Process for Creating a Custom Orthotic Insole using Foam Impressions, Photogrammetry, Solid CAD Modeling Techniques, and 3D Printing.

Casper Clausen
Digital Product Development
Ian Williams
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The following document is a process description of creating a custom 3D printed orthotic insole. It surveys the techniques necessary to to create an orthotic insole using foot impression boxes used in custom insole manufacturing, photogrammetry techniques and software, 3D mesh modeling software, solid body modeling software, and 3D printing software and hardware. The process to create a custom orthotic insole by a first-time user required a total of 35 hours. The work to process the photographs using the software accounted for half of the time. A refined process could take as little as 7 hours with experience using the techniques as well as more representational 3D images from the photogrammetry software.

Figure 1

An impression of the foot was taken in a copyfoam foot impression box manufactured by Formschaum Gronau GmbH in Gronau, Germany. The foot impression was taken at an orthotic sole clinic in Basel, Switzerland on April 2nd, 2018. The impression was photographed in 60 images from different angles in the ground-floor designs studio of the ALEX Design Exchange at University of Wales Trinity Saint David, Swansea. The images were taken of the impression box at distances varying from 5cm to 60cm from the impression box and at degrees between about 180 degrees on forward-vertical and horizontal-vertical axes. The images captured details of the foam impression box and its immediate context, which included the chair the box rested on, the floor beneath the chair, and part of a desk next to the chair. The images were taken with the assumption that differences in shadows produced by the photographer as we as shine and luster from the metallic chair may affect the accuracy of the photogrammetry tool the pictures were imported to.

The 60 images were imported to the Photos application on the photographer's MacBook Pro and exported to a file as .jpg files. The files were, then transferred to a computer at University of Wales Trinity Saint David and imported into the application Recap Photo by Autodesk Inc and submitted for photogrammetry processing in order to create a 3-dimensional mesh file to be edited. The process was left to be completed overnight and was ready to be retrieved after 16 hours of cloud processing. The retrieved file showed visual signs of deformation around areas where the shine on the metallic chair had changed depending on the position of the camera during photography; however, there were no signs that the impression box's geometry had deformed, since the rectangular shape of the box seemed retained in the topologized output file from Recap Photo (Figure 1). Recap Photo's user editing tools were use to isolate the impression of the left foot in the file. The section tool was used to remove large portions of the 3D image at once. The selection tool was then used to further remove excess portions fo the impression box and isolate mostly the imprint. The "Smooth Boundary" tool was used to create a smoother boundary around the remaining impression in the 3D image (Figure 2). The scan was then exported as an STL file and imported into Meshmixer for further smoothing of the impression.

The 3D image of the impression had missed detail in the heel and left the image with a shallower heel than found in the impression. Therefore, the move tool was used to create a cup-like indentation where the heel was present in order to match the geometry of the impression as best as possible. The "Bubble Smooth," "Shrink Smooth," and "Robust Smooth" tools were used to smooth the 3D image into a smoother surface that was also more representational of the impression. The instep height of the 3D image also needed to be increased to match the impression, since that area of the 3D image from Recap Photo did not accurately represent the impression (Figure 3). The file was saved in Meshmixer as an STL file and then imported into Autodesk Fusion 360 for further editing and solid body modeling. Fusion 360 could not create a surface from the STL file because it was a triangular mesh. A quick google search revealed that Fusion 360 can only create parametric surfaces from quad meshes. Therefore, the edited file from Meshmixer was imported into Recap Photo and repaired by removing particles before being exported as a quad mesh OBJ file with a target triangle count of 15,000. The output OBJ file was imported into Fusion 360 for Solid Modeling.

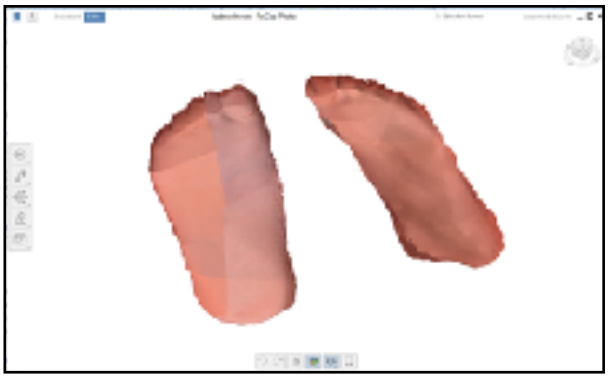


Figure 2

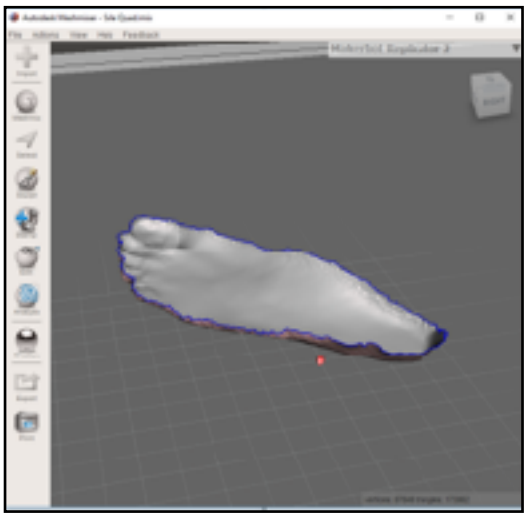
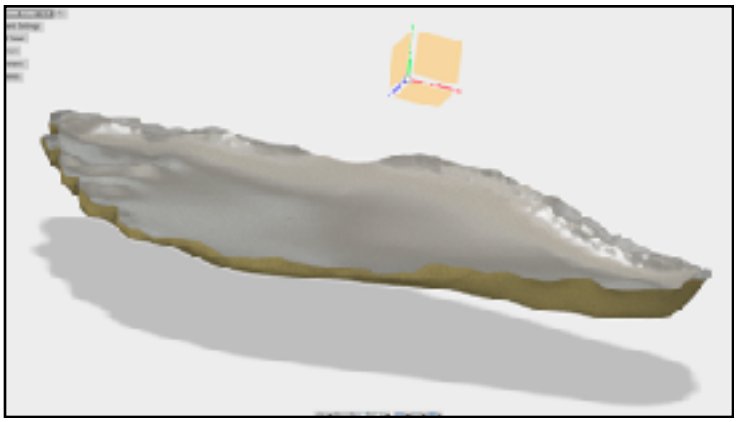


Figure 3

The imported mesh in Fusion 360 was reorientated to be in line with one of the axes and that the bottom of the balls of the feet intersected with the XZ plane (Figure 4). This was done to ensure that the scanned profile would produce an orthotic sole that would stabilize the foot without forcing supination. The imported mesh also measured distance of less than 30 millimeters. Therefore, the imported surface was measured between two recorded points using the "Inspect" tool in Fusion 360. The distance between the two corresponding points on the foam impression was also measured. The quotient between the impression and the mesh was 14.517; therefore, the mesh was scaled by that factor to produce an accurately sized model. After the scan was imported, sized, and orientated, the "Create Form" tool was used to create a T-Splines surface from the Quad Mesh by using the "Convert Form" tool with the specification "Quad Mesh to T-Splines." The surface successfully converted into a T-Spline surface. After the surface was created, modeling of the bottom profile of the sole stared.

A sketch was created on the XZ plane whereupon the "Spline" tool was used to create a general profile encompassing the heel, outer edge, balls, and instead of the foot (Figure 4). The profile could not be extruded because the sketch existed on a profile that already intersected with the surface the "Extrude" command was applied to. Therefore; the sketch was lowered to an offset

Figure 4



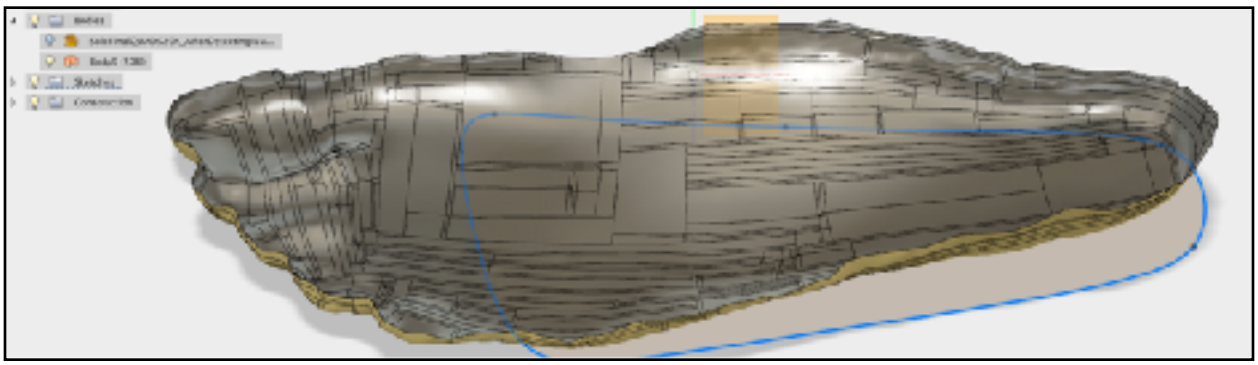


Figure 4

plane below the XZ plane such that the sketch could be extruded to the T-Spline surface. The extrusion created a body that created support for the foot surface as well as The Body was then sliced along the XZ plane using the “Split Body” tool (Figure 5). A copy of the T-Spline surface

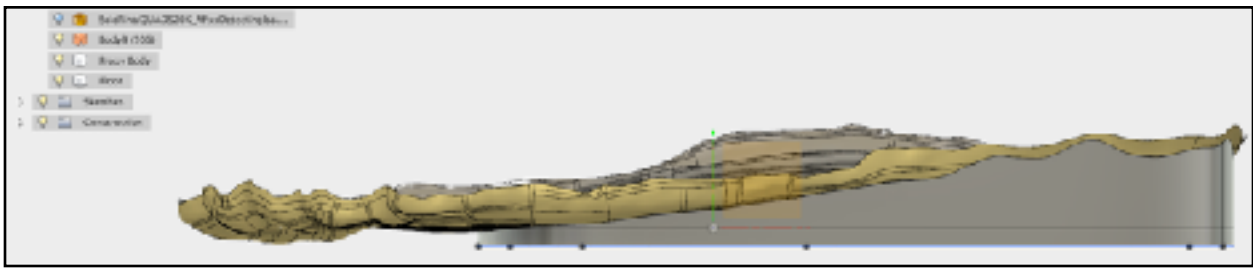


Figure 5

representing the foot was made and moved 1mm in the y-direction to split the body and create a 1mm-thick top surface where, theoretically, a softer surface of the insole should be added (Figure6). A second sketch was then created on an offset plane 1mm above the XZ plane with a manually drawn offset of the bottom profile of the extrusion to hollow out the interior of the insole with a wall thickness of between 1 millimeter in tall zones of the created body to 2.5 millimeters in thin zones. The profile was then extruded the bottom of the top surface of the insole to create a body that represented

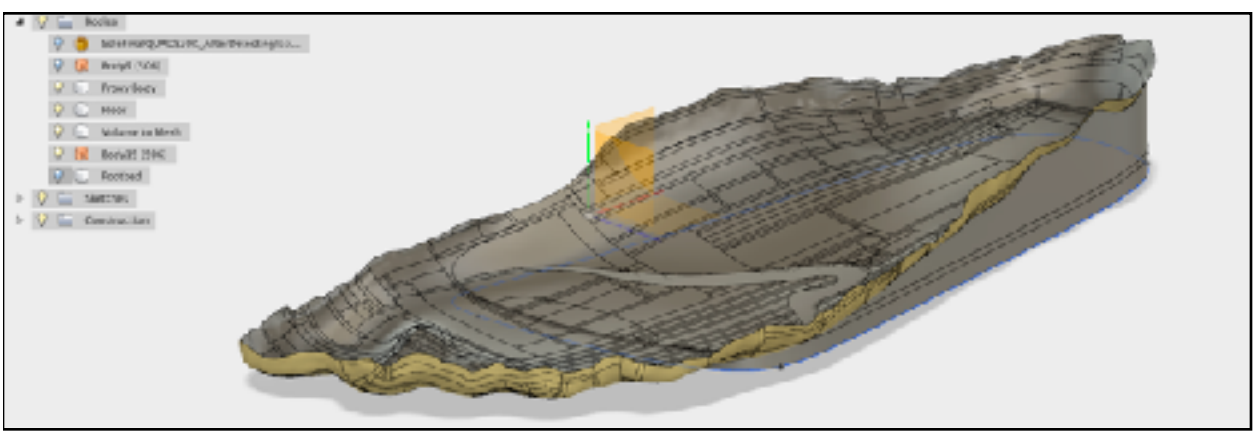


Figure 6

the inner volume of the insole.

The inner volume of the insole was then imported into Meshmixer to create a manually created star lattice structure using the “Make Pattern” tool. The tool was used to create a lattice with tubes at 45-degree angles to the XZ plane such that support material would not be needed during FDM printing. An attempt to create a spherical gradient from 1mm to 2mm lattice diameter was attempted

to enable greater theoretical flexibility in the fore of the insole and allow greater support in the more rigid aft portion of the foot (Figure 7). This was abandoned because Meshmixer crashed upon creating the mesh. Therefore, a lattice of uniform diameter was created and saved as an STL file. The file was imported into Netfab for converting the triangular mesh into a Quad mesh. An attempt to create a Quad mesh from the file using Netfab failed and subsequent attempts to repair the mesh recognized much of the mesh as particles. The attempt to create a custom lattice inside the sole using a star lattice was abandoned because the finished Quad mesh did not cover sufficient area of the insole to allow for enough foot support as well as serve as support structure during 3D printing. A second attempt at creating a custom lattice was inspired by Matthew, the current Ph. D. student studying in the ALEX Design Exchange at University of Wales, Trinity Saint David.

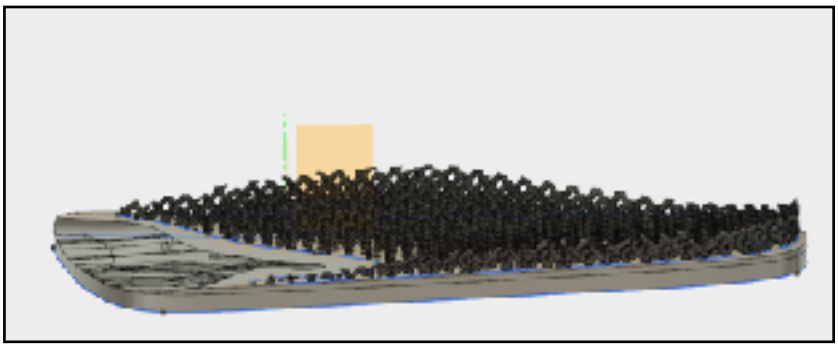


Figure 7

Matthew suggested using a Voronoi diagram to create an infill of the sole, as the Autodesk Fusion 360 YouTube user had posted a video on YouTube about using Voronoi sketches and how they can improve part rigidity in flexible bodies. A second attempt at creating a custom structure inside the orthotic was attempted using a Voronoi diagram to serve as support matrix for the footbed. The Voronoi Sketch Generator was dowloaded from the Fusion 360 App Store. A 23cm x 13cm sketch with 100 cells was created and overlaid within the boundary of the sole wall using several different generated sketches to select the sketch that filled the insole volume and represented the profile with Voronoi cells most accurately. The cells were, then, offset and extruded as bodies joining the footbed and the floor of the insole.

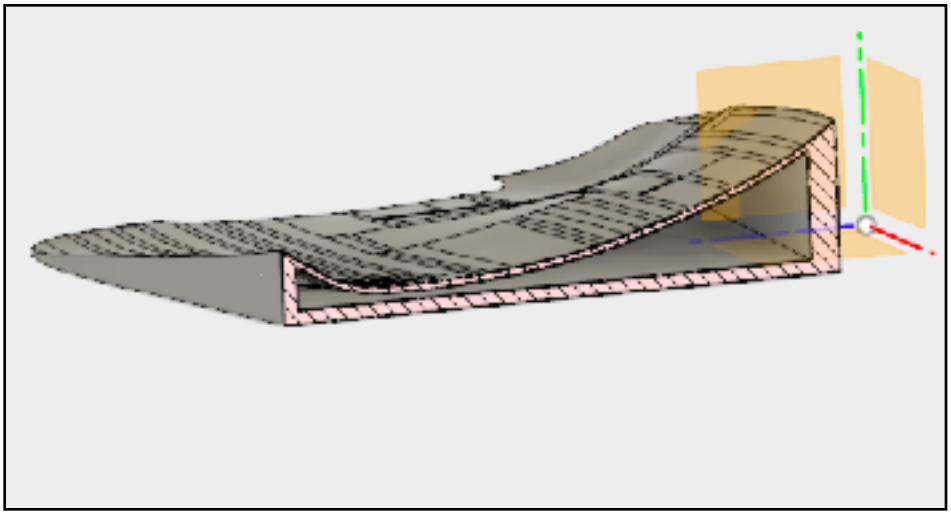


Figure 8

Creating the Voronoi insole (Figure 8) occurred after printing a two-piece orthotic sole with a grid infill of 50%-60% on a fellow student's Anet A8 Desktop printer with an unknown filament polymer type. A hollow sole body was split into a total of one toe and one heel piece were exported as STL files using Fusion 360's "3D Print" tool. The body was split to fit the entire insole print on a single bed. The insole printed successfully in two pieces with an infill of 50%-60%. The Voronoi infill file did not print because the dimensions of the sole had increased unintentionally. Investigation into how the size increase was determined by either exporting the orthotic sole with the Voronoi pattern using Fusion 360 or the slicing application for the Anet A8 printer is necessary to print an accurately fitting orthotic insole using a Voronoi pattern as footbed support.

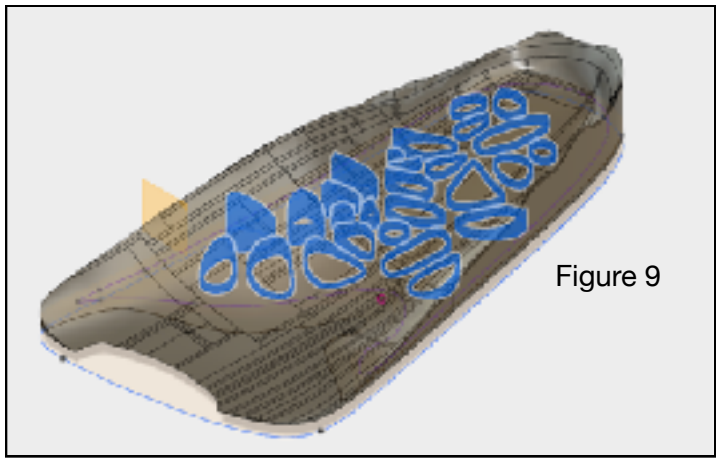


Figure 9

Creating a custom orthotic footbed using the process described above creates possibilities for designing custom products that can relieve dependences on one-size-fits-most design philosophy. The time required to create a custom orthotic sole can be reduced to around 7 hours of labor using the described process. The orthotic was designed as a conceptual model and would require material adaptation in order to create a working model. For instance, the footbed would have to be made of a softer material than the plastic used to 3D print the conceptual model. The bottom of the insole would also need to be tapered to fit into a shoe. Finally, the support material would also have to be made of a more pliable material that also supports the foot and, preferably, uses a closed-cell material to prevent moisture from changing the characteristics of the orthotic sole's performance. Such a material could be Polyethylene foam (Material Choices in Foot Orthotic Design, n.d.). The process described above presents a promising future for custom products as well as user-created custom products as the technology for 3D scanning, solid and mesh modeling, and 3D printing continue to improve.

Sources

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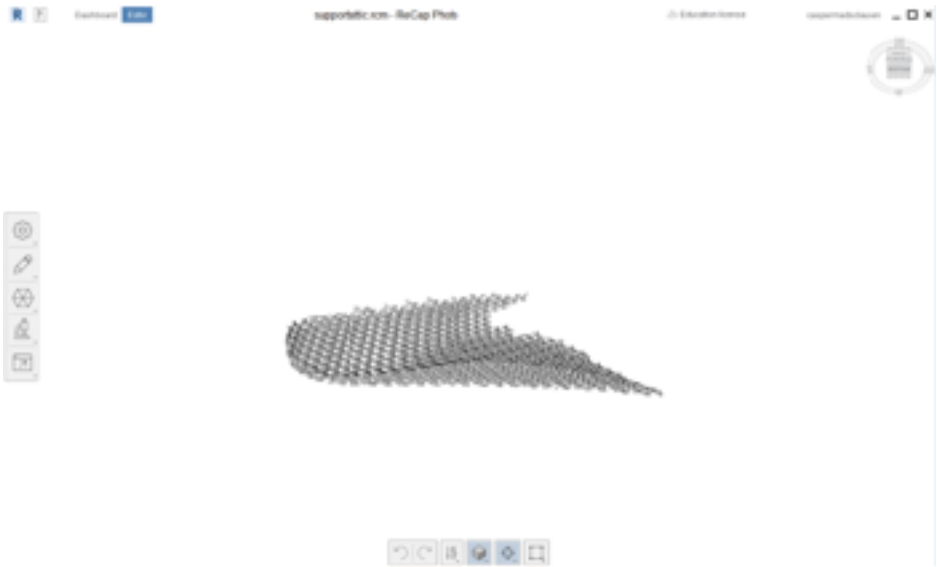

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