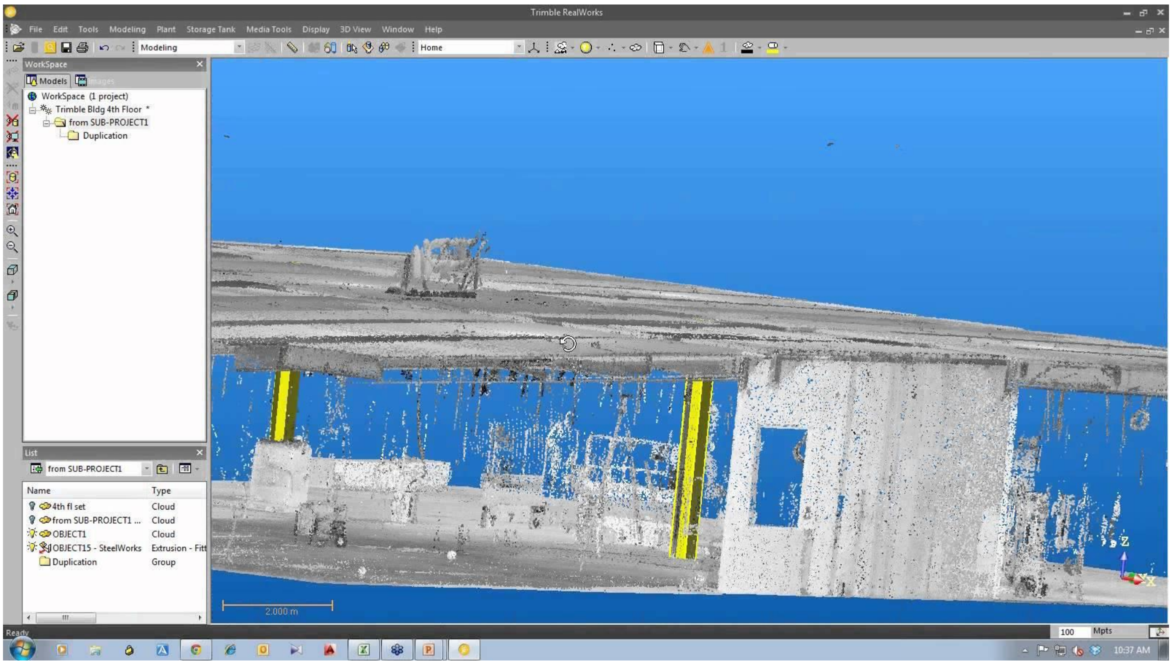


Figure 19: Trimble Realworks

Tasks performed by realworks are (Trimble Inc. , 2006):

- Data Import and Basic Management: Allow standard data management tasks like importing and exporting common data formats. It also, have tools for data visualizations and preparation for export into common CAD applications.
- Data Registration: Tools in Realwork allow to quickly register projects and analyse the results. It has auto-extract targets and register option which speeds up the process. Also, target Analyzer Tool allows to quickly analyse and edit targets.
- Advanced Registration: it allows target-less registration with automatic

registration. Also, it is possible to refine the registration with the tools.

- 2D and 3D Deliverables: the 2D and 3D tools in the software, allows to create: Cross sections, meshes, contours, volumes, line work, ortho-photos, models.
- Advanced 3D Deliverables and Inspection: the tools in Trimble Realworks are ideal for monitoring applications. The deliverables allow richer, more detailed and more helpful information.
- 3D CAD Model Generation: Modelling module allows to create partial or full model very quickly. The software can model diverse shapes to represent the as-built environment using CAD geometries. This allows the analysis of data faster and it is the most efficient way to run simulations.

The workflow for developing a model by scanning and trimble realwork is shown in the Figure 20:

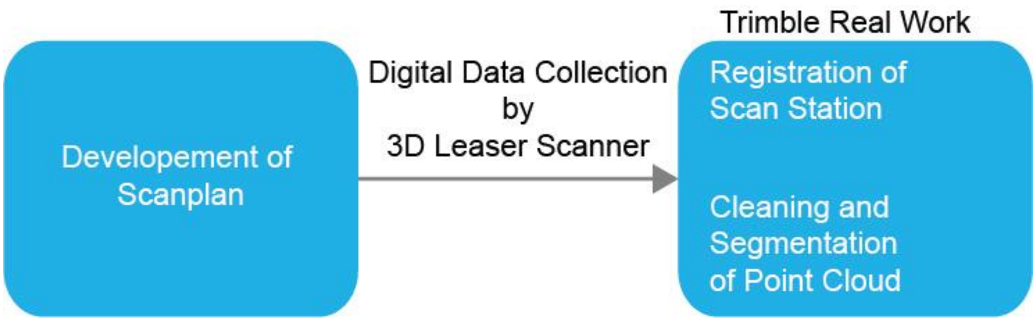


Figure 20: Trimble Realwork Workflow

The workflows show that after developing a scan plan and scanning the building with a 3D scanner the scan data in point cloud format is transferred into trimble realwork software. The point cloud data will have registered according to scan station, the next step would be cleaning the data from any noise like shadows, tree or reflection from glasses. There is an option for segmenting the point cloud or model according to objects too. This process is known as reverse modelling. The process is demonstrated in chapter 5.2.2, with the case study building.

Trimble Realwork is very powerful program, it has compatibility between other AEC programs, like Autodesk Revit, 3Ds Max and other similar programs. It allows export/import into different formats, which allow the data/model to be used with any other software. The Table 4 below shows, the formats which are allowed by software to be exported or imported (Anon., n.d.):

Format	Import	Export
xyz	×	
E57	×	×
PTX	×	×
PTS	×	×
LAS	×	×
LAZ	×	×
ZFS	×	
RSP	×	
FLS	×	
DP	×	
ASC		×
DWG		×
DXF		×
DGN		×
POD		×
TZF		×
BSF		×
KMZ		×
FBX		×
OBJ		×

Table 4: Trimble Realwork File Format (Trimble Inc. , 2006)

As stated from Trimble, the DWG, DXF and DGN are drawing interchange format. The software allows to prepare drawings from the point cloud data, which could be exported into drawing files.

FBX and OBJ, is a file format, which contain the 3 – dimensional information and data. The software can register the point cloud data and create a 3 – Dimensional model, which could be exported into the two-different format. These formats are recognizable by the Unity 3D program to converts AEC models into VR environments. The file format supported by the Unity 3D and process involved will be described in later Chapter 4.6.

4.4 Autodesk ReCap

As part of the research, model was also prepared by capturing data, using drone. Point clouds generated from the drone images was developed by Autodesk ReCap. Autodesk ReCap is a software developed by Autodesk, it converts reality into 3D model or 2D drawings (Autodesk Inc, 2017).

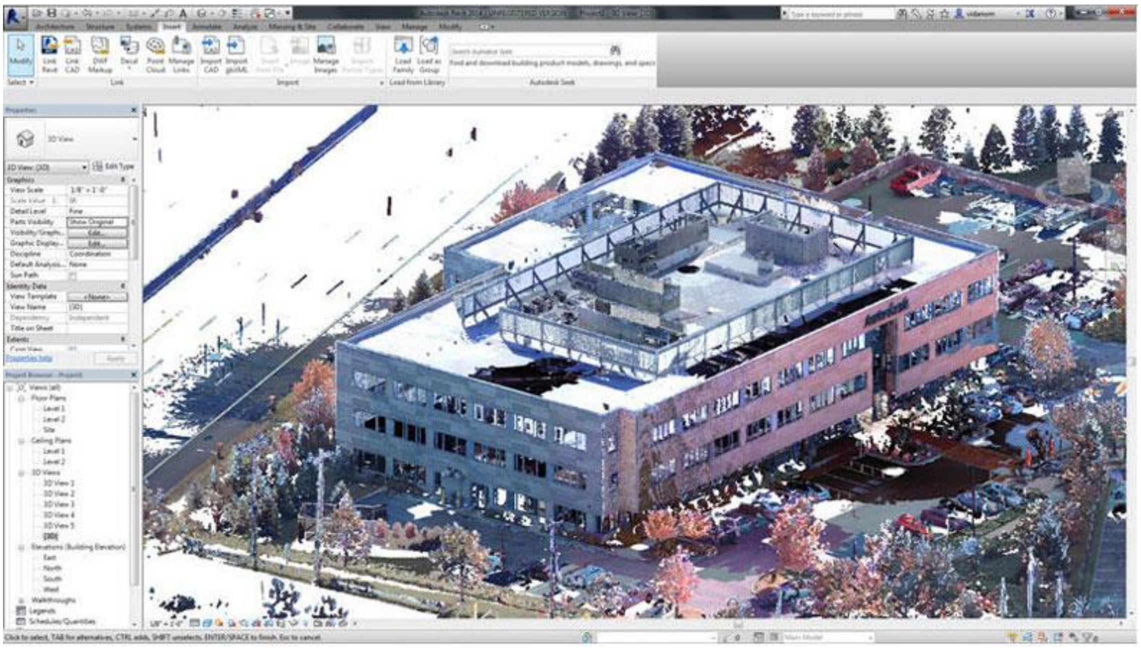


Figure 21: Autodesk ReCap

ReCap allows data to be collected from various sources, like:

- Photo
- Laser Scans
- 3D Scans

and convert them into formats which could be used by different software suites in the AEC and FM industry. The primary task of ReCap is to create a visually-useful, high-performing point cloud from images which could be used by other Autodesk product, also they could be transferred into other formats which will allow the points clouds to be used by other AEC software suites. According to Autodesk, ReCap has features listed below:

- Preparation Tool: Registration, Alignment and Editing, clean-up.
- Interrogation Tools: Visualization and Measurement.

- Collaboration Tools: Annotations and Presentation Tools.

The workflow for preparing model of existing building using the Recap software are shown in Figure 22:

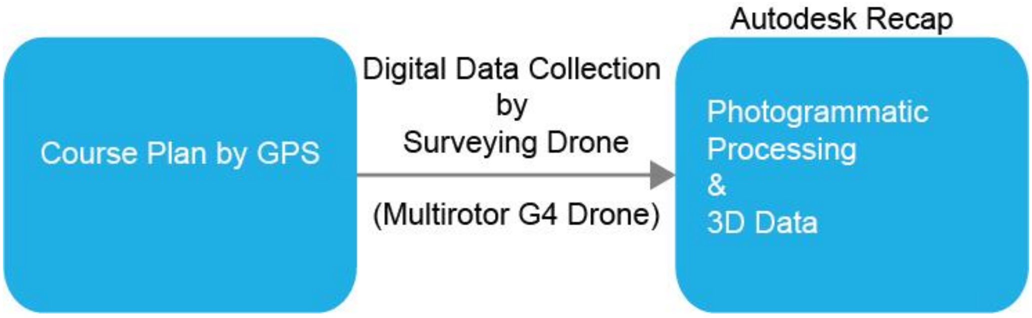


Figure 22: Workflow of Autodesk Recap

Data collected from the drone is processed with Autodesk Recap. The photogrammetric point-cloud transferred into Autodesk Recap is processed and stitched. The 3D data could be later used as 3D model. Sub – chapter 5.2.3, shows how the case study building is transferred into model using the workflow.

Autodesk Recap like any other AEC software suites allows transfer of data into different format. This allows the data to be used by other applications different companies and software's of Autodesk alike. The format that are allowed for import and export through Autodesk Recap are shown below in Table 5:

	Format	Import	Export
Point Cloud Formats	CL3	×	
	CLR	×	
	E57	×	×
	FLS	×	
	FWS	×	
	LSPROJ	×	
	LAS	×	
	PCG	×	
	PRJ	×	
	PTG	×	
	PTS	×	×
	PTX	×	
	RCS	×	
	RDS	×	
	TXT	×	
	XYB	×	
	XYZ	×	
	ZFS	×	
	ZFPRJ	×	
	PCG		×
	RCP/RCS		×
Photogrammetry Formats	JPEG	×	
	FBX		×
	OBJ		×
	RCM		×
	RCS		×
	ORTHO/.TIF		×

Table 5: Autodesk Recap File Format

4.5 Autodesk 3Ds Max

Autodesk 3Ds Max is a tool used by architect and designers for 3D modelling and rendering. The 3Ds Max was developed by Autodesk, to produce professional quality 3D animations, renders and models. In the recent versions, ability to create VR content are also added (Autodesk Inc, 2017).

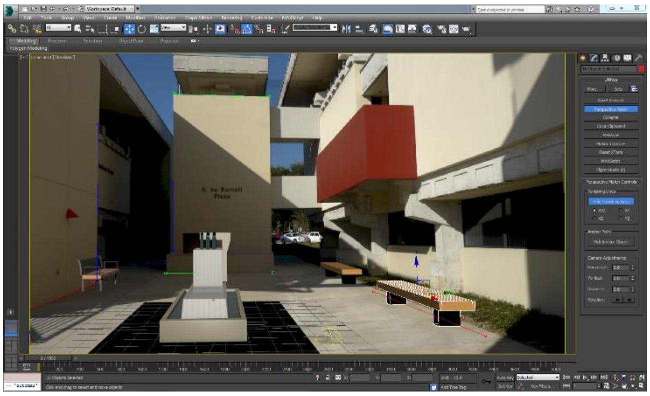


Figure 23: Autodesk 3Ds Max

According to Autodesk the top benefits of using 3Ds Max are (Autodesk, 2012):

- Rendering Revolution
- Smart Data
- Usability

The reasons for choosing 3Ds max for our research is the interoperability of the data. Autodesk 3D Max allow enhanced data exchange between wide range of applications. Specifically, Autodesk 3D Max support data from (Autodesk, 2012):

- AutoCAD® 2013
- Autodesk® Revit ®
- Adobe® After Effects®
- Many other CAD products

Data contained by the Autodesk 3Ds Max are mainly 3D geometry, with material information. 3DS (.3ds) is one of the file formats used by Autodesk 3Ds max. it allows models to be transferred between 3D programs and allow to store models for 3D resource catalogues. This format only contains essential geometry, texture and lighting data, with some extra information for Autodesk 3Ds max. though 3Ds is an industry standard and allow a wide range of data exchange, but it is not the most suitable format. Important disadvantages for this format is given below (Okino, n.d.):

- Meshes should be triangles.
- Texture filenames are limited to 8.3 DOS format.
- The number of vertices and polygons per mesh is limited to 65536.
- Accurate vertex normal cannot be stored in the .3ds file.
- Object, light and camera names are limited to 10 characters. Material names are limited to 16 characters.
- Directional light sources are not supported.

A detail table of file format supported as import and export by Autodesk 3Ds MAX is given in Table 6:

Format	Import	Export
3D Studio Mesh (3DS)	×	×
3D Studio Project (PRJ)	×	
3D Studio Shape (SHP)	×	
Adobe Illustrator (AI)	×	×
AutoCAD (DWG)	×	×
AutoCAD (DXF)	×	×
Initial Graphics Exchange Standard (IGES)	×	×
FiLMBOX (FBX)	×	×
Lightscape Solution (LS)	×	
Stereolithography (STL)	×	
VRML (WRL, WRZ)	×	×
ASC Scene Export		×
Lightscape Material (ATR)		×
Lightscape Blocks (BLK)		×
Lightscape Parameter (DF)		×
Lightscape View (VW)		×
Lightscape Preparation File (LP)		×
Stereolithography (STL)		×

Table 6: File Format supported by Autodesk 3Ds Max

4.6 Unity 3D

Unity 3D is a 3D application for real-time and multimedia. It is also 3D and physics engine, which is used to create game, animation and interactive contents with audio, video and 3D objects.

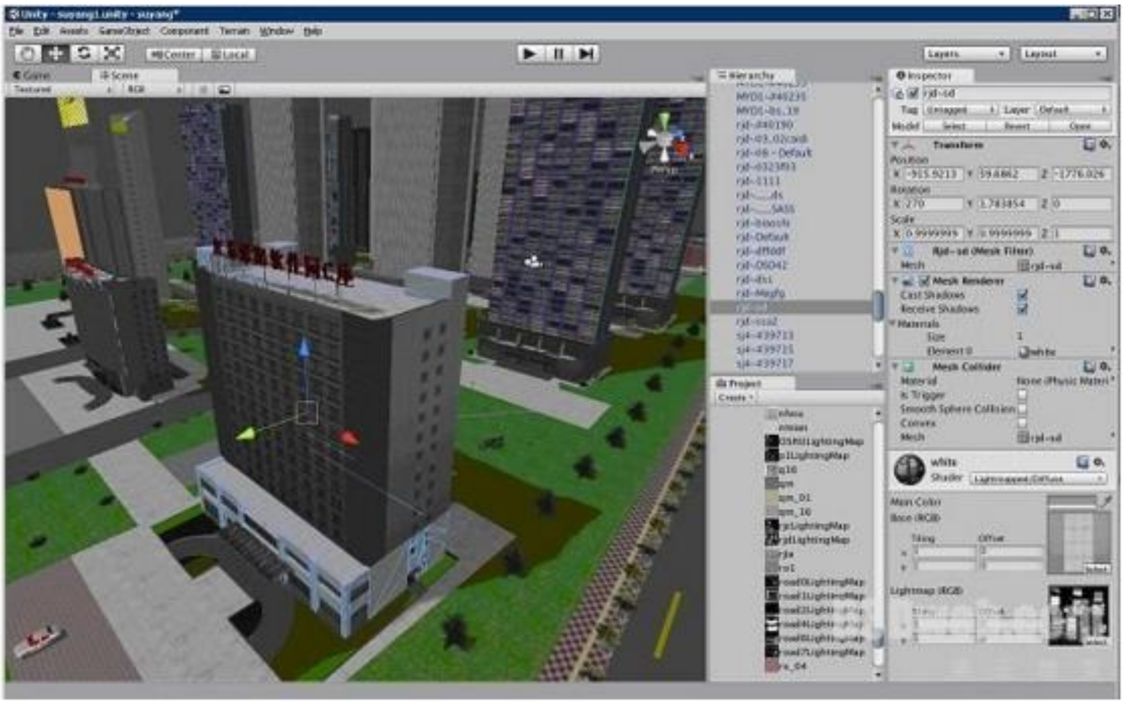


Figure 24: Unity 3D

OpenGL and DirectX are the two graphic libraries used by Unity 3D for generating three-dimensional interactive applications. The engines allow to manage the ASSETS, which may include, geometries, textures, animations and son on. The standard asset allows three-dimensional graphic content to be included. For the study purpose, to achieve better three-dimensional modelling FBX format must be used. FBX format is the standard in the digital entertainment industry for file transfer between industry practiced modelling program.

The main reason for implementing UNITY game engine is because of the compatibility issue between the Unity 3D and HTC VIVE. Main factor for choosing Unity for this research includes the ability of the HTC VIVE, the agreements between the Unity 3D technologies and HTC Vive, for the use in Virtual Reality. Another reason being, the extensive support by default Steam Valve software of HTC VIVE for UNITY. The extensive support makes it a multi-platform for any kind of VR integration to the facility planning.

Additional advantages are easy handling and interface capabilities for creating a virtual environment. Also, the licensing procedure is an additional advantages. It provides a free license for the personal user, which has been used in the research. Additional capabilities include the efficient way to use it, adding graphics and audio-visual content without the need of programming. In case of programming requirement, it is easy to incorporate high-level languages like C#, Java Script and Boo.

For able to use Unity to create a virtual experience, a better understanding of the formats of the model, with texture and other information was needed. For this reason, few typical routine checks were needed to be carried out, so that it was important to answer few important questions. The questions are:

- Which formats are compatible?
- How to import them?

Response to these questions allowed to incorporated data from Autodesk Revit BIM software and 3D scanned data, to the research.

For the research, more than one applications were used to develop real-time virtual environment. Therefore, the need of a format which compatible with several programs of modelling and texture arise. The aim of the research was to standardize a format, which will allow to create a VR environment easily for the facility planning tasks.

FBX format, was used to export the three-dimensional models from different software to Unity. FBX-format is an 3D asset exchange format, which is compatible with wide range of 3D tools (SANTAMARÍA, 2015). By definitions, the FBX is capable to transfer geometries, texture, animations, simple materials, with the capabilities of exporting cameras and light. In this research, all the options were implemented in the chapter 5. Previously, it was stated Unity allows importing FBX-format. For the benefits of the research the conversion methods of files from other programs, like Autodesk Revit to Unity FBX format, were explored.

According to Ondrej, Meshes, Textures, Animation and Bones are important components of the FBX-format, which should be supported by Unity. The components are described below (Mazan´y, Articulated 3D human model and its animation for testing and learning algorithms of multi-camera systems):

- Meshes – Mesh are created with triangles arranged in the 3D space to give the impression of a solid object. The triangles consist of three corner points, which are also known as vertices.
- Textures – Texture is image printed on the surface of the objects. The model uses texture to create minute details on its surface. The mesh triangle uses triangle area of the image to be fitted on the mesh.
- Animation – in unity animations system use the concept of Animation Clips. Animation Clips contain the information of how certain objects change their positions, rotations and other properties with respect to time.
- Bones – It is the representation of the anatomy of the character-humanoid. Animator use this method to create computer animation.

Unity Inc. provided a list of 3D package that support the components for the Unity. The FBX interchange format for the import of graphic content into Unity 3D was verified according to this Table 7. Table 7 shows the program which is compatible with unity and allows to import files in FBX format.

3D Package Support

	Meshes	Textures	Anims	Bones
Maya .mb & .ma[1]	✓	✓	✓	✓
3D Studio Max .max[1]	✓	✓	✓	✓
Cheetah 3D .jas[1]	✓	✓	✓	✓
Cinema 4D .c4d[1,3]	✓	✓	✓	✓
Blender .blend[1]	✓	✓	✓	✓
modo .lxo[2]	✓	✓	✓	
Autodesk FBX	✓	✓	✓	✓
COLLADA	✓	✓	✓	✓
Carrara[1]	✓	✓	✓	✓
Lightwave[1]	✓	✓	✓	✓
XSI 5.x[1]	✓	✓	✓	✓
SketchUp Pro[1]	✓	✓		
Wings 3D[1]	✓	✓		
3D Studio .3ds	✓			
Wavefront .obj	✓			
Drawing Interchange Files .dxf	✓			

[1] Import uses the application's FBX exporter. Unity then reads the FBX file.
[2] Import uses the application's COLLADA exporter. Unity then reads the COLLADA file.
[3] Cinema4D 10 has a buggy FBX exporter.

Table 7: Unity 3D package support (Polsinelli, 2013)

4.6.1 Import of 3D Model to Unity

This chapter discuss the process for importing 3D model to Unity and the consideration needs to be taken during and after. Import of 3D model can be done with the import inspector.

Process: Assets> Import New Assets

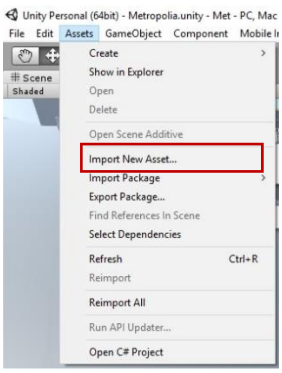


Figure 25: Import Inspector

For the importing of 3D mode, the type of file that need to be imported must be considered. According to Unity, there are two different types of files for importing Meshes (Unity Technologies, 2017):

- Exported 3D file formats – such as .fbx or .obj.
- Proprietary 3D application files: for example .Max and .Blebd file formats from 3D Studio Max or Blender.

For the research, wither way was possible to import the meshes into Unity, but there are few considerations for which type to choose from:

EXPORTED 3D FILES

Unity can read .FBX, .dae (Collada), .3DS, .dxf and .obj files.

Advantages:

- Only export the data you need.
- Verifiable data.
- Generally smaller files.
- Encourages modular approach e.g. different components for collision types or interactivity.
- Supports other 3D packages whose Proprietary formats we don't have direct support for.

Disadvantages:

- Can be a slower pipeline for prototyping and iterations
- Easier to lose track of versions between source (working file) and game data (exported FBX for example)

PROPIETARY 3D APPLICATION FILES

Unity can also import, through conversion: Max, Maya, Blender, Cinema4D, Modo, Lightwave & Cheetah3D files, e.g. .MAX, .MB, .MA etc.

Advantages:

- Quick iteration process (save the source file and Unity reimports)
- Simple initially

Disadvantages:

- A licensed copy of that software must be installed on all machines using the Unity project
- Files can become bloated with unnecessary data
- Big files can slow Unity updates
- Less validation, so it is harder to troubleshoot problems)

4.6.2 Comparison between .obj & .fbx

For the research, it was important to choose a file format which would be better to transfer the model into Unity. Important question to answer is, FBX or OBJ, which format is better? According to comparison between two formats, FBX is considered as the higher quality 3D exchange format. Compared to OBJ, FBX can contain more information, while OBJ is a simple model format.

OBJ (Blender, n.d.): is a simple data-format, which mostly contain 3D geometry, the position of each vertex, the UV position of each texture coordinate vertex, vertex normal, and the faces for the polygons as list of vertices ad texture vertices.

Digital-Tutors asset library is used by the OBJ file format and it consists only the 3D model. This allows as alternative for the software proprietary formats for flexible way to import 3D mesh data into any 3D software.

<u>Limitations of OBJ file type</u>: OBJ is one of the most common transfer format for 3D models for most of the industry-standard 3D application. OBJ files have limitations for holding polygon data, UV maps and some standard materials. Also, it cannot contain rigged or animation data.

FBX (Serrano, 2011)**:** it is another prominent 3D asset exchange format, which is compatible with many 3D tools. FBX is greatly supported by Autodesk, it allows higher-fidelity data exchange and support few third-party applications. FBX allows better file transfer with more data and able to work more efficiently.

FBX file format uses Digital-Tutors asset library for all rigged or animated assets. It is one of the most flexible format for importing the rigs and animations with 3D software.

Limitations of FBX file type: FBX file format allows to support mapping, standard mapping, standard materials, rigging and animation. There is different versions of FBX, which allows the level of information to be imported according to the versions. FBX do not allow to import proprietary materials or shaders.

Table 8 represent a detail comparative comparison between FBX and OBJ files.

Description	**FBX**	**OBJ**
Animation	Yes	No
Mesh	Yes	Yes
Skeleton	Yes	No
Morphs	Yes	No
Vertex Animation	Yes	No
Texture	Link	Link
Material	Yes	Link
LightMap, DetailMap, NormalMap	Link	No
Animation Takes	Yes	No
Binary Format	Yes	No
Instancing	Yes	No
Scene Hierarchy	Yes	No
Multiple Channels Mappings	Yes	No
Interchange File Format	Yes	Yes

Table 8: Comparison of FBX and OBJ Formats Properties (Simmons, 2014)

4.7 HTC VIVE

HTC Vive is a high end virtual reality device, it was made as a Head-mounted display (HMD) with wide field of vision. It was developed by Valve, creator of PC gaming platform Steam and mobile company HTC (Prasuethsut, 2015).

Figure 26: HTC VIVE

HTC Vive turns a room into 3D space. two stationary station, called base station track the head mounted display unit and the handheld controllers. This allow the users to move freely and interact in the 3D environment. With the help of organic light-emitting diode (OLED) display HTC Vive provide a resolution of 2160X1200, the refresh rate is 90 Hz with a field of view (FOV) of about 110 degrees. The head mounted display unit has HDMI 1.4, DisplayPort 1.2 and USB 2.0 connections. There is a 3.5 mm audio jack to connect headphones and built-in microphone. Detail specification of HTC Vive is given in Table 9 below:

Display	OLED
Resolution	2160 X 1200
Refresh Rate	90Hz
Platform	SteamVR, VivePort
Field of view	110 degrees
Tracking area	15 X 15 feet
Built-in audio	Yes
Built-in mic	Yes
Controller	Vive controller, any PC compatible gamepad
Sensors	Accelerometer, gyroscope, Base Station laser tracking system, from-facing camera
Connection	HDMI, USB 2.0, USB 3.0
Requirements	NVIDIA GeForce GTX 970/AMD Radeon RX 480 equivalent or greater Intel Core i5-4590 equivalent or greater 4GB+ of RAM Compatible HDMI 1.3 video output 1x USB 2.0 port Windows 7 SP1 or greater
Price	$800

Table 9: Specification of HTC VIVE (Digital Trends, 2016)

4.7.1 Head Tracking and Sensors

HTC VIVE contains sensors including gyroscope and accelerometer. Also, there is an external camera for tracking the headset position. the base station also contain sensor which is used to track the position of the headset and the controller. The information generated from the sensors of the headset, controller and base station is combined to determine the position of the user in the real work, which is letter synchronize with the user's virtual view in real time.

The following figure shows the desired room setup and how the base station with the controller and head-set communicate to synchronize the user's position in the virtual world.

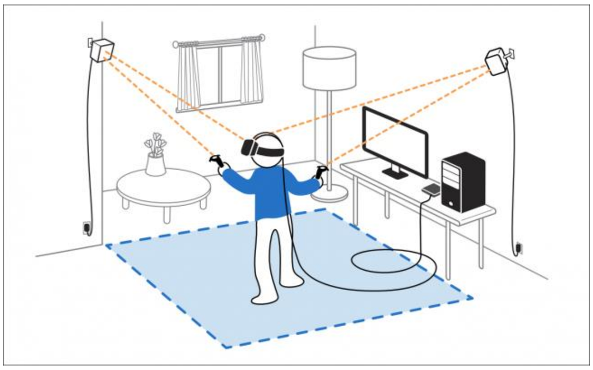


Figure 27: HTC VIVE Room Setup

4.7.2 HTC VIVE Plug-in

Steam VR is the plug-in which allows compatibility between UNITY and HTC VIVE. The plug-in is free for download from the website of steam and allows users to install and set up the HTC VIVE.

It allows the tracking of the headset and controllers. Also update the framework for the controllers, head set and base stations. Shown in the Figure 28:

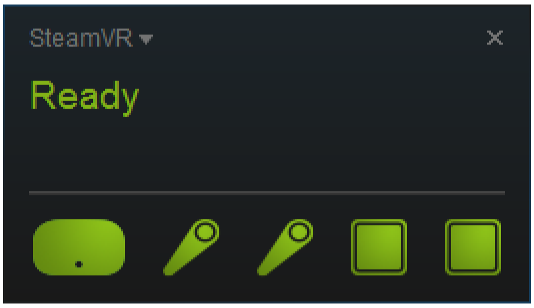


Figure 28: Steam VR Window

It also comes with an online library, which allows published games for the gamers to download and play. In unity, Steam VR camera rig could be attached which allow the VR experience to be possible in HTC VIVE. Camera Rig is an additional plug-in for Unity which could be downloaded from the library and added in the Unity. It replaces the regular Unity Camera within a scene. The SteamVR camera rig could be dragged into the scene and start viewing the scene with the VIVE. The SteamVR camera rig controls the stereo rendering and head tracking. This interface is used as the main interface between the Unity and the cameras. It is attached to prefab, which makes it easy to add VR support to a scene.

There are also different kind of controllers, for example fly by controllers, which allows the user to navigate in the virtual environment using the VIVE controllers. It is normally a camera rig attached with character controller. It includes the physics and the movement system.

5 DESIGN: FIELD TEST

This section illustrates the steps needed to be taken to achieve the research objective of “viewing the IVE model for the facility planning.” A work flow will be generated for developing a virtual reality model of a selected building. The basic 3D model would be generated in three separate ways:

- Autodesk Revit
- Photometry of Drone
- 3D Laser Scanner

The process would state, how the 3D models are converted into format for the IVE, using verity of software and the precaution needed to be taken to minimize the loss of data in the process.

5.1 Field Test: Building Description

For this study, Heizhaus building from the HTW University of Applied Sciences Berlin, Wilhelminenhof campus was chosen. The complex is an old factory complex, built for the Kabelwerke Oberspree (KWO) in 1904/1905 (HTW BERLIN, 2017). During 2000s the complex was renovated and rebuild for HTW Berlin. The location of the campus with the test building is shown in the Figure 29.

Figure 29: Location of Test Building (Source: Google)

The building is a single storey, build to house the heating system for the campus. It is a mechanical building, containing pipes and machines.

Figure 30: Arial View of the Test Building

Figure 31: Interior of Test Building

Using students, the model of the building was developed in Autodesk Revit. As part of pilot project, the drone and 3D scanner was used to getter the point cloud data for the building. The models generated of the building in the three-different way was used for the study to develop into a Virtual Reality (VR) model using HTC VIVE.

5.2 Field Test: 3D Models

As stated earlier, three models were developed of the test building. Models were developed using:

- Autodesk Revit
- 3D Scanner – Trimble TX8 – Trimble Real Work
- Drone - Multirotor G4 – Autodesk Recap

5.2.1 Autodesk Revit – 3D Model

Students were given a task to develop a model of the test building using old plans and sections of the existing building.

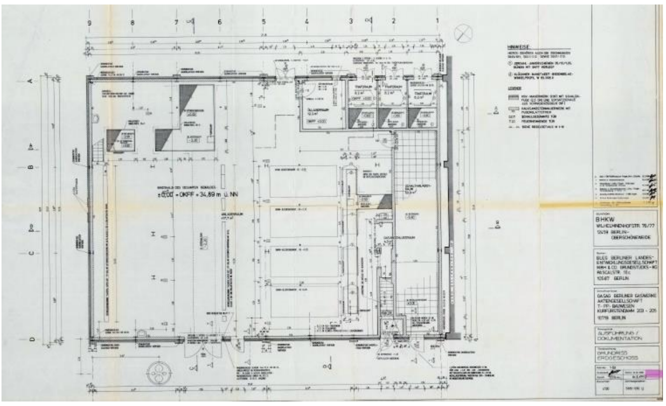


Figure 32: Plan of the Test Building (Source - HTW Berlin)

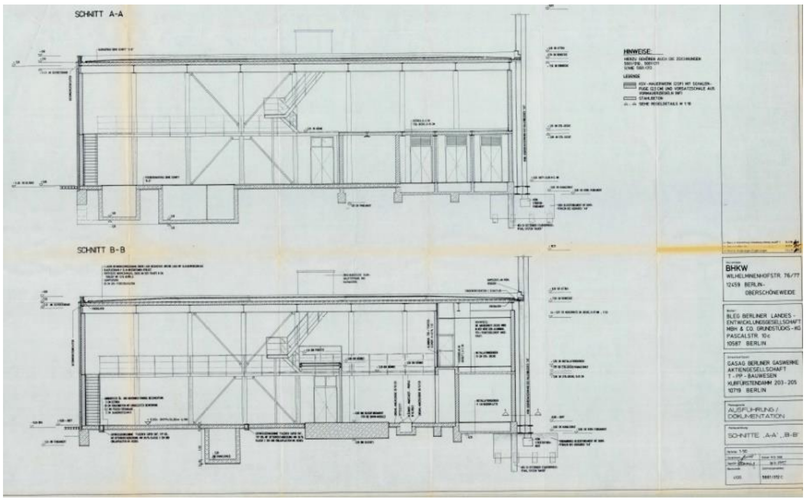


Figure 33: Section of the Test Building (Source - HTW Berlin)

The main purpose of the task was to familiarize the students with producing a 3D model with the existing plans, elevations, and section. The Autodesk Revit model lacked basic information like, ceiling, floor, BIM data. But it contains information like wall, steel columns and beams, stair, pipes and pumps. The model was created using Autodesk Revit 2016.

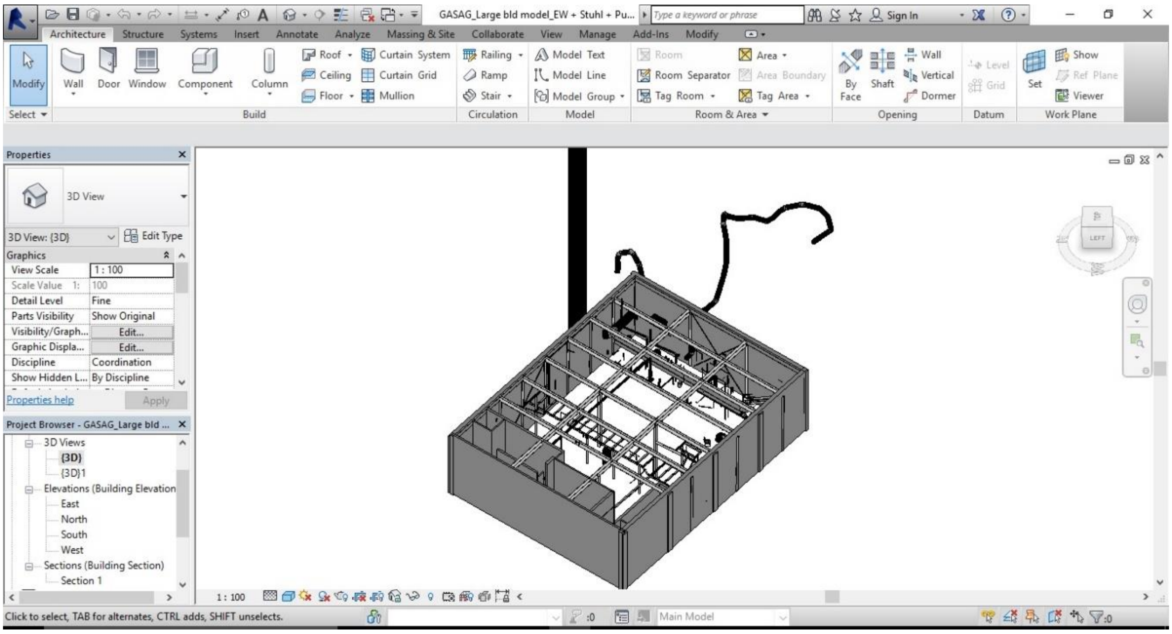


Figure 34: Autodesk Revit Model of Test Building (Source - HTW Berlin.)

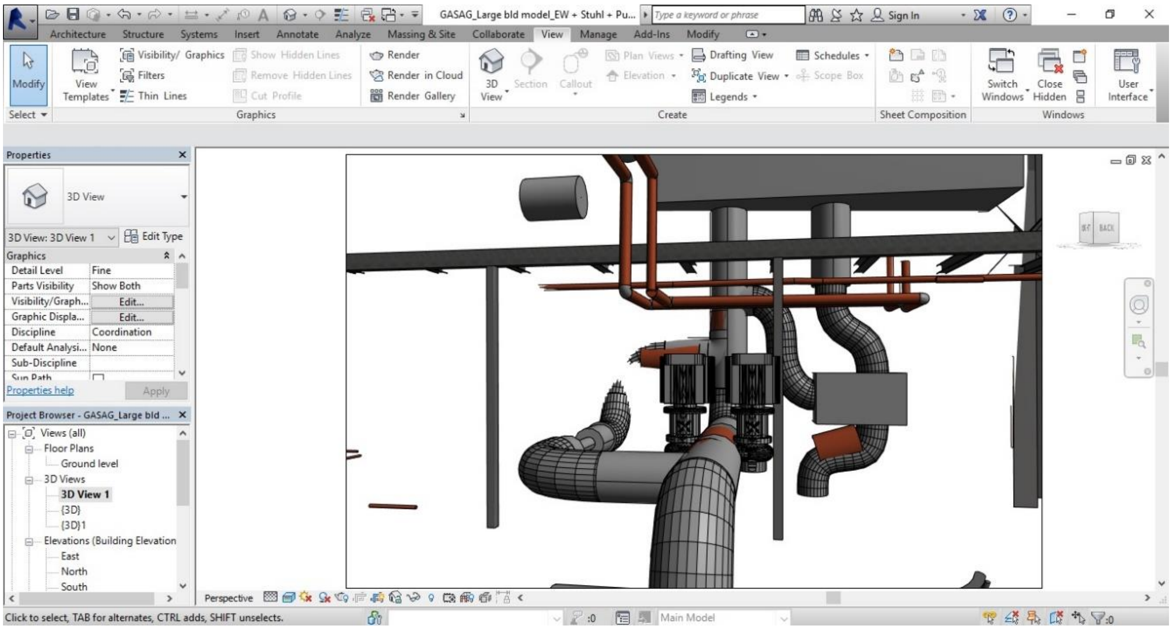


Figure 35: Test Building Revit Model of Pump (Source - HTW Berlin.)

As stated above the model lacked valuable information like floor sab and BIM data, but for the use of the study the model provided important geometric information like the walls and pump. This information could be used in Facility planning to gain the understanding of the physical size of the building and the mechanical instrument present inside the building.

The file format for this model was .rvt which is an original file format for Autodesk Revit. The file contains all the information about 3D graphics. On the next step, Autodesk Revit was used to convert the 3D graphics into FBX format, which is recognisable by Unity 3D to convert it to virtual environment. The steps for conversion of the file show more discussed on chapter 5.3.

5.2.2 Trimble Realwork – 3D Model

For preparing the model through 3D scanner, Trimble TX8 Laser scanner was used. Trimble Real Work was used to register and clean the point clouds, the data file format from the 3D scanner was .E57. the point - cloud data contain x,y,z coordinates of each points.

Workflow for generating point cloud model is shown in Figure 20.

Step 1 – scan plan had to be created for better scan, which will allow to have overlap and allow to have a better and complete scan.

Step 2 – scan is done according to the plan. Point Cloud data from the scan is transferred into Trimble Realworks. There is an option for automatic registration, which will identify the vertical plane of the points and use the plans to register the data. After the automatic registration is, it will create a model in the format .E57, which will be later converted into FBX using Trimble Realwork.

After the automatic registration is complete, issues regarding the reflection created by glasses and unwanted data could be cleaned out manually. The Figure 36, shows the point cloud model of the test building.

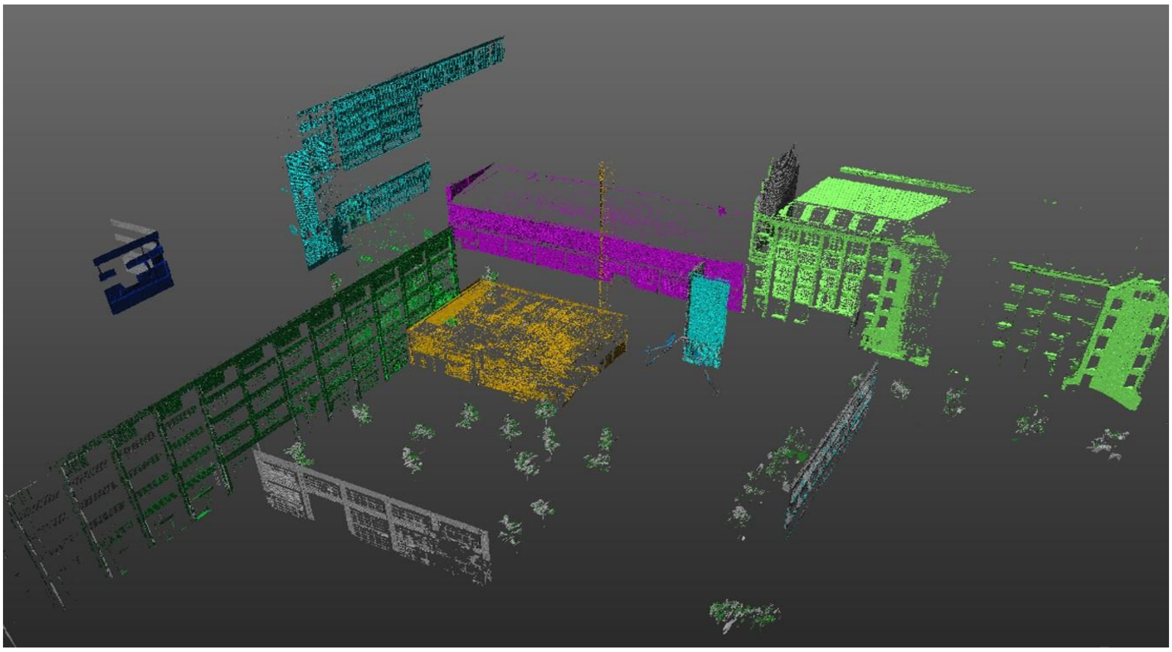


Figure 36 : Point Cloud Model of Test Building (Source - HTW Berlin)

5.2.3 Autodesk Recap – 3D Model

Multirotor G4 Drone, shown in Figure 37, was used to capture photogrammetric data of the test building. The drone allows to detect the terrain and building envelope. It is very useful for the building parts which are not visible to the 3D Scanner. The drone normally has camera, as shown in Figure 37 which take pictures in an advanced programmed path with the help of GPS.

Figure 37: Multirotor G4 Drone

The workflow for developing 3D geometrical model from drone photogrammetry is shown in Figure 22.

Step 01: As stated above, with the help of Global Positioning System (GPS) the course had to be planned. According to the plan the drone, using its camera takes picture.

Step 02: Data was converted into processed in Autodesk Recap.

5.3 Analysis of Exporting 3D Files

The process of export of three-dimensional models to Unity is performed through interchange format, FBX format. FBX format allows transferring data, including geometries, textures, animations, simple materials with the capability to also export cameras and lights. The workflow for creating VR model was developed keeping in mind the FBX format.

As stated in the chapter 5.2, the models were developed using more than one applications, this model were used for the final virtual reality environment. For this reason, it is required to use any file format which compatible for several design programs, this allows to standardize the process. The FBX-format, allows a better management of data conversion. As a result, the export of three-dimensional models to unity is done through the FBX format.

Therefore, it is important to understand and test the process of transfer and the FBX-format to understand their capabilities and limitations. This will help to create useful format for the development of virtual environments. It will improve models with minimal loss of information. Therefore, according to the workflow tests are carried out in export import between the Autodesk Revit, Trimble Realwork, Atuodesk ReCap, Autodesk 3Ds Max and Unity game engine. This process will allow to make comparisons between the benefits and problematic of the FBX format as a three-dimensional model transfer between this application.

5.3.1 Autodesk Revit Model: FBX Files

The export of model created in Autodesk Revit, were done using the export option of the in-built export function in Revit. The workflow shown in Figure 38, was used for the conversion.

Figure 38:Revit to Unity Workflow

Autodesk Revit, has the capability to export a model into FBX, which is the format suitable for Unity game engine to interpret the model and use it for Virtual Model, but still it is needed to be converted or transferred through the Autodesk 3Ds Max, like the Revit to Unity workflow shown in Figure 38. The reason for using Autodesk 3Ds Max as an intermediary platform is, as of 2011 the material library of Autodesk all are converted into protein 2 material file (Studica News, 2012), Unity game engine do not understand the texture properly.

According to the workflow Autodesk Revit convert the model into FBX format, which is transferred into Autodesk 3Ds Max. In the Autodesk 3Ds Max the model is optimized for better handling of the data and specially the material and geometry. The optimization normally includes, texture/material optimization or model optimization but it will depend according to requirement of the project. After all the optimizations, the model is converted into FBX format again through the Autodesk 3Ds Max. The FBX model from the 3Ds max is transferred into the Unity game engine for the development of Virtual Model.

5.3.2 3D Scanned Model: FBX Files

For the research, the scanned data of the test building was used and converted into Unity game engine for creating the Virtual Reality Model. For the benefit of the research FBX format was used, as FBX is better format for handling data in Unity. It uses the similar workflow as shown in Figure 39.

Figure 39: Trimble RealWork to Unity Workflow

Figure 39, shows the workflow followed to convert the model into Unity game engine. The point cloud data is converted into Trimble RealWork, reverse modelling was done in the application, then converted into FBX format through RealWork. For any kind of geometric or texture optimization or modifications, the model could be modified into the Autodesk 3Ds Max. the modified model is converted into FBX and transferred into Unity game engine.

5.3.3 Drone Model: FBX File

The research also involve data captured by drone. The drone data is transferred into Recap, following the workflow shown in Figure 40. The model is converted into Unity game engine for the development of Virtual Reality Model.

Figure 40: Autodesk Recap to Unity Workflow

In Autodesk Recap, after preparing the model by reverse modelling the model is converted into Autodesk 3Ds Max through FBX format. After doing the geometric and texture optimization in the Autodesk 3Ds Max the model is transferred into Unity game engine for the Virtual Model development. The process is shown Figure 40. Like previous all the data the export process is done through FBX format for better handling of the data involved.

5.3.4 FBX File Comparisons

FBX files created using the basic data from Autodesk Revit, Trimble RealWork and Autodesk Recap are all checked for the ability to be used in the research. They were all compared in few of the factor, which would help to develop the Virtual Reality model. The comparison table is shown Table 10:

	File Size	Geometric Property	Texture/Material Property
FBX 1 (Revit)	16.7 MB	Good Condition	Loss of Material from Revit
FBX 2 (Revit)	19.8 MB	Same as FBX 1	Optimization of Material
FBX 3 (RealWork)	437 MB	Point Cloud – Point representation.	Lack of material information due photogrammetry.
FBX 4 (RealWork)	437 MB	Point Cloud – Point representation.	Lack of material information due photogrammetry.
FBX 5 (Recap)	20.7 MB	Good Condition – only plan.	Lack of material information due photogrammetry.
FBX 6 (Recap)	20.7 MB	Good Condition – only plan.	Lack of material information due photogrammetry.

Table 10: FBX file Comparison

FBX 1 & FBX 2 – the model created in Autodesk Revit is the first batch of conversion in Autodesk 3Ds Max. FBX 1 and FBX 2 file size varies as material is optimized for Unity 3D. FBX 2, will contain more data. The geometric property is good easy to handle and comprehend, there is no loss in geometric data.

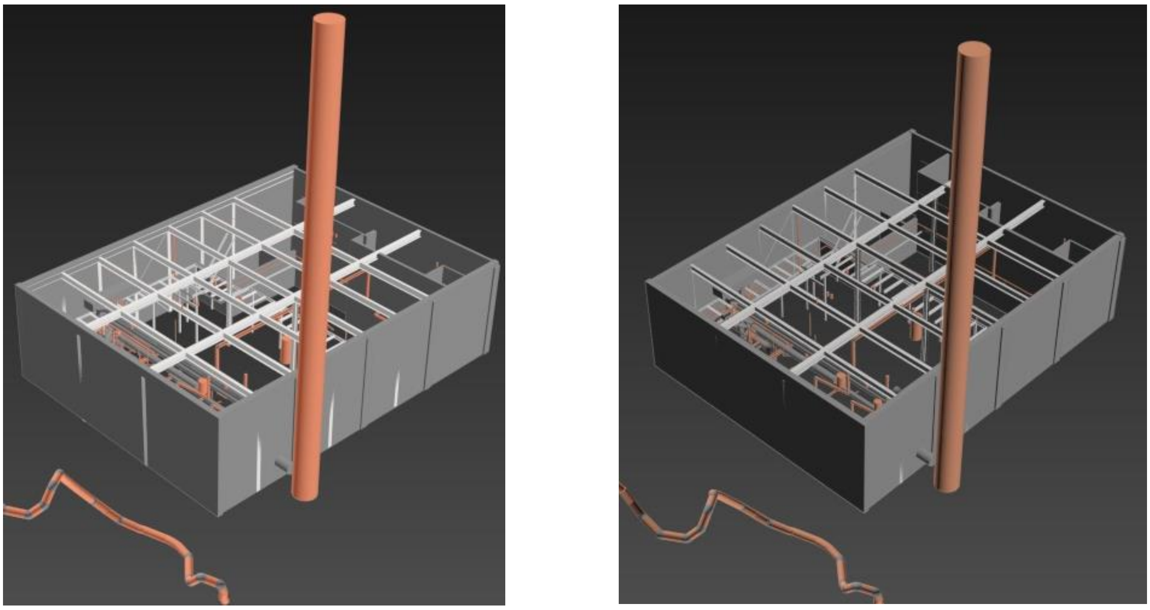


Figure 41: FBX 01 & FBX 02

FBX 3 & FBX 4 – models in this conversion are collection from the 3D scanner. Original data contain point clouds. Only registration process was done, therefore, the model lacks geometric information like Autodesk Revit model. As it is point cloud data there is no material attached with the model. the file size was compatibly larger than others.

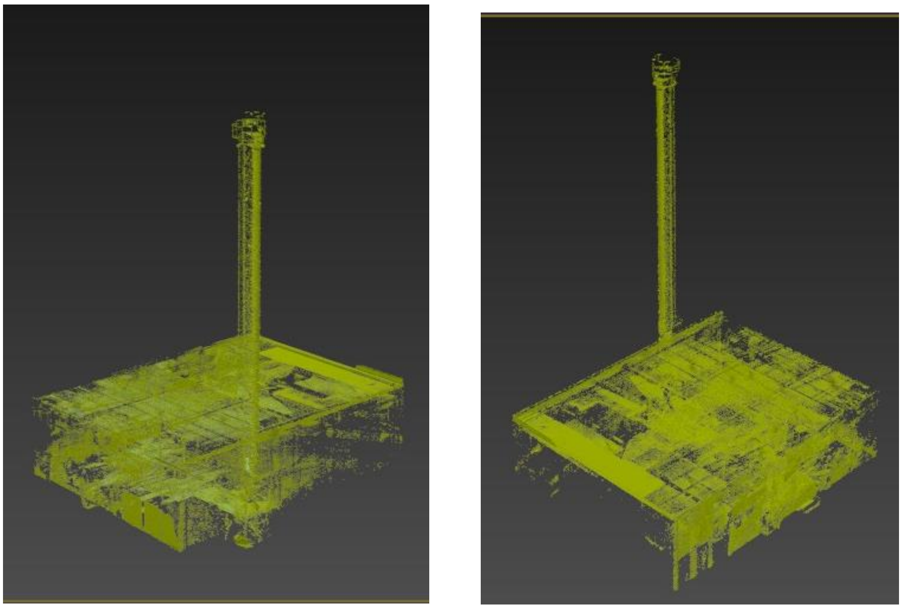


Figure 42: FBX 3 & FBX 4

FBX 5 & FBX 6 – Autodesk Recap data was used. It lacked 3-dimensional geometric data. There was lack of material.

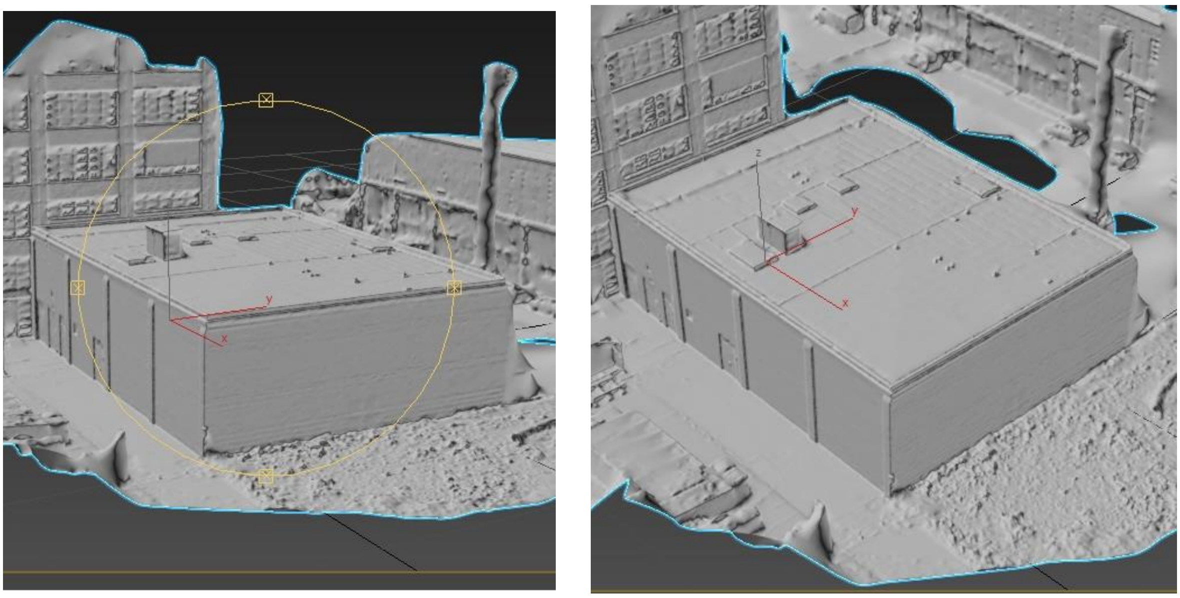


Figure 43: FBX 5 & FBX 6

5.4 Optimization in Unity

After the model has been imported to Unity 3D, there is possibility to implement optimization to Models which will improve the VR experience. Below are the details of optimization tools that is provided by Unity 3D and used to develop the models.

- **Geometry** – it allows to simplify the geometry. To make rendering in VR easy. It allows to remove any faces in Unity that were not possible in 3D software. It allows to make the model mesh simplified.
- **Meshes** - Materials are used in conjunction with mesh renderers, particle systems and other rendering components used in UNITY. They play an essential part in defining how object is displayed.

  Meshes make up a large part of your 3d worlds. Aside from some asset store plugins, UNITY does not include modelling tools. UNITY does however have great interactivity with most 3d modelling packages. UNITY supports triangulated or quadrangulated polygon meshes. Nurbs, nurms, subdivide surfaces must be converted to polygons.
- **Level of Detail (LODs)** – it is way to increase performance. It reduces the number of triangle rendered of the object as the distance increases. LODs help to reduce the load on the hardware, it does that by improving rendering performance. It add LOD component and provide lower detail mesh for the objects further from the camera.
- **Fillrate, overdraw and culling** - reducing overdraw, where furthest objects are drawn to a pixel first, redrawing the pixel with each closer object subsequently on top. This is a issue with VR and mobile devices that have ultra-high resolution displays. A large amount of overdraw combined with a larger number of pixels kills fillrate. Texture filtrate is one of the key limiting metrics in GPUs.

  Some solutions are provided with occlusion culling and frustum culling. Frustum culling doesn't render objects that are outside of the camera's frustum. Occlusion culling gets rid of objects that are occluded by other objects in front of it. Rooms behind a door, for example, can be left out entirely. By default, works occlusion culling works on your entire scene, but proper level design will allow you to cull out entire levels of your game.
- **Rigid Body** – Rigid bodies enable GameObjects to act under the control of physics. The Rigidbody can receive forces and torque to make objects move in a realistic way. Any GameObject must contain a Rigidbody to be influenced by gravity, act under added forces via scripting, or interact with other objects through the NVIDIA PhysX physics engine.

- **Box and Mesh Collider** – The Mesh Collider builds its collision representation from the Mesh attached to the GameObject, and reads the properties of the attached Transform to set its position and scale correctly. It is possible to define the invisible geometry as collision boxes within UNITY, these boxes can be exported from modeling programs, although it is also possible to assign collision geometry directly without create a modeling software, this will need to select the object and then define the type of collision as required.

Depending on the optimization required a project could be optimized in Unity. Above mentioned are the important optimization done in the research to get a successful IVR models.

5.5 Asset Store

This store contains lots of Assets and applications already created in Unity and uploaded by other developers.

Standard assets are set of tools and prefabs used to create design and prototyping. It provides with First or Third Person controller, car, plane, trees or 3D character. Also, useful tools like touch control setup. There are some assets which are free others are paid assets.

The main assets are:

- 3D Models
- Animations
- Audio
- Complete Project
- Editor Extensions
- Partical Systems
- Scripting
- Services
- Shaders
- Textures & Materials

- Unity Essentials

Some of the assets were used in the research, which help to prepare the target IVR model.

5.6 Build Settings

Unity 3D allows to generate a game PC version. The steps are very easy and could be done quickly. Steps are given below:

File>Build Setting

After previous steps, the screen in figure Figure 44, will appear. The seeting allows to compile the game for several PC, iOS, Andriod, Xbox 360 and etc. platforms. In the case of the research, PC is used. Once the game is gernereated into .exe file. The file should be uploaded into the Steam VR interface and run with in HTC Vive.

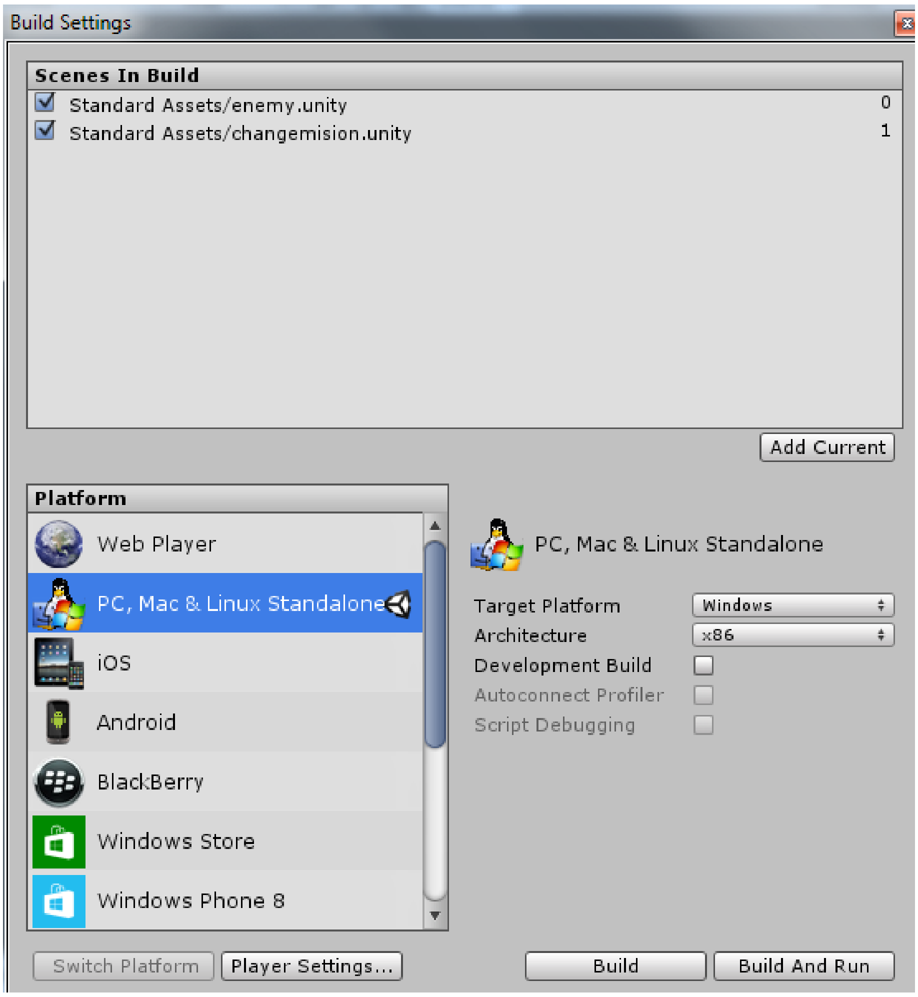


Figure 44: Build Setting

6 RESULTS & DISSCUSSION

This chapter will state the result of the research. In chapter 1.2, three questions were stated, which was used to develop the research. The main aim of the research was to evaluate the process of developing an immersive virtual reality environment with BIM data for facility management planning purposes. The questions are:

- Is Immersive Virtual Environment, a valuable tool for AEC and FM industry?
- What are the available Immersive Virtual Environment platform, software and tools for the AEC and FM industry?
- What is the most viable virtual reality system setup for view a model for FM planning?

To derive the answers, study of previous research and development of models based on HTW Berlin research project was carried out.

Question 01 – Is Immersive Virtual Environment, a valuable tool for AEC and FM industry?

During the design – construction – operation planning process of a building the outcome mostly depends on the involved technical and non – technical persons interpretations and perceptions. The AEC and FM industry often involves many different actors and people with different experiences, level of knowledge and ability to interprets information.

In most of the project the user involvement is mostly restricted to reviewing the traditional 2D plans and 3D models, which is difficult to interpret for all the different stakeholders in the project. Previous research has proved that, having a first-person perspective in a 1:1 scale model, with the ability to navigate in an immersive environment allow the user to have a better understanding. The development of Immersive Virtual Environment model, showed equivalent results. It was showed to group of students and non-technical participants, they all mentioned equivalent results. The participants expressed this kind of visualizations provide with new possibilities to understand, share, experience and provides better decision-making process.

In the previous research surveys it was seen that IVR was used as a collaboration tool, supporting design review, critique, consultation and task sharing among multiple participant. The ways IVR environment could be useful for the industry are:

- Supporting understanding and perception of space.
- Supporting decision-making and resolving of design issues.
- Supporting construction planning and assembling.

Question 02 – What are the available Immersive Virtual Environment platform, software and tools for the AEC and FM industry?

To understand the capabilities and usefulness of IVR, a research in the current development of the software and hardware technology was carried out. Though IVR technology has been used for a long time, the development in this field has been done on the resect years. With the development of mobile and gaming technology in the recent year IVR has developed and mass use is seen in other fields. The development of IVR two folds, in the research we have seen development has been done in hardware and software sectors.

Software – the gaming industry is pioneer in the IVR software. Gaming software like Unity 3D and unreal, is very famous in gaming industry. They are used to develop many well-known games. They are choice for transferring 3D models into the IVR environment. the software in the AEC industry is still lacking behind in the IVR and we have seen in the previous research mostly using the gaming software like above mention to prepare the IVR environment. the 3D and BIM software in the AEC and FM industry lacks mostly the format extensions required for the IVR environment, therefor the gaming software after conversion are used to prepare the models. In the recent time BIM authoring software like Autodesk Revit and Naviswork has been developed to integrate IVR capabilities. The information level of this software mainly depends on the rendering of 3D geometries and lack other valuable information in the AEC field. More research is being done on increasing the capabilities of representing information through the BIM software in IVR environment.

Hardware – a survey into the previous and current research in the field of hardware for IVR environment, found that in the recent year with the rapid development of the mobile technology has involved the hardware in the IVR market. Previously, IVR was restricted to researcher and government industries, due to its unaffordable prices. The hardware was reasonably complicated to use. But nowadays it is more affordable and easy to use. The trend of use of IVR technology into different field is increasing and we are seeing the result of affordability and ease of use in AEC and FM industry.

The hardware for IVR environment depends on the characteristics of the environment, as explained in chapter 3.1. The characteristics are:

- Non – Immersive VR System
- Semi – Immersive VR System
- Fully – Immersive VR System

In the AEC industry, we have seen the application of all the system. Normally normal computer monitor could be used as the non – immersive VR systems. Semi – immersive VR systems are projection based system. Fully – immersive systems are where CAVE and HMDs systems are used. Also, in the recent year Google Glass like hardware are researched to be implemented on site, which will project information about construction directly to the glasses. Then there is tablet technology doing the similar projection like glasses. Researcher are conducting research how to change the flow of information and increase the capabilities of the hardware.

Question 03 – What is the most viable virtual reality system setup for viewing model for FM Planning?

One of the main scope of this thesis was to prepare and test workflow for preparing model for IVR environment. The model in the IVR environment should benefit in FM planning. Key factor for preparing model for FM planning is understanding:

- Geometrical information of building and equipment’s.
- Texture

Techniques developed in the thesis are very important for IVR environment to be used during and design and planning process of a project.

Workflow stated in Figure 12, was used for the development of model for the research. It is a very popular workflow that is used by the industry to develop IVR models. The workflow used models created in BIM software platform to be converted into IVR environment. The 3D models had to go through optimization in 3D software and gaming engine to deal with the loss of data due to the Interpol ability between the software's. Important finding was the use of FBX format as the data exchange format between the software. FBX allowed better geometrical and material information to be transferred between the software. By previous research survey and tests during the thesis it was proved that FBX is one of the best format for 3D model to be transferred into IVR environments.

A HTW Berlin research project data was used for the thesis. 3D models as stated above was generated in three different process:

- BIM Model – Autodesk Revit.
- 3D Scanned Model – Trimble Realwork.
- Drone Model – Autodesk Recap.

Three different data set from different method and software allowed better understanding to the workflow. It provides better understanding into format and data handling. The workflow required a 3D software to optimize the data in software for preparation of IVR model. Autodesk 3D studio Max was used for the optimization of the 3D data. It optimized the data:

- Geometric Data created into BIM software.
- Materials Data created into BIM software.

Unity 3D was used for the next step of the process. Unity 3D allowed the creation of VR environment. It included collision control, optimization: scaling, geometric and material apply, character control. HTC VIVE was used as VR hardware. Reason for choosing this hardware was, lightweight and easy to use and setup. Steam VR is the interface between the hardware and software. The executable file of the model created in Unity 3D was uploaded into steam VR and experienced through HTC Vive. IVR models created is shown in the Appendix B to D.

The three IVR models were compared, according to:

- Geometric & Material Properties.
- Navigation and movement ability.
- Easy to comprehend and handle the project.

According to IVR model comparison:

- Revit Model (Model 01) – Easy to understand and navigate the environment. best solution for FM planning purpose, according to the test. They represent the geometric and material properties created.
- Real Work Model (Model 02) – Conversion took extra time, as the file size was big due to large amount of data of point cloud. Loss of geometric and material representation, due to black and white point cloud. For better representation, reverse modelling must done with extra care. That is a back draw for converting this model directly and using for the FM planning purpose.
- Recap Model (Model 03) – the navigation and representation was better that traditional point cloud data. It still lacked material information but was understandable, as the point cloud was image format and they well coloured. The model lacked geometrical information, they were just images past on plan. It could be useful tool to understand the size and location for FM planning purpose but for better understanding a reverse modelling is needed to be carried out.

To what extent the technical contributions and ultimately the final system will pave the way for a more integrated use of VR during the FM design and planning process remains bit an unanswered question. As the requirement might vary from project to project with diverse levels of data. As evaluated against the geometric and material requirements it has all the properties needed to function well in practice.

7 CONCULSION

IVR environment is a new paradigm for the AECO industry. 3D project and facility review and planning has developed into new height with the VR environment. In the industry, it has been successfully tested for feasibility on real cases and it has been adapted to a variety of situations involving AEC and facility management industry.

The study was attempted to understand the process of transforming 3D models from different model sources into an immersive visualization environment. This study provides a proof of concept for using 3D model data and interactive simulation in a widespread industry process. The work explores how the industry personal could improve the examination of design, construction and facility planning with a better understanding of the 3D model for both the technical and non – technical personals.

For the study, research in the development of the IVR software and hardware a was carried out. It is a developing field; a lot of research is carried out by research institute and companies in the field. Gaming and mobile industry is the pioneer in IVR research. In the AEC industry, in the recent year we had found out lot of development in the software and hardware for IVR environment. For the study, Unity 3D was used in the development of IVR environment, the software allowed easy integration of the models. Also, for the Head mounted display unit, HTC vive was used. It also allowed easy integration for the IVR model created with Unity 3D. Though the study was limited to transfer of the geometric model with specific software and hardware, the find of this research could be implemented into other tools like Autodesk Navis work or CAVE and Oculus Rift to find out the efficiency of the process used in this study.

The workflow developed through research and testing in the project, was used for converting geometrical data into IVR environment, for checking the level of geometries details and better understanding. Though the workflow lacks the integration of other essential information for the develop of projects in the Planning process. Still it provided better understanding dues to the integration of geometries in the IVR environment. Stream lining the process to with other software and data containing the mechanical and scheduling information, with material integrations directly from the BIM software could be a future aspect of research. This will make the facility planning process easier, time consuming and less error prone for the AEC industry.

As a conclusion, the thesis investigate how IVR prototype could be implemented in the facility planning process. The prototype provide evidence that it is possible to transform 3D models to an immersive visualization system. Though implementing the framework for the use of VR are endless. Also, there are many aspects of the research that could be used as the basis of future research and development.

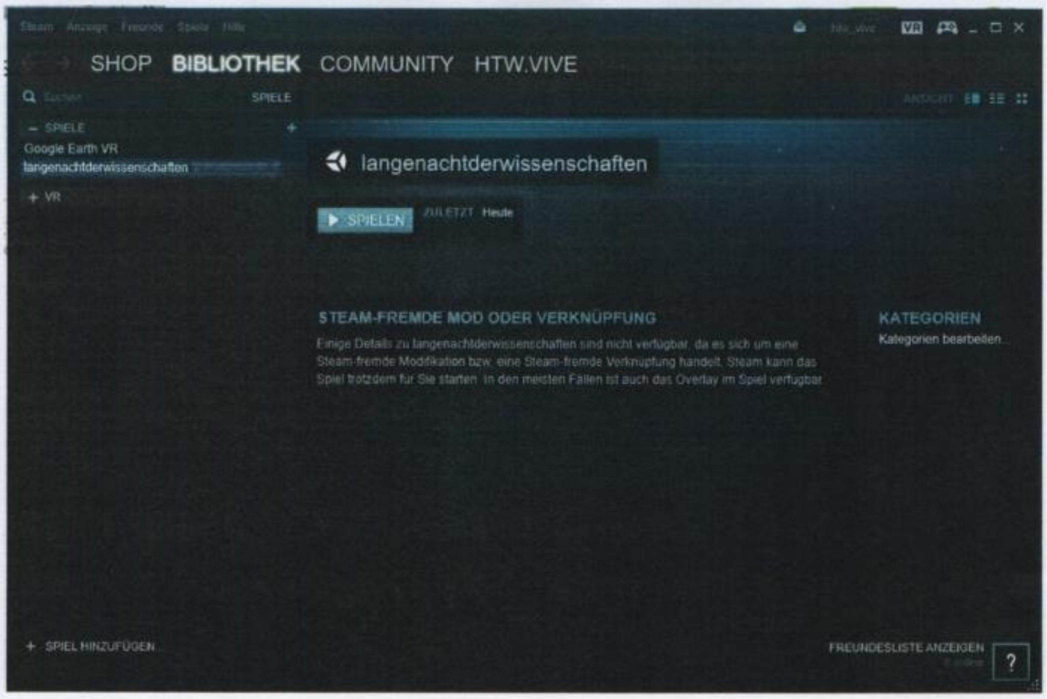
DECLARATION OF AUTHORSHIP

I hereby declare that the attached Master's thesis was completed independently and without the prohibited assistance of third parties, and that no sources or assistance were used other than those listed. All passages whose content or wording originates from another publication have been marked as such. Neither this thesis nor any variant of it has previously been submitted to an examining authority or published.

______________________	______________________
Date	Signature of the student

APPENDIX

Appendix A



Statusfenster sollte sich öffnen.Angezeigt wird das HeadMountedDisplay, 2x Controller, 2x Basisstationenwenn alles grün ist, wurden alle Komponenten initialisiert.
WICHTIG: Die Controller und das HMD müssen im VR-Bereich sein, sonst werden sie nicht erkannt.

3.) Projekte in Steam laden

Im Steam-Client unten links ist der Menüpunkt "Spiele hinzufügen", darauf klicken und die gewünscht .exe suchen.
Standartmäßig ist diese nach dem Build-Vorgang (Siehe Unity5-Projekt erstellen/ 3.)Build) im Projektverzeichniss zu finden.

4.) Projekte starten

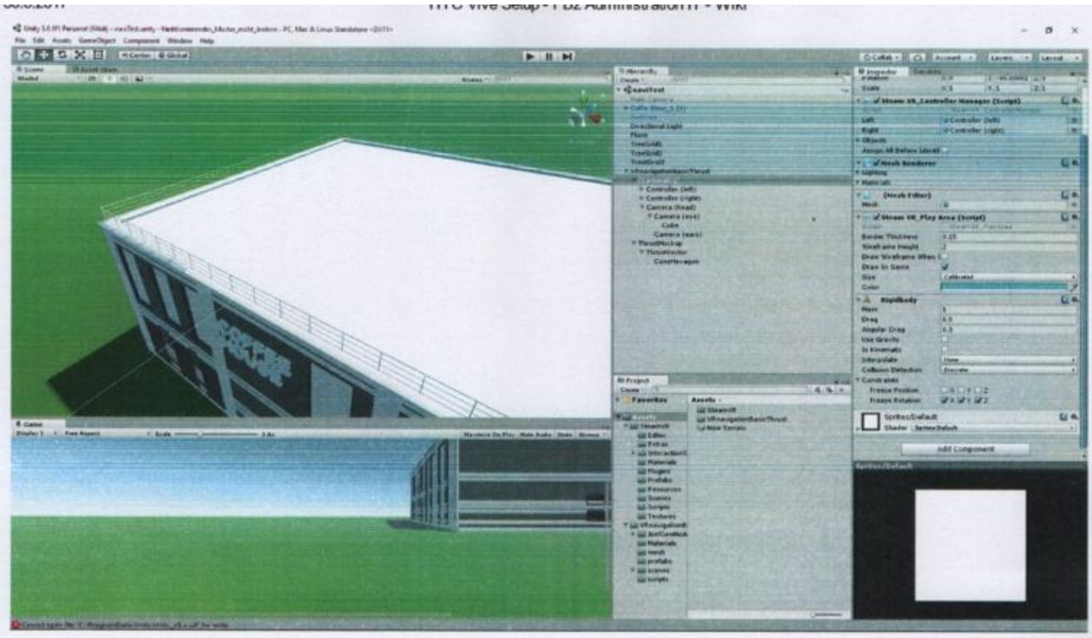
Steam->Bibliothek, links in der spalte werden VR-Inhalte angezeigt, einfach auf starten drücken

Unity5-Projekt erstellen:

1.) Musterprojekt laden

Kopie des Musterprojekts von: "S:\Labor Computer\HTC VIVE" ziehen und anschließend die naviTest.unity-Datei öffnen.

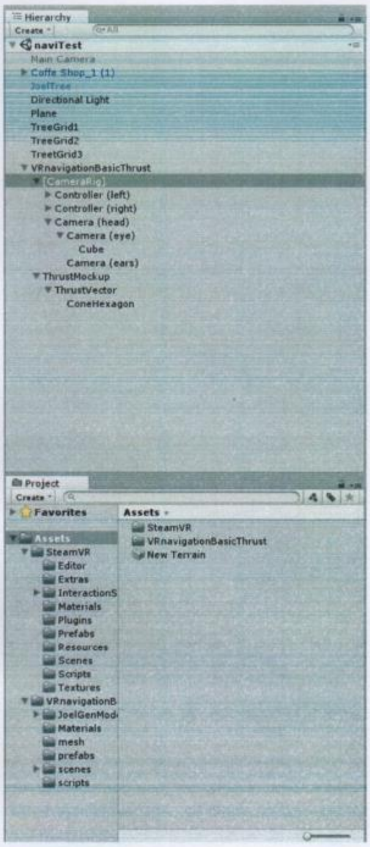
Folgendes Bild ergibt sich dann:



2.) Eigenes Modell laden

Die Datei "Coffe Shop_1 (1)" kann durch ein eigenes Model ersetzt werden.

TreeGrid1 -3 können optional gelöscht werden.



Hierfür einfach das Model (vorzugsweise als .fbx) in das "Asset-Fenster" ziehen,dies kann je nach Modell eine Weile dauern, und anschließend in das "Hirarchy-Fenster".
Jetzt kann das Modell in der Szene plaziert werden.
Nun Shift gedrückt halten und auf den expand-pfeil rechts neben dem Modellnamen klicken, dadurch öffnen sich alle Unterpunkte automatisch.
Dies ist grade bei sehr großen Modellen sehr hilfreich.
Danach alle Teile des Models markieren und auf den Button "Add Component" klicken.
Hier den "Mesh Collider" auswählen und die Eigenschaft "Convex" true setzen. Nun ist es nicht mehr möglich durch das Objekt hindurch zu fliegen/laufen.
Der Mesh Collider sollte bei Türen wieder gelöscht werden.

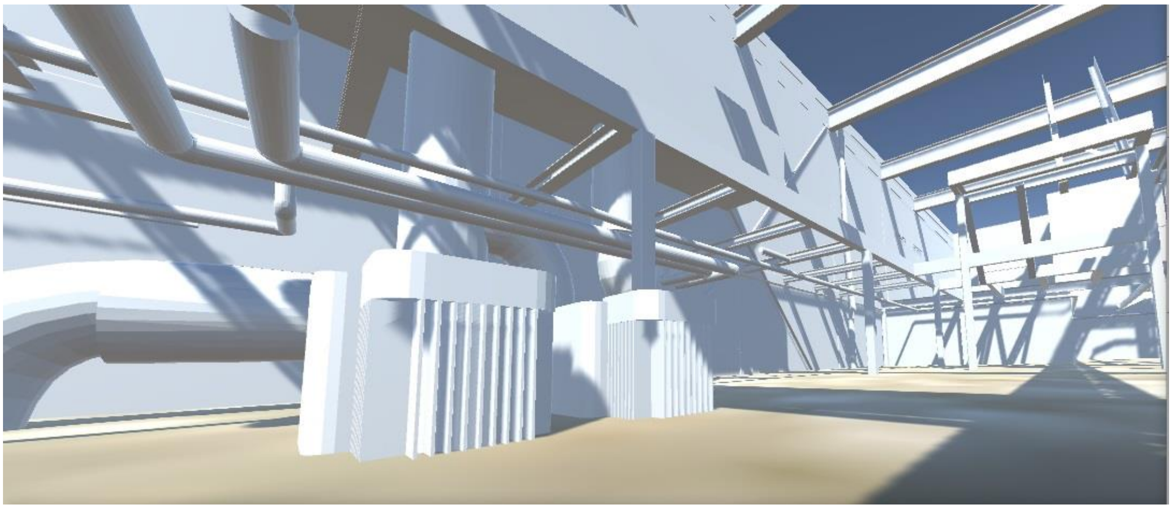
3.) Build

Unter dem Menüpunkt "File" den Eintrag "Build and Run" auswählen und anklicken.
Standartmäßig wird das Fertige Build (besteht aus einer .exe und einem Data-Ordner) direkt in das Projektverzeichniss gespeichert.
Unter "S:\Labor Computer\HTC VIVE" befindet sich in dem Ordner "fertiges build" ein Beispiel.

Um das Projekt in Steam zu laden siehe "Starten der VR-Anlange/ 3.) Projekte in Steam laden".

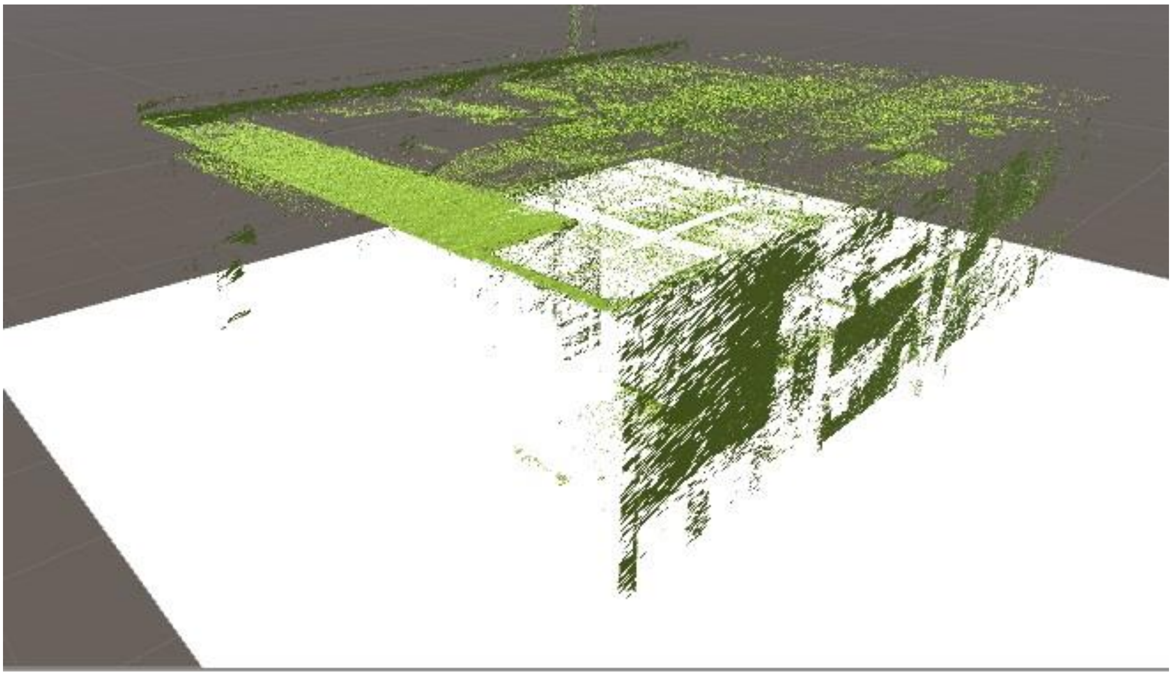
Appendix B

Autodesk Revit IVR model.



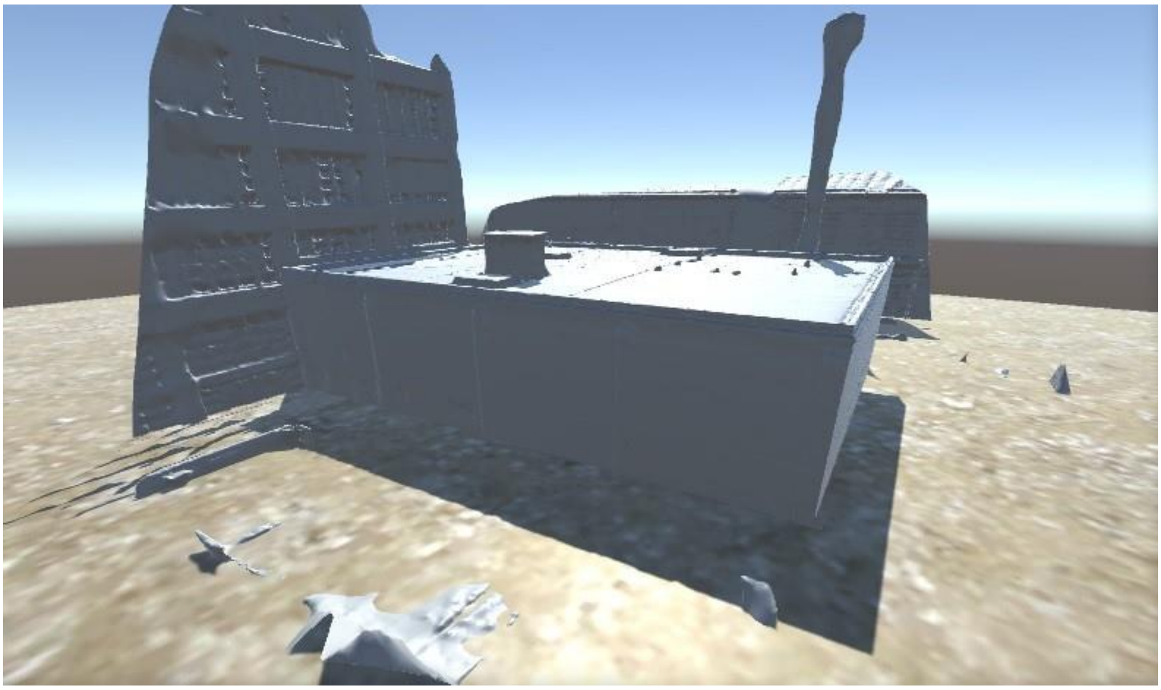
Appendix C

Trimble Realwork IVR Model



Appendix D

Autodesk Recap IVR Model



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