Application of Virtual Reality to the Engineering Design Process

A Major Qualifying Project Report
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Abstract

As technology progresses faster with every innovation, design engineers are now able to go through the engineering design process with increased efficiency. With advancements in software engineering and the miniaturization of sensors and displays the resulting development of Virtual Reality technology allows users to explore and interact with a 3D computer generated environment. We hypothesize that recent and future improvements to Virtual Reality will allow engineers to apply this technology in all aspects of the design process. To prove this hypothesis, two case studies were conducted using Virtual Reality in all steps of the engineering design process. In the first case study, a methodology was created to include VR wherever possible for each step of the design process with the deliverable being an optimized design of a mechanical component. In this case, VR was applied to the steps of Background Research, Ideation and Analysis as well as assisting in all other steps. The second case study was developed towards designing custom devices for medical applications. In this case, we demonstrated the use of 3D Digitization and utilized VR as a mesh editing and visualization tool. Through these case studies we found that VR has the potential for wider application to the engineering design process, however, exciting and expected future developments on this and related technologies are still required.

Acknowledgements

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Authorship

All team members contributed equally to this project.

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Objective

The objective of this project is to create and demonstrate a methodology that shows how Virtual Reality can be applied to the engineering design process. Other technologies evaluated alongside VR were Mixed Reality, 3D Digitization, and Rapid Prototyping. Additionally, the current and future developments of the technology must be researched to extrapolate the methods in which engineers can interact with their designs in upcoming years. The project was on a time, budget and resource limit; equipment used sustained by a budget of $500, or procured from WPI departments or sponsor donations.

1 Introduction and Background

Technology has advanced to a place where additive manufacturing and mixed reality are beginning to garner important roles within engineering, business and education. In the same way, these technologies have been developed to a level where engineers could save time and energy while innovating. Additive manufacturing allows designers to create physical models of their product as a tangible prototype. The process of “3D Digitization, computer-aided design (CAD), computational and analytical modeling, additive manufacturing, and non-destructive testing of fabricated components to functional prototypes” is what is known as Integrated Rapid Prototyping (IRP) [1].

The goal of this project is to demonstrate how new technologies can be used to streamline the IRP process in every step from conceptualization to implementation of a custom fit ergonomic grip. Companies are beginning to realize the full potential of a streamlined engineering process using state of the art technology in the early phases of design, therefore many new tools are being developed to make integration that much easier. Our methodology capitalizes on the most well-developed and affordable of these new tools to make our process attainable and simpler for others to replicate.

1.1 Engineering Design Process

The engineering design process is a set of steps that one follows to achieve a final product. The process does not have to be linear, in fact steps will be revisited in most projects. Every design begins with the same step: Identification of a problem. This is the first step because there is no need to waste time and resources on a design that will not benefit a purpose. The second step: background research, will build the foundation for the design and will answer key questions such as “is there already a solution to this problem?” and “is a solution for this specific problem possible?”. After researching a goal statement must be made, it should be concise and address the problem alone. With an objective in place the product will need to adhere to design constraints, otherwise known as performance specifications. Again, these specifications should not hint towards a specific solution but address the key requirements of the final product. Ideation is the step where concepts for solutions are developed usually accompanied by sketches or diagrams. Once several initial designs are made each one should be compared to the constraints to select the best option for the next phase of the design. The next three phases often repeat in a cycle until the final design is finished and, in some cases, even after the final design is out on the market. First is creating a detailed design which establishes all dimensions and material properties needed for manufacturing; this is usually a 3D model created with Computer-Aided Design (CAD) software. Second, a prototype of the detailed design needs to be created to obtain a tangible prediction of how the final product will look and function. Thirdly, this prototype(s) should be tested to either validate the design or find where improvements need to be made. Once this cycle of designing, prototyping and testing produces a product acceptable enough to finalize, the design will be used to manufacture the final product. In many cases, prototypes will be the product itself, and will be constantly improved upon as time goes on. The engineering design process is shown in its entirety in Figure 1.1 below, the steps filled in with orange are the steps our process will be addressing.

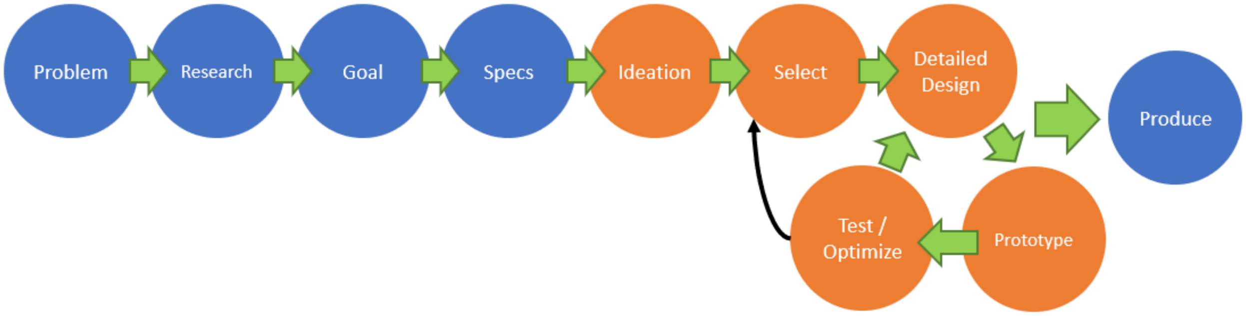


Figure 1.1 - Engineering Design Process Diagram

1.1.1 Identification of Need

Engineers start with the most rudimentary step of, identification of need or the problem statement. In order to work on a project, engineers need to understand what the problem is and how to solve it. As one of the most unchanged steps in the last 100 years, understanding what your problem is may seem like an easy step, but when working on a larger project, this could be the beginning of disassembling the project into smaller subsections for clarity and understanding.

1.1.2 Background Research

Once they understand the problem, they would naturally research what the best solution could be whether they researched this in the library or on the internet, engineers still heavily rely on previous innovations in order to avoid reinventing the wheel. In order to understand the scope of their work, after researching, engineers typically would decide on the goal they are trying to accomplish in order to reduce redundant work.

1.1.3 Specifications

With the goal in mind, engineers would then move onto the design specifications. This would result in constraints for the project in order to make sure that their solution to the problem would completely satisfy the need of the project.

1.1.4 Ideation

After thinking of multiple different designs that could satisfy the problem while still operating within their constraints, the engineers would have to select which potential solution would work the best. In order to do this the engineers would analyze each possible solution for possible pitfalls and then would likely draft up sketches.

1.1.4.1 Hand Sketched

Before the implementation of CAD software engineers would have to draft everything by hand. Any design created would have to be sketched out on paper with drafting tools in pencil, and if the design underwent changes, the engineer would have to rewrite everything by hand again. They would use tools such as squares, protractors, tracing utensils and compasses as shown in Figure 1.2.

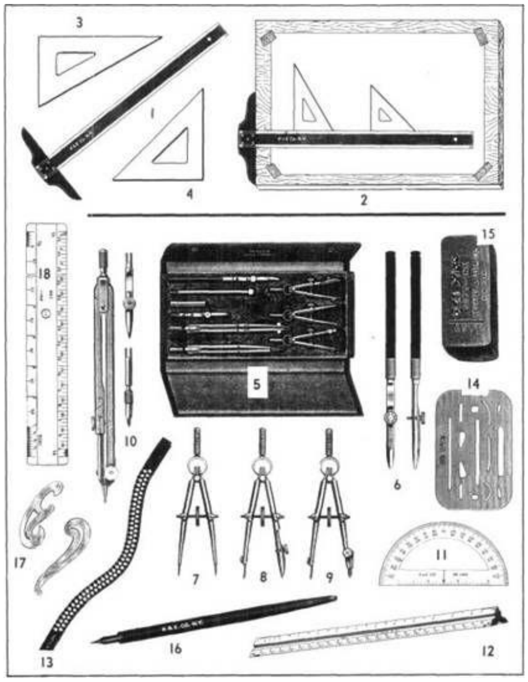


Figure 1.2 - Hand Drafting Tools

1.1.4.2 Digitally Sketched

Digital sketching is a common tool used for generating and communicating ideas during the ideation process. Devices from computers to smartphones are capable of creating digital sketches. Because the sketches are in digital form they can be projected or saved instantly. The users can naturally draw as if using a pen and paper, reducing the time to create the sketch. Collaboration with this tool is as easy as projecting onto a screen such as a SMART Board where multiple users can interact with the sketch by drawing on the board it is projected onto. These sketches can be used to create the model at the detailed design phase, but because they are two dimensional the model has to be made from scratch.

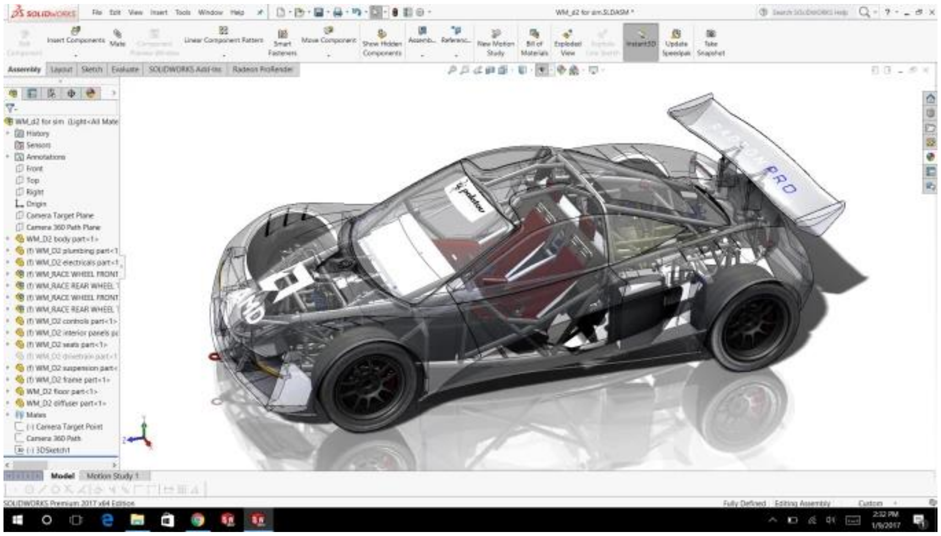


Figure 1.3 - Full Assembly of a SOLIDWORKS Design

1.1.5 Analysis and Selection

Upon creating drafts of multiple different solutions engineers would typically go through a selection process. In the selection process the team would decide which design satisfied the goal of the project the best by breaking down each solution and applying a selection matrix. This selection matrix would help engineers apply weight to each solutions' aspects and then decide on which features are the most important and applying a weight to each feature. This process clearly shows which option is the best for the project. Engineers would also have to mathematically calculate whether their design would satisfy the physical constraints that the part has to be able to accomplish, such as being able to withstand a certain stress, strain, tension or even torsion. This would be incredibly tedious to have to do by hand for each individual part created.

1.1.6 Detailed Design

With current technologies such as SOLIDWORKS or PTC Creo, a user can create a design (shown in Figure 1.3) and then test that part with Finite Element Analysis (FEA) (shown in Figure 1.4). What this function does is it allows for the in-depth analysis of designs by applying a certain type of force, such as tension, compression or torsion. By having the preconceived specifications, a user is able to see what forces the design is able to withstand based on the specified part materials. This allows for easy and quick FE analysis which has made the process of selection easier with current technologies.

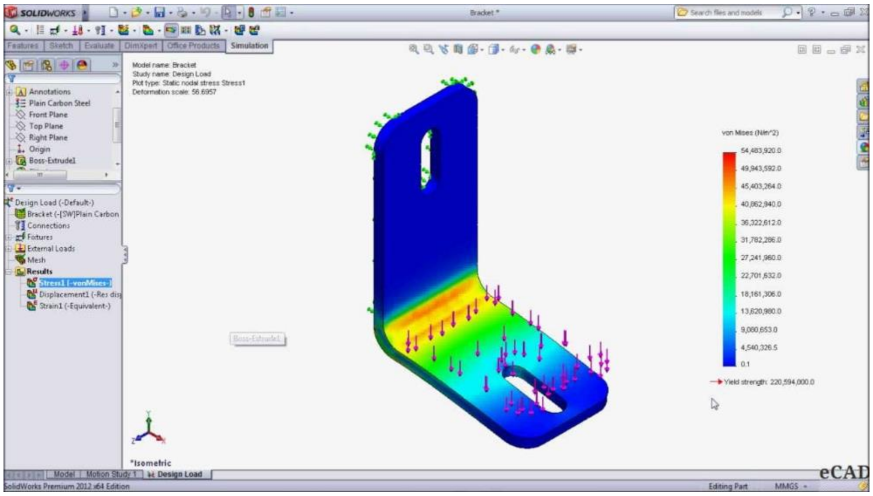

Model name: Bracket
Study name: Design Load
Plot type: Static nodal stress Stress1
Deformation scale: 56.6957

Figure 1.4 - FEA analysis of SOLIDWORKS design

1.1.7 Prototyping

After drafting up potential solutions they would physically create these solutions. Currently this is where current day engineers would take their created CAD models and write the production code using CAM software to have programmable machines create the parts. Before the time of CAM, however, engineers would use whatever was at their disposal to try and create their potential solution.

After creating a makeshift solution, or prototype, the prototype would undergo testing in order to make sure it can satisfy its purpose to the full extent. After testing engineers would then create a final copy of the solution out of more durable and longer lasting materials and would complete their project.

Current technologies for prototyping include the use of 3D printing designs right from the CAD design files. These files can be saved as .STL files which is a layer-by-layer format perfect for 3D printing. After 3D printing, these designs can be tested using the physical properties of the printing filament, and then cross referenced with the real material properties to make sure they fulfill the constraints previously established. This has decreased the cost and time required to get fully functioning parts and has significantly increased production and efficiency.

1.2 How Can New Technology Enhance the Engineering Design Process?

New technology can completely change the way that we think about creating part designs. With innovations to virtual and augmented reality, engineers now have the option of having their 3-dimensional parts presented in a completely different format. By using VR technology, engineers can create their design inside of the 3D space. Using virtual reality users can create any designs they want in a completely 3-dimensional space, which allows for an increased understanding of the dimensions as well as the operation of the design. By being able to visual the part directly in front of you using all 6 degrees of freedom, the user reaches a better understanding of how the part connects with the rest of the assembly or better understand the part’s function.

1.3 Mixed Reality Spectrum

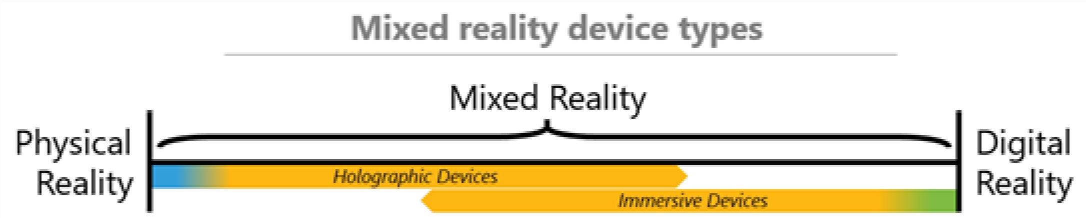


Figure 1.5 - Mixed Reality Spectrum

1.3.1 Virtual Reality

The mixed reality spectrum (shown by Figure 1.5) is very simple, as each type of reality is pretty self-explanatory. Virtual Reality consists of headsets such as the Oculus Rift or the HTC Vive, and what they specialize in, is complete virtual immersion. They intend to completely immerse the user in the programmed world, whether it's a fantasy realm, the amazon jungle or even an empty space. By combining audio with interactive visuals in a motion-controlled headset, virtual reality allows the user to have nearly unlimited new experiences. While this is ideal for gaming, being completely immersed for several hours at a time could draw upon the risk of motion sickness or mental fatigue.

1.3.2 Augmented Reality

Augmented Reality being the next type of reality in the spectrum, allows for the use of screen and augmented audio to help mix reality with digital reality. An example of this would be the popular mobile game, *PokemonGo*, which used the mobile phone's camera to superimpose a fictional creature onto the real world.

1.3.3 Mixed Reality

Mixed Reality being the widest section of this spectrum, allows for the use of totally immersive technology supplemented with reality. Examples of this include the Microsoft Hololens which allows the superimposition of digital reality into a real space through the use of glassware. This glassware is also augmented with front facing cameras and near ear audio outputs to help immerse the user, but does not try to completely fool the person into thinking they are in virtual reality.

1.4 Current State of the Art VR, AR, and MR Technology for Engineering Design

1.4.1 Ideation

Ideation is the step of the engineering design process where creative problem solving is first applied. It should be done in a manner allow for concepts to emerge organically, thus usually follows a set of sub steps often used either intentionally or unintentionally because of its roots in psychology. These steps are: idea generation, frustration, incubation and eureka [2]. The point of these steps is to pitch solutions until one runs out of ideas, leaving the parties involved to take a step back and return later. During the time away from the project, the mind's subconscious is still at work and many times is the time when the most innovative ideas emerge.

A commonly used method for generating ideas is brainstorming, in which a group of people share their thoughts without a fear of ridicule to allow for a large number of ideas to be expressed with an encouragement to combine the best parts of several different concepts. Ideas should be able to be pitched in as quick and comprehensive manner as possible in order for brainstorming to be effective. Long discussions of the concepts certainly are inevitable and at times helpful; however, brainstorming would be near to useless if each idea took more than a few minutes to be pitched to the whole group.

Technology has played a large role in facilitating brainstorming for several decades at this point. Monitors or projections allowed multiple people to visualize concepts being put forward. Scanners allowed people to digitize hand drawn sketches. The internet allowed people to create analogies by instantly obtaining information on topics they would normally have to spend hours searching for in textbooks and encyclopedias. As technology has advanced, so has the potential grown for quicker and more immersive methods of brainstorming. Not only that but with virtual and mixed reality concepts can be created as 3D models and used later in the design process to cut down on time.

1.4.1.1 Digital Sketching

Digital sketching is a common tool used for generating and communicating ideas during the ideation process. Devices from computers to smart phones are capable of creating digital sketches. Because the sketches are in digital form they can be projected or saved instantly. The users can naturally draw as if using a pen and paper, reducing the time to create the sketch. Collaboration with this tool is as easy as projecting onto a screen such as a SMART Board where multiple users can interact with the sketch by drawing on the board it is projected onto. These sketches can be used to create the model at the detailed design phase, but because they are two dimensional, the model has to be made from scratch.

1.4.1.2 Augmented Tabletop

Upper Austria University of Applied Sciences and University of Canterbury created a tool specifically designed for enhancing collaboration during ideation using Augmented Reality (AR) techniques [3]. The tabletop allowed multiple users to each have their own pen and write simultaneously. Pages and images could be imported from computers or tablets, drawn on with the pens, and dragged across the canvas for all participants to see. Users could also replace the tips of the pens with other mediums, such as a paint brush, to achieve different results. A projection was made on the wall in front of the table to be used by a facilitator to show key information to all the participants. The technical setup for the entire system is depicted in Figure 1.6.

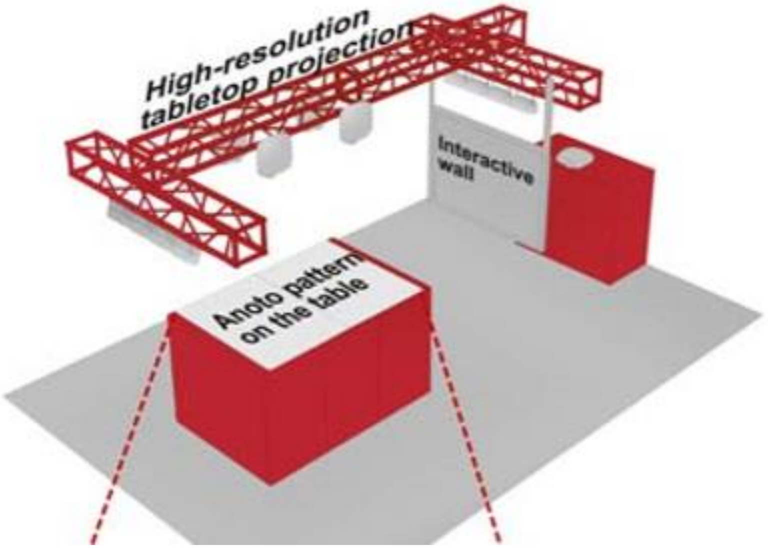


Figure 1.6 - Augmented Tabletop Set Up [3]

1.4.1.3 Immersive Hybrid Ideation Space

The Hybrid Ideation Space (HIS) is an implementation of mixing AR with digital sketching to create a tool which can be both immersive and natural to use [4]. A virtual environment is created through projection onto a specially made hemisphere shaped screen that encloses the user. In the middle of hemisphere is a setup of consisting of a projector, laptop computer, HD camera, spherical mirror ball and a drawing tablet. Above the user is a spherical mirror centered on the projector. The image is drawn in an altered perspective but projected in a normal perspective with the spherical mirror. The mirror ball is used with the HD camera to allow the user to modify and move in the environment while maintaining their scale. The setup of the HIS is shown in Figure 1.7.

Figure 1.7 - Hybrid Ideation Space Set Up [4]

1.4.1.4 Mobile Device 3D Sketching and Augmented Reality

Smart phone applications in recent years have utilized augmented reality as a way to immerse audiences in games and entertainment. However, companies are beginning to see the potential of this tool being used in engineering and business. The company Augment created an app (shown in Figure 1.8) that displays a product or prototype model in augmented reality [5]. They have offered it as a solution for design and marketing, as it allows users to easily visualize the model in a real-world environment. There exist separate applications to create 3D sketches and models directly on tablets and smart phones. Combining 3D sketching with augmented reality could create a cheap and effective tool for the ideation process.

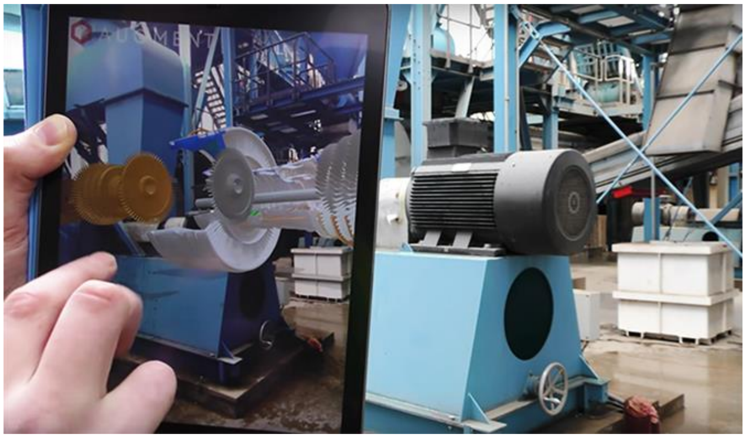


Figure 1.8 - Augment App Being Used for Accelerated Prototyping [5]

1.4.1.5 Virtual Reality Sketching and Modeling

Virtual Reality has been used by companies to create immersive mockups of building exteriors and interiors to present to stake holders. Not only is it possible to view CAD models in a virtual environment but there are several programs on the market to create 3D models using VR equipment. Generating concepts in 3D would be ideal for reducing the time to advance in the engineering process. Gravity Sketch is one such software where users can mix 3D sketches and simple models to create entire designs in VR [6]. Verto Studio VR is a VR CAD software able to create 3D sketches from flat planes as well as create, import and manipulate simple models with tools commonly used in traditional CAD software such as duplicating, extruding, welding among many others [7] (as shown in Figure 1.9).

Figure 1.9 - Verto Studio VR Being Used to Manipulate a Cube [7]

1.4.1.6 Mixed Reality Sketching and Modeling

Technologies developed for Virtual Reality and Augmented Reality combined into what is known as Mixed Reality, allowing users to interact with 3D objects in a real 3D environment. Microsoft’s HoloLens is a leader in this field, working with companies such as PTC, BAE Systems and many others to create immersive holograph experiences for a wide variety of applications [8]. HoloLens utilizes a combination of a custom-built processing unit, HD light engines, motion sensors, environment understanding cameras, light sensors, and microphones to quickly capture as much of the user’s environment as possible and project 3D holograms on the waveguide lens of the device [9] (as shown in Figure 1.10).

Figure 1.10 - Microsoft HoloLens Sensors Close Up [9]

Production of software used to create models in mixed reality has shifted from Microsoft’s Holo Studio to third-party developers such as SketchUp, and Verto Studio (shown in Figure 1.11), giving users more freedom in how they use the technology. With Leap Motion, an input device which that recognizes hand gestures, creating and interacting with 3D models can be simplified just as touch screens in smart phones are used [10].

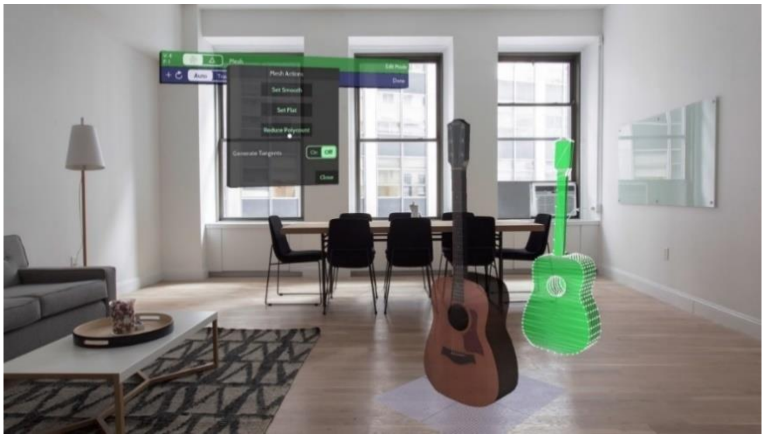


Figure 1.11 - Verto Studio VR in Mixed Reality Using Microsoft HoloLens [7]

1.4.1.7 Artificial Intelligence Generative Models

Evolutionary algorithms have been used to solve problems in software engineering for quite some time. Because of the successes of these artificial intelligences, engineers have been developing machine learning to compute an ideal design for a problem with multiple variables. These digital designs, shown in Figure 1.12, are called Generative Models. A generative model made with Autodesk Dreamcatcher was able to take about 4 billion points of data from sensors attached to a standard race car and generate a design for the lightest possible chassis considering all the other requirements of a race car frame. This process requires a significant amount of computing power and several hours [11]. Despite this Generative Models have huge potential for the future.

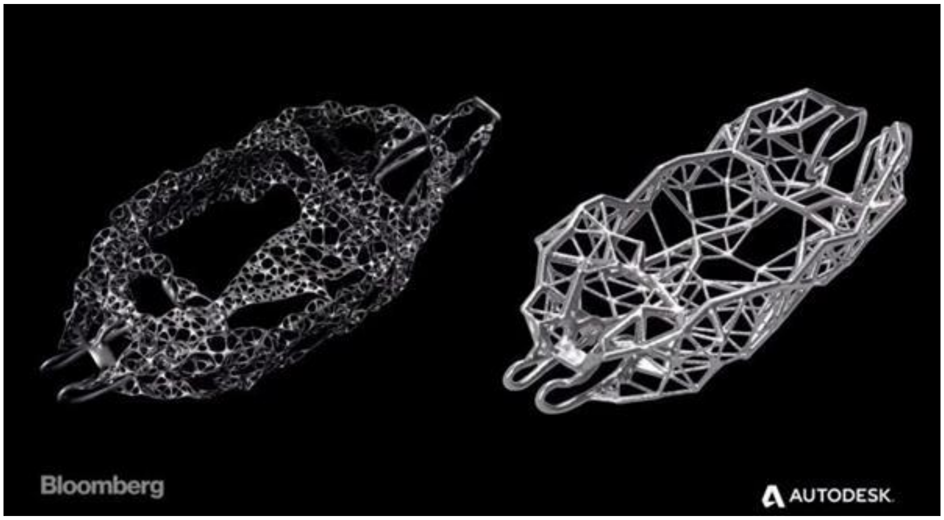


Figure 1.12 - Hack Rod Chassis Frame Created with Generative Model [11]

1.4.2 Analysis and Selection

The analysis and selection step takes the ideas and designs generated during ideation and selects one design concept to move forward with, develop, design, prototype, and test. Analysis of the designs is in regards to the performance of the design. Selection takes the analysis into consideration compares this with any other important criteria in order to make an informed decision about which design is the best to move forward with [2].

1.4.2.1 Analysis

The analysis stage may be fairly general at this point in the design process. This stage utilizes a few analysis techniques in order to assess the performance of a given design [2]. In order to apply these techniques, the ideas or designs must have some of their basic dimensions specified. Every dimension does not need to be specified yet, but there needs to be enough information present in order to identify how large the design would be and how it generally would operate. Knowing these factors, the engineer can utilize position, velocity, and acceleration analyses in order to assess the performance of the design [2]. A position analysis tells the engineer where the various parts of a design are located in space as the assembly would operate. This information provides insight into potential interference issues between the design and its intended environment. A velocity analysis tells the engineer how quickly or slowly various parts of the design are moving throughout operation. This information can provide insight into the energy present in the design as it operates. An acceleration analysis tells the engineer how quickly or slowly various parts of the design are accelerating or decelerating. This information can provide insight into the forces acting on and being exerted by the design during operation.

1.4.2.2 Selection

After analyzing the performance of the generated ideas and designs, other important criteria on which each design can be assessed need to be identified. A weighted decision matrix is typically used for this stage. A weighted decision matrix assigns a weighting factor to each criterion based on the perceived “importance” of that criteria. Then each design is given a rating for each criterion. The rating of each criterion is multiplied by the corresponding weighting factor. Then the resulting scores for all of the criteria are added together to obtain a total score for each design [2].

The engineer must exercise judgement in deciding what criteria the designs need to be assessed by and their weighting factors [2]. This process can be accomplished with the aid of a team or through input from potential customers [12]. The involvement of more perspectives in the definition of criteria and weighting factors can help to make this step less subjective and more representative of what is needed in a functional product. Another approach would be to define the criteria based on the functional specifications that are defined earlier in the engineering design process and are based on background and market research.

In order to efficiently screen the ideas and designs that were generated, it may be useful to utilize a third-party service. One such service that has been used for this application is Amazon Mechanical Turk [13]. Amazon Mechanical Turk “gives businesses access to a diverse, on-demand, scalable workforce” [14]. This service was used to assess a large amount of design sketches. The sketches were then rated on how creative, novel, useful, and clear they were [13]. The metric for rating the sketches was defined by the researcher who submitted the sketches to this service. A similar approach could be applied to the engineering design process where the metric for rating who be the criteria. The average score for each criterion could then be used with the weighting factors in order to compare the designs in a traditional decision matrix.

1.4.3 Detailed Design

After analyzing the ideas that were created during the ideation step and selecting a design to move forward, it is time to move on to the detailed design step. The detailed design step of the engineering process is the step where the selection design idea is developed and fleshed out into something more tangible and more representative of the final product. This development of the design includes creating a complete set of assembly or part drawings or computer-aided design (CAD) part files for every part to be used in the final design [2]. The created drawings or CAD files must contain all information needed in order to create a prototype.

There are a number of technologies being implemented into the detailed design step to either make the development of designs more efficient or to aid in the visualization of the final product. Some of these advancements include the use of traditional CAD software, virtual reality (VR) CAD software, augmented reality (AR) CAD software, and the use of 3D scanning.

1.4.3.1 Traditional CAD Software

Traditional CAD software is the use of computer software in aid in creating and modifying individual parts or an assembly of parts [15]. CAD software is currently being used by engineers as a replacement for traditional drafting techniques. The software has a number of tools to create complex shapes and surfaces in order to create an accurate 3D representation of a particular part or design concept. After creating the 3D model, CAD software is used to generate technical drawings that detail each and every dimension of a part, manufacturing tolerances, material specifications, and any other information that will be needed to create a prototype. The software is also used to generate a Bill of Materials (BOM) for entire assemblies of parts [16].

One of the main reasons that engineers moved from drafting techniques to utilizing CAD software was the efficiency of the process. If changes are made to a design throughout the design process, technical drawings and the BOM do not need to be recreated. Updating the CAD part files will allow for previous elements of the design to be reused and the drawings and BOM can be updated quickly and efficiently [15]. CAD also allows for dimensions to be scalable [16]. This means that the overall size of a part can be modified and all of the dimensions will be scaled accordingly. The utilization of CAD software also allows for higher precision in dimensioning parts and in part tolerances, contributing to a much lower margin for error [16].

CAD software has been utilized for decades and has had functionality added to it as technology has evolved. It is a proven technology and still sees use in the engineering design process. However, there are new and emerging technologies that could provide even more benefit to the engineering design process and have the potential to utilize the functionality of traditional CAD software. Some of these technologies will be discussed in the following sections.

1.4.3.2 Virtual Reality CAD Software

Virtual reality (VR) CAD software utilizes CAD functionality in a VR setting. VR is a 3D, computer generated environment [17]. This means that VR CAD software is a 3D, computer generated environment in which the user can view and interact with CAD models as well as utilize some CAD functionality. VR can be used in a number of ways. There are a number of applications available that allow the user to utilize some basic CAD functionality in order to create relatively simple models. There are also ways to take already created CAD models to be viewed in VR.

The first way VR can be utilized is through the use of an application. There are two notable applications available, MakeVR Pro and Verto Studio VR, that allow users to create, modify, and export relatively simple 3D models. These applications allow users to import common file types such as OBJ or STL files [7] [18]. This is important as it allows the user to work with previously created models or with scanned 3D data. The applications allow users to create models by utilizing common premade shapes. These shapes can be manipulated, resized, and positioned as needed. After the model is created, it can be exported as an STL file for use with a 3D printer or for use by another individual in any form of CAD software [7] [18].

VR can also be used to take models created in traditional CAD software and view them in a 3D environment. A process has been developed that utilizes a third-party program in order to make Solidworks files viewable in VR [19]. This process utilizes a game design engine known as Unity to import the Solidworks data (as an OBJ file) and create a VR scene displaying this data. Since the Solidworks data is being imported as an OBJ file, this process could be utilized by any CAD software that can export in the same format. There has been an add-in designed for Fusion 360, another CAD software, that allows users with no programming experience to turn CAD models into a VR experience that can then be shared with colleagues [20]. This process allows an engineer to better visualize a design. By being able to walk around and see the design more clearly, an engineer can identify potential problems in manufacturing the part (is physically possible to assembly the design given how tightly parts fit together) and in maintaining the part (can a person physically access the areas that will need to be maintained) [21].

VR CAD has all of the benefits of traditional CAD software. In addition to those benefits, the engineer is able to better visualize the design, as the model will be full-scale and not scaled down to fit entire on a computer monitor. However, as VR hardware and applications are still being developed, it is not possible to create designs that are incredibly detailed and precise as is possible with traditional CAD software.

1.4.3.3 Augmented Reality CAD Software

Augmented Reality (AR) CAD software utilizes CAD functionality in an AR setting. AR is the use of technology to superimpose information onto the world we see [22]. This section will look at two ways this is accomplished. The first is through a headset, such as the Microsoft HoloLens, that transforms the information into holograms that are then projected onto the world. The second is through the use of a mobile device, such as a smartphone or tablet, that utilizes the device's camera to show the information in the world.

AR CAD software is at a similar point in development was VR CAD software. There are few applications available that allow users to create models in this setting. One such application is also Verto Studio VR as mentioned above in Virtual Realty CAD Software. This application was further developed to be used in an AR setting as well as a VR setting. This software offers AR functionality similar to the VR functionality described earlier [7].

Typically, AR is used to display CAD information rather than to create models. One use of this is to display information about mechanical loading or heat distribution. AR can take this information and display it on the part being examined [23]. This allows the engineer to better visualize and examine problem areas on a part and identify the areas that need to be redesigned. A number of traditional CAD software applications are developing add-ins that allow for the model to be viewed in AR. Solidworks allows for eDrawings to be viewed in full scale in AR utilizing an iOS device [24]. The add-in for Fusion 360 mentioned earlier also allows users to transform models into an AR experience that can be viewed and shared with others [20].

AR CAD software has the same benefits as VR CAD software, in that it allows for better visualization of the design. AR CAD software offers better visualization than VR CAD software, as the design can be viewed in full scale and in its intended setting. However, as with VR CAD software, this technology is still being developed and does not yet offer the same amount of functionality as traditional CAD software.

1.4.3.4 3D Scanning

3D Scanning is the process of creating a “point cloud” of data based on the surface of the object that can be used to recreate that surface in CAD software [25]. There are a number of types of 3D scanners that accomplish this goal in different ways. 3D scanners can be classified into two groups: contact and non-contact. These types can be further divided. Figure 1.13 shows how 3D scanners are classified.

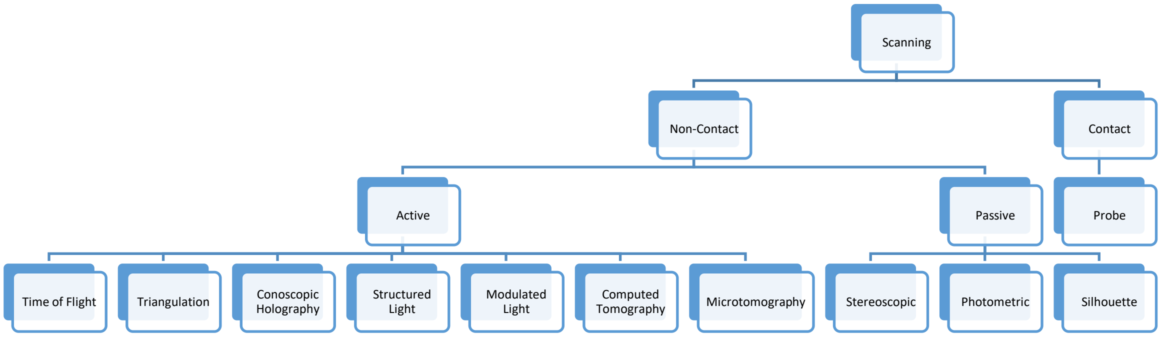


Figure 1.13 - Different Types of 3D Scanners [1]

Contact scanners use a probe to physically touch the object at points of interest in order to create a model of that object [26]. Non-contact scanners can be further separated into two more groups: active and passive scanners. A non-contact active scanner emits some form of radiation and detects that radiation's reflection or passing through the object in order to create the model. A non-contact passive scanner does not emit any form of radiation, but detects reflect ambient radiation in the environment in order to create the model [26]. These two types of non-contact scanners can be divided further.

Non-contact active scanners include time of flight, triangulation, conoscopic holography, structured light, modulated light, and computed tomography scanners [26]. Time of flight scanners measures the distance to a point based on the speed of light [26]. Triangulation based scanners emits a laser onto the object. A camera is used to analyze the deformation of the laser on the object and determines the shape of the object based on trigonometric calculations [27]. Conoscopic holographic scanners emit a laser through an objective lens in order to focus it. The laser hits the object to be measured, and reflects, partial back into the sensor. The pattern resulting from this reflection is detected and processed in order to calculate the distance to the surface of the object being scanned [28]. Structured light scanners project a light pattern onto an object. A number of sensors are used to look at the edges of the projected shapes in order to determine the shape of the object using similar calculations to triangulation scanners [29]. Modulated light scanners shine a continuously changing light on the object being scanned. A camera is used to detect the reflected light and how much the pattern has shifted in order to determine the distance travelled by the light in order to recreate the shape of the object [30]. Computed tomography (CT) scanners take hundreds or thousands of 2D projections around a 360-degree rotation of the object. Then algorithms are used to transform the 2D projections into a 3D volume [31].

Non-contact passive scanners include stereoscopic, photometric, and silhouette scanners [26]. Stereoscopic scanners take two images of the same object at slightly different angles in order to make measurements about the distance and size of the object [32]. Photometric scanners gather images of the object under different lighting conditions and from different angles. Using this data, a precise mathematical 3D image of the surface is created [33]. Silhouette scanners place the object on a turntable and gather images as the object rotates. The object will have a predetermined background behind it, in order to separate the object from known surroundings. The created 2D “silhouettes” are used to create a 3D volume of the object [34].

The data obtained from 3D scans is used to aid in the design of freeform surfaces [35]. It is easier and more efficient to create an organic shape out of a material that can be molded easily and then scanned and imported into CAD software than to try to create the same organic shape in the CAD software directly. Scan data is also useful for creating a part that must fit into an assembly that is already created [35]. This allows for the engineer to design the part around existing geometries and ensure that there will be no interferes between the part and the assembly. Scan data is particularly useful when creating a form-fitting product for a person [35]. This allows for products to be custom fit to the consumer and ensures proper and comfortable fitment.

1.4.4 Prototyping

Prototyping is the process of creating a physical representation of a final product that allows for the testing of functional requirements, materials, and/or processes. A prototype is not fully tested and may not work or operate as intended. The purpose of the prototype is to test the design solution under real conditions. By creating a prototype, the development group is able to understand the failures and successes of the current iterations and make improvements to eventually produce a final product. During the engineering process, a product may undergo several prototype iterations before the final product is decided on.

1.4.4.1 Rapid Prototyping

Rapid Prototyping (RP) can be described as a group of techniques that are used to create a scaled model, physical part or assembly using three-dimensional computer aided design software (CAD). This group of techniques is comprised of different forms of additive manufacturing or in other words, 3D printing. In essence, 3D printing is the process and rapid prototyping is the end result. Thanks to rapid prototyping, companies and manufactures are able to quickly and inexpensively bring ideas to creation.

With the introduction of 3D scanners, companies have been able to replicate already existing parts in order to recreate them as virtual parts. This new form of data acquisition allows companies to edit the data prior to manipulation in a CAD software. The implementation of this kind of data acquisition results in a process called integrated rapid prototyping (IRP). Integrated rapid prototyping has opened up the possibilities for new advancements in the fields of engineering that allow users to customize their parts or models further than what standard CAD software allows.

As mentioned above, the IRP process begins with the data acquisition step. Data acquisition involves creating a complete 3D data set and then preparing that data set for prototyping [36]. This data set is created through a 3D CAD model, digitized data, or mesh data. The 3D CAD model is typically created using traditional CAD software as previously discussed in the Detailed Design section [36]. The 3D CAD model can also be created using the VR or AR CAD processes also previously discussed in the Detailed Design section. It is beneficial that whatever CAD software is used can export the data in the STL format, as this format has become a rapid prototyping industry standard [36]. Alternatively, digitized data can be used to create a model. This data would be obtained using a 3D scanner. There are numerous types of 3D scanners as previously outlined in the Detailed Design section. The mesh data is generated from either the CAD model or the digitized data. The mesh data will then be used by the selected rapid prototyping method [36]. Following are descriptions of the various rapid prototyping methods that can be used.

Stereolithography (SL) works on the principle of photo polymerization to create 3D models made of UV sensitive resin [37]. The resin reacts to a laser which hardens the material on contact and follows a layer by layer process. As each layer is hardened the resin tank is lowered and the surface is smoothed, thus allowing the laser to harden the next layer. Because this process requires the laser to harden every layer a single point at a time, a full model created using this method may take several hours, depending on the size. Depending on the size of the model being created, the SL process may take several hours to produce the end result, but because it is laser hardened, this allows for very fine resolution and increased material properties.

Digital Light Processing (DLP) is similar to SL because they both use photopolymers but is very different in execution. While SL uses a laser to harden each point of the layer at a time, DLP uses a more conventional light source with a liquid crystal display to project an entire layer onto the resin to harden [38]. The layer is broken down into small pixels of light projections called voxels. This inherently limits the resolution of DLP models to the size of the voxels created by each individual printer. By projecting and hardening an entire layer of resin simultaneously, DLP printing produces full models much faster and more efficiently than SL printing, and generally without the need for supportive structures. With DLP’s higher accuracy (up to 10 µm) and high printing speed, it is able to outperform SL printing in most manufacturing scale production [39].

Fused filament fabrication (FFF) is the process of depositing a continuous thermoplastic or wax filament alongside or on top of previously place filament through the use of an extruder. This extruder heats the filament to its melting point allowing the fusion of the filament through heat and adhesion [40].

Selective laser sintering (SLS) is the process of creating a 3D model through the use of metal, glass, or ceramic powder. This powder is heated through the use of a high-powered laser that fuses the powder creating a hardened material with similar properties to the powders original form. As the laser passes through each layer, the tank then drops lower allowing a roller to smooth the powder surface for the next layer of sintering [41]. This allows for the use of additive manufacturing when creating structurally secure parts that could not be printed using conventional printing methods.

Selective laser melting (SLM) is a process very similar to SLS, but with a difference being that SLM refers to specifically mono-material metals, while SLS can refer to glass, ceramics, and metal alloys as well. Because SLM fully melts the material powder, it requires a uniform melting point, as opposed to SLS which allows for different melting points. The last large difference between SLM and SLS is that SLS heats the metal powder enough to fuse the powder together on a molecular level and allows the control of the porosity of the material [42].

Electron beam melting (EBM) refers to a process very similar to SLS and SLM, with one major difference, the light source. SLS and SLM printing require the use of protons while EBM, as the name suggests, requires the firing of electron controlled by electromagnets fired at the powder in a vacuum to prevent the oxidization of the metal powder. The main advantage of this process as opposed to SLS and SLM is the minimization of waste. SLS and SLM printing uses only 20% of the original material for the final product and the waste cannot be recycled. With

EBM, since the metal powder is not oxidized (due to being created in a vacuum) it allows for the direct recycling of material reducing cost and waste [43].

Laminated object manufacturing is the process of creating a layer by layer model using a continuous roll of material. This roll us unwound layer by layer and cut into the desired shape of the layer. Then the layer is pressed and heated by a large roller which fuses the layers together [44]. This technology can also be furthered by the addition of a high-performance polymer powder to increase durability and strength.

After the prototype is created, it must be refined and optimized through a variety of testing methods. The testing methods will vary based on the needs of the product being created. These testing methods will ensure that the created product meets or exceeds the functional specifications that were defined earlier in the engineering design process. Once the prototype is satisfactory, it can then be used in the preparation for mass-production of the product.

1.4.5 Technology Being Created

The VR industry is rapidly growing and rapidly changing as new technologies and new innovations are being presented every year. In the most recent years there have been many innovations in VR/AR technologies such as mobile VR headsets, and Google Hololens. This, paired with software that allows collaborative work through a single screen, has created partnerships such as the collaboration of manufacturer, Howden, and the 3D modelling software company, PTC. This is just one partnership along with several new startups in the VR industry such as Oblong, Mersive, and Prysm, which have been working towards software that allows for collaboration through both 2D and 3D work. This includes video chats, conference calls, presentations, and many other forms of communication. Companies like this can spearhead innovation in the 3D environment to allow more fluid collaboration in 3D space.

PTC’s partnership with Virtalis, a world-leading Virtual Reality (VR) and advanced visualization company, has allowed for the creation of Visionary Render, a software which provides the ability to work collaboratively on massive models in Virtual Reality in real-time, as shown in Figure 1.14. This software has created the opportunity to redesign the way engineers interact with each other and with different parts of their organization that perhaps don’t have the technical understanding to understand classic 3D modelling software or technical drawings.

Figure 1.14 - Visionary Render Alongside PTC Creo

As displayed in the image above, users are able to accurately create parts using PTC Creo without having to sit at a computer screen. This also allows people who are not technically gifted to visually understand the parts they have to interact with, such as sales, and advertising.

Figure 1.15 – Collaboratively View AR/VR Images

By having a virtual image shared between multiple people, this can increase productivity, reduce down time, and allow for clearer and more organized shared thoughts, as depicted in Figure 1.15. This would be a massive help to all different types of companies, as down time results in massive losses throughout whole organizations. By allowing for instant real time collaborative work, companies can reduce the time it takes to work on new products as well as reduce the time needed to explain products and ideas to different sectors of each company.

This can also help improve customer employer relations as this would allow customers to stay up to date on their products. That is where the company, Howden, came into play. They wanted to create a seamless process that allowed for the improvement of aftermarket long term service agreements. In order to do that they decided to implement PTC's Vuforia Studio which allows customers to view and understand the equipment in a 3D and immersive environment through the use of the Google Hololens, as shown in Figure 1.16. This is to show their customers, in context, the operating conditions, and performance of the equipment to improve day-to-day operation. Predictive maintenance alerts, rapid parts identification and easy to follow repair sequences provide all the information relevant to resolving problems and keeping the equipment running as efficiently as possible to prevent failures and downtime [45].

Figure 1.16 - Using Vuforia Studio to Understand Equipment

2 Methodology

The goal of this project was to apply Virtual Reality to the engineering design process. This was accomplished by demonstrating the implementation of the technology in two ways. The first approach focused on analyzing and integrating VR in every step of the design process as much as possible. This approach was used in the case of redesigning a connecting rod for an Opposing Cylinder Opposing Piston (OPOC) engine. The second approach focused on integrating VR, 3D Digitization and Rapid Prototyping into crucial steps towards the goal of creating a custom fit ergonomic design for medical applications. The device chosen for this development was an endoscopic surgery telescope, the product being a prototype of a custom ergonomic handle.

The process for the first case study began by identifying the need via visualizing the connecting rod in a state where the stress applied would cause it to fail. Ideation was done using 3D digitization and VR CAD to generate concepts of connecting rods. After, each design's feasibility was compared to each other until one design was selected. The concept from the ideation phase was used to create the design that would be refined in future steps. VR CAD was used to create the design and exported to traditional CAD software once it was ready to be analyzed. The design was converted to a solid object and then processed through a Finite Element Analysis (FEA). With the information from the initial test, the connecting rod was optimized to succeed in keeping the allowed stress concentrations as well as design specifications.

The second case study was accomplished by creating a clay impression of a personalized grip which was then scanned by an infrared 3D scanner. The model was imported into Blender to streamline the shape and develop the handle prototype. The model of the handle was modified to include a hole where the telescope could fit inside so that it would have support as the user held the grip. Afterwards the handle was imported into Verto Studio VR to be visualized for any faults. The mesh was then exported and 3D printed for physical testing.

3 Case Study 1

This case study focused on applying VR to each step of the engineering design process. With the currently available technology and software, VR was best suited towards visualization to complement the methods traditionally used in each step of the engineering design process. First, an assembly of an opposed piston opposed cylinder (OPOC) engine was recreated in VR. Then, an individual part from the OPOC engine was redesigned and taken through the entire engineering design process while trying to incorporate VR into each step. The dimensions for the original engine were provided in an article that was split into two parts, written by James Donnelly [46] [47]. In a previous course at WPI, ME 3323 – Advanced Computer Aided Design, these parts were modelled, assembled, and had very basic analyses run on the assembly in PTC Creo Parametric 4.0. These analyses included a motion analysis in order to identify the position in which the connecting rods felt the greatest net force and then multiple FEA analyses, one of which was looking at the connecting rods under the greatest felt net force.

3.1 OPOC Engine CAD Model

First, the original assembly created in Creo was saved as an STL file so that it could be opened in Verto Studio VR. Then, the individual part files were saved as STL files so that they could also be opened in Verto Studio. Verto Studio did not retain the dimensions of the STL files, so each part had to be resized. The parts were resized and positioned using the model of the entire engine to ensure that each part had the correct proportions and that the engine was assembled as closely to the Creo model as possible. During the process of remodeling the engine in VR, a variety of subassemblies were made, similar to how a large assembly would be made in a traditional CAD software such as Solidworks or Creo. Figure 3.1 shows a comparison between the assembly made in Creo (left) and the assembly made in Verto Studio (right).

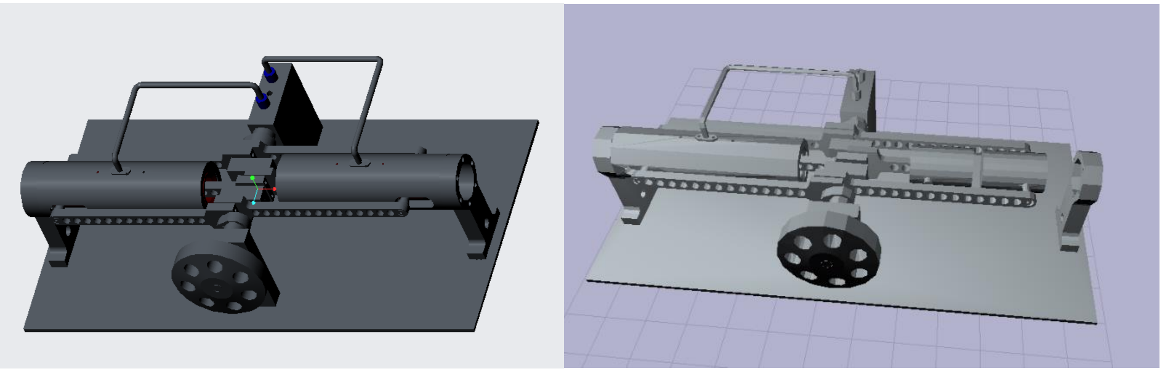


Figure 3.1 - Engine Assembled in Creo (Left) and Verto Studio (Right)

The subassemblies included the base structure, the crankshaft, and the inner and outer pistons and their connecting rods. After creating the subassemblies, the center of rotation of each one was moved in order to better represent how the parts would move in relation to each other in the engine.

VR CAD software does not currently have the same capabilities as traditional PC-based CAD software. As such, there are no relations for mating the subassemblies and parts together, everything had to be positioned correctly. If the crankshaft were to be rotated, the piston subassemblies and the connecting rod subassemblies would need to be manually repositioned; they don’t move as the crankshaft is rotated like they would in a traditional CAD software. Verto Studio also did not retain the dimensions of the STL file, which led to a tedious process when trying to create an assembly.

3.2 Redesign of the Connecting Rods

The original FEA testing done used the force put on the crankshaft as a result of the motor turning the crankshaft. This was only a force of 2.845 N and was not representative of forces that a connecting rod would be subjected to under an actual load. However, increasing the forces felt would only affect the magnitude of the resulting stresses. Therefore, while the original FEA testing did not provide any information as to whether or not the connecting rod would fail under load, the resulting stress distribution would remain unchanged. From this stress distribution, we could see that there was a significant stress concentration around the holes in the connecting rod. Figure 3.2 shows the stress distribution on the original connecting rod design.

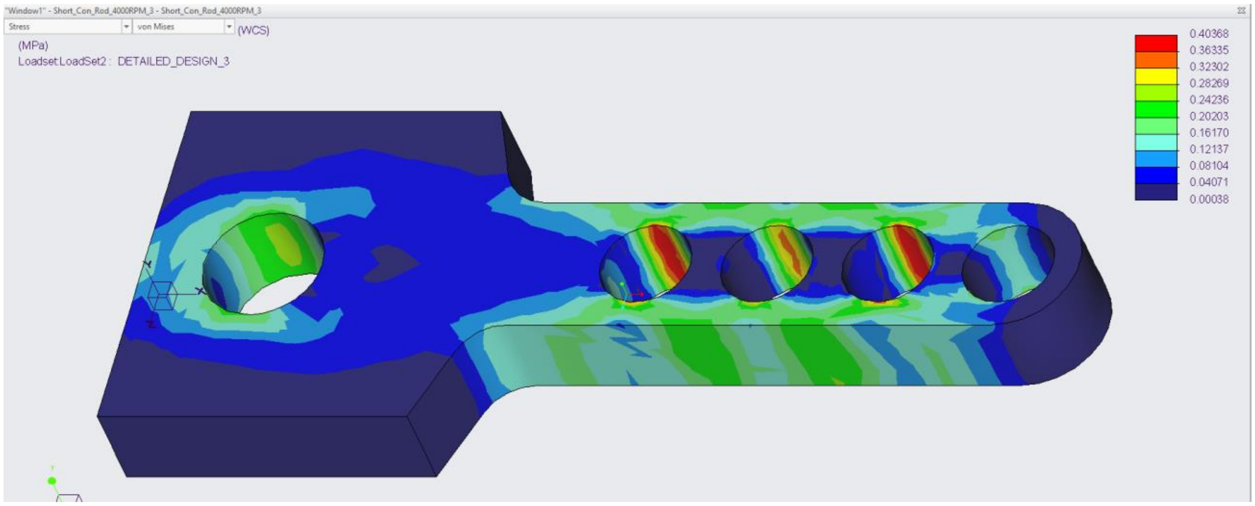


Figure 3.2 - Stress Distribution on Original Connecting Rod Design

3.2.1 Identification of Need

The first step of the engineering design process is to identify the need for this design. From the stress distribution is it possible that the connecting rod may fail due to the stress concentrations, but retesting with a realistic force was necessary in order to determine the likelihood of a failure.

Multiple studies have been done on the design and analysis of a connecting rod under static loads and fatigue. One study, from the Wuhan University of Science and Technology, designed a connecting rod made of a structural steel with a yield strength of 250 MPa and applied a load of 4500 N. The maximum stress felt by this connecting rod was 56.624 MPa [48]. In order to ensure that the load applied to our connecting rod was proportional to its size, we estimated the cross-sectional area of the connecting rod used in the design study by solving the basic stress equation (Stress = Force/Area) for Area since the other two variables were known. This gave an area of 0.123 in^2. Our connecting rod had an original cross-sectional area of 0.056 in^2 at the locations with stress concentrations. This area was approximately 45% of the area from the design study, so we planned to use a force that was equal to approximately 45% of the force applied in the design study. However, our connecting rod was specified to be made of brass which has a yield strength of slightly greater than half of that of structural steel at 135 MPa [49]. Therefore, after taking a force 45% of the applied force, the result was halved, in order to give a force that was proportional to the size and material properties of the connecting rod. The force that would be applied in the new FEA test was 1000 N. In the original test, the maximum force was felt when the connecting rod’s center axis and the force vector were parallel.

After retesting, the new maximum stress felt in the connecting rod was 141 MPa. The yield strength of brass in 135 MPa. The factor of safety (FoS) was calculated by FoS = Yield

Strength/Max Stress and calculated to be 0.9574. A safety factor of less than 1 signifies that the part will fail. Since the maximum stress felt was larger than the yield strength of the material, the connecting rod would deform plastically under load and needed to be redesigned in order to reduce or eliminate the stress concentrations. The resulting FEA results were brought into Verto Studio to be viewed alongside a 3D VR model of the connecting rod with the stress distribution displayed on its surface. Figure 3.3 shows the FEA test results of the connecting rod under a 1000 N axial force.

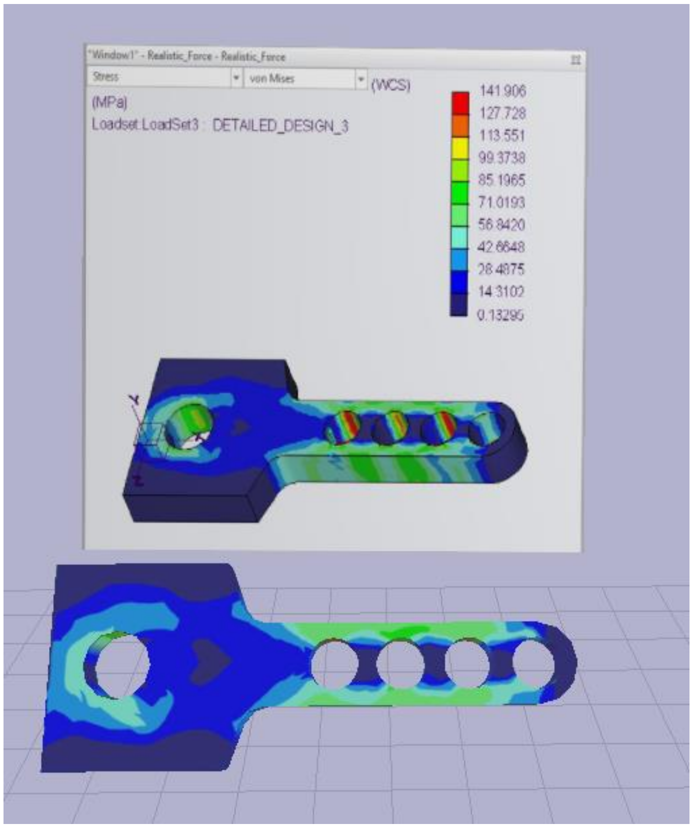


Figure 3.3 - VR Scene Showing FEA Results with 3D Model of the Connecting Rod

3.2.2 Background Research

Next, background research was conducted in order to fully understand the problem being solved. Multiple design studies were used to understand typical cross-section shapes that are used to reduce stress as well as a target safety factor for connecting rods. The design studies each used a variation of an I-Beam style cross-section [50] [51] [52] [48]. The factor of safety varied widely among the design studies. In one study, the factor of safety for multiple locations on the connecting rod ranged from 2 to 3 [50]. Another study had a safety factor range from 3 to 15 at various locations on the connecting rod [51]**.**The last study had an allowable safety factor of 1.047 [52].

More research was done in other styles of connecting rods in order to provide some variation to the I-Beam cross-sections found in the design studies. These alternative styles were brought into Verto Studio as STL files in order to visualize the connecting rods and to better compare the designs side-by-side in a 3D, interactive environment. Figure 3.4 shows the different connecting rod styles brought into VR for visualization.

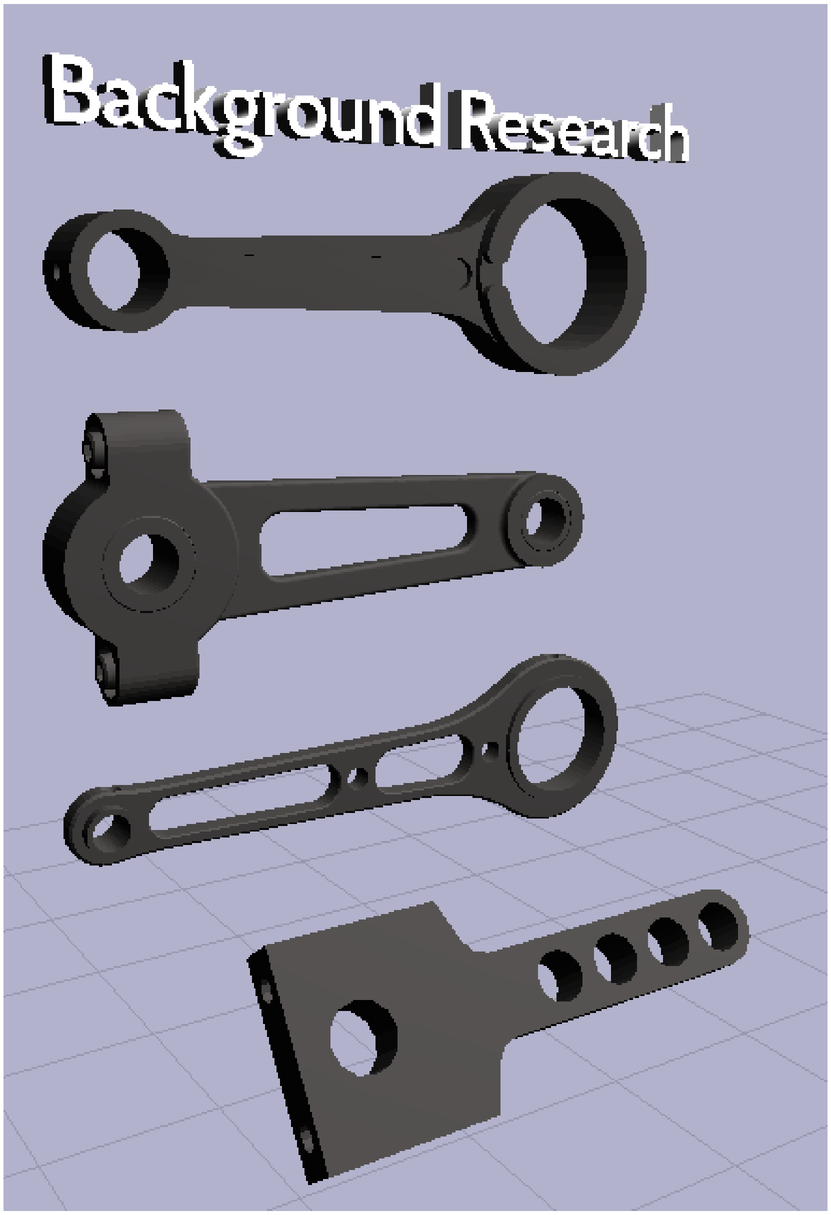


Figure 3.4 - Various Connecting Rod Designs Viewed in VR

3.2.3 Performance Specifications

Based on the information found during the background research step, we were able to define performance specifications for the new design. Due to the wide range of safety factors, a safety factor greater than 1 was used. The mass of the connecting rod and overall dimensions should remain unchanged or remain close to the original values. This would ensure that the same amount of material is being used and the stress is not being reduced by simply adding material but by redesigning the shape of the cross-section and eliminating stress concentrations.

The original connecting rod's dimensions were brought into Verto Studio to be viewed as projections from the model of the connecting rod. This created an easy and efficient method of visualizing the size of the current design and understanding that area that the new connecting rod would need to fit in to. Figure 3.5 shows the original connecting rod model accompanied by engineering drawings in order to allow the user to visualize the size of the connecting rod and understand the space that the new design will need to occupy.

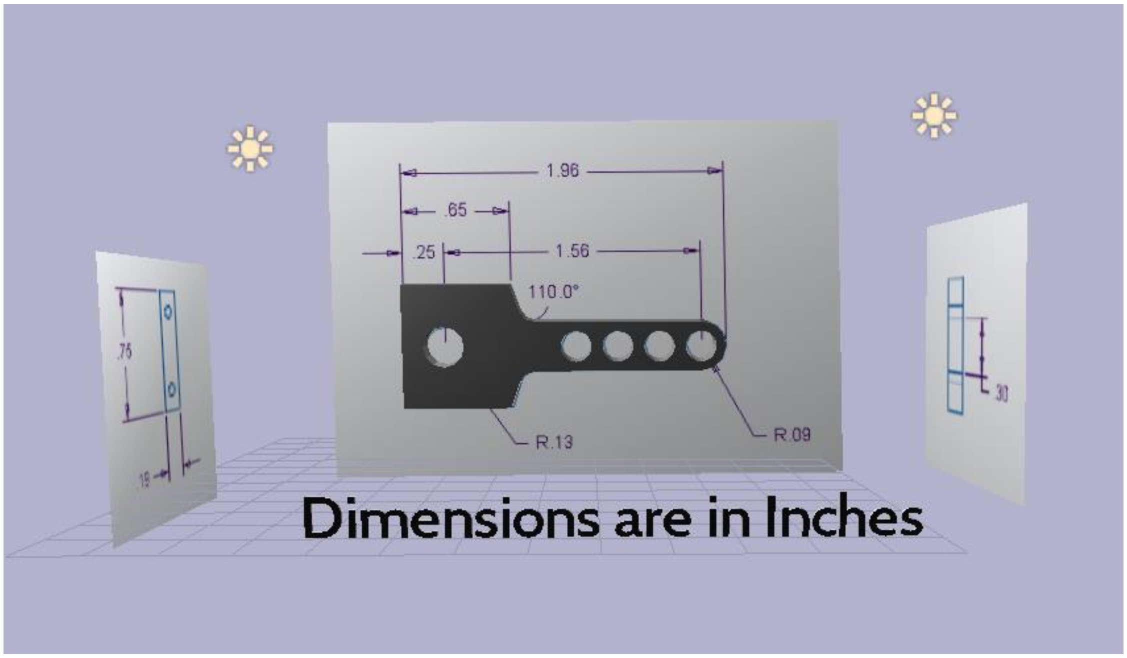


Figure 3.5 - Original Connecting Rod Accompanied by Engineering Drawings with Dimensions

3.2.4 Ideation

After defining performance specifications, Verto Studio was used as the medium for the ideation step. This step entails creating rough concepts of potential designs to be analyzed and have one selected for development. Verto Studio allows the user to create basic 3D shapes. These basic shapes were used to create two concepts. The first concept utilized the original connecting rod STL as a base shape, filled in the holes, and created an I-Beam cross-section similar to the design studies as shown in Figure 3.6.

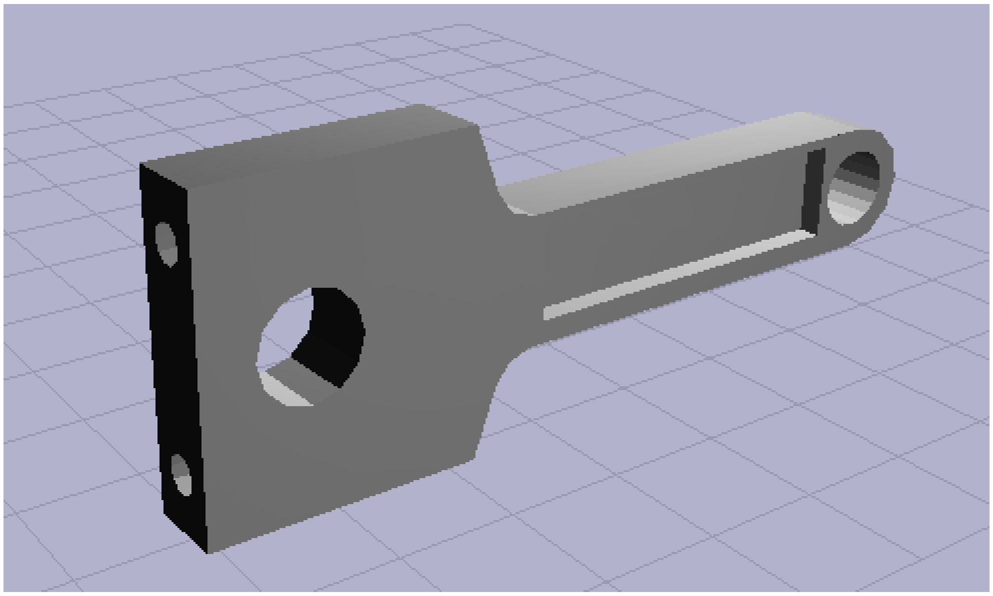


Figure 3.6 - Design Concept 1 – Connecting Rod Utilizing an I-Beam Style Cross-Section

The second concept was based off of the original design as well, but instead of using it as a base the concept was created using only the shapes in Verto Studio. The rational for this design was to reduce weight in a similar manner to the original holes while reducing the number of stress concentration locations in the connecting rod. Figure 3.7 shows the second design concept – a connecting rod reducing mass through the use of a single larger hole rather than multiple smaller holes.

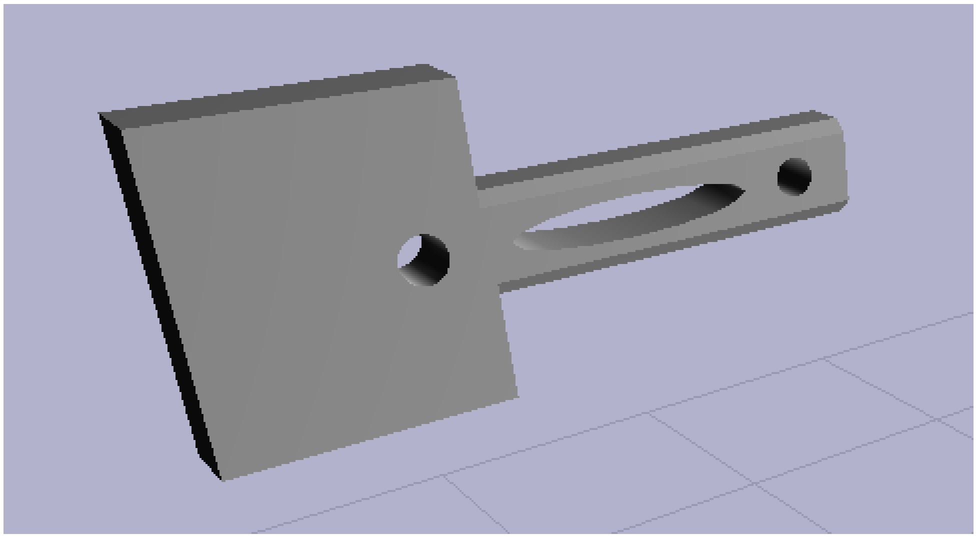
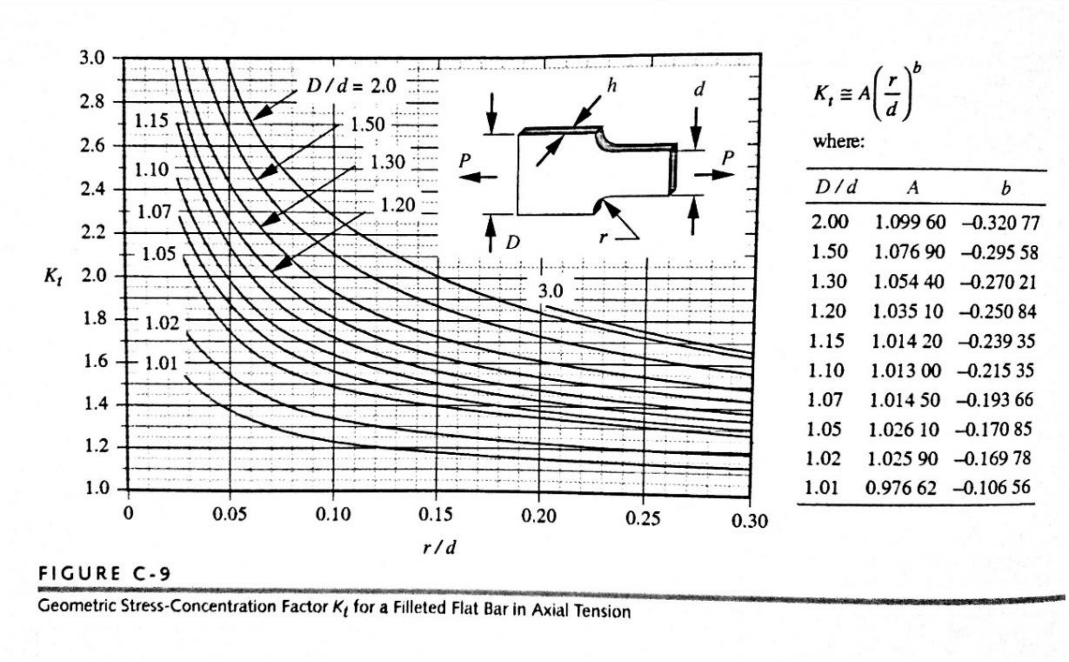


Figure 3.7 - Design Concept 2 – Connecting Rod Made in VR Utilizing a Single Large Hole for Mass Reduction

3.2.5 Analysis

After creating the design concepts, basic analysis was done to determine which design to move forward with. Stress concentrations at the shoulders of the connecting rod were calculated using the following chart in Figure 3.8:



$$K_t \cong A\left(\frac{r}{d}\right)^b$$

where:

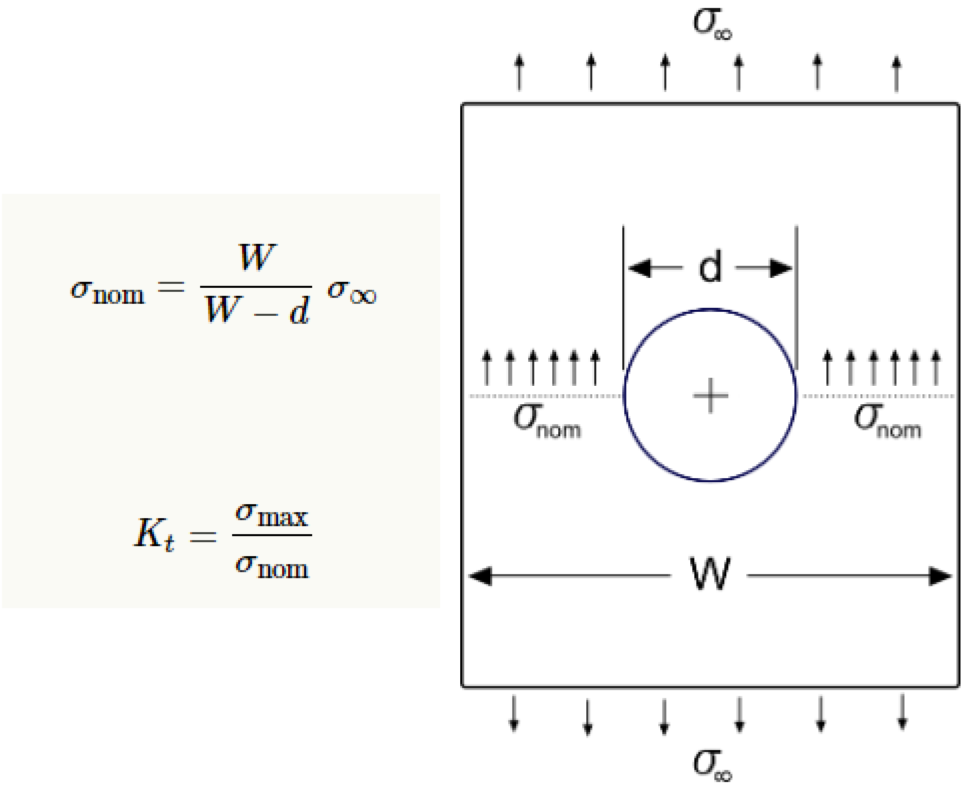
D/d	A	b
2.00	1.099 60	–0.320 77
1.50	1.076 90	–0.295 58
1.30	1.054 40	–0.270 21
1.20	1.035 10	–0.250 84
1.15	1.014 20	–0.239 35
1.10	1.013 00	–0.215 35
1.07	1.014 50	–0.193 66
1.05	1.026 10	–0.170 85
1.02	1.025 90	–0.169 78
1.01	0.976 62	–0.106 56

FIGURE C-9

Geometric Stress-Concentration Factor K_t for a Filleted Flat Bar in Axial Tension

Figure 3.8 - Stress Concentrations for a Stepped Bar Under Axial Loading [53]

Then the stress concentration at the holes was calculated. For a plate with a hole in the center, the maximum stress is located at the edge of the hole. Figure 3.9 shows the equations needed to find the stress concentration, K_t, at the edge of the hole.



$$\sigma_{\text{nom}} = \frac{W}{W-d}\,\sigma_\infty$$

$$K_t = \frac{\sigma_{\text{max}}}{\sigma_{\text{nom}}}$$

Figure 3.9 - Equations to Calculate Stress Concentration for a Hole in a Plate [54]

The stress concentration was found by dividing the max stress by the nominal stress in the cross-section given by: $\sigma_{nom} = \frac{W}{W-d}\sigma_\infty$, where W is the width of the plate, d is the diameter of the hole, and $\sigma_{\square}$ is the remote stress (applied stress).

These calculations were carried out using the original force values, not the values used during the retest. After the calculations were completed, the original FEA test was redone using the two new designs concepts. The FEA results and the calculations were then able to be brought into Verto Studio to be viewed alongside the accompanying concept model. For both concepts the maximum stress at the hole for the crankshaft was estimated to be 0.073 MPa and at the hole for the piston pin was estimated to be 0.183 MPa. In the I-Beam design concept, the maximum stress in the arm of the rod was estimated to be 0.102 MPa. While in the concept with the ellipse-shaped hole the maximum stress in the arm of the rod was estimated to be 0.183 MPa as the ellipse would have a minor diameter equal to the diameter of the pin hole. Figure 3.10 shows all of the analysis calculations brought into VR to be viewed alongside the connecting rod models.

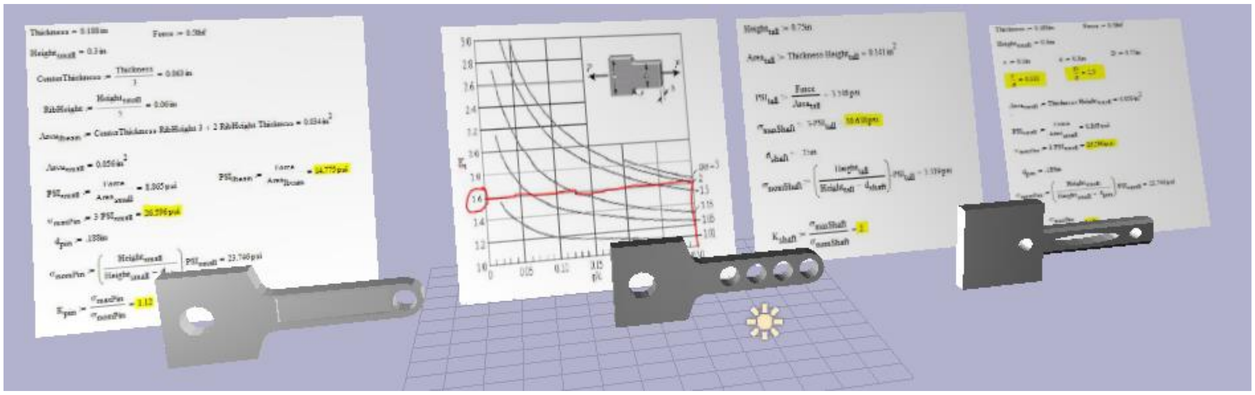


Figure 3.10 - Analysis Calculations and Connecting Rod Models Being Viewed in VR

3.2.5.1 Selection

The design utilizing the I-Beam cross-section was selected for further development based on the findings from the analysis step. The two new designs had similar maximum stresses but the I-Beam concept had a slightly lower maximum stress. When a higher force is applied, the difference between the two designs will be more pronounced.

3.2.5.2 Detailed Design and Testing

Once a concept was selected, the design must be fully developed using CAD software. The height of the cutout section was 3/5 of the original height of the connecting rod's arm. The depth of the cut was 1/3 of the original thickness of the connecting rod. All other dimensions were unchanged. The new cutout was mirrored about the center plane of the connecting rod, creating the I-Beam cross-section. The new connecting rod design was modelled using PTC Creo Parametric 4.0. Figure 3.11 shows the new connecting rod design after being modelled in Creo.

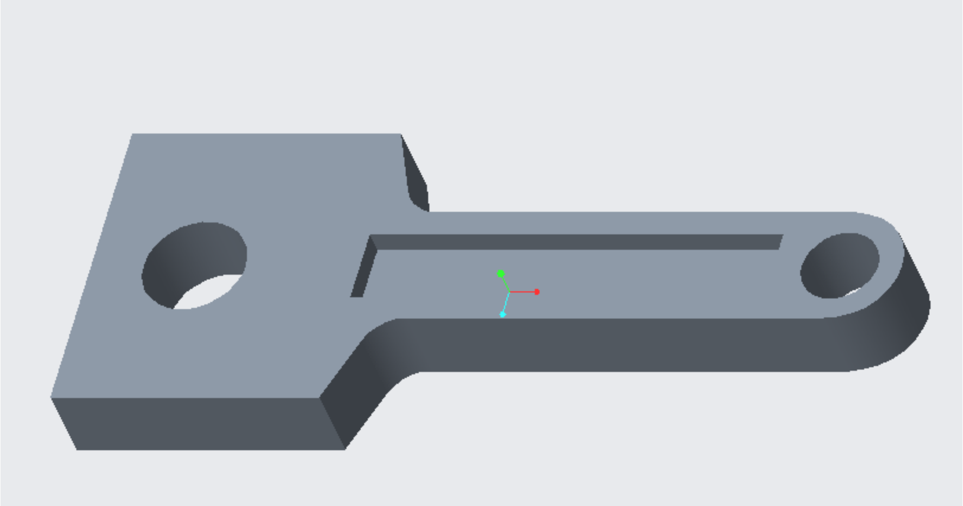


Figure 3.11 - New Connecting Rod Design in Creo Parametric 4.0

After modelling the new design, its mass was 16.765 grams. The original connecting rod had a mass of 17.545 grams. The new design has a lower mass than the original, but it is within 5% of the original rod's mass.

Next, the connecting rod was brought into Creo's FEA Simulation application. A bearing load of 1000 N was applied to the end of the connecting rod where the crankshaft is located in order to simulate the stress the connecting rod will feel during operation. A pin constraint was used to fix the other end of the connecting rod, simulating the pin connecting the rod to the piston.

The FEA test showed that the new maximum stress felt in the connecting rod was 89 MPa. This gives a safety factor of 1.51 which was acceptable according to the define performance specifications. The new FEA results were brought into Verto Studio for visualization alongside a 3D VR model of the stress distribution of the connecting rod as shown in Figure 3.12.

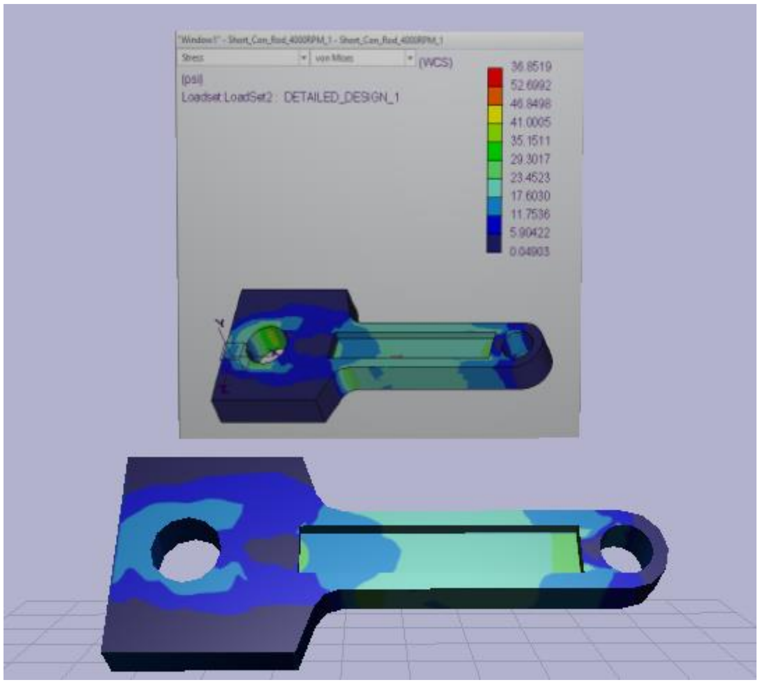


Figure 3.12 - FEA Results and Connecting Rod Model Being Viewed in VR

3.2.5.3 Prototyping

After designing the new connecting rod and testing it against the defined performance specifications, the part was ready for prototyping. This step creates a physical representation of the final design. This is particularly useful for visualizing the final product and test fitting the part if need be. However, due to the use of VR for visualization, there was already a strong idea of what the final part would look and feel like.

To create our prototype, the new design was 3D printed by Stratasys Parts on Demand using a multicolor PolyJet process. This process allowed for a single part to be printed with multiple colors. The connecting rod was printed in the same colors as the stress distribution found from our FEA tests. This created a physical representation of our design and our testing results. Having the 3D printed part/FEA results created an easy way to see and understand the size, dimensions, and stresses of the final design. Figure 3.13 shows the 3D printed prototype.

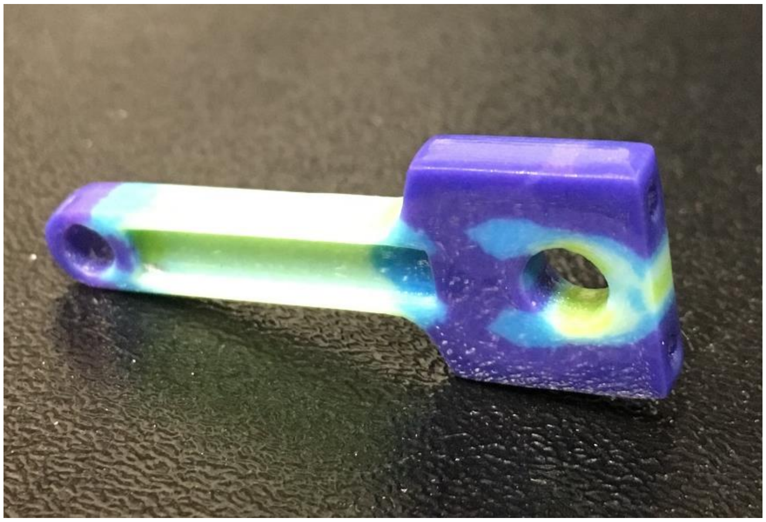


Figure 3.13 - 3D Printed Connecting Rod and FEA Stress Distribution

4 Case Study 2

3D Digitization is being used for a growing number of applications including custom fitting medical applications. This case study focused on using 3D Digitization effectively for designing a custom fitting handle for an endoscopic surgery device (specifically a cardiovascular telescope). Endoscopic surgery instruments are often used for hours at a time. Cardiovascular telescopes are used in open heart surgeries, the most common type of open heart surgery is the Coronary Artery Bypass Grafting(CABG). According to the National Heart, Lung and Blood Institute, a CABG can last between 3-6 hours [55]. Ergonomics are essential in an operating room for procedures that are several hours long, so much so that Duke University implemented an “Ergonomics Team” whose sole purpose is to “…(identify) ergonomic risk factors when assessing general work tasks, including awkward postures and prolonged duration of tasks performed” [56]. The objective of this case study is to demonstrate the benefits of new technology in designing a custom ergonomic handle for an endoscopic surgery device. Custom sleeves would be less costly than a custom handle which contains expensive lenses and circuitry [57]. Without access to the complete endoscope kit, this was next best option to demonstrate the potential of the technology through a prototype of a custom ergonomic handle.

4.1.1 Methodology

This process is a proof of concept towards creating a custom ergonomic endoscopic handle which fits onto a telescope in a similar manner to the original handle. The steps of the procedure were to create a mold which would be fitted around the telescope, then 3D scanned to create a model of a handle with a custom grip. After scanning, the design would be refined to a simpler shape, removing any bumps or unnecessary curvature. The handle would be printed as a prototype with ABS plastic to test how well it fit the device & the user’s grip. Lastly, after refining any issues found from the hard-plastic prototype, the handle would be printed with a flexible material for a comfortable grip.

4.1.2 Molding the Handle

Model clay was used to create the handle, carefully smoothed into a cylinder encasing the end of the telescope where the valve of a handle would be attached. The telescope was wrapped in plastic and taped to protect against clay being embedded in the instrument. The clay was then gripped to create a custom hand imprint and any bumps or scratches were smoothed out as to not be picked up during scanning, the result is shown in Figure 4.1.

Figure 4.1 - Clay Molded into a Custom Grip for the Cardiovascular Telescope

4.1.3 3D Digitization

A 3D portable scanner, iSense 3D scanner for iPad Air 2 and the Scanner app developed by Structure, were used to take scans of the molded grip as shown in Figure 4.2. The scanner projects a randomized dot pattern onto the objects in front of it, which the app then uses to create data points corresponding to what the camera is observing. Before the scan can be taken the object must fit within a wireframe box which can be scaled by the user to exclude other objects from being scanned. Additionally, Figure 4.3 shows the app as it previewed what it was capturing; this feature allows the user to adjust themselves or the object to an optimal position for the clearest scan possible. The scanner needs to be rotated around the stationary object to create a complete model, often times the app will prompt the user to pause in order to capture a keyframe. Once the user is satisfied with the scan, they can stop the scan which will bring up a preview of the model that they can then discard or sent via email. Undesired holes, bumps or extra objects may have to be fixed in modeling software such as Solidworks or Blender.

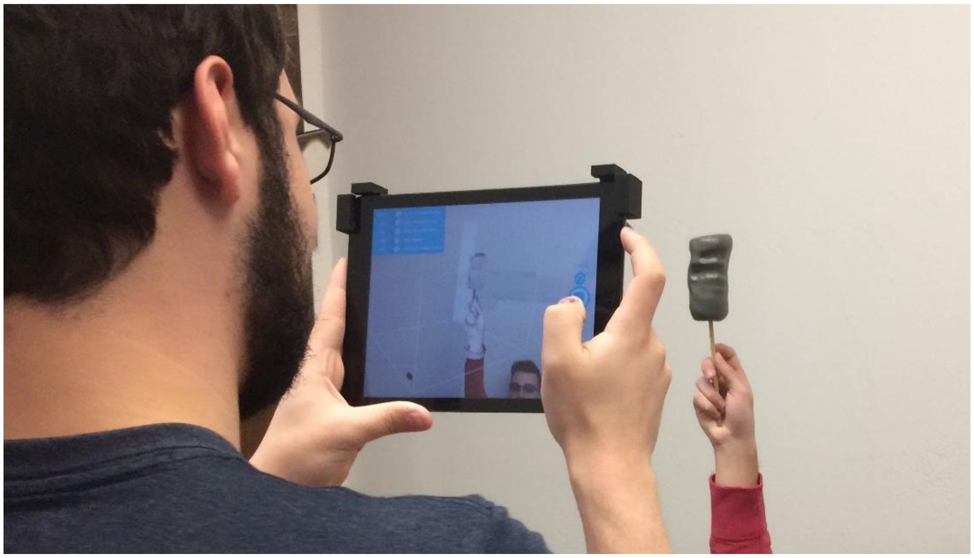


Figure 4.2 - 3D Scan of Custom Grip Being Taken with iSense and Scanner App

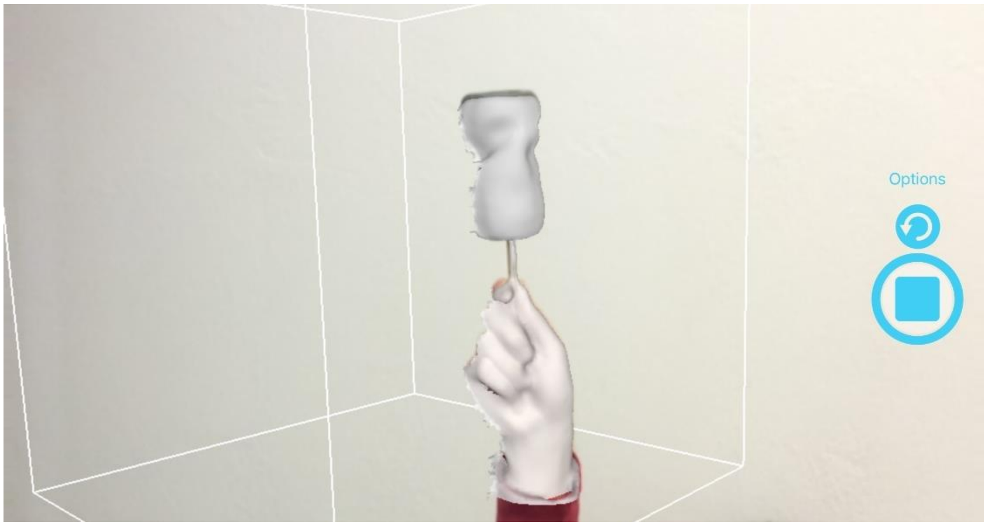


Figure 4.3 - Preview of the Scan in Progress on the App

4.1.4 Development of Handle

After scanning, a combination of Verto Studio VR and Solidworks could be used to trim excess material, fill holes and reduce polygons on the data point cloud. Blender was used to smooth out the faces of the triangular mesh to create a streamlined version of the handle. The detailed steps of this process are expanded upon in Appendix B.

The measurements of the telescope were taken to create a means of support while being held in the handle prototype, the dimensions are shown in Appendix D. The largest diameter of the telescope was 1.25 inches at the bottom where the lens is located. The length of the telescope before reaching the horizontal nozzle was 1.84 inches. The design of the handle was altered in Blender to fit as much of the telescope while also maintaining structural integrity. A hole 1.25 inches in diameter and 1.75 deep was subtracted from the mesh.

Next a support bearing component was made to fit around the smallest diameter of the endoscope below the horizontal nozzle, 0.7 inches, while fitting inside the 0.3 hole. The support bearing was made as thick as possible to increase the amount of surface area the telescope is held by, the final thickness being 0.75 inches.

The height dimension of the grip was measured for 3D printing purposes, as the model was not automatically scaled when the file was uploaded to the slicing software. A rapid prototype of the handle was printed first to confirm that the telescope fit in the hole at the end and that the grip was still comfortable for the user. After both of these requirements were met, the model was then sent to be 3D printed with a mix of solid & flexible filament for better ergonomic design.

4.1.5 Results

A prototype of an ergonomic handle for an endoscope equipped with a cardiovascular telescope was created while integrating 3D Digitization, Virtual Reality and Rapid Prototyping to enhance the process. The preparation of the telescope and clay grip took less than an hour to make and the 3D scan took less than 5 minutes to take. 3D printing allowed for prototypes to be quickly made and evaluated for any flaws before sending to be produced. Such a custom and complex shape would take more time to create using traditional CAD software and even longer to physically evaluate the model after manufactured through injection molding. The process taken during this case study adequately demonstrates the ways in which the engineering process was enhanced through utilizing new technologies of 3D Digitization and VR.

5 Recommendations

5.1.1 Further development of portable 3D scanners

The iSense scanner and Scanner app is a valuable tool for engineering design because of its ability to bring objects from the real world into digital form with little effort. However, there are still many areas where this technology could be improved for a more streamlined and efficient experience. The software does a good job identifying objects that are immediately differentiable from the environment. However, any objects less than six inches in all dimensions often took multiple attempts before the object was recognized and a reasonable scan was obtained. The major problems experienced when using a portable 3D scanner were either the app locking onto the wrong object or the scan would be aborted in the middle of scanning. The first issue was either due to the object being too small in comparison to its surroundings, causing the app to lock onto the wall or person holding the object. Locking onto the background would also happen with clear objects or if it easily reflected light. The second issue occurred when the user did not have enough room to keep a consistent distance from the object, which was often between 2-3 feet between the object and the camera.

5.1.2 Further Development of VR CAD

Verto Studio is by far the most advanced version of CAD available for Virtual and Mixed Reality systems on the market at the time of this report. However impressive the capabilities (such as mesh editing by points, freehand and polygon sketches to model, and textures), Verto Studio is lacking in some basic CAD features such as view presets, precision dimensioning, and creating assemblies.

Currently with Virtual and Mixed reality, scale is determined loosely by perception alone. It is possible to evaluate designs with approximately the correct scale; however, a reference will always need to be present. When CAD for VR and MR is able to read in information about a model's dimensions, the efficiency of the engineering design process will be increased considerably.

Creating Assemblies with specific mating constraints & relationships between parts does not exist within a Virtual Reality CAD Software. Once a feature such as this is developed, VR and MR could become a great asset in the process thus increasing efficiency. Many times, in CAD software on the computer, users have to wrestle with adjusting their view manually with a mouse and keyboard. In a virtual environment the gaze of the user determines the view, thus it is much more natural and better suited towards assembling designs. VR & MR CAD software developers that wish to utilize this advantage should take note that being able to walk around an assembly would be the ideal way to adjust view of an object, because it's natural and less likely to disorient the user compared to teleporting or floating.

However pertinent it is for CAD software to have certain essential features, the potential of Virtual and Mixed Reality extend well beyond the conventions of current CAD software. Gesture commands are already used in the Mixed Reality version of Verto Studio, but could be improved to both better receive input and perform different actions depending on the gesture. Currently Verto Studio's HoloLens version only allows one gesture: to select and click with a pointer finger; in the future this could be extended to multiple gestures that control basic functions such as rotation, scaling and deformation as described in a study which used Leap Motion and HoloLens to achieve these results [10]. Haptic response in Virtual and Mixed Reality is a feature which many developers are working towards to increase the user's immersion. This functionality would restrict motion wherever an object would exist, enabling engineers to completely experience and assess their designs. In engineering design, it would exponentially assist the designer as they will be able to physically feel their design without wasting any time or resources.

6 Conclusion

Virtual Reality offers multiple new and exciting technologies that should be introduced into the engineering design process in order to reduce costs, reduce project development time, and for the vast applications of VR. These applications are also growing and changing as new advancements are made every year.

In terms of scanning, the iSense scanner used in this project produced the results we wanted to a certain degree. It lacked the ability to scan objects of small thickness as well as objects that had a reflective surface. This could prove problematic for many larger companies as their subjects could contain either of these properties.

The VR CAD software used in this project, Verto Studio, was also not suitable in its current state for the applications needed in the engineering world as it lacks many key features. Of course, innovations in the VR CAD industry would result in a smoother transition from mesh to 3D printing as well as provide a more dedicated VR CAD software that would allow users to make more detailed and accurate parts using only VR.

The use of Augmented Reality could also be used as a replacement to VR with the ability to visually see the necessary part and how it would fit into the real world. Using our case study of the ergonomic grip for example, AR could allow users to receive a better visualization of the ergonomic grip, and whether it would fit relative to the end users hand.

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7 Appendices

7.1 Appendix A: Importing STL files into Verto Studio

In order to import an STL file into Verto Studio, either from a 3D scanner or developing an STL file in a CAD software, you need to open Verto Studio to the main menu and select “Import Scene,” as shown in Fig. 7.1.

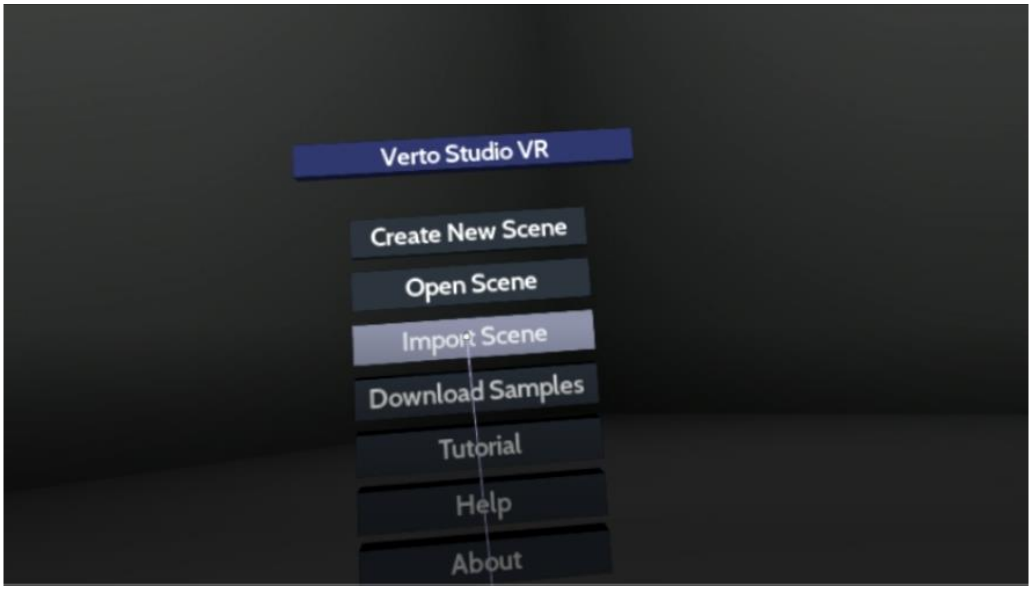


Figure 7.1 - Importing an STL to Verto Studio

This will prompt you to then select from where you would like to upload the STL file from, meaning Verto Studio needs you to locate the file so it may import it. Figure 7.2 shows the menu where you select the desired file’s location in order to import it.

Figure 7.2 - Selecting Location of Save File

In this project we had saved every STL file into the computer hard drive for ease of access and ease of location. This allowed us to keep all of our STL files in an organized and memorable way. Figure 7.3 shows how files are located once a directory is chosen.

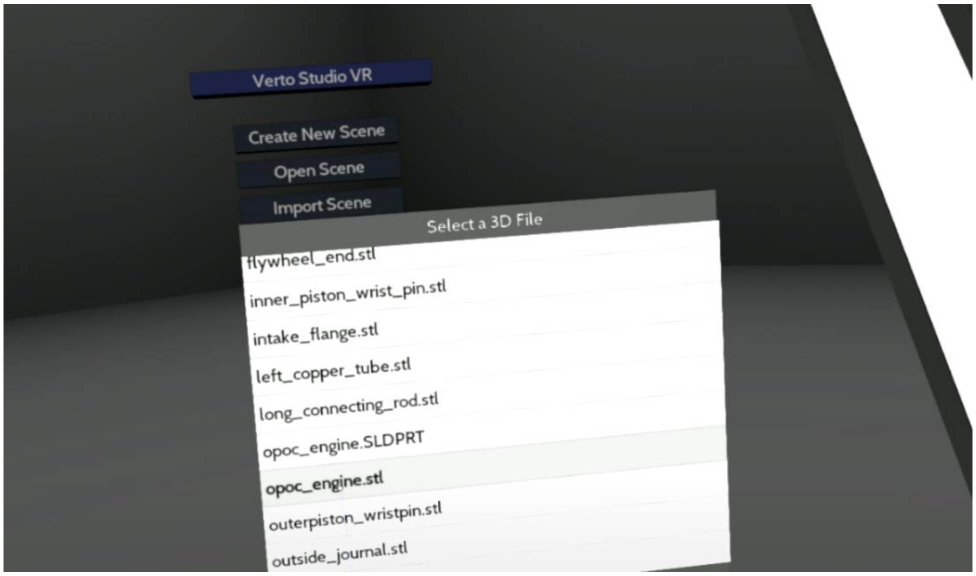


Figure 7.3 - Locating File-Path to STL

After going through the file-path to find the file to import one must simply click on it with the right controller and it will automatically open a new scene with the STL file in it as shown in Fig. 7.4.

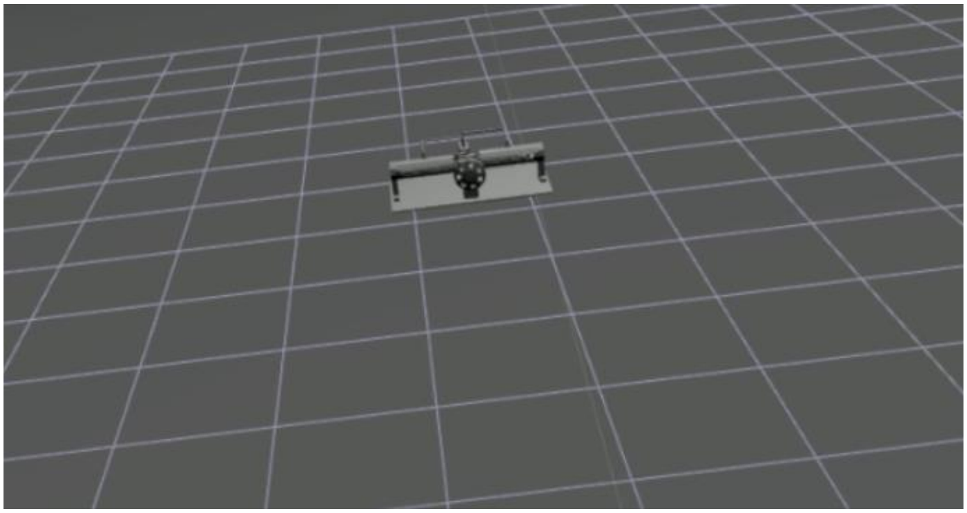


Figure 7.4 - STL Imported into Scene

If you would like to bring this STL file into an already existing scene, then you only have to select the STL and using the touchpad on the left controller you need to select “Copy” and open the scene you want to place it in and then select “Paste” to bring it in as depicted in Figures 7.5 and 7.6.

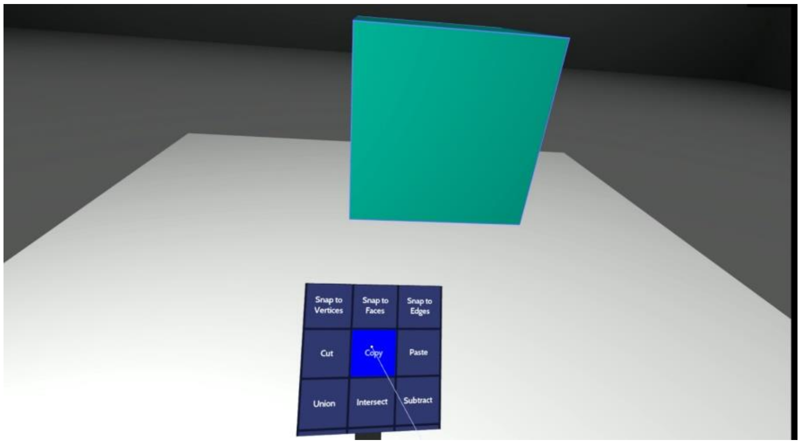


Figure 7.5 – Copying a Model

Figure 7.6 – Pasting a Model

Once the STL file is in the intended scene, it can then be manipulated in a number of ways similar to a computer CAD software. The object can be scaled, rotated, extruded, and moved. All of these actions are done by selecting the object and then scrolling left or right on the left controller's touchpad to the desired tool.

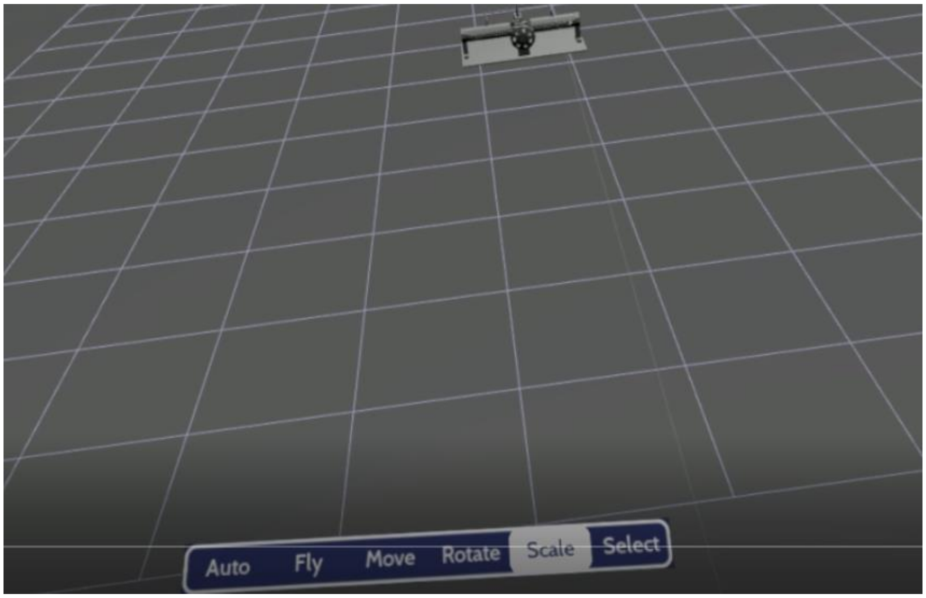


Figure 7.7 - Selecting "Scale" Tool

As shown in Fig. 7.7, the tool "Scale" is selected which allows the user to extrude the object in any direction or keep the aspect ratio and scale the entire object.

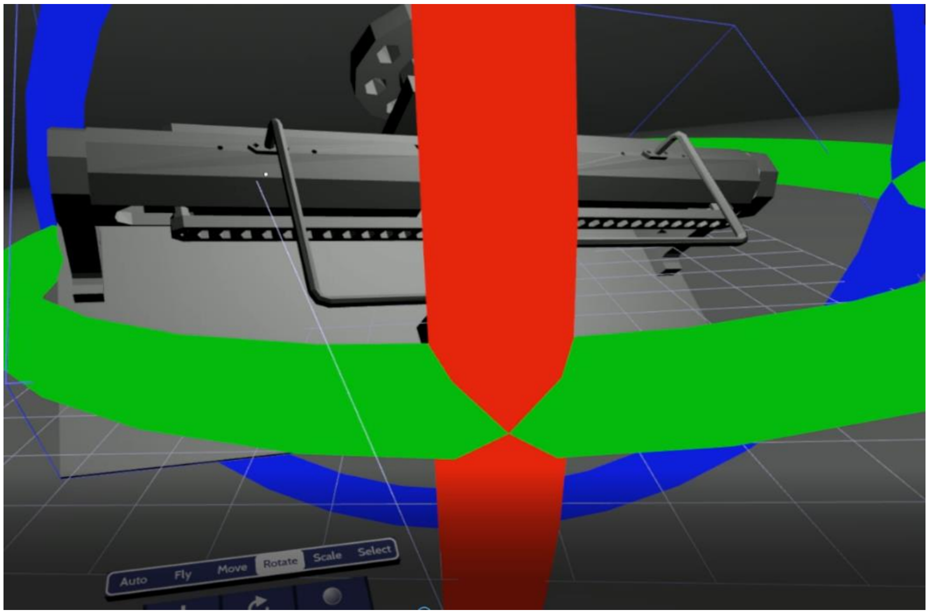


Figure 7.8 - Selecting "Rotate" Tool

By selecting the "Rotate" tool, shown in Fig. 7.8, the user is able to select one of the three color coded axes and rotate the object in that particular axis. The user is also able to rotate the object along all three axes at once by selecting the object itself instead of one of the axes.

7.2 *Appendix B: Modifying Mesh Details Using Solidworks, Blender, and Verto Studio*

After collecting data using the iSense 3D scanner, the mesh details need to be modified further to remove unnecessary or undesirable bumps or object captured by the scanner. The mesh details were able to be modified, with varying degrees of success, in Solidworks, Blender, and Verto Studio.

The most basic method of modifying the meshes generated by the scanner was using Verto Studio. The iSense 3D Scanner saves meshes as an OBJ file types. Verto Studio can open this type of file without any conversion or modification. Using Verto Studio, extraneous object can be removed from the mesh. First, mesh edit mode needs to be enabled as shown in Fig. 7.9. In order to enable this mode, the mesh needs to be selected. This is indicated by a green box surrounding the mesh.

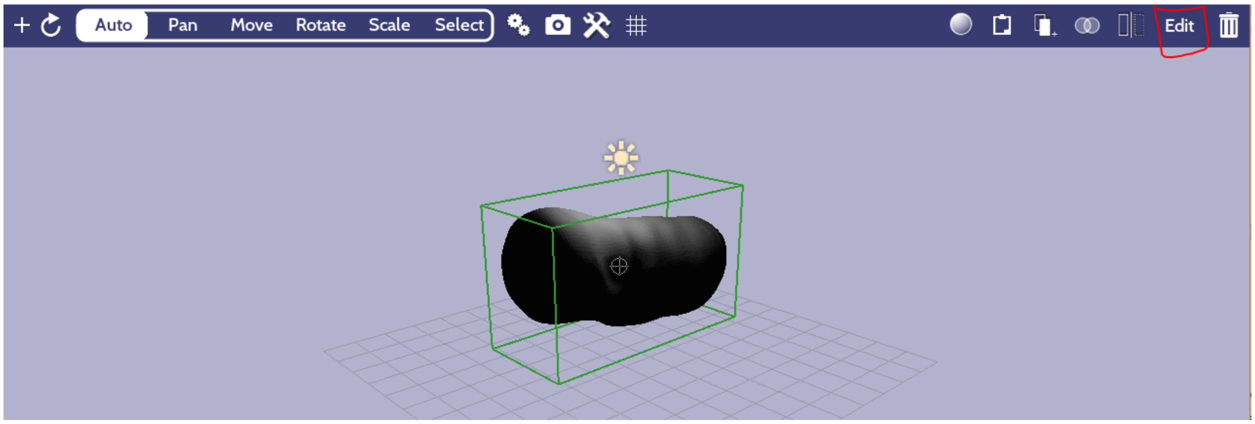


Figure 7.9 - Entering Edit Mode in Verto Studio

Once in edit mode, the Select function can be used to select a single point/face or to select a group of points/faces. Selecting a group is completed by clicking and dragging over the desired area. Once the desired points are selected, they will be highlighted in yellow as shown in Fig. 7.10.

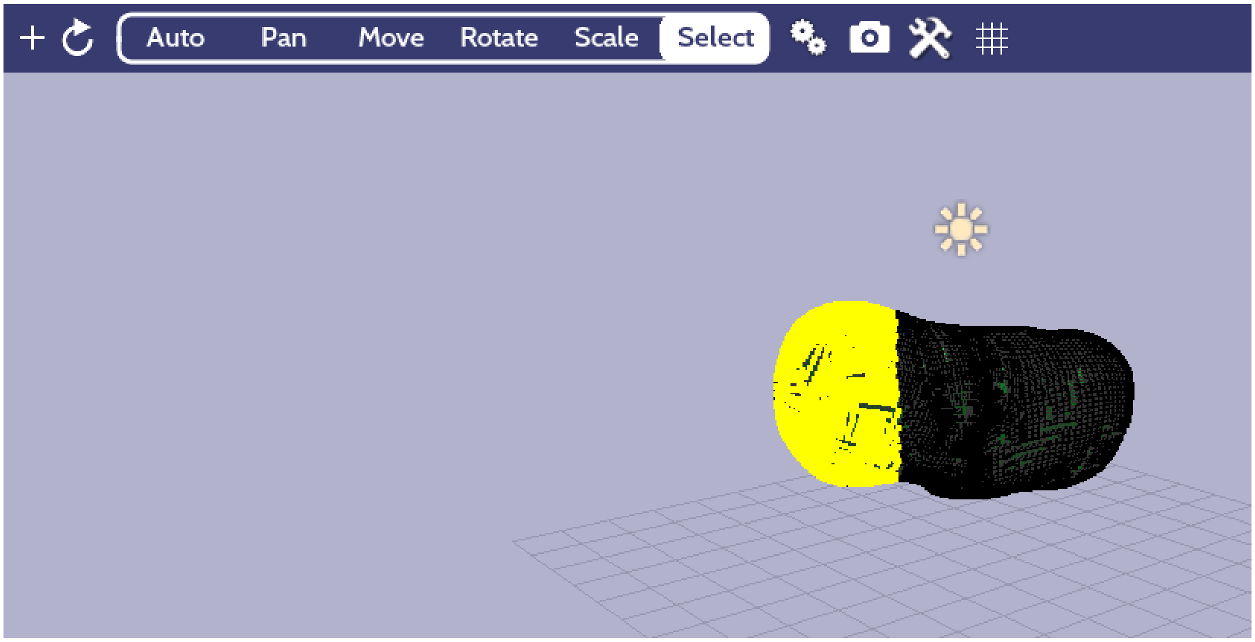


Figure 7.10 - Selecting a Group of Mesh Points in Verto Studio

Once the desired points are selected, they can be deleted by clicking the garbage can icon as shown in Fig. 7.11.

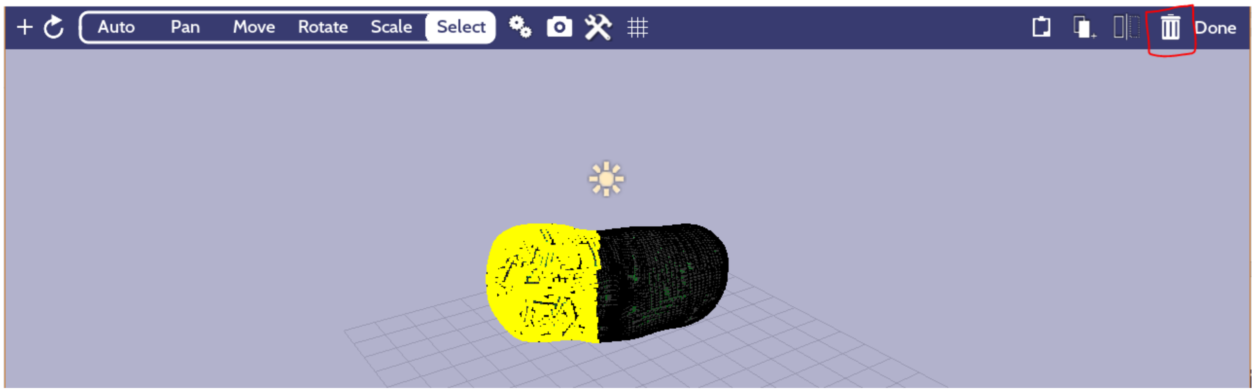


Figure 7.11 - Removing a Group of Points in Verto Studio

The next method used to edit meshes was through Solidworks. A similar process may be available through other PC based CAD packages; however, these steps will pertain to Solidworks specifically. In order to import mesh files (STL and OBJ) the ScanTo3D add-in must be enabled as shown in Fig. 7.12.

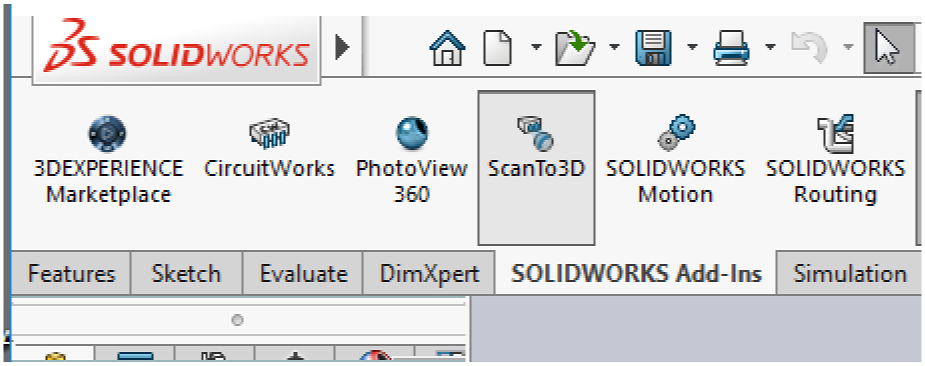
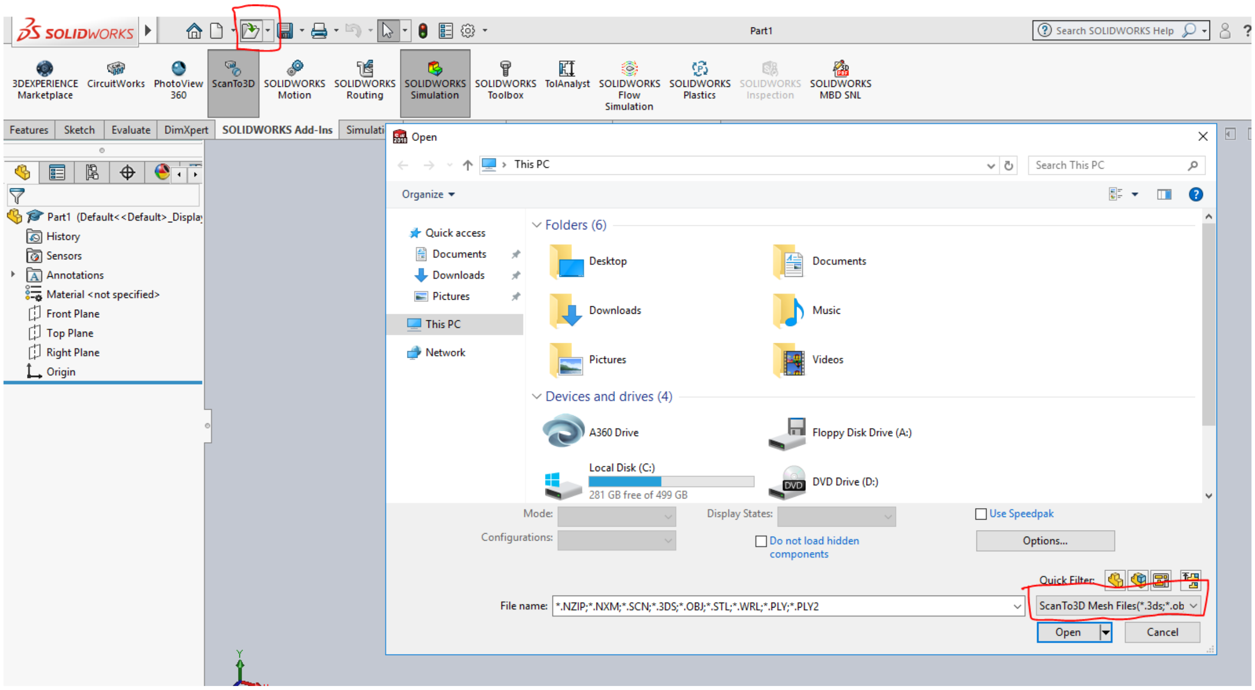


Figure 7.12 - ScanTo3D Solidworks Add-In Enabled

Using the Open File menu, the file type must be set to “ScanTo3D Mesh Files”, as shown in Fig. 7.13.

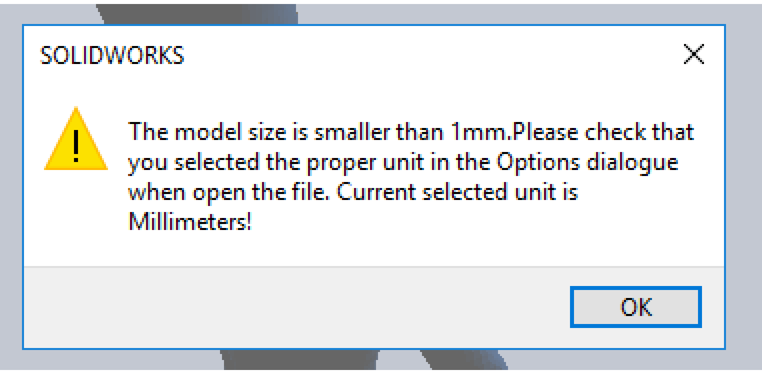


File name: *.NZIP;*.NXM;*.SCN;*.3DS;*.OBJ;*.STL;*.WRL;*.PLY;*.PLY2

ScanTo3D Mesh Files(*.3ds;*.ob

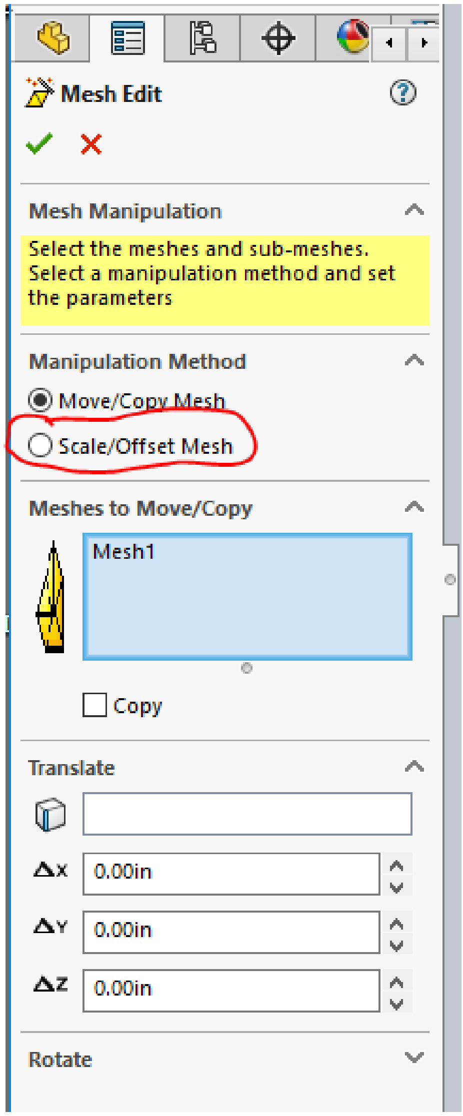
Figure 7.13 - File Type Set to “ScanTo3D Mesh Files”

Then, the desired mesh file can be opened in Solidworks. When using the iSense 3D Scanner, Solidworks gave an error that the mesh was too small as shown in Fig. 7.14. In this case, the mesh needed to be uniformly scaled up by right-clicking the mesh feature in the Feature Tree and selecting “Mesh Edit” as shown in Fig. 7.15.


SOLIDWORKS

The model size is smaller than 1mm.Please check that you selected the proper unit in the Options dialogue when open the file. Current selected unit is Millimeters!

Figure 7.14 - Solidworks Mesh Size Error


Mesh Edit

Mesh Manipulation

Select the meshes and sub-meshes. Select a manipulation method and set the parameters

Manipulation Method

● Move/Copy Mesh

○ Scale/Offset Mesh

Meshes to Move/Copy

Mesh1

☐ Copy

Translate

ΔX 0.00in

ΔY 0.00in

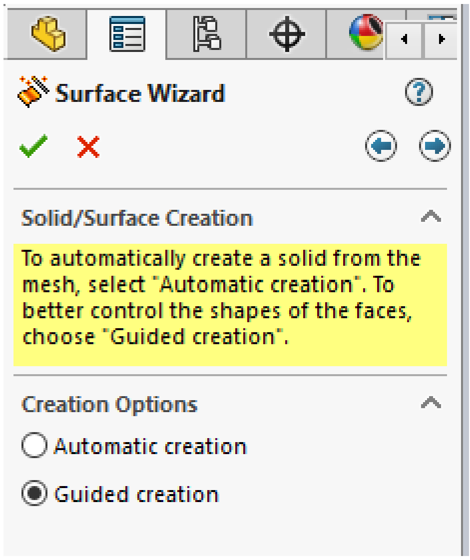
ΔZ 0.00in

Rotate

Figure 7.15 - The "Mesh Edit" Tool in Solidworks

Once the mesh is in a usable state, it can be prepped and edited by right-clicking the mesh feature in the feature tree and selecting "Mesh Prep Wizard". Using this tool, the mesh can be reoriented, trimmed, simplified, smoothed, and have holes filled as needed. For our applications, the meshes were typically simplified in order to reduce the file size to something more manageable by the software packages being used, had holes filed in order to create a continuous surface, and had unnecessary data points/faces trimmed.

After using the Mesh Prep Wizard, the Surface Wizard can be opened auotmatically. If the Mesh Prep Wizard does not open the Surface Wizard, it can be accessed by right-clicking the mesh feature in the feature tree and selecting "Surface Wizard". In the Surface Wizard the user must select a Surface Creation method as shown in Fig. 7.16. For our applications, "automatic creation" was selected as it was more suited to the organic shapes being used.



Solid/Surface Creation

To automatically create a solid from the mesh, select "Automatic creation". To better control the shapes of the faces, choose "Guided creation".

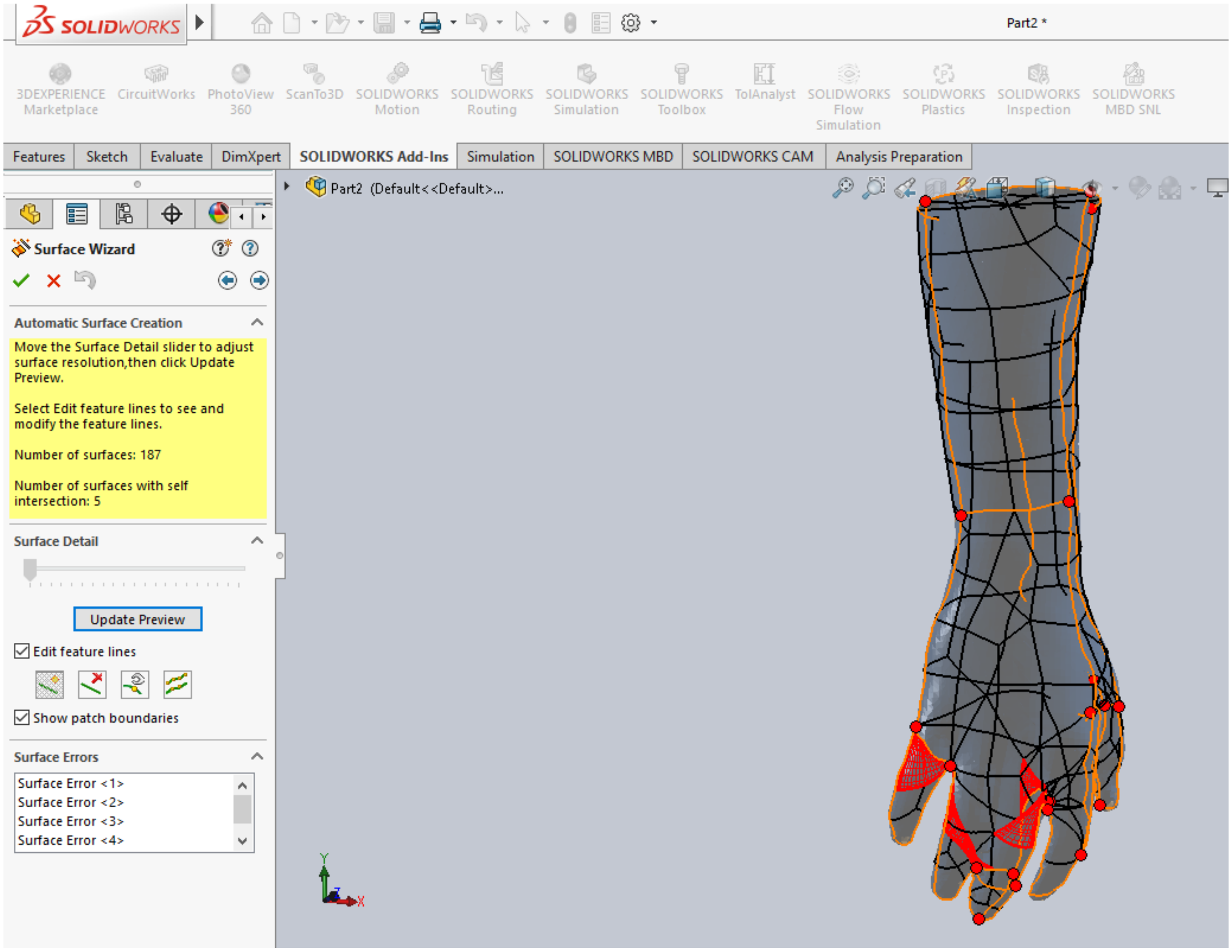
Creation Options

○ Automatic creation

● Guided creation

Figure 7.16 - Surface Wizard Surface Creation Method Selection

After selecting automatic creation method, the surface detail needed to be selected. For our applications a medium to low surface detail was used in order to keep the file size down and the surface simple for use in other software. As we were working with very organic shapes, using a lower surface detail also smoothed out some unwanted bumps and imperfections in the mesh. Once the surface detail is selected and the preview is updated, any surface errors are shown and need to be addressed as shown in Fig. 7.17.



Surface Wizard

Automatic Surface Creation

Move the Surface Detail slider to adjust surface resolution,then click Update Preview.

Select Edit feature lines to see and modify the feature lines.

Number of surfaces: 187

Number of surfaces with self intersection: 5

Surface Detail

Update Preview

☑ Edit feature lines

☑ Show patch boundaries

Surface Errors

Surface Error <1>
Surface Error <2>
Surface Error <3>
Surface Error <4>

Figure 7.17 - Surface Errors to be Addressed in the Surface Wizard

The Surface Wizard provides a few tools to deal with these errors; however, for our use the most successful tool to use was the “Relax Feature Lines” tool. This tool is the fourth option from the left located under the “Edit feature lines” check box in Fig. 7.17. Continuing to the next step can be done at any time. If the surfaces errors are not fixed, Solidworks will delete them and allow you to use one of the other tools in Solidworks to create a surface in the newly created hole. In our use, we always repaired the errors before continuing. Once the mesh is done being modified, the file can be saved as an STL file to be used in a variety of other software packages or for 3D printing.

Lastly, Blender was also used to modify mesh data. Blender was primarily used for smoothing out any unwanted bumps or imperfections on surfaces. This method was particularly intuitive and was very easy to create the desired surface. In order to open then mesh data in Blender go to File > Import and then select the appropriate file type from the menu. With the desired mesh opened, ensure that the mesh is selected. This will be indicated by an orange outline around the mesh as shown in Fig. 7.18.

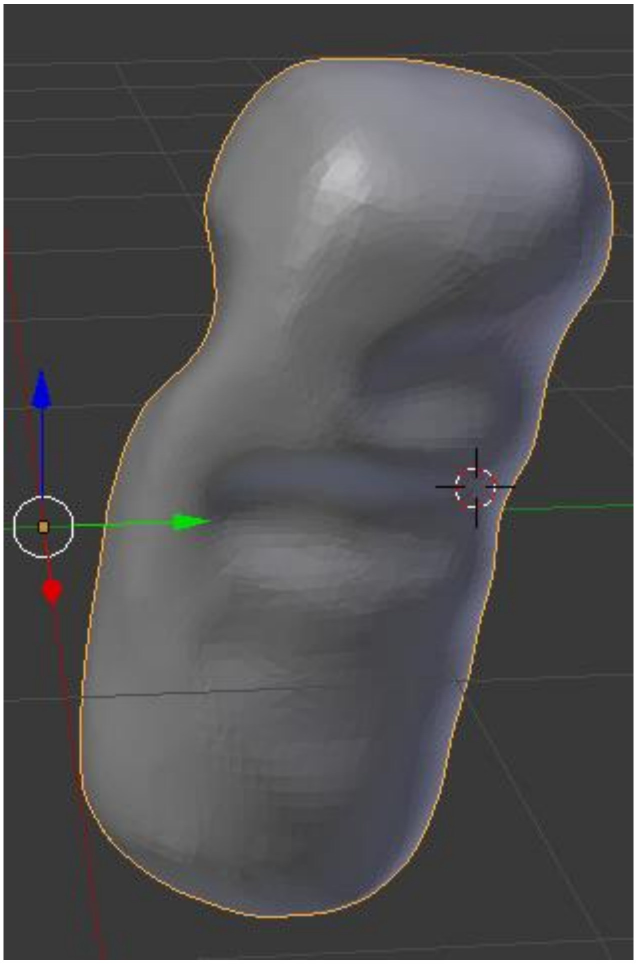
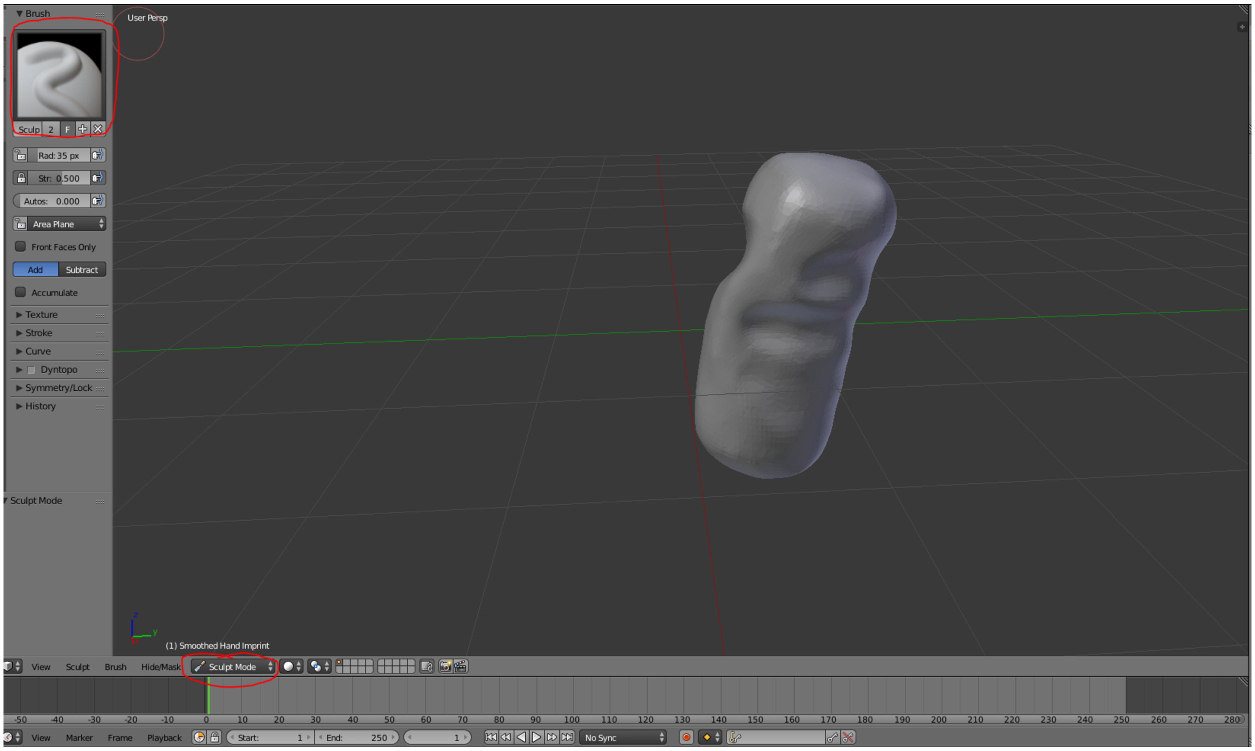


Figure 7.18 - Mesh is Selected in Blender

With the mesh selected, enter Sculpt Mode as shown in Fig. 7.19. The tool being used to sculpt the mesh can be changed in the top left of the screen as shown in Fig. 7.19. For our purposes, the “Scrape” and “Smooth” tools were used most often.



Rad: 35 px
Str: 0.500
Autos: 0.000
Start: 1
End: 250
1

Figure 7.19 - Sculpt Mode and Sculpting Tools Shown in Blender

The Scrape Tool was useful for removing imperfections and bumps near corners or edges. This tool would create a smooth transition between the two surfaces by removing very small amounts of material and still retaining the corner or edge. The Smooth Tool was useful for removing large imperfections or bumps by removing much more material. This tool had a tendency to degrade corners and edges, eventually turning them into flat surfaces if used for too long. Figures 7.20 and 7.21 show the Scrape and Smooth Tools being used respectively. Both figures show a before and after image of a mesh being modified with the respective tool. Both tools needed a few passes before differences on the surfaces were noticeable. For these figures, both tools were used for the same number of passes in order to highlight the difference in the amount of material removed.

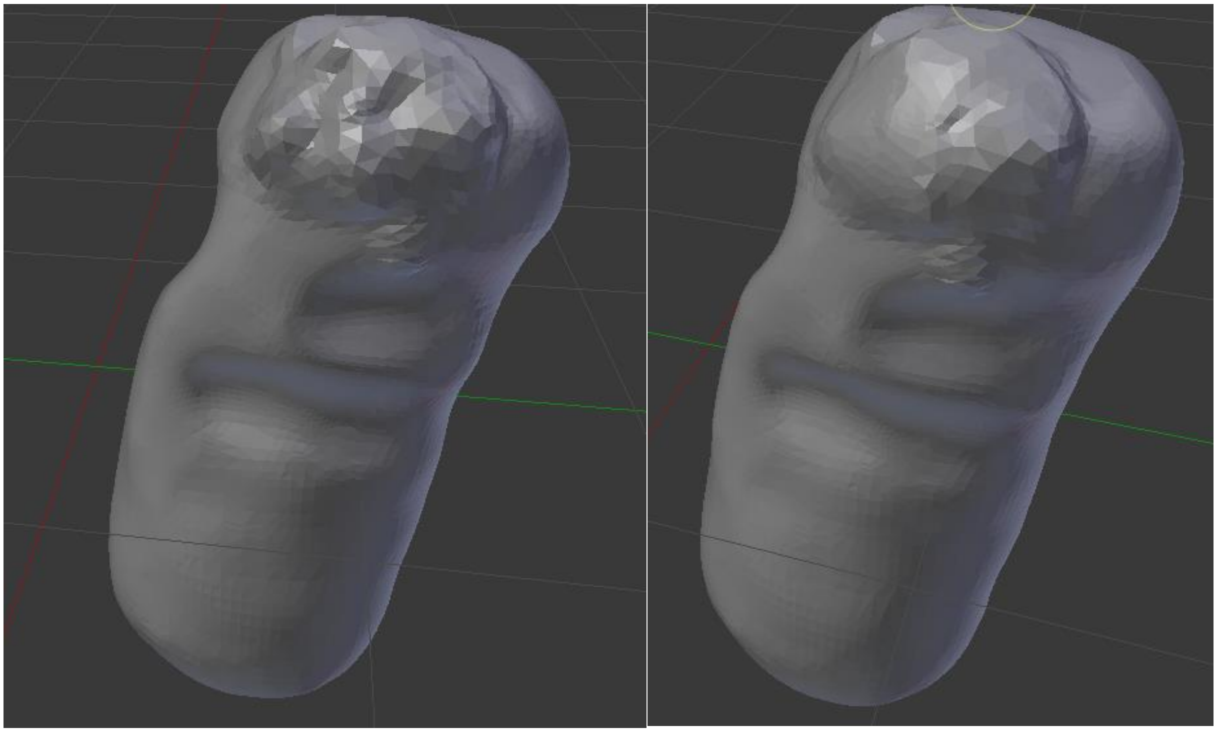


Figure 7.20 - Before (Left) and After (Right) the Scrape Tool Was Used

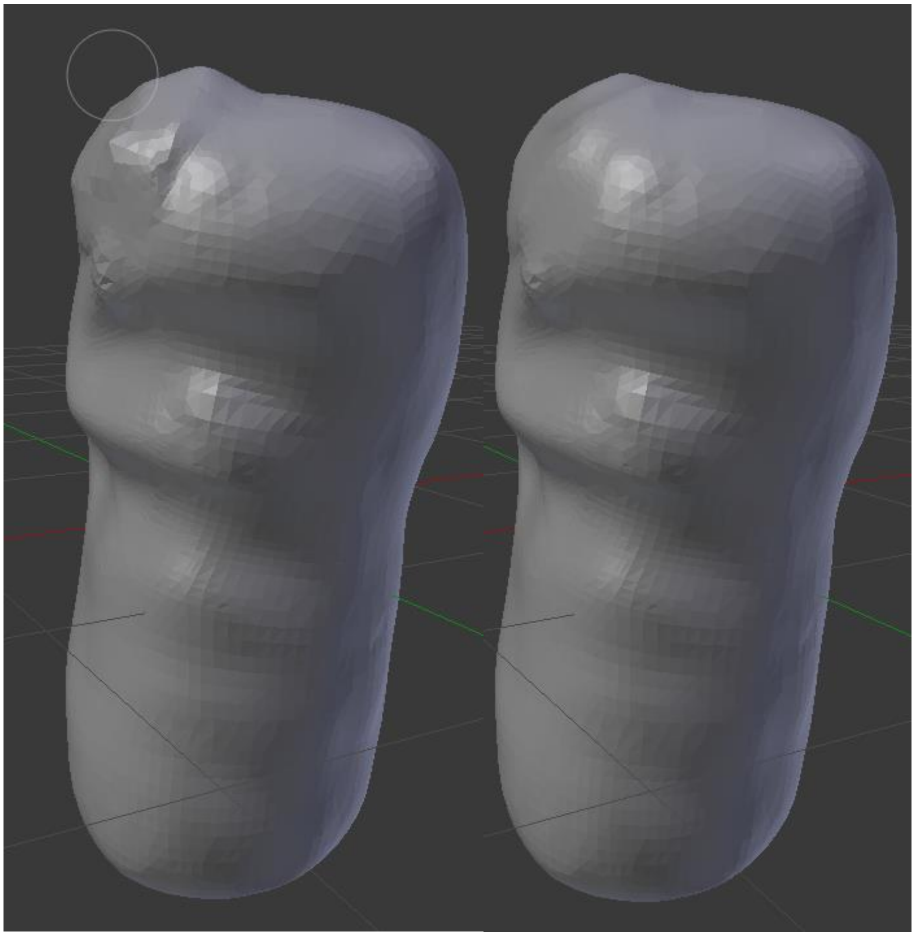


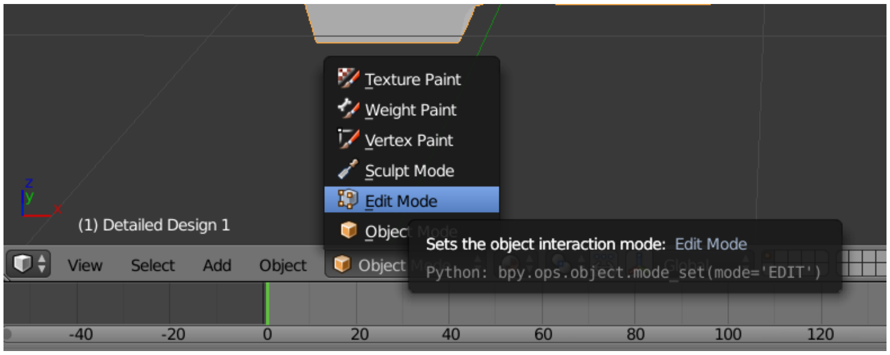
Figure 7.21 - Before (Left) and After (Right) the Smooth Tool Was Used

7.3 Appendix C: Replicating FEA Models for VR CAD

Verto Studio VR lacks the capability to read in textures from OBJ files without a custom-made bitmap and MTL file. If the user tries to apply a texture onto a model that they either created or scanned, Verto Studio VR cannot apply any changes beyond color. Details from any PNG or JPG will disappear leaving only one solid color and any ability to map multiple colors to a model in a specific way does not exist in the user's options within the application. The method suggested by the developer is to bake the texture into the OBJ, which can be done through Blender and photo editing software.

7.3.1 Creating a Bitmap Image

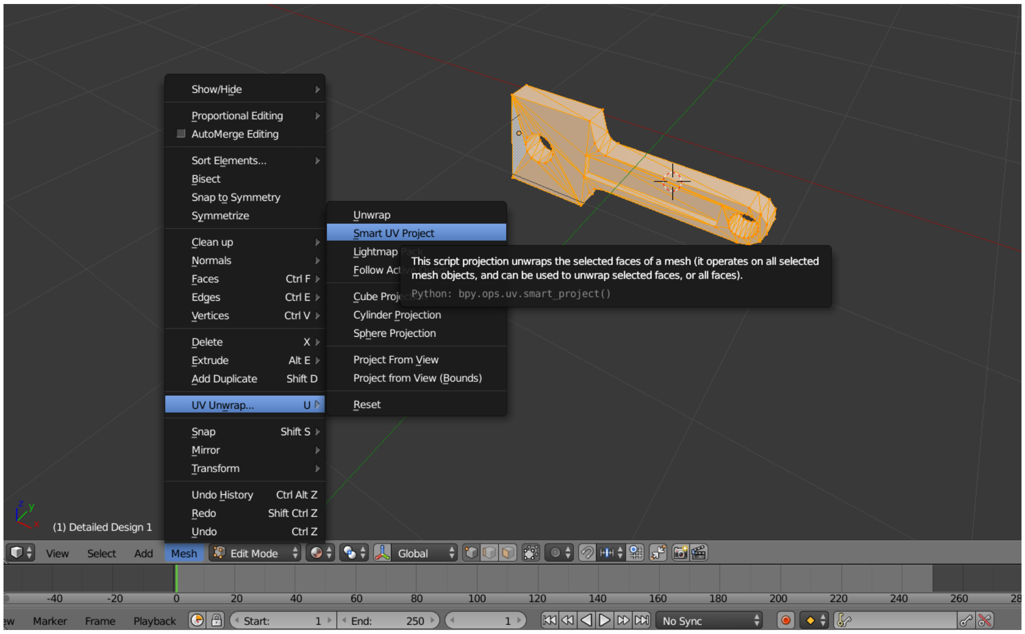
The first step to creating a custom multicolored texture for any model is to UV Unwrap the model in order to create a bitmap image. This was done in Blender by first importing the model and going into edit mode by toggling the option at the bottom of the screen as shown in Fig. 7.22. In edit mode the user is able to now select all the faces of the object by pressing A, which will result in the model turning orange to indicate what has been selected. To unwrap the model, the "Smart UV Project" option was selected under Mesh > UV Unwrap > Smart UV Project as shown in Fig. 7.23. A prompt will appear, press OK. The user can view the UV bitmap by changing the view to "UV/Image Editor" which will show a transparent bitmap image upon starting the process as shown in Fig. 7.24.



Sets the object interaction mode: Edit Mode

```
Python: bpy.ops.object.mode_set(mode='EDIT')
```

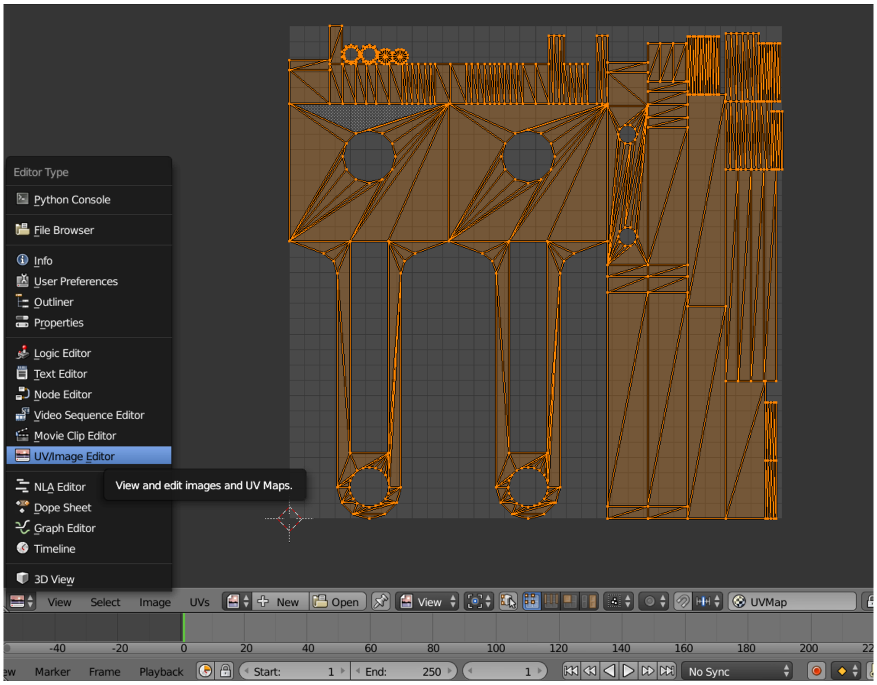
Figure 7.22 - Location of the option to switch to Edit Mode



This script projection unwraps the selected faces of a mesh (it operates on all selected mesh objects, and can be used to unwrap selected faces, or all faces).

```
Python: bpy.ops.uv.smart_project()
```

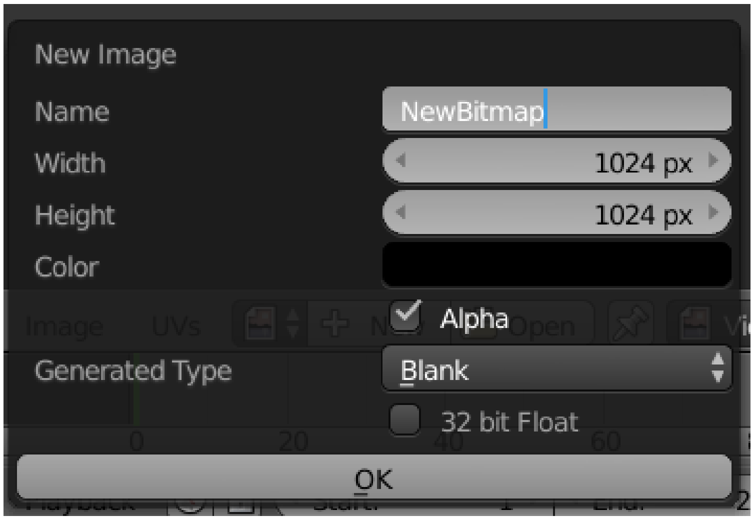
Figure 7.23 - Selected Object Being Unwrapped via Smart UV Project Option



View and edit images and UV Maps.

Figure 7.24 - UV/Image Editor Mode with Blank Bitmap

A new bitmap image was created by pressing the new button at the bottom of the screen. A prompt appeared where the name, size, and other preferences of the image could be changed as shown in Fig. 7.25. The image was then saved as a PNG which was opened in a digital art program called Krita, shown in Fig. 7.26. In Krita the bitmap image was completed through a long process of reapplying the texture in Blender to monitor the changes on the model itself. A reference image was used while the image was painted over as shown in Fig. 7.27.



New Image

Name: NewBitmap

Width: 1024 px

Height: 1024 px

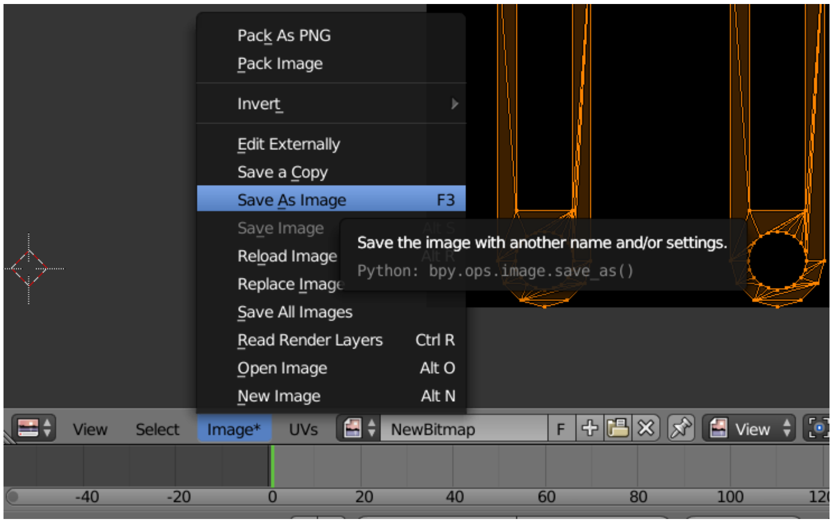
Color

☑ Alpha

Generated Type: Blank

☐ 32 bit Float

Figure 7.25 - Prompt to Create a New Bitmap Image



Save the image with another name and/or settings.

```
Python: bpy.ops.image.save_as()
```

Figure 7.26 – Saving Bitmap Image as a PNG in Blender

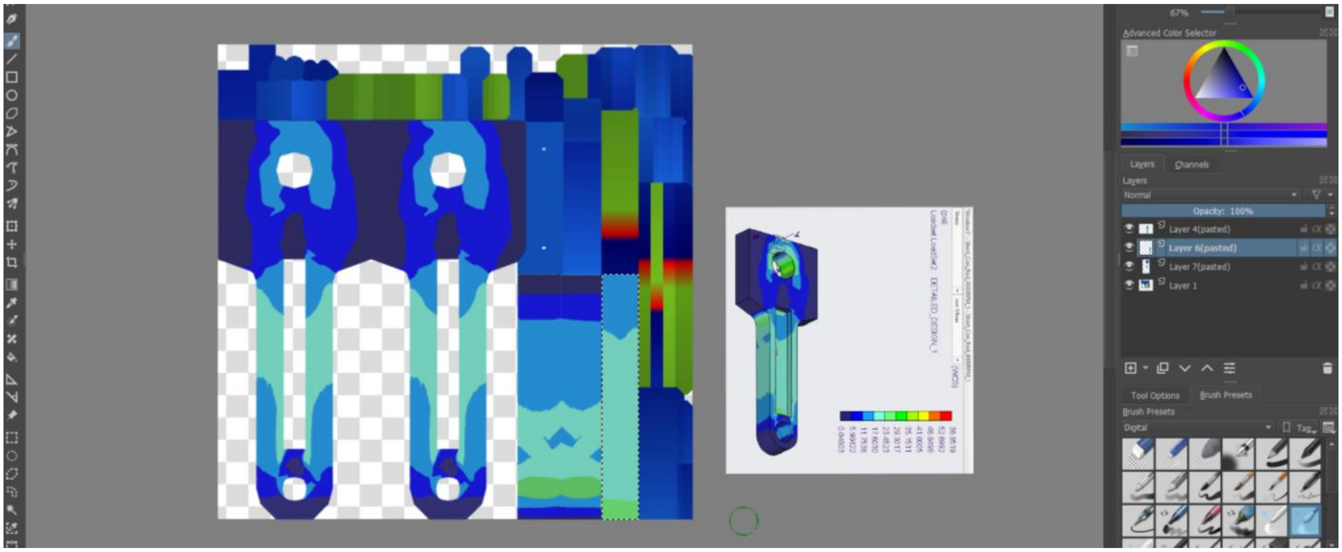
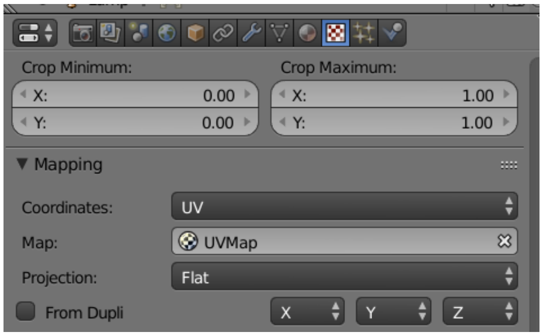


Figure 7.27 - Bitmap Image Being Edited in Krita

7.3.2 Texturing the Model & Creating the MTL file

Once the bitmap image was completed, it was baked onto the model in Blender. The model was opened in Blender, unwrapped via Smart UV Project to start the process. In Edit Mode, the mapping settings under the Texture tab were changed to UV for Coordinates, UVMap for Map, and Flat for projection as shown in Fig. 7.28. Above the Mapping section in the Texture tab, the bitmap was uploaded by selecting the Open button and opening the bitmap. After the texture was applied, the model was baked and then saved as an OBJ. The texture was baked to the model by unselecting the clear option then pressing the Bake button under the Bake tab shown in Fig. 7.29. The MTL file isn't created until the model is exported as an OBJ, also shown in Fig. 7.29.



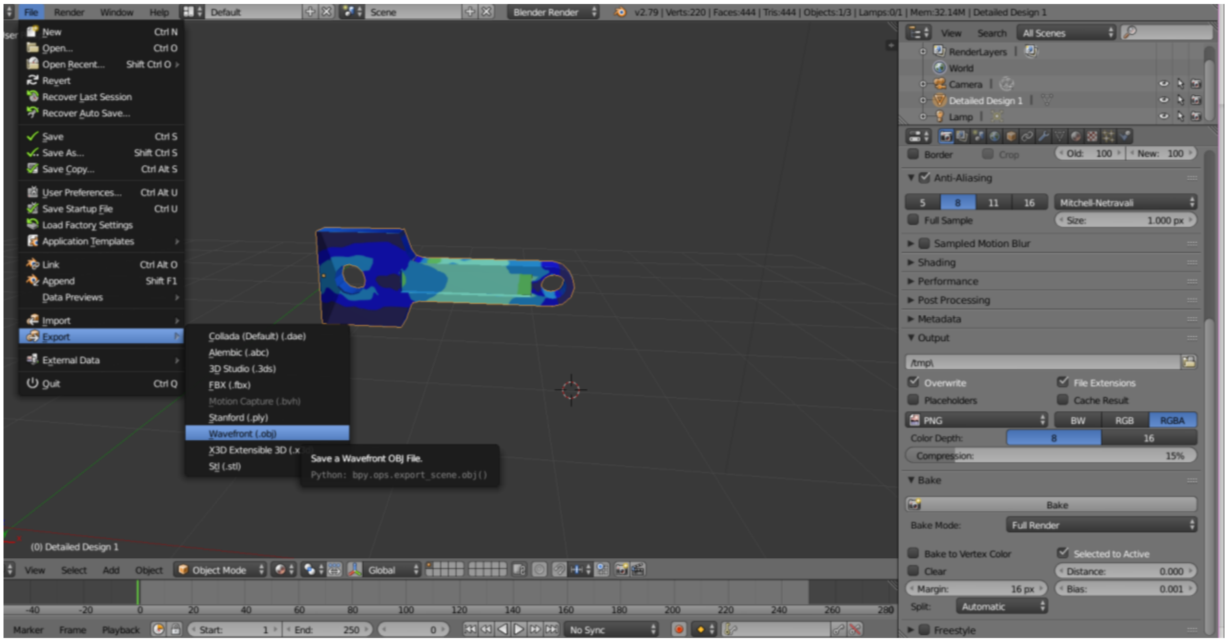
Crop Minimum:
X: 0.00
Y: 0.00

Crop Maximum:
X: 1.00
Y: 1.00

▼ Mapping

Coordinates: UV
Map: UVMap
Projection: Flat
☐ From Dupli
X Y Z

Figure 7.28 - Map Settings for the Texture



Save a Wavefront OBJ File.

Python: bpy.ops.export_scene.obj()

Output: /tmp\
☑ Overwrite ☑ File Extensions
☐ Placeholders ☐ Cache Result
PNG BW RGB RGBA
Color Depth: 8 16
Compression: 15%

Bake Mode: Full Render
☐ Bake to Vertex Color ☑ Selected to Active
☐ Clear Distance: 0.000
Margin: 16 px Bias: 0.001
Split: Automatic

Start: 1 End: 250

Figure 7.29 - Baking the Model and Exporting to Create MTL File

7.4 Appendix D: Endoscopic Telescope Dimensions

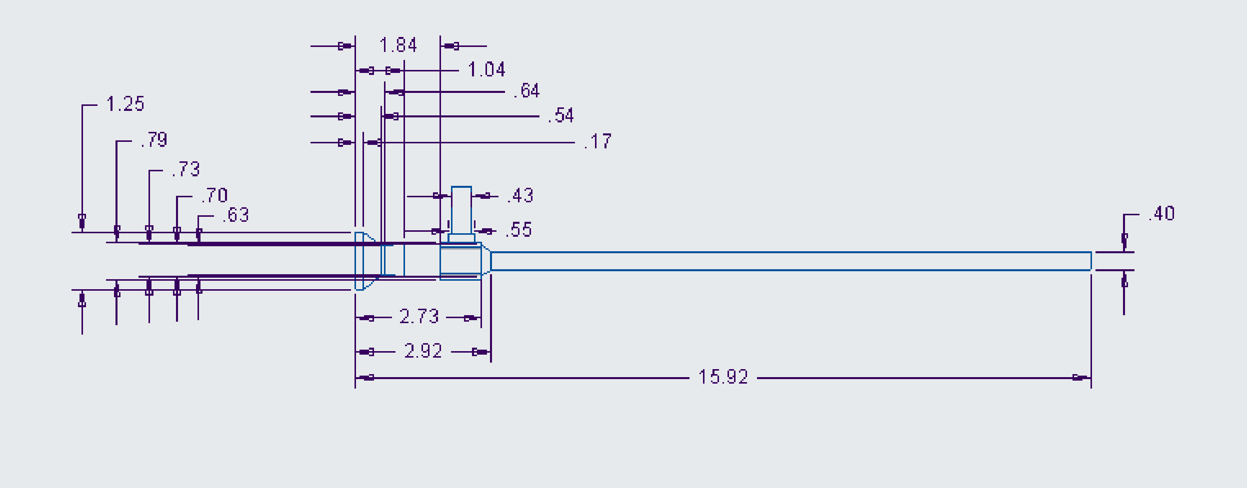


Figure 7.30 - Endoscopic Telescope Model Dimensions in Inches

7.5 Appendix E: Hardware and Software Used

Throughout this project a number of pieces of hardware and software were utilized in order to assess their capabilities and the advantages that they could bring to the engineering design process. The hardware and software used will be listed in the sections to follow.

7.5.1 Hardware

The system used throughout this project was an HP Workstation Z VR Backpack. This system had an Intel Core i7-77820HQ CPU, an NVIDIA Quadro P5200 GPU, 32GB of RAM, and was running Windows 10 Pro 64 bit. This system comes with a docking station so that it could be used as a traditional desktop computer. However, it also came with a backpack holder so that the system can be worn on the users back in conjunction with a VR headset.

The VR headset used was an HP Windows Mixed Reality Headset. This headset came with the left- and right-hand controllers included.

The system and VR headset were donated to WPI by HP.

The portable 3D Scanner used was an iSense 3D Scanner with an iPad Air 2. This scanner and iPad were available to borrow from Professor Erica Stults at WPI.

7.5.2 Software

A number of software packages were used throughout this project. For CAD software, we used Solidworks and PTC Creo Parametric 4.0. Both of these software packages were available through WPI's remote desktop server located at windows.wpi.edu using our WPI login information. Most computers around WPI's campus also have this software installed already.

The software used to edit meshes was Blender. Blender is an open-source, free software available at blender.org. Once the software is downloaded, the installation application can be started, where the Windows Installation Wizard will take the user step-by-step through the installation process.

The VR software used was Verto Studio VR. This software is available through the Windows Mixed Reality Store that comes preinstalled on the system. This software is also available though the Steam store. The Steam application can be downloaded from store.steampowered.com for free. In order to access this store an account must be created; however, it is free to create an account. Verto Studio VR is a paid application and costs $30 on the Windows Mixed Reality Store or $20 on Steam.

The application used on the iPad with the iSense Scanner was preinstalled on the system that we borrowed.

7.6 Appendix F: Software Issues and Workarounds

There were several issues when working with the HP Z Virtual Reality system and the VR software. The technology is new and the companies & developers have only been releasing content for the Windows Mixed Reality platform in the past 3 years. Many times, there were bugs encountered due to incompatibility issues between Microsoft, Verto Studio and Steam VR. This is a comprehensive list of issues that occurred during the time of the project, and how the team solved those issues or found a different way to achieve the same goal.

7.6.1 Windows Mixed Reality Issues

Many incompatibility issues arose such as apps not launching if the user is not signed into Microsoft account it was purchased with. Or developer's apps not working due to glitches in the Microsoft Mixed Reality software. The team encountered this while trying to purchase and run Verto Studio VR from the Mixed Reality store. The app succeeded to launch properly for several days but would then inexplicably fail to launch the application. The developer for Verto Studio was contacted and confirmed that it was on Microsoft's end. The team worked around this issue by downloading the Steam VR plugin and purchasing Verto Studio from the Steam store instead.

7.6.2 Verto Studio Audio Glitch

After Steam VR proved successful for running Verto Studio VR, the team ran into another problem which would not allow the application to run. The bug would occur when launching Verto Studio through Steam VR, it would launch the Steam VR application but not the Verto Studio VR app, giving an error that mentioned an audio plugin malfunctioning. This was fixed by inserting headphones into the computer or headset. For the remainder of the project headphones were left in the audio jack to avoid this issue.

7.7 Appendix G: Hewlett Packard Mixed Reality Headset Setup

Our equipment setup requires several outlets to power the necessary monitor, charging base, and backpack battery charging station. As shown below in Figure 7.31, our setup consisted of connecting the charging base power supply, the HP headset video input into the computer, the monitor connection from the base to the monitor, as well as mouse and keyboard connection in order to use and be able to startup the mixed reality device.

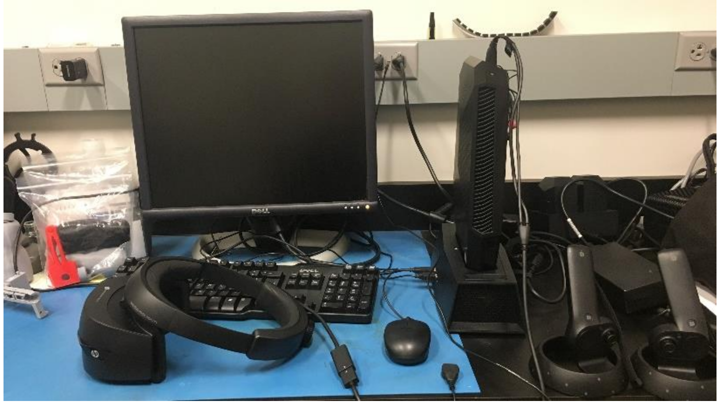


Figure 7.31 Entire Equipment Setup

Figure 7.32 shows the power connection necessary to run the computer in its charging base.

Figure 7.32 Power Connection From Outlet to Charging Base

Figure 7.33 shows the video (HDMI) and USB connection necessary for the headset to operate.

Figure 7.33 Headset Connection via USB and HDMI Connection

Figure 7.34 and 7.35 depicts the mouse and keyboard connection as well as the button layout on the computer and charging dock, respectively.

Figure 7.34 Mouse and Keyboard Connection

Figure 7.35 Charging Dock

7.8 Appendix H: Use and Initialization of Hardware and Software

After pressing the power button (depicted in Figure 7.36) on the computer, the computer will turn on and prompt you to sign into your Microsoft account in order to operate the system.

Figure 7.36 Location of Power Button on HP Z Computer

Buy this software as a gift for a friend

Buy Verto Studio VR

$19.99

Figure 7.37 Verto Studio VR on Steam Marketplace

After signing in, the desktop will appear and “Windows Mixed Reality for Steam VR” should be preinstalled on the system. In order to use Verto Studio, the user will have to download the Steam marketplace from the internet. When in the Steam application, and after signing in to an existing steam account, the user will have to buy and download “Verto Studio” from the Steam marketplace and have that install onto the system (shown in Figure 7.37). Once Verto Studio is downloaded, to start the software it should be as easy as opening the Verto Studio application with the VR headset plugged in. This should cause “Windows Mixed Reality for Steam VR” to automatically start up and display what the user sees through the headset. In order to begin anything in Verto Studio the user has to turn on the controllers as well as put on the headset. Turn on the controllers by holding down the Windows Menu button on the controllers until the lights on the rings light up, as shown in Figure 7.38. After getting everything running the main Verto Studio menu will appear and you can begin working as shown in Figure 7.39.

Figure 7.38 Location of Windows Menu Button on Controller

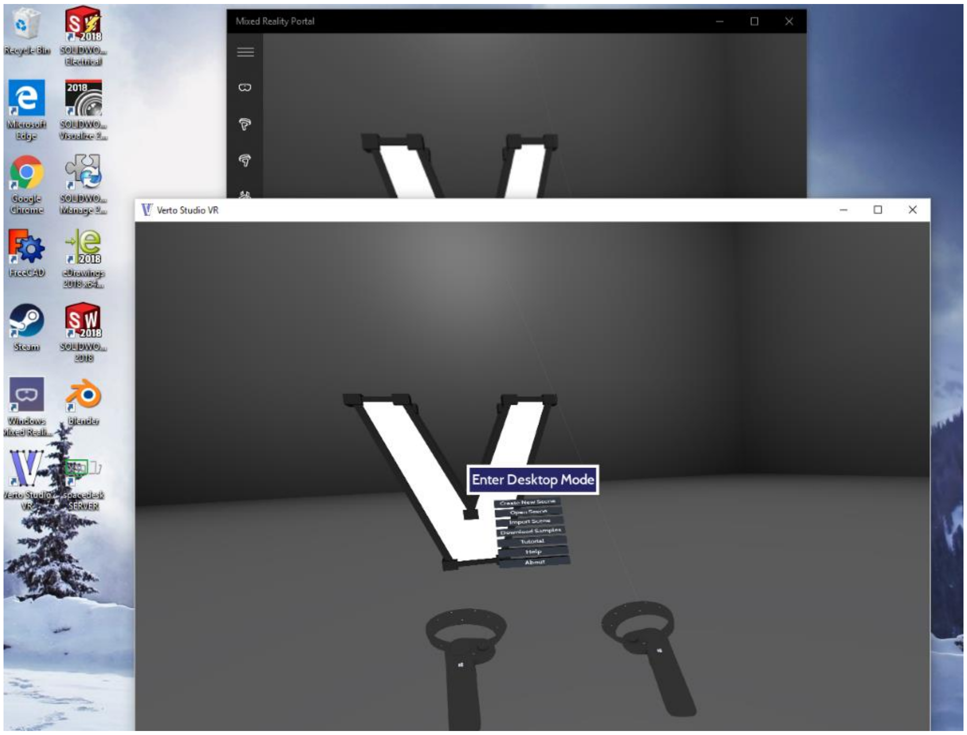


Figure 7.39 Verto Studio VR on Start Up

7.9 Appendix I: System Maintenance and Care

There have been no incidents of hardware malfunctions during the duration of this project. To move the system, make sure the user unplugs everything from the computer charging base and computer itself prior to change of locations. This will allow the user more comfort in transportation and easier setup at the new location. As long as the system is not physically harmed, (from drops, banging, or impacts) the system should perform as expected.

Throughout this project there have been several incidents involving software issues, either from bugs or uninstalled features. To remedy this, make sure all software is updated to the newest version.