SD500053

Using Fusion 360 to Design Patient-Specific Prosthetic and Orthotic Devices

Michael Peirone
Victoria Hand Project

Learning Objectives

- Define Fusion 360's use by healthcare professionals in an orthotic and prosthetic context
- Model designs parametrically with a user interface for quick and easy customization
- Implement Fusion 360's API to make the design process easier for users who have little to no CAD experience
- Create workflows to generate user-specific devices using Fusion 360

Description

The Victoria Hand Project (VHP) is a non-profit organization with a mission to provide low-cost orthotic and prosthetic (O&P) devices to resource-poor areas of the world. VHP's in-country clinical partners previously used pre-made models to make custom O&P devices for 3D printing, but were limited in sizing and customizability. For many healthcare providers, creating custom devices in Fusion 360 can be difficult, as they do not have experience using CAD tools. VHP created software which utilizes the Fusion 360 API to develop custom prosthetic arm sockets and orthotic braces for scoliosis. Healthcare providers enter a patient's anatomical measurements into the software, which are then used in a parametric Fusion model to be custom sized. The software provides clinicians the ability to create patient-specific devices which fit more comfortably and function better. This case study presents how VHP created a UI and Fusion 360 Add-In to allow non-technical users to design and print custom O&P devices.



Speaker(s)

Michael Peirone is the Chief Operating Officer of the Victoria Hand Project (VHP); a Canadian non-profit organization with a mission to provide prosthetic care to low-income communities around the world. Michael has been a core member of VHP since its conception in 2015; assisting with the research and design of the first Victoria Hand, a low-cost, 3D printed prosthetic device. As COO, Michael oversees the day-to-day operations of Victoria Hand Project, and also assists with the long-term vision of the organization. With extensive knowledge in 3D printing, engineering design, and the orthotic and prosthetic field, Michael has trained many of the VHP's partners around the world on manufacturing and fitting the Victoria Hand. His expertise and passion for making a difference has driven the success of the project over the years, and he continues to be closely involved with innovation and design improvements.

Introduction

This industry talk will provide a case study on how the Victoria Hand Project uses the AutoDesk Fusion 360 API to create patient-specific prosthetic and orthotic components in low-income regions around the world. By implementing the Fusion API into the workflow, Victoria Hand Project was able to streamline the process of creating the devices, allowing non-technical users to create parametric designs, and help more people access care.

Victoria Hand Project Background

The Victoria Hand Project (VHP) uses 3D printing and 3D scanning technologies to create custom prosthetic and orthotic devices for low-income communities around the world. The Victoria Hand is a low-cost, highly functional, 3D printed prosthetic arm, which recipients use for tasks at home, work, and school, helping amputees gain back their independence. VHP's international partners make each of these arms custom-made for each user, to create a more comfortable fit, and a natural looking prosthetic device. The shape of the limb is captured by using 3D scanning, and is used to digitally create a custom prosthetic socket, which is fabricated using 3D printing. The entire end-to-end process is completed by clinicians and technicians in the world's poorest communities, getting these devices to the people who need them most, close to home.

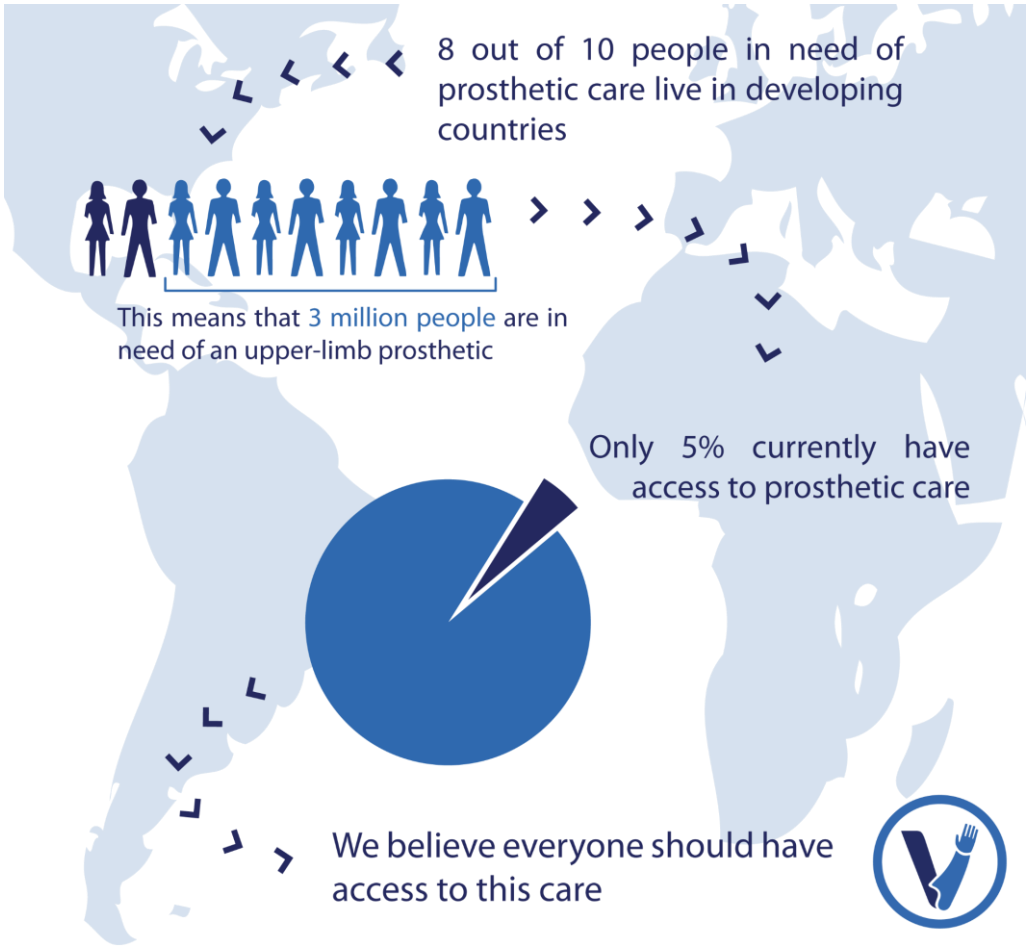


Figure 1: Millions of amputees around the world do not have access to proper prosthetic care.

The World Health Organization (WHO) and the International Society for Prosthetics and Orthotics (ISPO) estimate that 80% of amputees live in developing countries, yet only 5% have access to prosthetic care[1]. Healthcare systems in many developing countries do not receive proper support from their governments and are not able to provide amputees with sufficient care. This is due to a variety of factors, such as the high cost of prosthetic devices, a lack of infrastructure to manufacture the devices, and a scarcity of trained prosthetists to help provide these devices to patients. This means that many amputees end up going without a prosthetic device. In some developing countries, the loss of the limb has a stigma associated, and can lead to low self-esteem and social exclusion from the community. Limb loss may make it difficult for amputees to find and maintain employment. There are also many daily hardships associated with limb loss, including difficulties with eating, taking transportation, and dressing. These are all things that able-bodied individuals take for granted.



Figure 2: Countries where the Victoria Hand Project operates.

The Victoria Hand Project is a Canadian non-profit organization with a mission to provide low-cost, 3D printed prosthetic care to amputees in developing countries and low-income communities. VHP has also recently begun a collaborative research project with the University of Victoria (UVic) to create 3D printed orthotic back braces to help in the treatment of scoliosis. The Victoria Hand Project is currently providing the Victoria Hand in 8 developing countries, and is beginning expansion to remote and under-served areas of Canada and the United States.



Figure 3: The three key aspects to VHP's deployment model.

VHP partners with healthcare professionals and technology experts in developing countries, and trains them on how to manufacture and fit the Victoria Hand prosthetic devices themselves. By 3D printing the prosthetic devices in the communities where they are needed most, amputees can receive their custom prosthetic arms in less time, when compared to conventional devices. This also helps create high-tech jobs using advanced skills, such as computer aided design (CAD) and 3D printing. Clinicians using these tools to make devices for their neighbours helps foster a sense of pride in the community and leads to sustainable, on-going care.

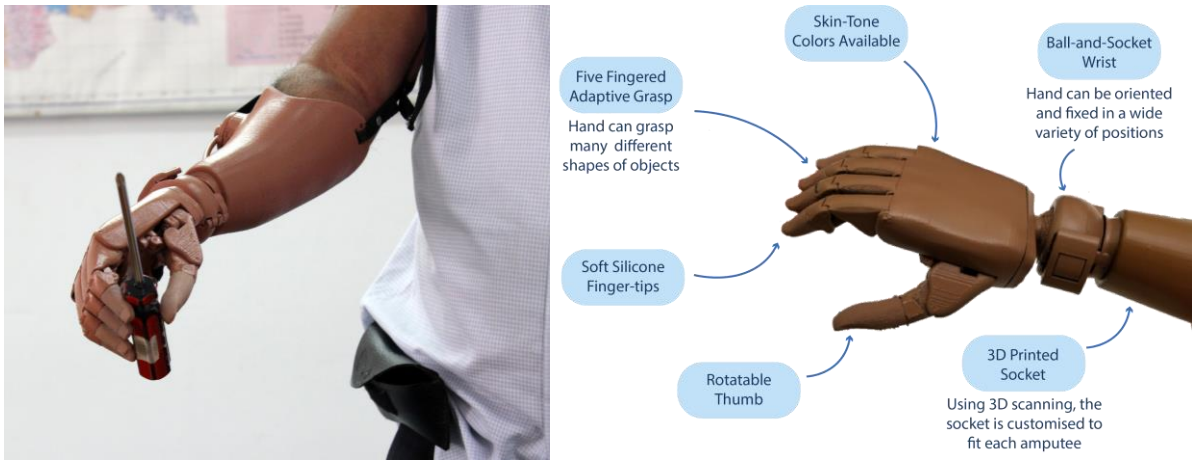


Figure 4: A patient using the Victoria Hand (left). The features of the Victoria Hand (right).

The clinicians VHP works with are incredibly busy, and are not able to dedicate time to properly learn CAD programs. They want to have cutting-edge technologies to increase their clinic's capacity and help as many people as possible. The desire to enable VHP's partners to maximize their impact is what drove VHP to develop software using the Fusion 360 API.

Making the Custom Socket

Each custom-made prosthetic socket uses the patient's anatomical dimensions to create a prosthetic device that is anatomically correct and comfortable. When the patient visits a clinic, the clinician will record the patient's anatomical dimensions and create an exact replica of the limb using Plaster of Paris, called the 'limb positive.' The limb positive is 3D scanned to create a digital model of the patient's limb. Using the patient's dimensions, a pre-made socket file (.stl or .obj file format) is selected from an online database. The 3D scan is aligned in the pre-made socket, according to the clinician's expertise and the patient's needs. The digital model of the limb is cut from the socket to leave a cavity the exact shape of the recipient's limb. After cutting out the limb shape, the custom-made socket is 3D printed. This entire process can be done by the clinicians in one day, and the patient can receive a custom socket the following day. In some cases, patient's need to wait a few days or weeks to receive their socket when using a traditional prosthetic.

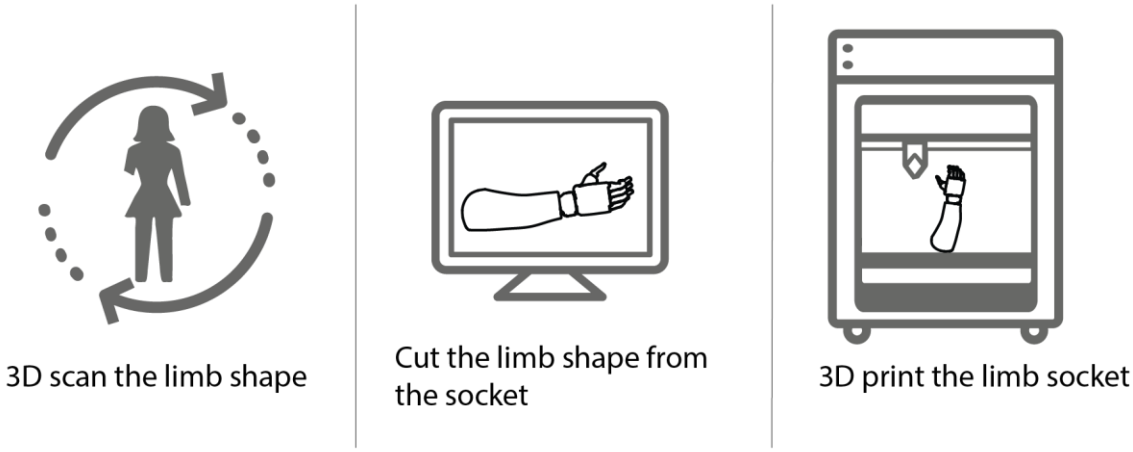


Figure 5: The three simple steps to make a custom socket.

The limb positive, also called the plaster impression, is 3D scanned using a technique called photogrammetry. Photogrammetry is a process which uses 60-80 photos of an entire object, to generate a 3D replica of the object on the computer. The reason VHP uses this method for 3D scanning, rather than using other scanning methods, is because it is much lower cost, and it provides very accurate scans with true color information.

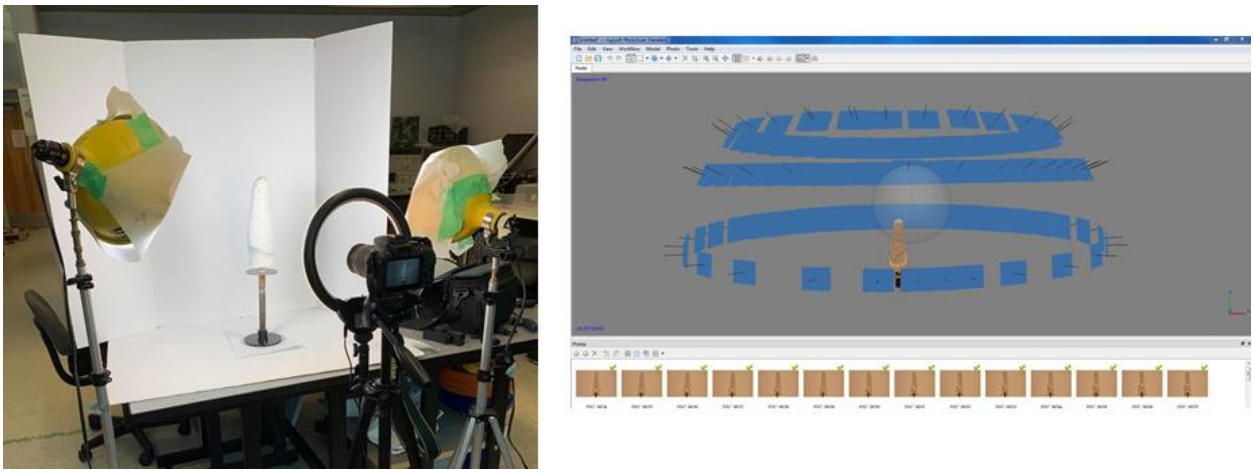


Figure 6: Taking images of the limb positive with a digital camera (left). Using photogrammetry to generate a digital model of the limb positive (right).

After 3D scanning the limb positive, it is loaded into a program named AutoDesk MeshMixer. MeshMixer, shown in Figure 7, is a free program for working with triangle meshes (i.e. .stl and .obj files formats). Next, a socket is selected from the online database of socket sizes, and is imported into MeshMixer as well. The 3D model of the limb positive is aligned within the pre-socket, and 'cut away' using a Boolean difference.



Figure 7: The scan of the limb positive in AutoDesk MeshMixer.

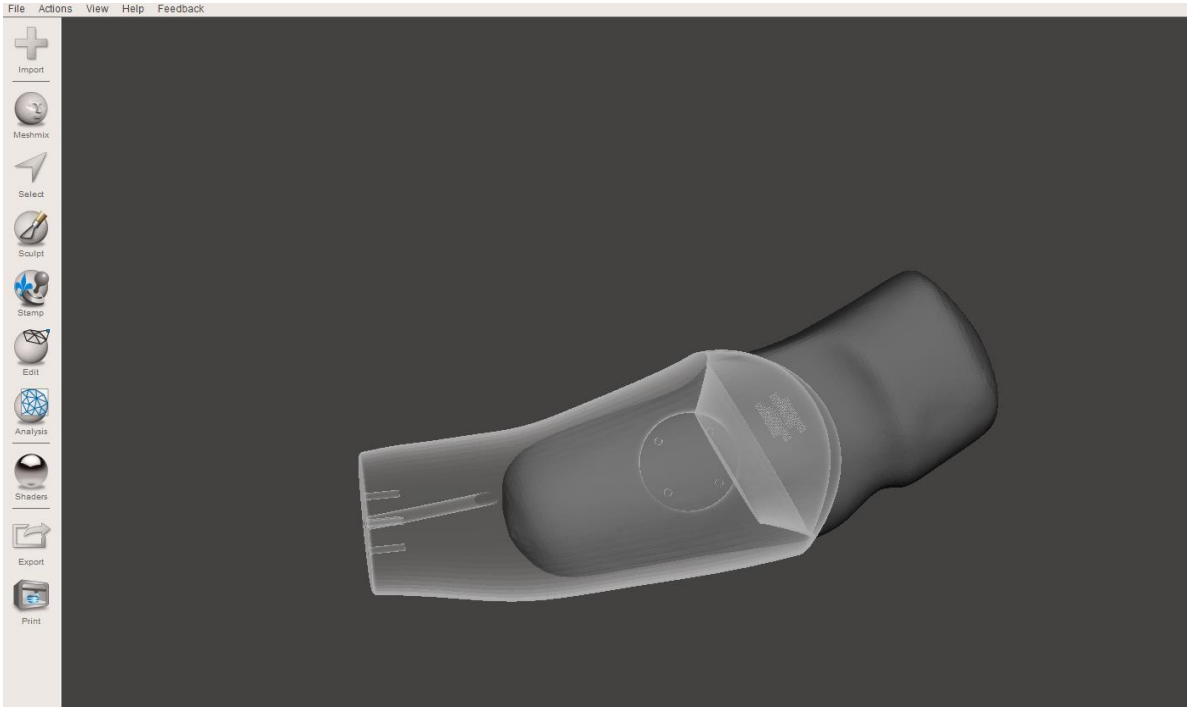


Figure 8: Aligning the limb positive in the socket in AutoDesk MeshMixer.

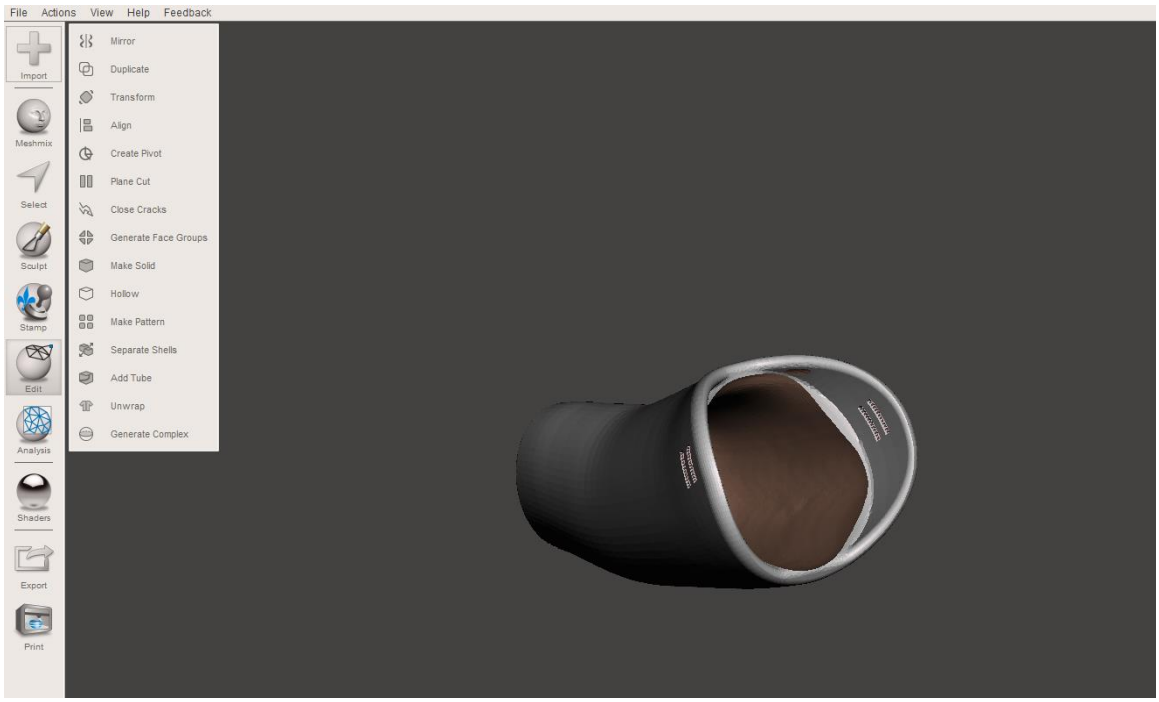


Figure 9: Performing a ‘Boolean Difference’ operation to cut the limb positive shape out of the socket.

A quick demonstration of making the custom socket in AutoDesk MeshMixer can be viewed here: https://www.youtube.com/watch?v=_0dcCScPKCM

The Socket Model

To make the custom limb socket, a pre-made socket is selected from an online library based on the patient's anatomical dimensions. The middle of the pre-made socket is filled in to create a solid region, and the limb positive is cut out of this solid region to create a cavity with the patient's exact limb shape. These sockets were designed by the Victoria Hand Project's engineering design team, and are provided to the partners so they can make the custom prosthetic sockets themselves.

The Old Method

The socket design was originally made in a CAD program using parametric measurements (using parameters in an equation), so that the socket model could be scaled to match each patient's size. This process allowed VHP to generate many different sizes of sockets, but due to limitations in the CAD program it made it very difficult to export the mesh files (.stl and .obj format) of these sockets. The socket contains 3 primary parametric measurements which are used to create custom sockets of various different sizes. The primary measurements are the Forearm Circumference, the Wrist Circumference, and the overall length. The dimensions of each socket needed to be entered in the Equation Manager and each socket must be exported manually. This process of creating each socket size was very time-consuming for the VHP engineers. By using this process, VHP had a library of over 6000 different sizes of sockets, each with different combinations of Forearm Circumference, Wrist Circumference, and length dimensions. To find the desired socket size, the clinician needed to search through various folders sorted by size, shown below, and then download the socket to test the fit with the limb positive in MeshMixer. The engineering team was very hesitant about making minor changes since each new version of the socket would need to be manually exported again.

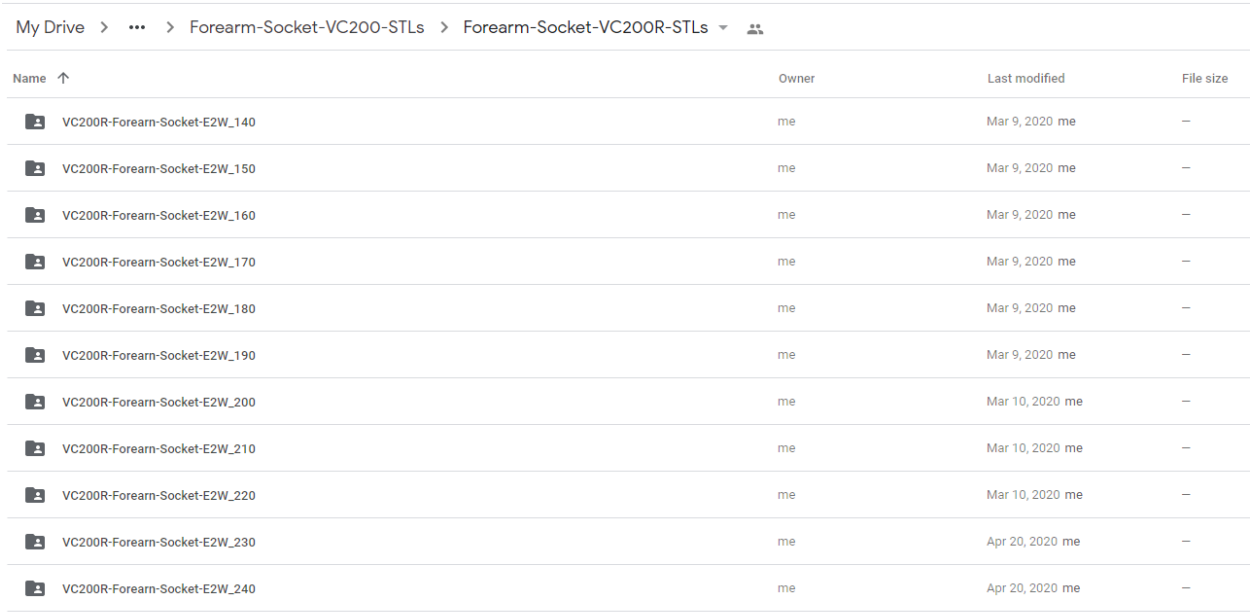


Figure 10: The online socket catalogue sorted by size. Within each folder is another series of folders to further sort the sockets.

The Decision to Use Fusion 360

The Victoria Hand Project engineering team redesigned the socket in Fusion 360. Fusion 360 provided more freedom over the design, and allowed for a more natural-looking shape of socket. To make the process of creating the sockets easier, a software script could be run in Fusion 360 to automatically generate each size of socket, then export them. This saved a lot of time during the process of generating each socket. Rather than entering the dimensions for a single socket, then exporting the socket, and repeating the process for each socket size, the scripting process could export the sockets as a batch. This script, named ParaParam, used spreadsheets with the lower bound (i.e. smallest dimension), the upper bound (i.e. the largest dimension), and the increments between each size. Every combination of dimensions within this range would be exported from Fusion with minimal input required from the user. This script worked very well and VHP was no longer hesitant to make changes to the socket design, since the export process was straight-forward.

ParaParam: https://forums.autodesk.com/t5/fusion-360-api-and-scripts/paraparam-script-for-fusion-360/td-p/5596124

(Please note, ParaParam was developed using the JavaScript (JS) programming language, but JS is no longer compatible with Fusion 360 Scripts and Add-Ins. ParaParam has been linked here for reference).

By using this method, VHP was able to easily cover a larger range of socket sizes. However, there were times that VHP's international partners would ask for larger or

smaller sockets to fit a patient, since they were outside the range of the sockets in the online database. Creating a custom-sized socket in Fusion was simple for the VHP team, but making extra sockets required time from the engineering team. VHP wanted to have a way for the clinical partners to easily create custom sockets on their own using Fusion 360. An issue was that the international partners are primarily clinicians and do not have experience with any CAD tools. VHP felt that the partners couldn't just be provided with a copy of Fusion 360 and ask them to make each socket themselves.

Orthotic Braces

The Victoria Hand Project also began conducting research on creating and manufacturing 3D printed orthotic braces using CAD tools. The original brace model was designed in a CAD program and used more than 20 parameters to create the correct sized brace. Entering these dimensions in the equation manager and updating the design was a very slow process. After the Victoria Hand Project's positive experience with using Fusion 360 to design the limb socket, the orthotic back brace was redesigned in Fusion 360 as well. This allowed for a more natural and organic shape, rather than a very mechanical-looking brace.

However, the brace design still required more than 20 parameters to create the base shape of the brace. This is due to the variability in sizes of patient torsos, and the need for the brace to closely fit the shape of the body. In the socket design, there are 3 primary measurements which are used to customize the socket for the patient. Using these 3 measurements, and expanding to accommodate most patients, a library of thousands of sockets was generated. Creating a similar library for the braces would not be feasible. The different combinations using the 20 primary measurements, and the additional adjustments, is much too high. If this online library was created, it would be close to impossible for the clinicians to find the size of brace that they need.

VHP determined that the best approach was to create a software program that can make the different sized braces by using the patient's anatomical dimensions. It was decided that using 3D scanning to capture the shape of the patient's torso would not be feasible. This is due to the high costs of full-body scanners (~ $100,000 USD) and the lack of access to these scanners in many developing countries and low-income communities. The brace design also needed to be easily adjustable. The entire brace is parametrically-designed so that the clinician can further adjust the shape by entering dimensions to perform twists, shifts, and bends in specific regions. It is not very difficult for an experienced CAD user to go into the Fusion 360 equation manager and make these adjustments, or to go directly into the design and change sketches or features. However, the Victoria Hand Project's clinical partners are not experienced in using CAD tools. It may be a little overwhelming for them to go into the design space and to make these adjustments themselves. VHP also didn't want to rely on their clinical partners needing to learn CAD tools to proceed with creating these custom braces.

It is also not a scalable solution for the Victoria Hand Project's engineering team, or other technical experts, to make one-off designs for each patient. It is much better to create a program that can

make each size of brace with minimal input from the clinicians. In many clinics in North America and other high-income nations, the prosthetists and orthotists will have a technician who works in their shop to help with creating the prosthetic and orthotic devices. However, in many places where VHP works, the clinicians do not have technicians to help out with the tedious labor and must do most of the end-to-end workflow themselves. The Victoria Hand Project wanted to design tools that can be used by clinical experts which will do the tedious tasks, helping free up the clinician's time to help more people.

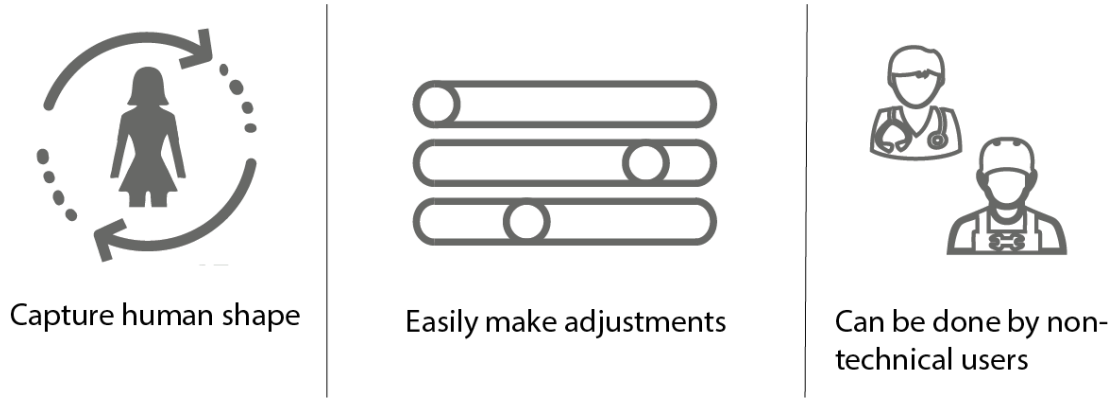


Figure 11: VHP's software must be able to capture the patient's shape, allow users to easily make adjustments, and can easily be used by non-technical users with little-to-no CAD experience.

Fusion Engineer Support

Fortunately, the Victoria Hand Project team was able to get some help on this project from AutoDesk employees, through the AutoDesk Technology Impact Program. This program helps startups and nonprofit organizations better reach their goals with the donation of AutoDesk tools and consulting from AutoDesk employees. VHP first got in touch with Brandon Cramer, a Principal Research Engineer at AutoDesk Research, through this program. Brandon also brought on Kevin Acker, a Senior Technical Consultant at AutoDesk, and Melisa Kaner, a Technical Consultant at AutoDesk. Brandon, Kevin, and Melisa provided the VHP engineering team with advice on tools and design workflows that could be used to create the parametric orthotic back brace design. They also help the VHP team implement the Fusion API into the design workflow to help with creating software to quickly and easily generate the custom back braces. Thanks to the help from Brandon, Kevin, and Melisa, VHP was able to speed up the design timeline, and reach milestones much more quickly.

The Fusion API

The AutoDesk Fusion 360 API (Application Programming Interface) is a simple way to control functions and features within a design, and streamline workflows. An API is an intermediary that works between two programs or applications. In this case, the API works between a script (i.e a software script) and Fusion 360. A developer will write a script to add the sketches, functions, or features into a Fusion 360 design. The API will read the script and add these sketches or features

into the model in Fusion 360 with little or no user input. For example, the following figure shows Victoria Hand Project's script using the API to select specific faces in the model and offset these faces by a predefined amount. This means that a user does not need to select the faces in Fusion themselves and then offset them; the API can do it automatically.

```
    Offset Feature

'''

# Create input entities for offset feature
inputEntities = adsk.core.ObjectCollection.create()
for face in faces:
    inputEntities.add(face)

# Distance for offset feature
distance = adsk.core.ValueInput.createByString('0 mm')

# Create an input for offset feature
offsetFeatures = features.offsetFeatures
offsetInput = offsetFeatures.createInput(
    inputEntities, distance, adsk.fusion.FeatureOperations.NewBodyFeatureOperation)

# Create the offset feature
# offsetFeatures.add(offsetInput)
offsetBody = offsetFeatures.add(offsetInput)

'''

    Thicken Feature

'''

# Create the thicken feature
thickenFeatures = features.thickenFeatures
inputSurfaces = adsk.core.ObjectCollection.create()
thickenFaces = offsetBody.faces
for face in thickenFaces:
    inputSurfaces.add(face)
thickness = adsk.core.ValueInput.createByString('3 mm')
thickenInput = thickenFeatures.createInput(
    inputSurfaces, thickness, False, adsk.fusion.FeatureOperations.NewBodyFeatureOperation)
thickenedBody = thickenFeatures.add(thickenInput)
```

Figure 12: Example Python code for the Fusion API. This selects the desired faces and offsets the faces (top image), then thickens the faces by a predefined amount (lower image).

The Fusion API is used for creating or altering 'object models,' which are sketches and features in Fusion 360, such as Lofts or Splines.

A chart showing the object models that can be added into designs by using the Fusion API is shown here: https://help.autodesk.com/cloudhelp/ENU/Fusion-360-API/ExtraFiles/Fusion.pdf

Fusion 360 already has a number of Scripts and Add-ins pre-loaded in when you download the program. You can access your scripts and Add-ins by clicking on Tools along the top bar and going to ADD-INS.

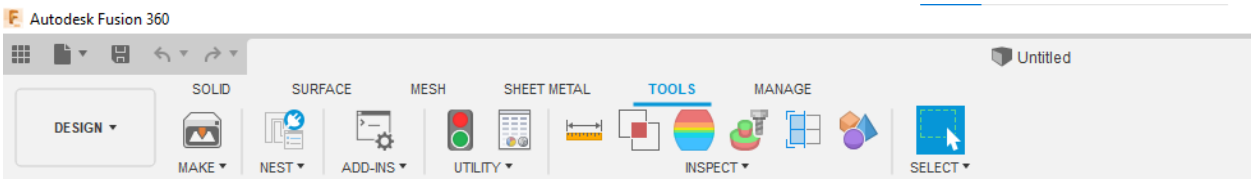


Figure 13: You can find the Add-Ins on the top bar of Fusion 360.

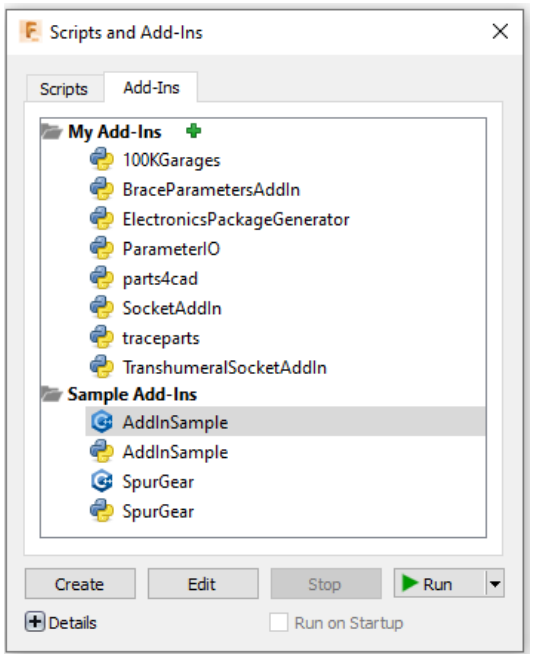


Figure 14: Add-Ins that can be run on Fusion 360.

If you would like to start developing a Script or Add-Ins for your specific design needs, you can also go to 'Create' and a pop-up will appear where you can begin to fill out the details of your Script/Add-In.

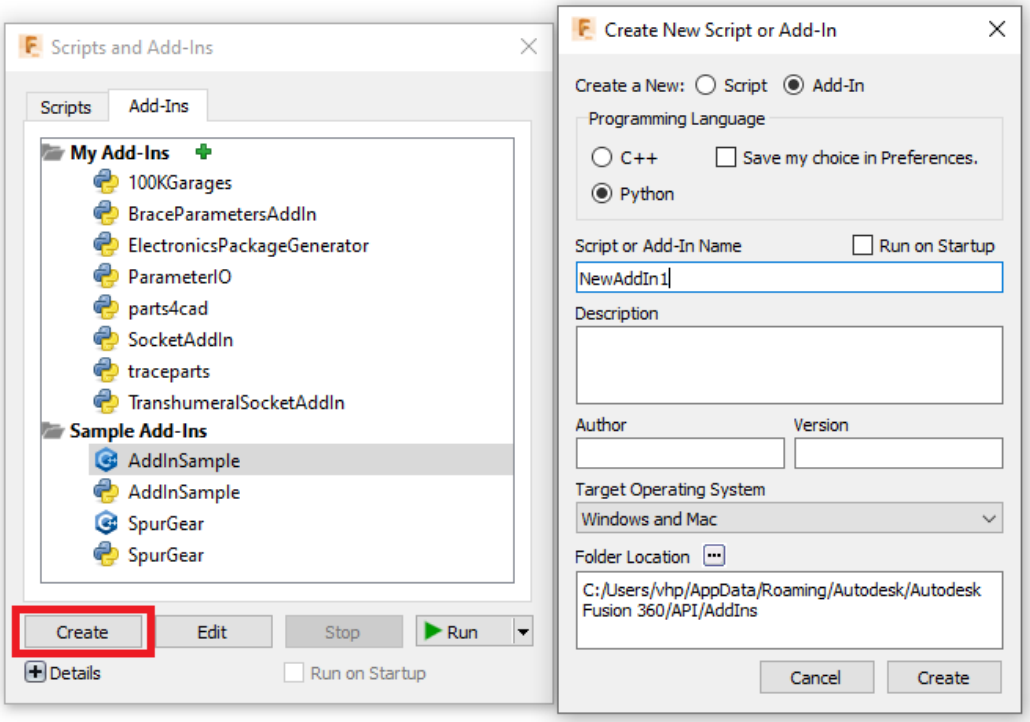


Figure 15: When you click on the 'Create' button, you will be prompted to begin filling in details of your Script or Add-In.

When you open the Script/Add-In in a code editor, some information will be pre-populated, as shown in Figure 16 on the next page. This will help you get started on developing your own Scripts/Add-Ins, while programming-specific questions can be found on the AutoDesk website.

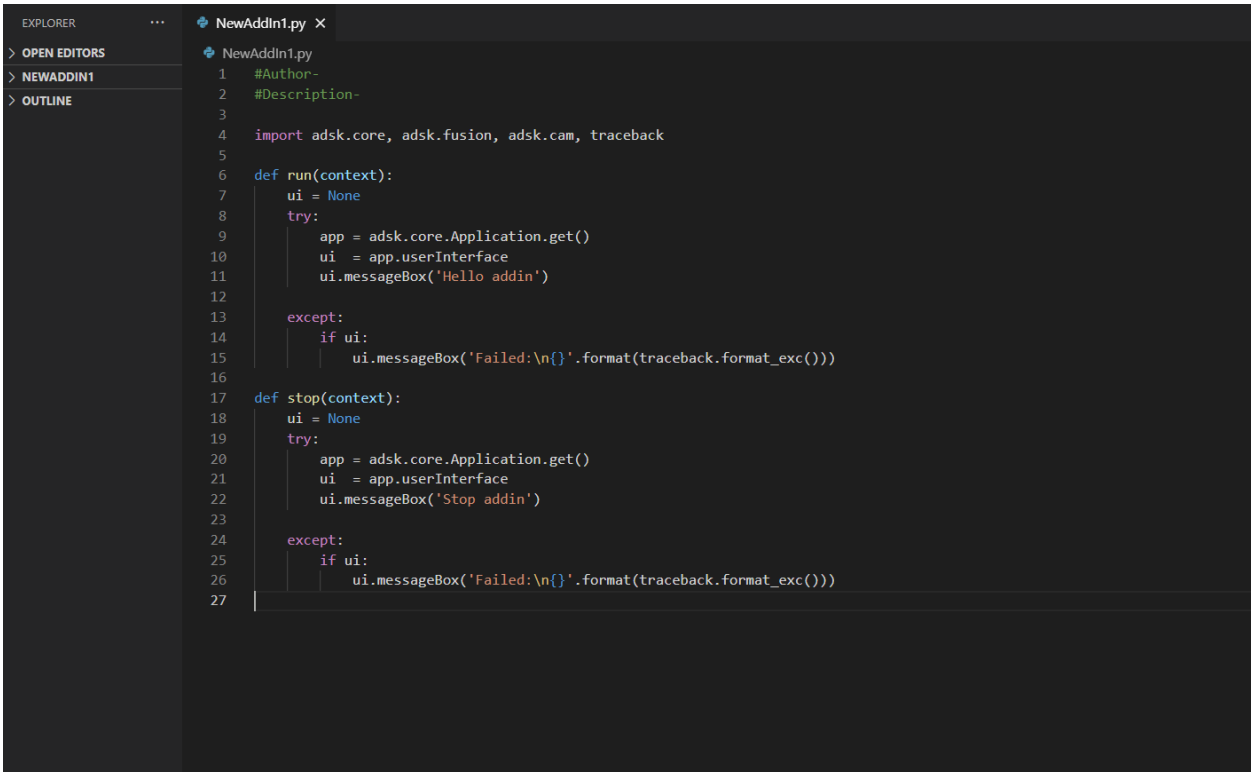


Figure 16: Fusion 360 will provide some code to help you get started on your Script or Add-In.

The AutoDesk site contains extensive documentation on how to get started with the Fusion API, the programming syntax, and coding examples. The Fusion API Scripts and Add-ins were previously written in both JavaScript and Python. However, after a recent update, the Scripts and Add-ins need to be done in Python or C++.

Further information about the Fusion API:

Introduction to Fusion API: https://help.autodesk.com/view/fusion360/ENU/?guid=GUID-A92A4B10-3781-4925-94C6-47DA85A4F65A

Fusion 360 API GitHub: https://autodeskfusion360.github.io/#section_welcome

Fusion 360 API Sample Code: https://help.autodesk.com/view/fusion360/ENU/?guid=GUID-DE98632B-3DC0-422B-A1C6-8A5A15C99E11

VHP Using the Fusion API

The Victoria Hand Project uses the Fusion 360 API to allow clinicians to quickly and easily build a custom orthotic brace or prosthetic socket, just by entering the patient's dimensions in a text

field. The process of updating the parameter values in CAD programs can be overwhelming for non-technical users. Opening the model file to perform adjustments to sketches and features may be difficult for people with no previous experience using CAD tools, and navigating the menus to find the equation manager, and updating the parametric values may be confusing. By utilizing the Fusion API, values of parameters in the design can be changed easily, and the CAD model can be adjusted accordingly, without the user ever needing to directly interact with the CAD program.

A demonstration video of using the Custom Socket Designer can be viewed here: https://youtu.be/ee8s5tQXPGE

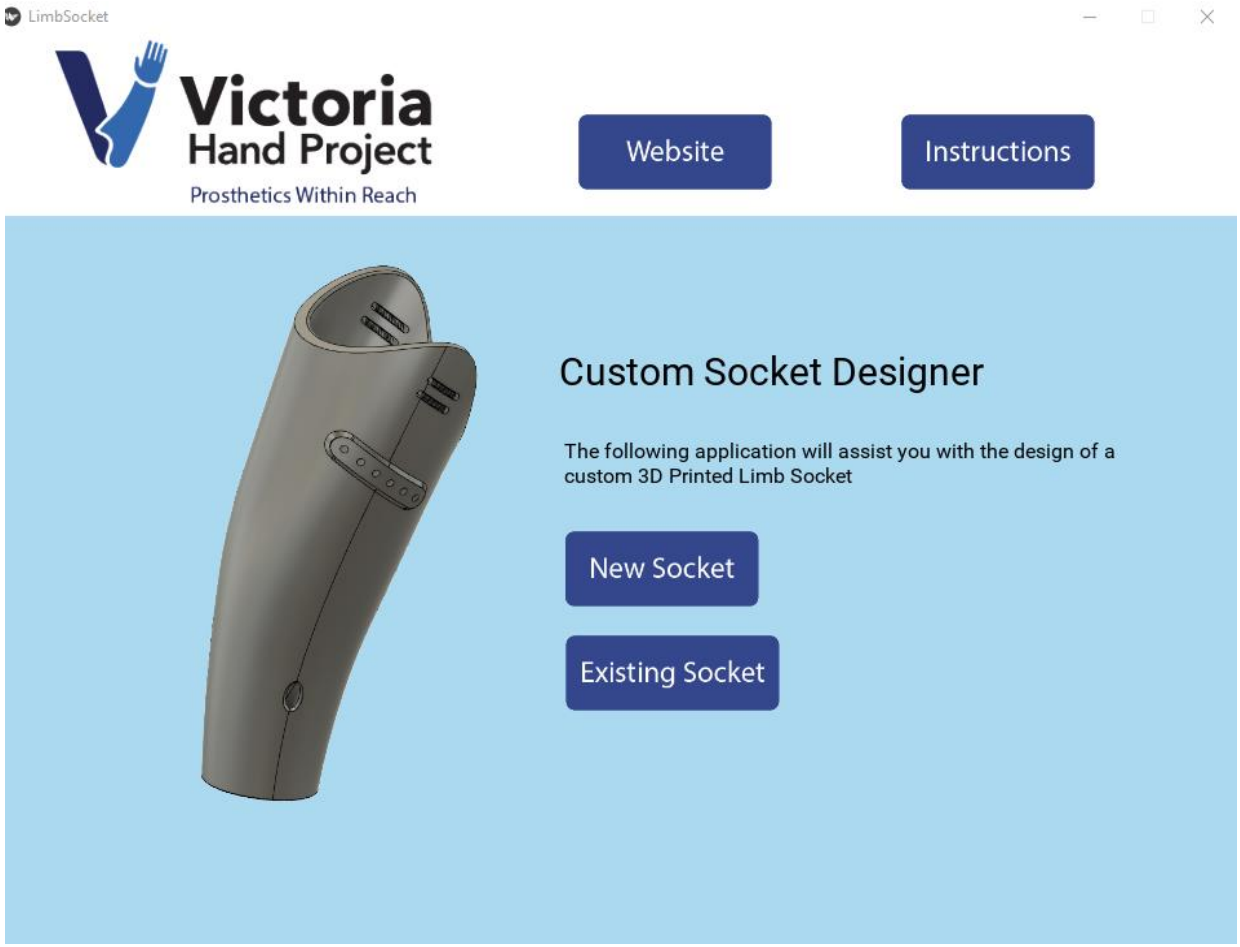


Figure 17: The home screen of VHP's Socket Designer program, where clinicians can choose whether they want to make a new socket, or update a previously-made socket.

The Victoria Hand Project wanted to use the Fusion 360 API to create programs which would quickly and easily allow clinicians to adjust parametric designs themselves, without needing to learn CAD. VHP created a user interface (UI) with text boxes where clinicians enter patient dimensions, and, by using the Fusion 360 API, automatically updates the corresponding

parametric value in the Fusion 360 equation manager with these dimensions. This updates the CAD model to reflect the patient's geometry, greatly reducing the time required of the clinicians to make the custom designs. Many of VHP's partner clinics are serving a large number of clients, and they do not always have technicians to assist them. This makes the clinician's time very valuable. Victoria Hand Project creates the tools which prosthetists and orthotists can use to increase the clinic's capacity, and help more people receive care.

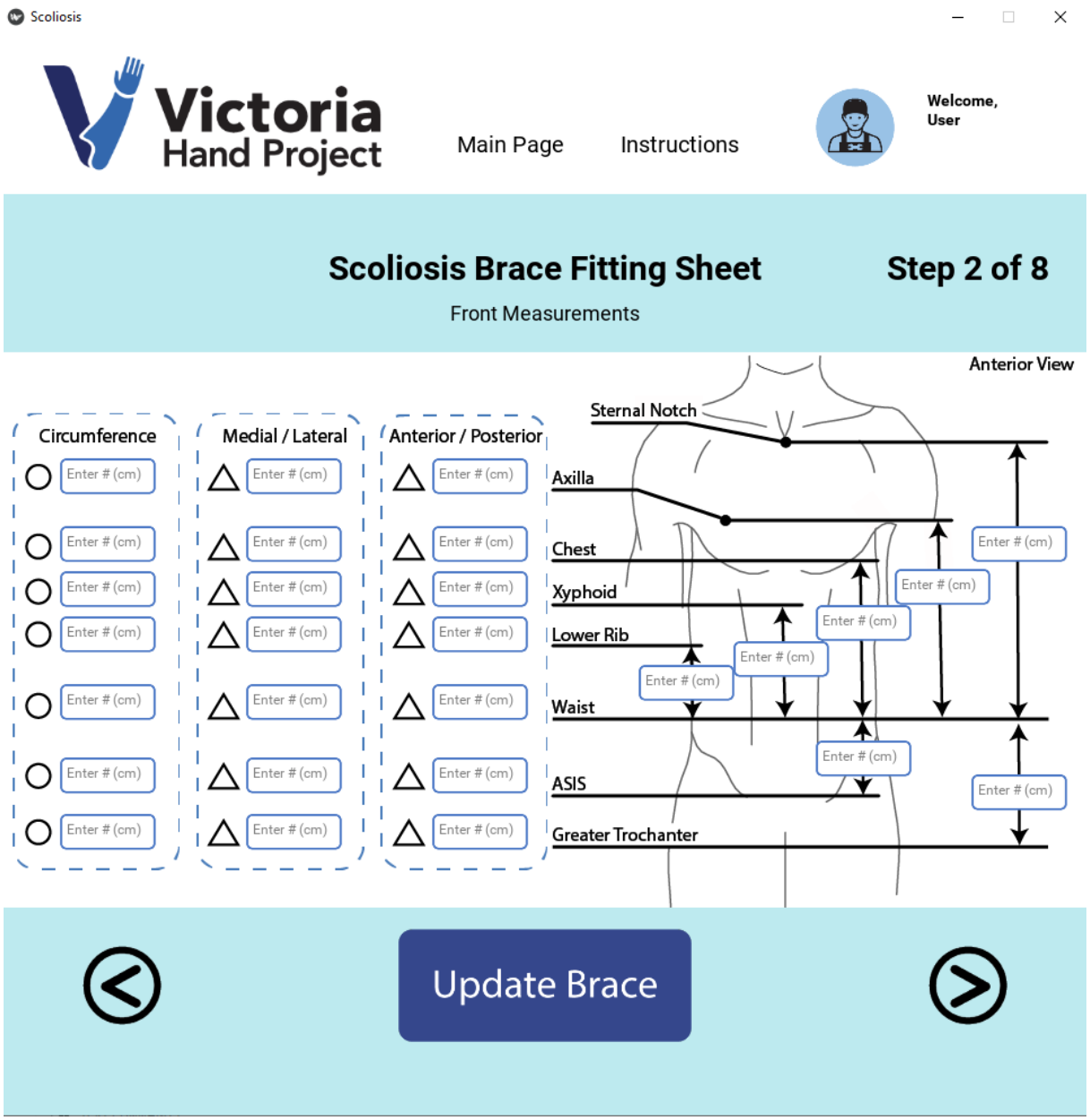


Figure 18: One page of VHP's program to make the orthotic back braces. Clinicians will enter the patient's dimensions on this page to make the base shape of the brace.

Another advantage of using the Fusion API is that it can automate adding new features into the design at the press of a button. The orthotic brace design contains many parametric dimensions and complex features, such as surfaces and patterns. In the initial versions of the brace and socket designs, all of the features were previously added in, and adjusted based on the input from the clinician. This included features such as Lofts, Surfaces, and Hole Patterns. Most of the dimensions used to build these features are parametric, which meant that if a feature earlier in the timeline needed to be updated, all of the subsequent features also needed to be rebuilt as well. This made the rebuild process very slow. It could sometimes take 10 minutes between each page to fully update the design. This is not ideal for clinicians who are busy helping many patients. Additionally, some patient measurements would 'break' the CAD model with all features pre-included, meaning the clinician would need to go into Fusion to fix these errors. By automating the process of adding features into the design after the clinician has entered all of the patient's dimensions, and has added the necessary adjustments, the model is much less likely to have errors and is able to update much more quickly.

One such feature VHP built in using the Fusion API functionality is the hole pattern throughout the brace. The clinician will select the hole pattern density from a dropdown menu, and then press 'Export.' Within the CAD model, parametric sketches are updated depending on the hole density selected by the clinician. The API selects these sketches, and they are used to perform hole cuts throughout the brace. After these cuts are performed and the other adjustments are completed, the brace model will be exported as a mesh and be automatically saved on the clinician's computer in the proper format, ready for 3D printing. These steps all happen behind the scenes - all the clinician had to do was click the 'Export' button. With the Fusion API doing the heavy lifting of CAD design, needing only minimal input from clinicians, it can help free up the clinician's time so they can help more patients.

Finally, the Fusion API also allowed VHP to introduce logic into the design process. VHP provides different hand types based on user preference, which are also offered in left and right hand models. The Victoria Hand designer software allows the user to select the type of hand the recipient will receive, and whether it is a left or right hand. Depending on the clinician's selection, the correct type of socket (depending on the selected type of hand) and the correct side (left or right) is opened in Fusion, and adjusted to fit the patient. The clinician's don't need to find the correct socket model themselves, and update it to fit the patient.

Future Work

With the success of the programs to create custom sockets and back braces, the Victoria Hand Project has plans to begin to develop additional programs for creating other prosthetic and orthotic components. VHP would like to develop a Fusion program to do the entire end-to-end workflow of creating a custom socket, similar to the workflow shown in MeshMixer earlier. This would involve the clinicians creating the custom-sized socket using the current Fusion program, importing the 3D scan of the patient's limb, aligning the 3D scan into the socket, performing the Boolean operation (i.e. cut), and finally clean up the socket before exporting for 3D printing.

Another program involves using Fusion 360 to make a socket for amputees who are missing their limb above their elbow, named a trans-humeral socket. This custom socket is currently created in

MeshMixer and it requires a lot of user input. A clinician needs to use a 3D scan of the patient's upper arm and shoulder to create a thin shell, the shape of the patient's shoulder. This is necessary to help with suspending the socket on the patient's body. VHP would like to create a custom program which can automate some of the steps in this workflow, to help make it easier for clinicians to create the trans-humeral socket. There will still be some input required from the clinicians, but automating steps will help reduce the time required to create the device and will reduce the likelihood of user error.



Figure 19: 3D printed trans-humeral socket.

VHP would also like to add T-spline functionality into the brace model, and allow for adjustments using the Fusion API. T-splines are an advanced modelling tool which allow for complex and organic shapes. These are objects which would be impossible or very difficult to create using other modelling tools. A user will select nodes on a quad mesh (i.e. a face where four lines join at a node, rather than three lines in a triangle mesh), and manipulate the model in unique ways. They can push and pull on these nodes to create very complex shapes, as shown below in Figure 20. By using T-splines, VHP can give clinicians more control over the shape of the brace, and allow for better adjustments. Unfortunately, the T-spline environment is not currently accessible using the Fusion API.

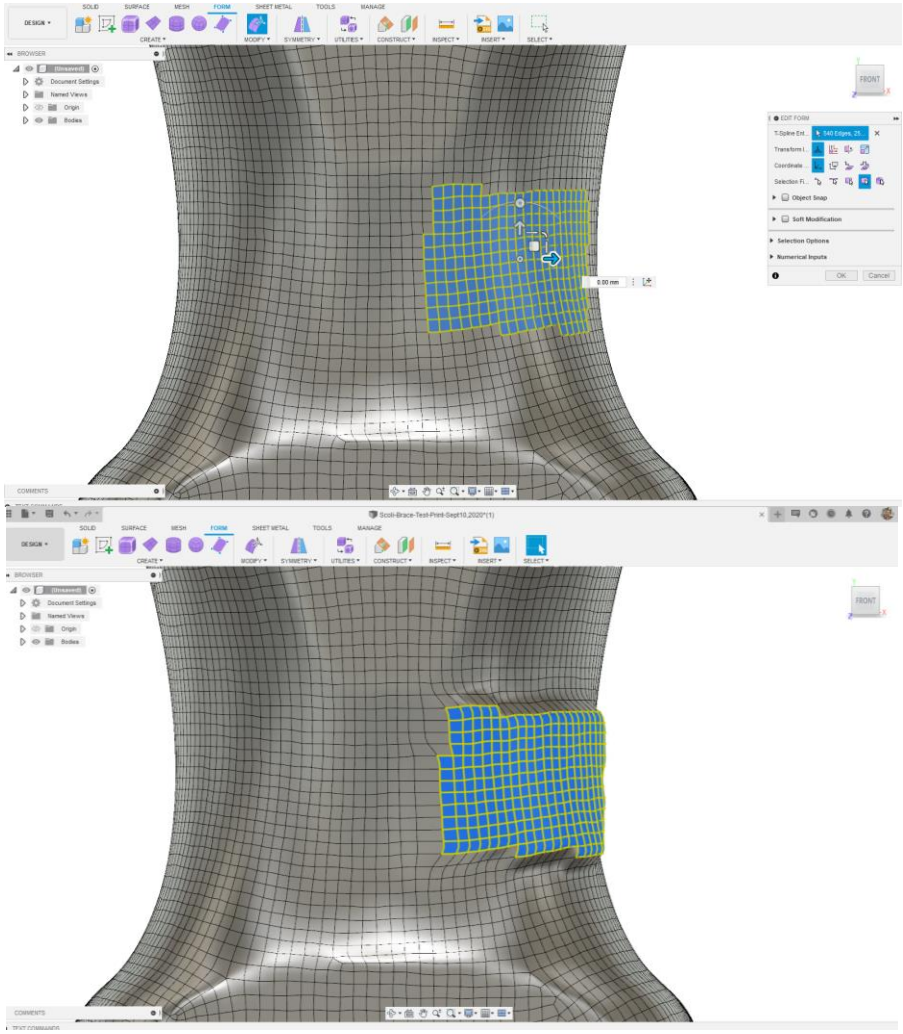


Figure 20: T-splines can be used to perform modifications on selected areas to create more complex shapes, which couldn't easily be made with other CAD tools.

Past AutoDesk University Presentation about T-splines:
https://www.autodesk.com/autodesk-university/class/T-Splines-Three-Ways-2019

T-Spline Video by AutoDesk Fusion 360 Channel:
https://www.youtube.com/watch?v=1Y7Ng9v04Cw

Resources

[1] M. Marino, S. Pattni, M. Greenberg and A. Miller, "Access to prosthetic devices in developing countries: Pathways and challenges", 2015. Available: https://www.researchgate.net/publication/285591611_Access_to_prosthetic_devices_in_developing_countries_Pathways_and_challenges. [Accessed: June 28, 2019].