CAD to XR

A guide to the conversion process

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Abstract

While researching our client, the Industrial Reality Hub, we found that many companies own digital versions of their product designs which could be utilized for immersive XR experiences. However, these files have been made in CAD software and are not natively supported by XR applications. To utilize CAD for XR purposes the CAD geometry has to be converted to a mesh. The conversion process is difficult and the quality of the results can vary widely depending on the workflow. We researched software that makes this workflow easier and better. We did this by testing different solutions based on criteria that are relevant for companies like the ones in The Industrial Reality Hub.

The most important criterion being the degree of optimization, where the converted data should be as performant as possible while keeping the visual quality of the original design. The ingenuity of the algorithm determines the maximum degree of optimization possible without sacrificing visual quality. This focus on optimization is necessary for XR, as XR itself is compute-intensive and some use cases on mobile devices have limited hardware capabilities.

During our research we found out that there are not many tools out there that are dedicated to this task. One propertairy application called PiXYZ can perform the complete process, which also has the best tesselator. A free alternative would be FreeCAD and Blender, although the polycount would be double and the workflow is more difficult.

Preface

We thank the members of the Industrial Reality Hub for their help and time. During our company visits we gained a lot of insight into the use cases of CAD for XR experiences. We would like to express our gratitude towards Bas Gunnink from Controllab, who's feedback and patience has been especially helpful for writing this paper. His previous research gave us a head start in identifying possible solutions.

A special mention to Matthijs Van Veen, who guided us throughout the project. His positive attitude and problem solving ability was of huge benefit to the assignment.

Glossary

3D	**T**hree **D**imensional
CAD	**C**omputer **A**ided **D**esign
VR	**V**irtual **R**eality
AR	**A**ugmented **R**eality
MR	**M**ixed **R**eality
XR	**E**xtended **R**eality
UX	**U**ser **Ex**perience
NURBS	**N**on-**U**niform **R**ational **B**asis **S**pline
FPS	**F**rames **P**er **S**econd
GPU	**G**raphics **P**rocessing **U**nit
UV	Two dimensional coordinates of a texture on a 3D mesh
Texture mapping	Method for defining surface information like color, height, reflection, etc
PBR	**P**hysically **B**ased **R**endering
OBJ	Wavefront object format
FBX	Filmbox object format

STEP	ISO 10303 data exchange format for CAD applications
Digital Twin	Digital replica of a living or non-living physical entity (Saddik, 2018)
Pipeline	Automated process that takes an input, performs predefined operations and exports the output
(Surface) Mesh	A 3D (surface) mesh is the structural build of a 3D model consisting of polygons. 3D meshes use reference points in X, Y and Z axes to define shapes with height, width and depth. (Rouse, 2019)
(Mesh) Decimation	Reducing the amount of triangles in a 3D model, while trying to preserve visual quality
Real time (friendly) data	For the purpose of this paper we assume that real time (friendly) data is displayed consistently at least sixty FPS
Polycount	Amount of triangles in a surface mesh
Vertices	A 3D coordinate that defines a single corner of a polygon

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1. Introduction

As 3D computer graphics technology progresses, new ways of interacting with the virtual world open up. Technologies such as augmented reality (AR), virtual reality (VR) and mixed reality (MR) are becoming viable tools for many different industries (Hui-Wen Chuah, 2018). These technologies are known under the umbrella term extended reality (XR) (Paradiso, Landay, 2009) and may prove useful for fields like design, construction, retail and employee training. XR requires real time rendering of 3D objects, which is usually done in game engines such as Unity3D. However, physical products are primarily designed in Computer Aided Design (CAD) software (Andy, 2017). The file formats in which they are saved are not natively supported by game engines (Rouse, 2019). To use CAD designs in a game engine, the file containing the CAD data has to be converted (Siljedahl, 2016).

1.1 Objectives of the client

The main question companies in the Industrial Reality Hub have regarding XR technology usually revolves around: "*How do we showcase a digital twin in XR?*". These product designs range from small to big items like gadgets, furniture, cars or even whole buildings. The reason why companies are interested in XR is due to the nature of "seeing is believing", which XR directly taps into. XR is not a new technology percee (it has been around since the 1990s (Stein, 2016)). However, consumer devices have only been able to pull it off since a few years ago. This is mainly due to the capabilities of last generation hardware finally being sufficient (Anthes *et al.*, 2016), paving the way to mass adoption. There is still a lot of research to be done on user experience (UX) design in XR, which would fall under the same question as "*how to showcase XR*". However, the paper will only cover the conversion process of existing CAD designs for XR purposes.

2. Problem statement

Companies are opening up to XR technology, but have difficulty utilizing their pre-existing product designs. There is a demand for converting product designs, consisting of CAD data, to formats that can be used for XR applications. Unfortunately there is no standard solution available on the market that is capable of performing this conversion perfectly in a few button presses. The conversion process can be tedious, difficult and time consuming. There is a lack of proper documentation on which software to choose, which workflow to apply and how to apply it.

In short, companies have difficulty in understanding the challenges of CAD conversion and therefore lack the knowledge to pick a suitable solution for their particular use case.

2.1 Main and Sub questions

Based on the problems stated above, the main question of the paper is:

- “ *What software and workflow do companies need to optimally use CAD designs for XR applications?* ”

The main question is subdivided into the following supporting questions:

- “ *How to convert CAD designs to a format that is usable for XR applications*? ”
- “ *How is the conversion workflow performed optimally*? ”
- “ *Which software solution should be picked under what circumstances?* ”

This paper answers the main question by answering the supporting ones in their respective order first. “*How to convert CAD designs?”* and “*how is the conversion workflow performed?”* are answered in the theoretical section. “*which software solution should be picked?”* is answered in chapter 4.

2.2 Goal

The paper aims to adequately inform the reader on existing challenges and possibilities of converting CAD files for XR applications, so an informed decision can be made on which solution to pick. The chosen software and workflow should provide the most value for the reader’s use case, meaning the highest outcome quality for the lowest cost possible. Therefore the goal of this research paper consists of two parts:

1. To provide a detailed overview of software solutions that can be picked from, supported by helpful information on core aspects.

2. To explain the necessary steps of a conversion workflow, provided in a tutorial format which is easily repeatable by the reader.

2.3 Conditions of satisfaction

To achieve the two goals stated above, the conditions of satisfaction of these goals are addressed respectively in the following manner:

1. Many programs will be tested for the software overview, including at least one alternative with free licenses. To be able to recommend software, we will visit the member companies of the Industrial Reality Hub to gain insight about their use-cases, needs for specific features, existing solutions and workflows and more. (For an overview of the company visits, please see Appendix C).

2. The conversion workflow is explained in a tutorial format. This tutorial has been repeated by employees of member companies in the Industrial Reality Hub. The employees have different skill levels to ensure that the process is repeatable by anyone.

3. Conversion theory

This theoretical section will provide an overview on the different geometry types and their use cases so that the conversion process becomes more logical. It also provides tips and useful insights for common operations that are performed in any conversion workflow disregarding specific software.

3.1 Geometry types

3.1.1 CAD

CAD software aids the manufacturing process of physical products by digitally defining their parts and geometry, allowing for computer aided machining and assembly. CAD uses Non-Uniform Rational B-Splines (NURBS) to define surface geometry. A NURBS is a mathematical definition of a 3D curve which can be used to describe geometrically perfect surfaces (Schneider, 2009). Basically, CAD is the vector format of 3D models. It allows for complex shapes, with the benefit of having only a single type of surface description (Rogers, 2001). CAD is not meant for visual appearance as it does not support transferring textures (Autodesk, 2017).

In order to exchange CAD data between applications, the data is intermittently stored in a file. There are many different CAD file formats, each supporting different features (Courter, 2013). For the purpose of conversion, a format has to contain information on part hierarchy. The hierarchy splits the object assembly into its components, allowing each component to be individually edited during the conversion process. Although CAD files do not support textures, some do allow basic color information. This can be useful for conversion pipeline configurations where textures are assigned based on the colors in the CAD files.

For simplicity, the STEP file format is assumed as the default file format when importing and exporting CAD data by this paper. STEP is widely supported between CAD software and has all of the desired features like part hierarchy and coloring (CADExchanger, n.d.). In the scenario where CAD files are given in another format, it is recommended to either convert it to STEP or check the compatibility with the conversion software of choice.

3.1.2 Mesh

The way geometry is defined in game engines is quite different from CAD. This is due to game engines having to render geometry at high frame rates to ensure smooth looking animations (Brunner, 2017). This is done through hardware acceleration using a Graphics Processing Unit (GPU). These dedicated hardware units can display millions of surfaces within milliseconds. However, they are only capable of rendering surface meshes (GLprogramming, n.d). The geometry of a mesh consists of many polygons (usually triangles), which in conjunction are used to approximate curved surfaces. The polygons are defined by their corners (i.e. vertices) which can be shared between multiple polygons in the same mesh. Usually these vertices and their associated polygons are saved as OBJ or FBX file format.

3.2 CAD to 3D model conversion

A general conversion workflow consists out of multiple steps that have to be performed in order. The flow chart below gives a simplified overview.

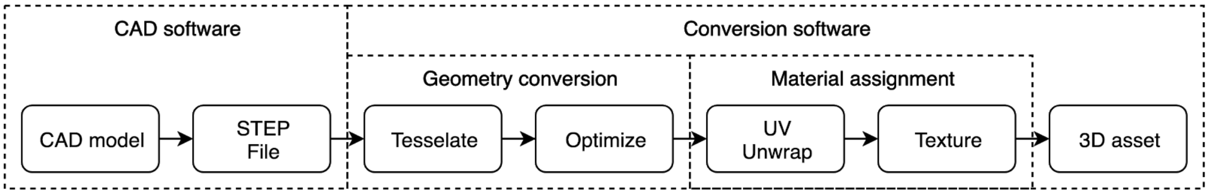

Figure 1. Generalized workflow of a CAD model to 3D asset conversion.

These steps can be seen in all conversion workflows in any converting solution. However, how all of these steps are performed differs vastly between software solutions. Not all software is capable of doing all of these steps, and some are better at certain steps than others.

3.2.1 Geometry conversion

Within the geometry conversion process CAD geometry is converted for use in a game engine through a process called triangulation. Triangulation involves approximating NURBS geometry to a mesh (Siljedahl, 2016). Triangulation is the critical step that determines how well the final 3D model will look and perform in real time applications. Usually conversion software offers parameters that influence the triangulation process, where the parameters represent conditions like the maximum size or angle before a surface subdivided into more polygons. Ideally the converted mesh has the highest quality possible while not impairing performance in the game engine because of too many polygons. The performance can be measured by checking how often the application is refreshed on the screen (usually referred to as refresh rate or frame rate) which is measured in frames per second (FPS). The frame rate should stay above a certain threshold to ensure a smooth experience. For applications that are displayed on a conventional screen, a framerate of thirty is minimal and sixty or more is optimal. For VR, 60 FPS is minimal and 90 or more is optimal (Oculus, n.d.). However, the framerate is highly dependant on context and difficult to predict due to many factors that influence it. This is why it is recommended to stay on the safe side by a large enough margin to prevent even the slightest drops below the threshold.

In order to convert models with a proper balance between quality and performance, it is important to consider the most influential factors for framerate like target platform and scene complexity. It is recommended to research and/or stress test the target hardware to see where the limits lie. Trial and error with different quality models and amount of models on screen may provide useful insights. With that in mind, the following tips will improve the final performance of the converted 3D model:

1. Reduce the amount of detail considering the use case of the model. For example: if the model is only used in the background, it does not need the same quality as models that will be visible from close by.

2. Parts that are not relevant to the final look like nuts, bolts and internal geometry that is invisible from the outside should be removed.

3. Not all subcomponents have and/or need the same kind of complexity. Use different conversion settings on different subcomponents for an optimal result.

The final result after the geometry conversion is an optimized mesh that has the same part hierarchy as the original CAD file. However, this hierarchy can be changed or merged. The mesh can usually be exported in OBJ format, which can be imported in 3D modeling software for the material assignment.

3.2.2 Material assignment

A material is applied on the surfaces of the mesh to give the final 3D model a realistic look. Materials consist of one or more textures (usually referred to as maps), which are used to color the pixels of the associated polygons. These textures are applied to the mesh through a technique called UV mapping, where a material is wrapped around a mesh. The UV information is saved in the mesh data, allowing for the material to be easily swapped. Advanced materials that consist of multiple texture maps are used for physically based rendering (PBR), which makes for a realistic looking end result.

Materials are applied to the converted mesh through a process called UV mapping. Because the mesh kept its hierarchy, separate materials can be applied to different subcomponents. This process is quite easy as most 3D software has auto UV mapping functionalities (AutoDesk, 2019), which only require the user to determine the density of the material. The downside of auto UV mapping is that it does not allow aligning the material in a specific way, for example with a wood material that has a grain.

There are two major export file formats that are suited for real time applications, which are OBJ and FBX. OBJ only saves the mesh and its UV map, while FBX can also include the materials and their associated textures (Houston, 2019). The main difference between these two file formats is that with OBJ the textures have to be provided separately to the game engine, while FBX can include everything in one file.

4. Software analysis

Based on the preliminary theory provided in chapter 3, different software (and combinations thereof) have been analyzed. The analysis is based on criteria that are relevant to real use cases of companies in the Industrial Reality Hub. An overview of these use cases can be found in Appendix Section C. The analysis enables the reader to make an informed decision on which software to choose based on the unique needs of the reader's use case. Examples of these criteria are the degree of optimization, pricing and ease of use. The paper aims to provide both a technical analysis as well as an unbiased opinion as not every aspect of the software is measurable. An example of this is conversion time, which depends on the user's familiarity with the software and the final goal.

4.1 Research method

our research method focused on consistency and repeatability. To ensure that the results are comparable to one another, the same 3D model has been used to benchmark the degree of optimization for each solution. The model in question features is a power socket with a variety of surfaces e.g. tubes, curved plates, holes, screws, etc. This ensures that the benchmark is relevant for most real-life scenarios.

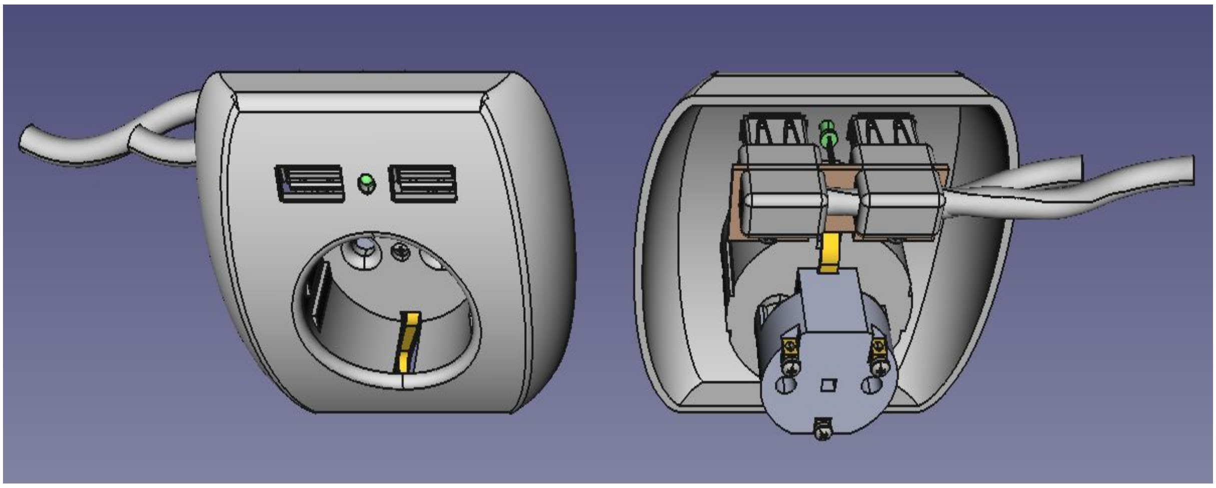

Figure 2. CAD Benchmark model as NURBS in FreeCAD.

4.2 Analysis criteria

4.2.1 Geometry and material capabilities

Not every program is capable of doing the complete conversion process. Most traditional CAD programs can only convert CAD geometry to a mesh, while some traditional 3D modeling programs cannot load CAD geometry but are great for applying materials. Using a combination can work, but may not be as user friendly as single application solutions.

4.2.2 File formats

There are many CAD file formats available. Although using STEP is recommended format, it may sometimes be helpful to load specific formats due to them having additional information that might be relevant for the conversion process.

4.2.3 Additional features

Converting the geometry and UV mapping the model are the absolute base requirements for the conversion process. However, some software has features that are convenient or allow for a greater degree of optimization. Great examples of these are auto mesh repair and decimation, respectively.

4.2.4 Test triangle count

The performance metric of a converted CAD model depends on the final triangle count of its mesh. The paper aims to have comparable visual quality and then measure the triangle count. As visual quality is subjective, the paper provides screenshots in Appendix D.

4.2.5 Ease of use

Ease of use determines many steps the workflow requires, how many parameters are adjustable and how intuitive the UI is. A higher ease of use means less labour per conversion, which saves companies labour costs and should therefore also be taken into account. The more conversions have to be done, the more important this criterion is.

4.2.6 Conversion time

Together with ease of use, conversion time describes how long it takes for a single model to be converted. Since the required amount of time highly depends on the user's familiarity of the program and the final goal, this cannot be measured using a number. Instead a description is given with a rough estimate.

4.2.7 License cost

Since most of the researched companies from Appendix C are small companies with limited budget, license cost of the software is a notable factor in deciding which solution to choose. Certain software have been excluded from the analysis due to being too expensive. The most notable example being Simplygon, which is $30.000,- per title per year.

4.3 Results

Program	G	M **	Import file support*	Export file support*	Additional features	Test triangle count
PiXYZ			STEP, IGES and more (PiXYZ, 2018)	OBJ, FBX, GLTF, DAE	Decimation, mesh repair, internal geometry removal, and many more convenient features.	6.400
FreeCAD			STEP, IGES and more (FreeCAD, n.d.)	OBJ	Mesh repair	14.327
Blender			OBJ, FBX	OBJ, FBX, GLTF, DAE	Decimation	11.658
Cinema 4D			OBJ, FBX, IGES and more (Maxon, n.d.)	OBJ, FBX, GLTF, DAE	Decimation, internal geometry removal	11.273
AutoDesk Maya			STEP, FBX, IGES and more (AutoDesk, 2019)	OBJ, FBX	Decimation	32.460
UE4 Datasmith			STEP, IGES and more (Unreal Engine, n.d.)	N/A		11.545

Table 1.. Technical analysis; G = Geometric conversion; M = Material assignment.

*Only noted relevant file formats.
**Material assignment includes automatic UV mapping.

Software	Ease of use	Conversion time	License cost
PiXYZ	Dedicated program for CAD conversion. Great to use, but needs more time to mature since it is quite new.	Lowest of them all, and the easiest to automate using scripts.	€2.000,- per year for studio. €10.000,- per year for pipeline.
FreeCAD	Free CAD modeller with the ability to convert to meshes. A bit more complex.	Needs a lot of trial and error to find the right settings for mesh conversion. Cannot do the material assignment.	Free.
Blender	Free 3D modelling software. Needs a lot of expertise to be worked with properly.	High, due to the need for converting the geometry first in other free software like FreeCAD. Geometry also has to be normal mapped.	Free.
Cinema 4D	Popular 3D modelling software. Easier than the FreeCAD/Blender combination, but it is still difficult to operate. Easier than Autodesk Maya.	Medium, due to the need for more operations and knowledge.	€3.451,- for permanent License. €713,88 yearly.
AutoDesk Suite	Contains many options to convert NURBS. However, these are very complex and require a lot of in-depth knowledge.	High, due to the need for more operations and knowledge. The operations themselves also take more time.	$2.825,- per year per seat.
UE4 Datasmith	Integrated import tool in the Unreal Engine 4. Very straightforward to use.	Much lower conversion time than the 3D modelling software due to its ease of use.	Included in Unreal Engine.

Table 2. Auxiliary information.

Software	**Scripting Language**
PiXYZ	Python
FreeCAD	Python
Blender	Python
Cinema 4D	Python/C++
AutoDesk Maya	Python/Maya Embedded Language (MEL)
UE4 Datasmith	Python/Blueprint

Table 3: Scripting languages per software

5. Discussion

The most unexpected discovery made during the analysis is the lack of software dedicated to the research goal of converting CAD models for real time applications. During our field research about the use cases of companies it became evident that there is a big market for a convenient and optimized solution. Our client companies were restricted to the region of Overijssel in the Netherlands. This indicates that there are many more companies around that run into the same issue.

PiXYZ is the only dedicated software for CAD conversion and preparation we found. Initially we expected that there would be competition between the software, but most established applications offer the CAD conversion as a side feature, which reflects in the quality. Their feature sets are huge, but make it difficult and cumbersome to use since we only need a fraction of their functionalities.

An additional unexpected discovery was the lack of research into the CAD conversion for real time applications. Since the conversion process is a crucial part for the emerging XR industry we expected to find already existing research we could build upon. The lack thereof inspired us to do this research paper, hopefully providing a foundation for future research.

An expected finding was the lack of a standardized system and scalability in the industry. Most companies that were interviewed relied on the individual expertise of few employees to convert CAD models (See Appendix C). Knowledge about the problem is scattered, leading to solutions that are inefficient, expensive, time-consuming and barely scalable. This exact situation lead to the inception of this research project.

As seen in Table 1, the best tessellation algorithm currently available is PiXYZ's. According to Metaverse Technology, the creator of PiXYZ, the algorithm has been developed from the in-house and therefore offers a better performance than general purpose solutions (See Appendix C). Testing concluded that their program has the fastest and easiest workflow, resulting in an optimized mesh with ~50% fewer triangles than other software (6.400 triangles vs. ~11.000 triangles).

Datasmith, Unreal Engine's integrated import tool, has a surprisingly good tessellation algorithm. While Unreal does not have any optimization tools like decimation, the algorithm itself produces results that are comparable to Cinema 4D or the FreeCAD/Blender combination (See Table 1). Due to being integrated with Unreal Engine 4 the user has access to the engine's texturing capabilities.

During the course of this research, many more software solutions have been considered but failed at one or more criteria, resulting in being excluded. For more information about their exclusion, please refer to Appendix B.

5.1 Additional features

Apart from the general rating criteria, there are certain features that stand out and are useful in specialized cases.

PiXYZ's internal geometry removal tool takes pictures from different angles around the converted CAD model to determine triangle faces that are not visible. By deleting all the internal triangles, some CAD models can be optimized, especially if they have complex interiors. During testing the benchmarked model could be consistently reduced from about ~9.000 triangles to about ~7.000 triangles, reducing the model's polycount by an average of 28% without impeding visual quality. This is especially useful when optimizing for low computing power platforms like mobile phones. The feature is not perfect yet, as it sometimes results in a broken mesh.

Another outstanding feature is the scriptability of all analyzed software. By having a scriptable pipeline, an automated process can be created that is able to process a large volume of files simultaneously. This is crucial to enable rapid prototyping. As illustrated in Table 3, Python is being used consistently throughout all analyzed software. This makes modifying the pipeline rather easy because it can be built in a single scripting language. However, some commercial products choose to price their pipeline capable licenses at up to ten times the normal price, making them unsuitable for smaller businesses.

6. Conclusion

As shown in Table 1, PiXYZ is the overall best software to use for the conversion process, due to its superior optimized results and easy workflow when compared to other solutions. PiXYZ offers a variety of useful features, has the fastest conversion functions and is easier to use than most other solutions (See Table 2).

The combination of FreeCAD and Blender provides a free alternative, but requires significantly more expertise to use. Because two programs are needed to complete the conversion process, complexity increases and time efficiency decreases. The optimization of the end result is similar to other 3D modelling software analyzed, such as Cinema 4D or AutoDesk Maya. These programs also require a lot of expertise to use efficiently and they are rather expensive, as evidenced in Table 2. Furthermore, it is hard to get good optimization results out of the box and time has to be invested to find the correct parameters. In the case where many models have to be converted, it is suggested to go for PiXYZ.

Datasmith offers a good out of the box solution for the conversion process, but can only be used inside of Unreal Engine. It also lacks further optimization techniques after the tessellation process.

7. Recommendations

For future research it is recommended to:

- Implement a pipeline that automates advanced features like material designation.
- Investigate what the ideal tessellation algorithm would be/what makes a tessellation algorithm suitable for this use case.
- Research into solutions for specific CAD software. This report focused on general CAD conversion, but there may be better solutions available exclusively for Solidworks, Rhino, AutoCad, etc.

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Appendices

Appendix A: Introduction to each piece of software

A.1 PiXYZ

PiXYZ is a specialized CAD data preparation and optimization tool (PiXYZ, 2019) by the French company Metaverse Technologies. It includes a custom, in-house built tessellation algorithm and other advanced features like automatic UV unwrapping, additional mesh decimation and removal of internal geometry.

A.2 FreeCAD

FreeCAD is an open-source parametric 3D modeler made primarily to design real-life objects of any size (FreeCAD, 2019). It offers many CAD editing tools, a selection of triangulation algorithms (FreeCAD custom, Mefisto, Netgen) and a broad selection of import/export formats.

A.3 Cinema 4D

Cinema 4D is a 3D modeling software developed by MAXON Computer GmbH in Germany. Due to its support of CAD file formats like STEP, IGES or SolidWorks and its generic 3D modeling functionality like mesh decimation, UV unwrapping, texturing and animations, it is capable of handling the entire conversion process.

A.4 Blender

Blender is the free and open source 3D creation suite maintained by the Blender Foundation. Its 3D modeling capabilities are on par with licensed applications like Cinema4D or Maya. However, it has no integrated importer for CAD file formats. These files have to be converted into a suitable format like OBJ or FBX by another program, like FreeCAD.

A.5 AutoDesk Maya

The AutoDesk Maya features a wide spectrum of 3D applications. Since all the software comes from the same company, the vertical integration of the individual pieces is excellent, enabling companies to have their entire workflow within the suit. From creating the CAD model itself to converting it to a 3D file format, as well as optimizing and texturing it, all of it can be done within the AutoDesk Maya.

A.6 DataSmith

DataSmith is a collection of tools that enable importing content into Unreal Engine, including CAD file formats. For importing CAD models DataSmith offers an integrated tessellator which produces.

Configuration: Chord Tolerance | Max Edge Length | Normal Tolerance	**Number of Triangles**
First try: 0,1 | 0,1 | 10°	125.000
Second try: 0,4 | 0,4 | 40°	17,978
Third try: 0,5 | 0,5 | 50°	13.084
Fourth try: 0,6 | 0,6 | 60°	10.804
Fifth Try: 0,7 | 0 ,7 | 70°	9.622

Table 4: Datasmith benchmark results

Appendix B: Honorable mentions

B.1 CADExchanger

CADExchanger offers offline and online solutions to exchange 3D data, including converting the data. The pricing for their software is relatively inexpensive, 449€ for a permanent license, and their customer support is used as one of their main advertisement features. The quality of their conversion algorithm is lacking however. Compared to solutions like PiXYZ or Cinema 4D their algorithm results in twenty to thirty percent more triangles for the same visual quality. Because the conversion quality is the most important feature, CADExchanger was not considered a candidate for the final software analysis.

B.2 InstaLOD

InstaLOD is a polygon optimization software. Their features seemed like a good fit for this research, as they offer CAD tessellation, Polygon optimization, Occlusion culling and integrated UV tools. However due to the expensive license (6.000 euros per seat per year) and because we did not receive a free trial version from them for the analysis, this software was disregarded.

B.3 Rhino6

Rhino6 is a 3D modelling environment that enables the user to use a variety of 3D modelling techniques, but primarily uses NURBS curves. Rhino is used for making CAD designs, 3D printing or similar fields. It offers a large number of plugins for functionality that is missing in the base program. Rhino is not particularly suited for the conversion process as it only provides limited conversion capabilities. These disadvantages could potentially be offset by the previously mentioned plugins, but the increasing complexity and risks of relying on plugins developed by third party developers and the inherently limited capabilities of Rhino as a conversion program, make it unsuitable as a candidate and thus is not included in the analysis.

B.4 Vuforia

Vuforia is the product of PTC and is marketed as a scalable AR solutions for enterprises without the need for extensive programming (PTC, 2019). We got the chance to see this software in action at CAD Services, where they use Vuforia to create AR applications that display CAD models you can download, to see any model anywhere. We decided to exclude Vuforia from our list of software, because their use-case is too specific. While we want to provide a solution that ultimately outputs a 3D file that can be used in any scenario, Vuforia is an integrated development environment and does not provide much value if you do not want to create an AR application. Additionally the tessellation algorithm used is underperforming and hard to control, e.g. the user has limited influence on the outcome. During our visit at CAD Services we were presented with a model that had one and a half million triangles after being put through Vuforia's tessellation, which is unfeasible if more than one of these objects have to be in a scene at any given time.

B.5 Keyshot

Keyshot is a 3D rendering software, capable of rendering CAD models from a variety of software: Rhino, Solidworks, SketchUp and more. When importing a CAD model into Keyshot, it automatically tessellates the model into a polygon model. As a 3D renderer, it also supports PBR materials, lighting and animations. However, all of this information is stuck in Keyshot as the only exportable 3D format is OBJ, which does not support light information, material information or animation information. This restriction, combined with the fact that we had already tested vastly better solutions, made us exclude Keyshot as a relevant software.

B.6 OpenCascade

OpenCascade offers an array of software dedicated to 3D preparation and visualization. Their preparation product, CAD Processor, is used to simplify CAD data to be used in downstream engineering use. However compared to other solutions like PiXYZ and Cinema 4D, the quality of the tessellation and decimation functions are underperforming massively. Since they also use their own UI, employees would have to get training to use the software. Due to those reasons, we chose to disregard it as a software candidate.

B.7 Simplygon

Simplygon is Microsoft's 3D optimization software. It is a market leader and widely used in the production of high-budget video games. The quality of the reduction functions are unmatched and recently Microsoft announced that it will support CAD files soon. The only downside is the massive license cost of thirty thousand euros per project per year, which is completely unfeasible for small companies. Because the software did not match the use cases of our clients, we excluded it as a software candidate.

Appendix C: Company visit/interview notes

C.1 Setup

- Use case
  - Method (AR/VR)
  - How many models per month
  - Team size
  - Budget
- Current workflow
  - Pipeline
  - Software
- Would value from
  - Deliverables
- Additional info

C.2 Control Lab

- Use case
  - VR only (PC, no hardware limitations)
  - Few models per month
  - Only one team member working on conversion (Bas Gunnink)
- Current workflow
  - By hand (Maya)
  - No pipeline
- Would value from
  - Software recommendation
- Additional info
  - Has done extensive research on conversion
  - Not their main business

C.3 Recreate

- Use case
  - VR/AR/MR
  - Many models per month
  - Multiple team members (including engineers)
  - medium/high budget
- Current workflow
  - Custom pipeline
    - “The Hedge”
    - Online
    - For customers
    - No texture support
    - Somewhat slow but has a queue
  - No information on used software
- Would benefit from
  - Omnidirectional pipeline

    - (free) software recommendations
- Additional info
    - High interest in hololens
    - Has experience with real AR projects
        - Housing
        - Civil

C.4 The Virtual Dutchmen

- Use case
    - VR (in-headset, limited performance)
    - Many models per month from customers
    - Multiple team members (Richard)
    - Medium/high budget
- Current workflow
    - Manual work and some scripting
    - No pipeline, although interested
    - Would like to have clients figure it out themselves
- Would benefit from
    - Documentation for their clients
    - Software recommendations
    - Use case
- Mainly aims to let customers resolve their CAD to VR issues by themselves
    - Would benefit from proper documentation on CAD conversion
- Does some conversion themselves
    - Done with scripts in Autodesk
    - Richard can tell us what issues they run into
- Gets files from lots of different source 3D software
    - Autocad
    - Sketchup
    - Revit
    - Solidworks

C.5 Twinsense

- Use case
    - Has a history of both VR and AR projects related to marketing and advertising, but wants to shift their focus on industry applications
    - Varies greatly depending upon the client. Generally about 10-20 CAD models per month
    - One Artist responsible for the conversion, two programmers for the applications
    - Low budget (> ~2000€)
- Current workflow
    - No pipeline in place
    - Manual labor done mostly in PiXYZ and Maya. They use a lot of time to bring the CAD models to their quality standards.
- Would value from

    - Efficiency improvements for their workflow, partial automation
- Additional info
    - The conversions per month are semi unreliable

C.6 CAD Services

- Use case
    - AR
    - Up to ten conversions per month
    - One employee, with an enthusiastic supervisor
    - Elaborated upon in next section
- Current workflow
    - No pipeline in place
    - Extensive use of Vuforia. Apparently they are a licensed user/reseller of Vuforia, which is why they use it as their main AR software with little intent to switch
- Would value from
    - They did not mention any specific problem area, but their optimization process is virtually non-existent, so they would benefit from more information about conversions.
- Additional info
    - The sole employee working on the AR project formerly worked at Benchmark, hence the similarities in software used

C.7 Benchmark

- Use case
    - AR
    - Currently put the AR project on hold due to lacking expertise, so zero
    - Zero employees working on the project, formerly one intern.
    - Large budget, works with Hololens and custom hardware components
- Current workflow
    - No pipeline in place
    - Relied extensively on Vuforia, fast iterations but low quality conversions
- Would value from
    - Since they are not currently having any VR/AR project they do not have specific problem areas to solve, rather they would benefit from a general report
- Additional info
    - The employee formerly responsible for Benchmarks AR efforts now works at CAD services, hence the similarities in software used

C.8 Metaverse Technologies France

- Use case
    - Service provider (PiXYZ software)
    - ~Twenty employees, still growing
- Current workflow

    - /
- Would value from
    - Free marketing from us
- Additional info
    - They have developed their algorithm in-house making it closed source and impossible to analyze but research indicates it is better than open source solutions
    - We asked if they considered to offer PiXYZ, especially the pipeline version, as a service for smaller companies. They said that the pipeline license is made for massive clients (like BMW or similar companies) and that they are currently trying to develop a service. They noted that they struggle a lot with finding a solution that is win-win for both parties.
    - When asked about some features we thought were lacking or desired (like a texture editor), all of those were included in an internal development roadmap, indicating that the product is only getting better the more time they have.

Appendix D: Conversion Screenshots

D.1 PiXYZ

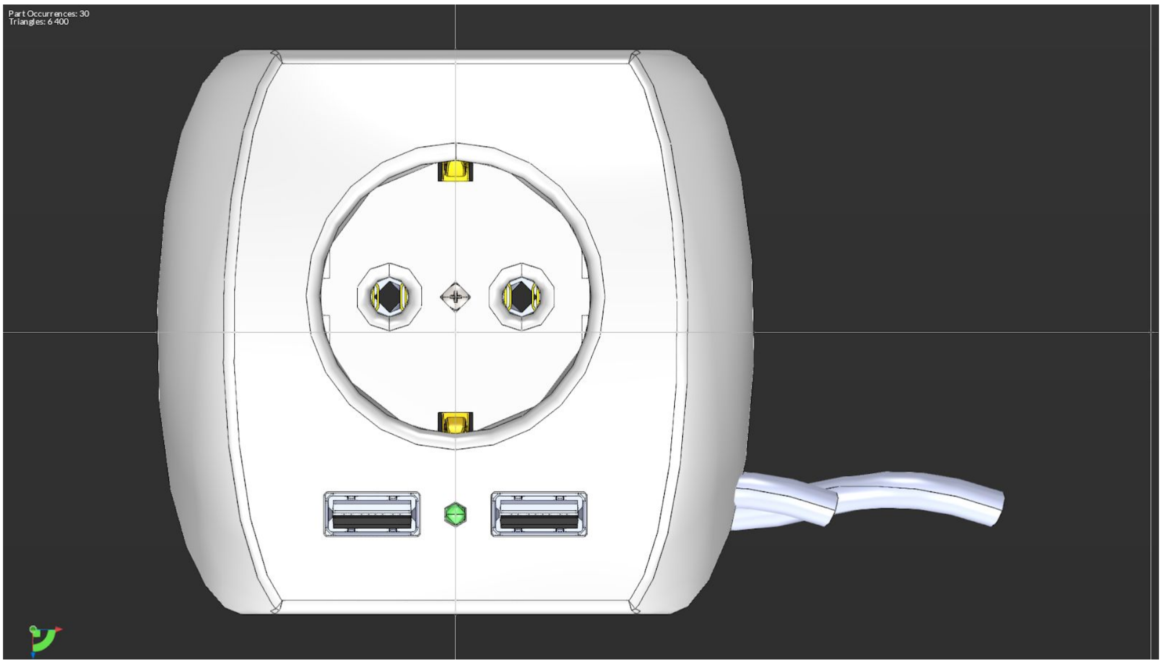


Figure 3: PiXYZ Tessellated and Shaded model

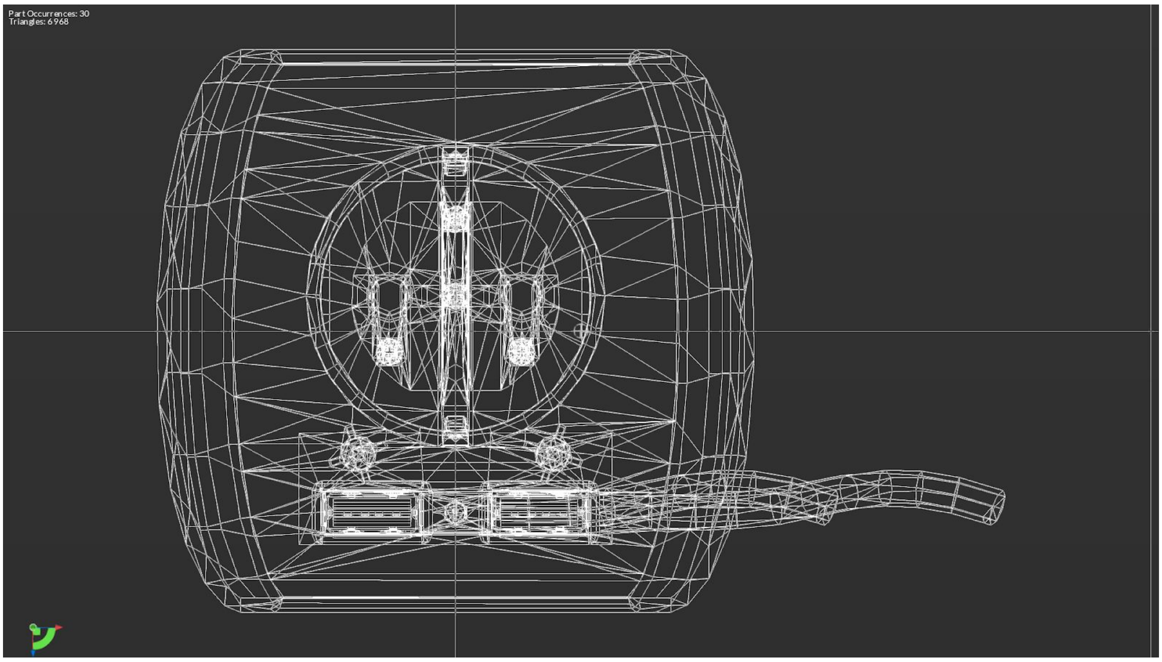


Figure 4: Wireframe of the previous model

D.2 FreeCAD

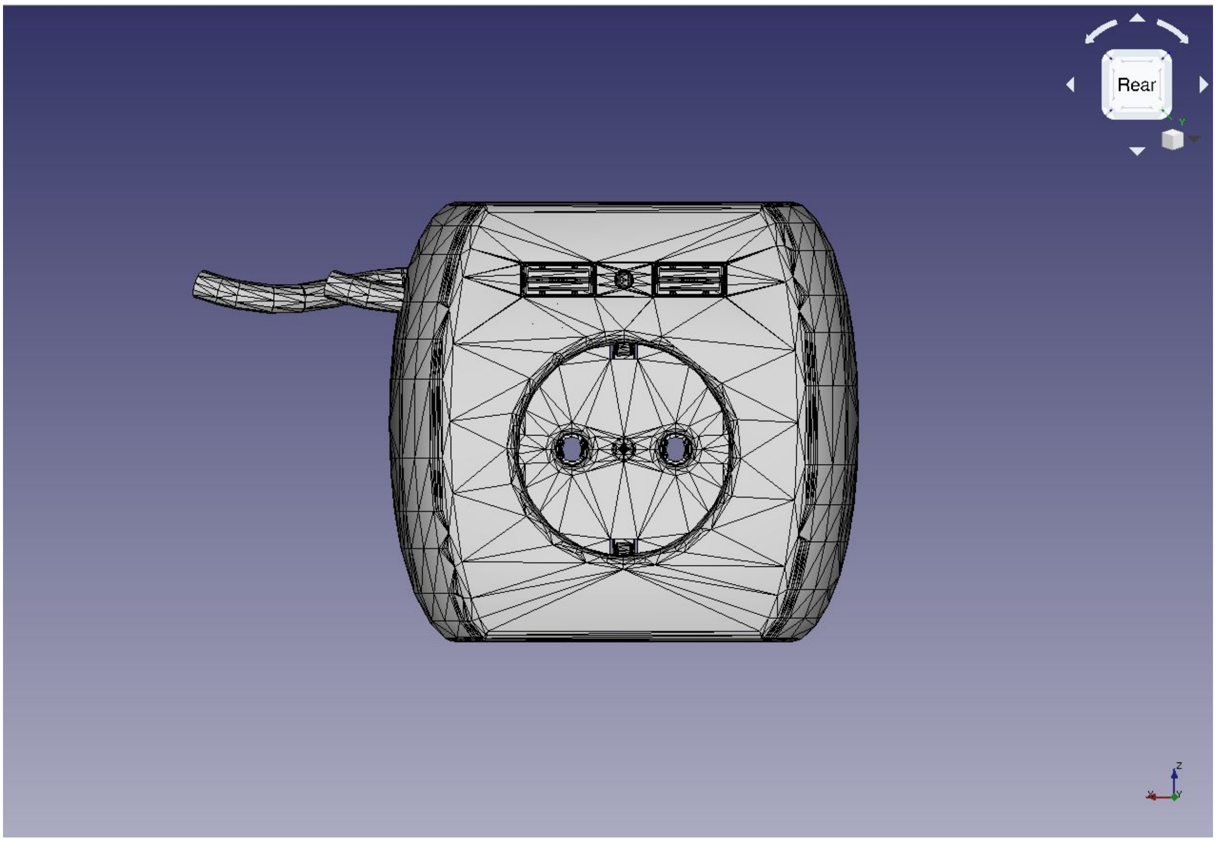


Figure 5: Tessellated model in FreeCAD

Figure 6: FreeCAD Polycount

D.3 Blender

Figure 7: Tessellated and Decimated model in Blender

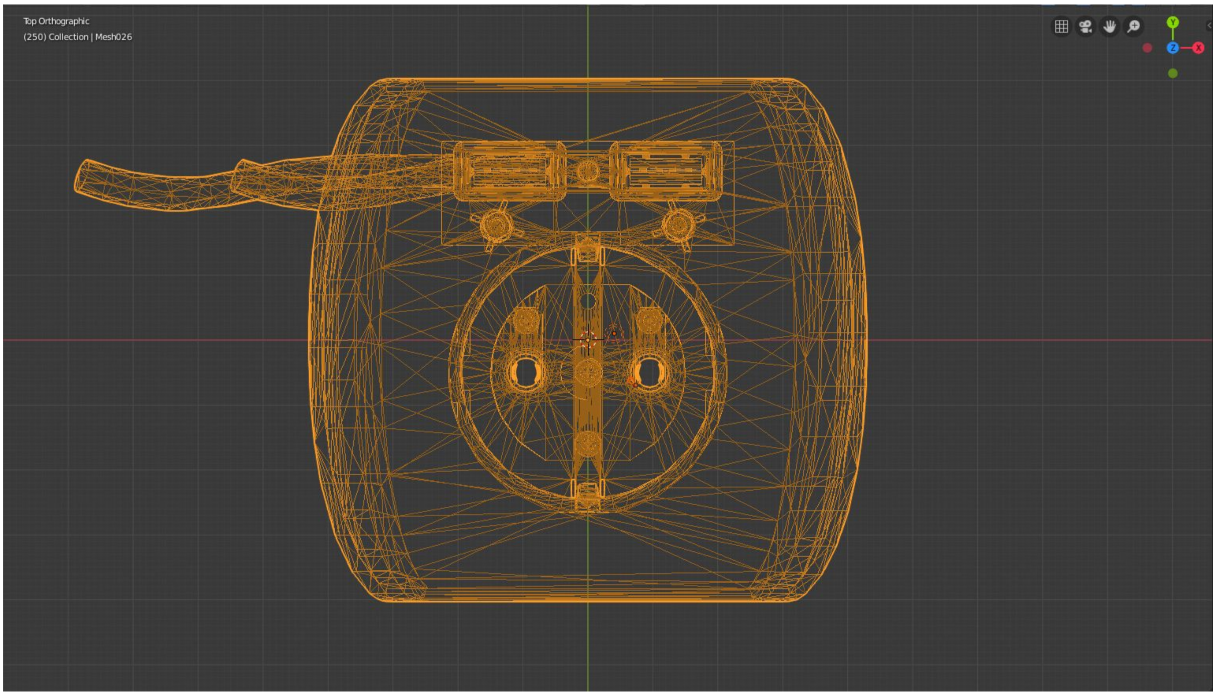


Figure 8: Wireframe of previous model

Figure 9: Blender polycount

D.4 Cinema 4D

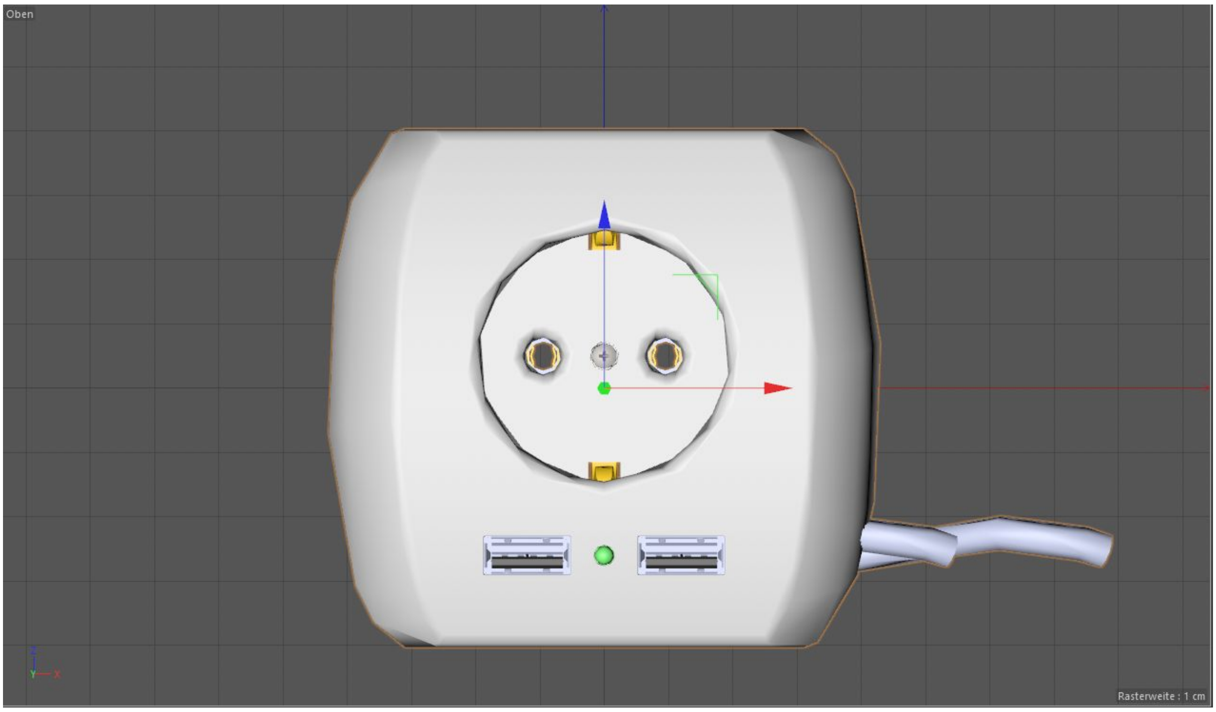


Figure 10: Tessellated with low preset and Shaded in Cinema 4D

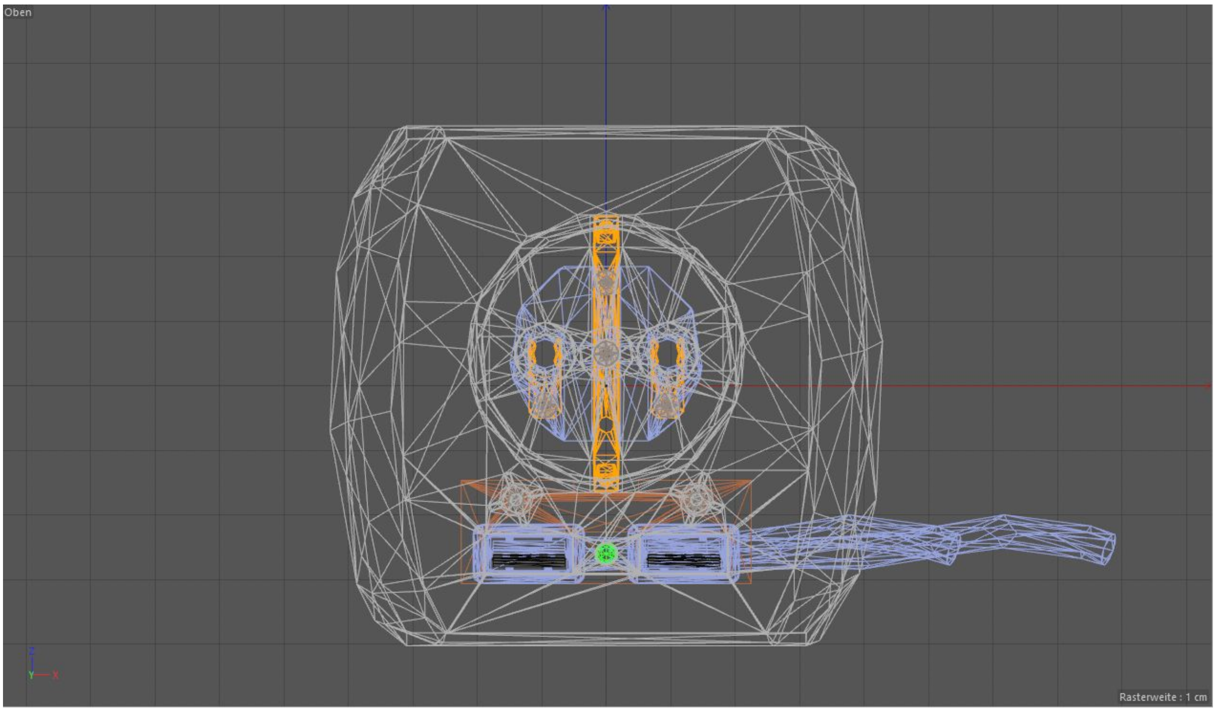


Figure 11: Wireframe of previous model

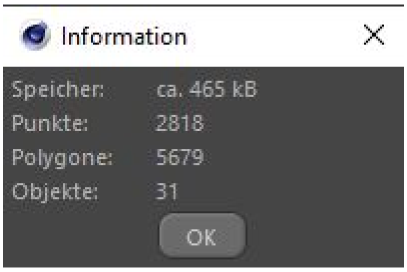


Figure 12: Polycount for low preset tessellation

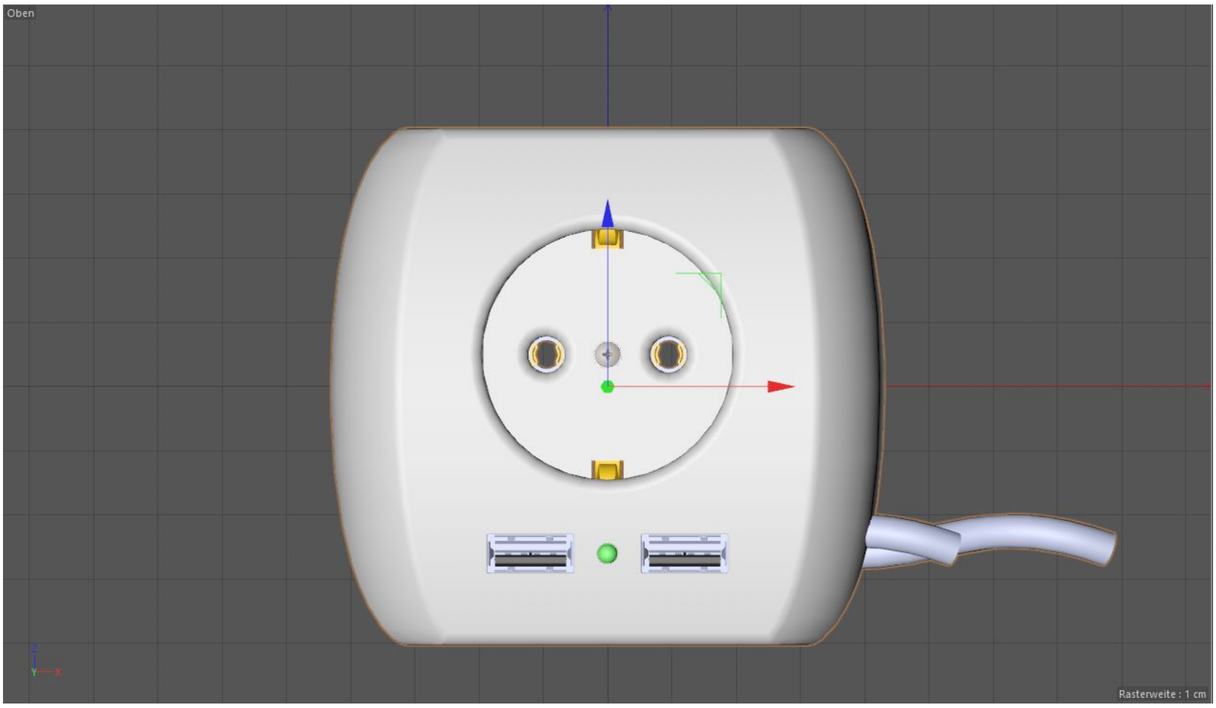


Figure 13: Tessellated with medium preset and Shaded in Cinema 4D

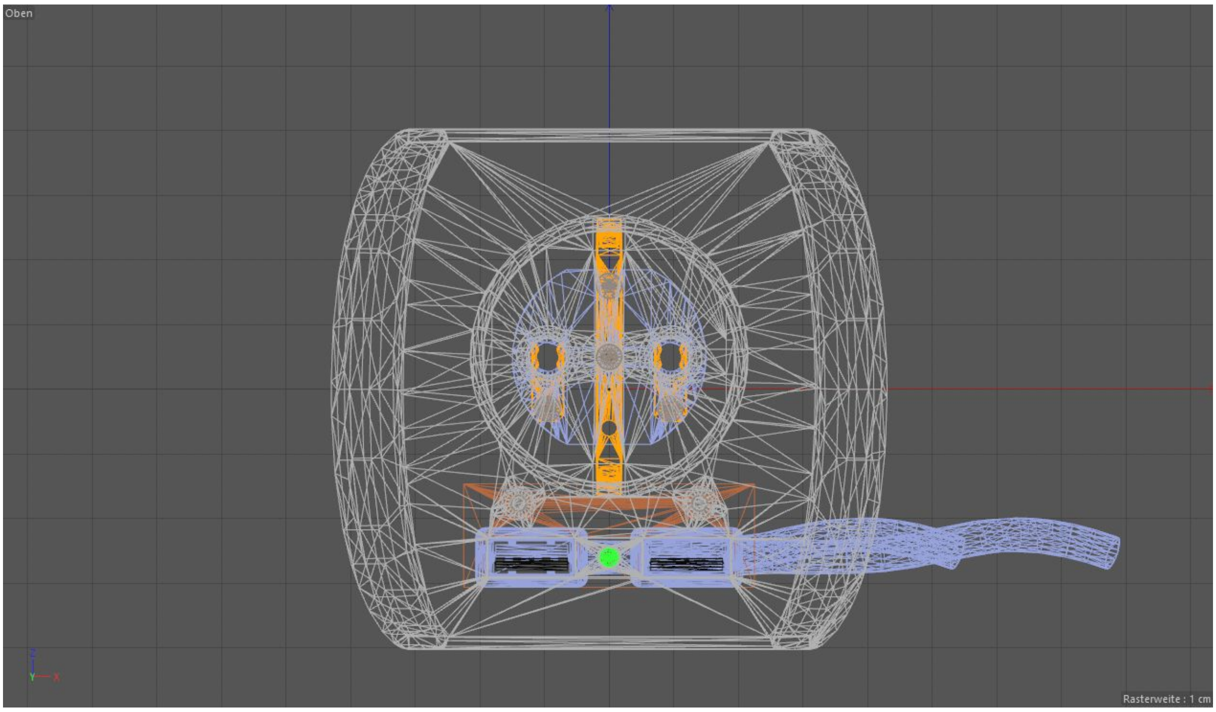


Figure 14: Wireframe of previous model

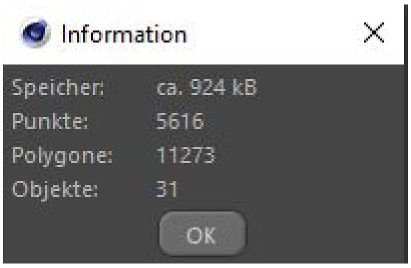


Figure 15: Polycount for medium preset tessellation

D.5 AutoDesk Maya

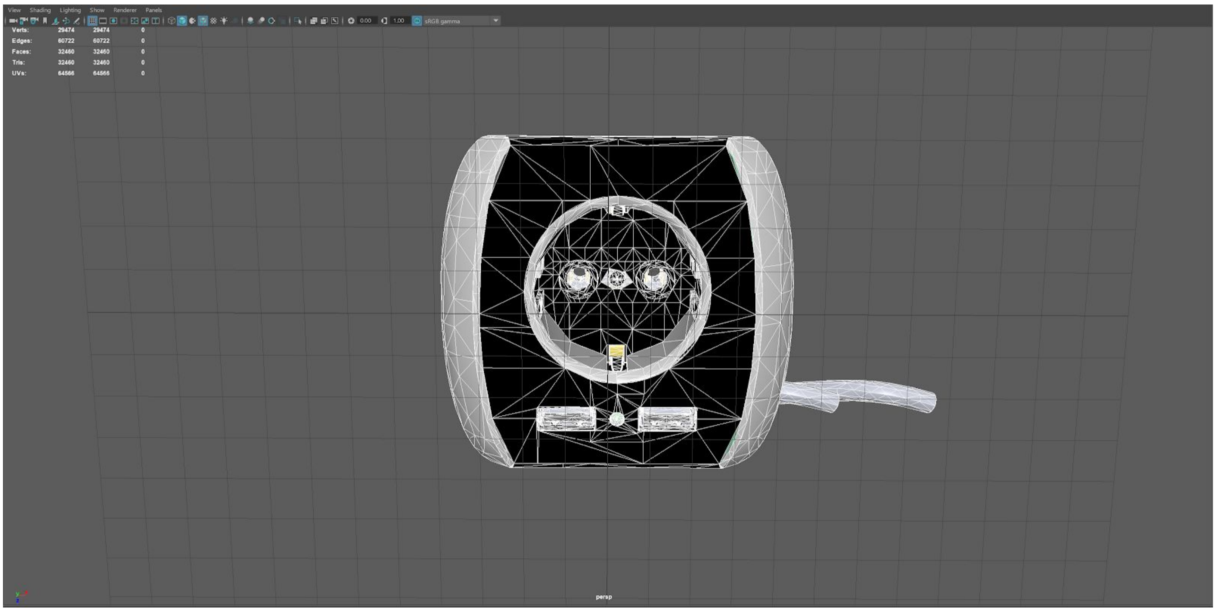


Figure 16: Tessellated model in AutoDesk Maya, with a texture bug

D.6 Datasmith

Figure 17: Tessellated model and Shaded model in Unreal Engine 4 after Datasmith import

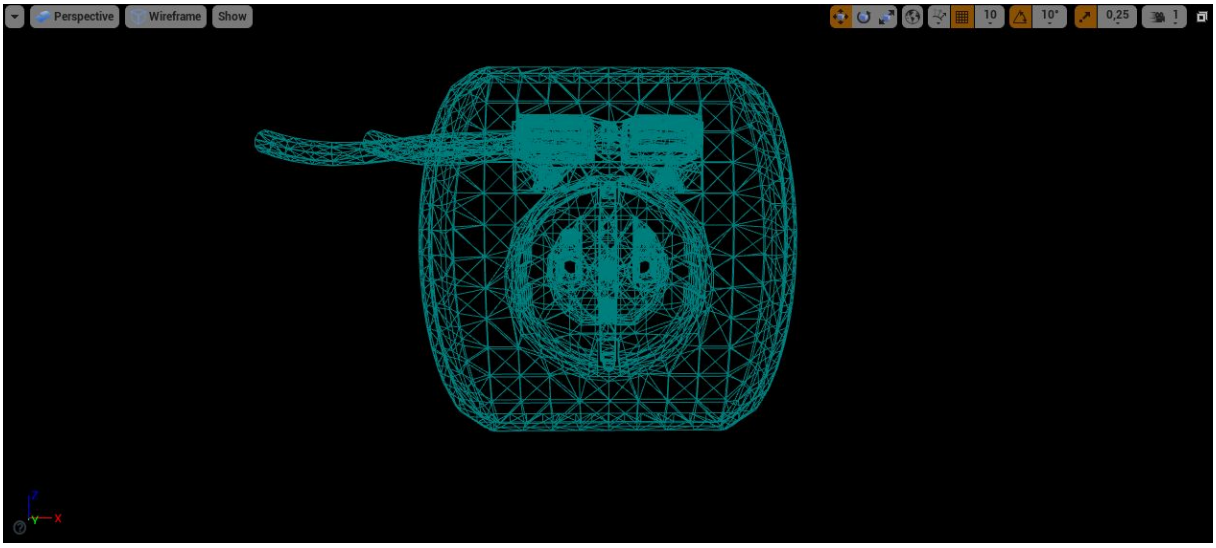
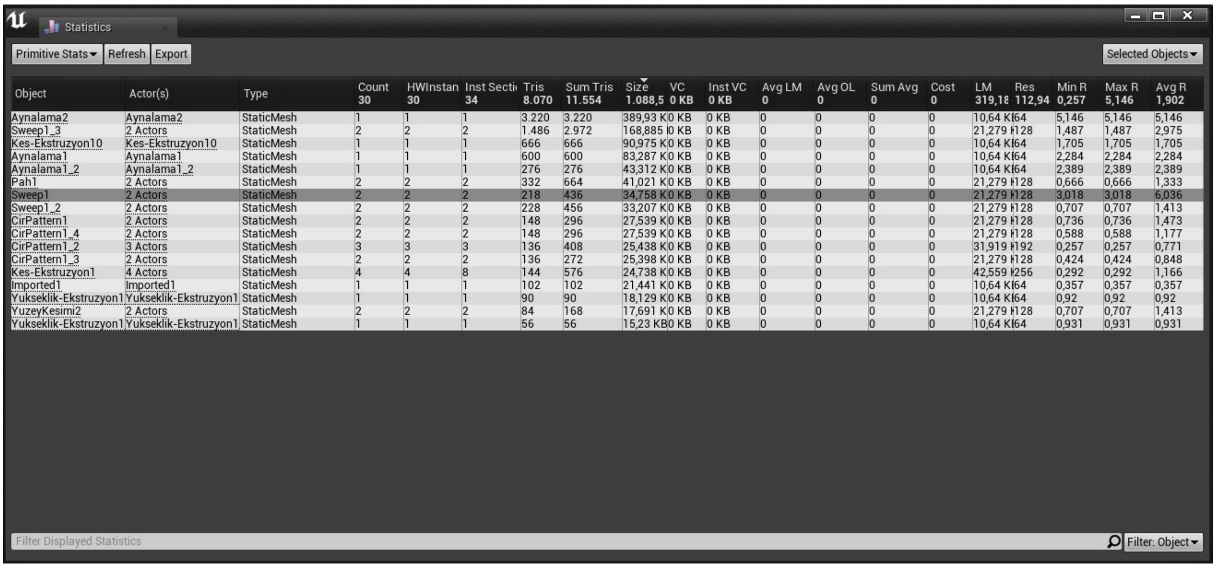


Figure 18: Wireframe of previous model



Object	Actor(s)	Type	Count 30	HWInstan 30	Inst Secti 34	Tris 8.070	Sum Tris 11.554	Size 1.088,5	VC 0 KB	Inst VC 0 KB	Avg LM 0	Avg OL 0	Sum Avg 0	Cost 0	LM 319,18	Res 112,94	Min R 0,257	Max R 5,146	Avg R 1,902
Aynalama2	Aynalama2	StaticMesh	1	1	1	3.220	3.220	389,93 K	0 KB	0 KB	0	0	0	0	10,64 K	64	5,146	5,146	5,146
Sweep1_3	2 Actors	StaticMesh	2	2	2	1.486	2.972	168,885	0 KB	0 KB	0	0	0	0	21,279	128	1,487	1,487	2,975
Kes-Ekstruzyon10	Kes-Ekstruzyon10	StaticMesh	1	1	1	666	666	90,975 K	0 KB	0 KB	0	0	0	0	10,64 K	64	1,705	1,705	1,705
Aynalama1	Aynalama1	StaticMesh	1	1	1	600	600	83,287 K	0 KB	0 KB	0	0	0	0	10,64 K	64	2,284	2,284	2,284
Aynalama1_2	Aynalama1_2	StaticMesh	1	1	1	276	276	43,312 K	0 KB	0 KB	0	0	0	0	10,64 K	64	2,389	2,389	2,389
Pah1	2 Actors	StaticMesh	2	2	2	332	664	41,021 K	0 KB	0 KB	0	0	0	0	21,279	128	0,666	0,666	1,333
Sweep1	2 Actors	StaticMesh	2	2	2	218	436	34,758 K	0 KB	0 KB	0	0	0	0	21,279	128	3,018	3,018	6,036
Sweep1_2	2 Actors	StaticMesh	2	2	2	228	456	33,207 K	0 KB	0 KB	0	0	0	0	21,279	128	0,707	0,707	1,413
CirPattern1	2 Actors	StaticMesh	2	2	2	148	296	27,539 K	0 KB	0 KB	0	0	0	0	21,279	128	0,736	0,736	1,473
CirPattern1_4	2 Actors	StaticMesh	2	2	2	148	296	27,539 K	0 KB	0 KB	0	0	0	0	21,279	128	0,588	0,588	1,177
CirPattern1_2	3 Actors	StaticMesh	3	3	3	136	408	25,438 K	0 KB	0 KB	0	0	0	0	31,919	192	0,257	0,257	0,771
CirPattern1_3	2 Actors	StaticMesh	2	2	2	136	272	25,398 K	0 KB	0 KB	0	0	0	0	21,279	128	0,424	0,424	0,848
Kes-Ekstruzyon1	4 Actors	StaticMesh	4	4	8	144	576	24,738 K	0 KB	0 KB	0	0	0	0	42,559	256	0,292	0,292	1,166
Imported1	Imported1	StaticMesh	1	1	1	102	102	21,441 K	0 KB	0 KB	0	0	0	0	10,64 K	64	0,357	0,357	0,357
Yukseklik-Ekstruzyon1	Yukseklik-Ekstruzyon1	StaticMesh	1	1	1	90	90	18,129 K	0 KB	0 KB	0	0	0	0	10,64 K	64	0,92	0,92	0,92
YuzeyKesimi2	2 Actors	StaticMesh	2	2	2	84	168	17,691 K	0 KB	0 KB	0	0	0	0	21,279	128	0,707	0,707	1,413
Yukseklik-Ekstruzyon1	Yukseklik-Ekstruzyon1	StaticMesh	1	1	1	56	56	15,23 KB	0 KB	0 KB	0	0	0	0	10,64 K	64	0,931	0,931	0,931

Figure 19: Polycount (Sum Tris) for Datasmith/Unreal Engine 4