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Additive Manufacturing: A 360 Approach

Joshua Best
Autodesk

Learning Objectives

- Learn about what is involved in an additive manufacturing workflow
- Learn how to apply best practices to an additive manufacturing strategy
- Examine where additive manufacturing could be used within your business
- Examine your readiness level for adopting additive manufacturing

Description

This session will discuss and demonstrate how design for additive manufacturing (DfAM), generative design, and integrated CAM functionality within Fusion 360 software can help businesses optimally capitalize on additive manufacturing (AM), and where opportunities often exist to apply this strategy. In considering requirements, we will briefly review technical AM hardware on the marketplace and how complimentary software including Fusion 360 and Netfabb software can integrate into AM workflows to enable businesses to break down barriers to digital manufacturing. Providing insights into the functional and collaborative tools and technologies available across CAD and AM, as well as opportunities for 3D printing, we'll explore some best practices that you could follow as you explore opportunities for applying additive manufacturing strategies.

Speaker(s)

Joshua Best is a qualified Mechanical Engineer currently working at Autodesk as a Technical Sales Specialist in the UK and Ireland with a core focus on Fusion 360, Autodesk's cloud Computer Aided Design, Manufacture and Engineering Platform. Josh has prior experience working within Applications Engineering and Technical Sales in the Additive Manufacturing industry in the UK and is twice published in academic papers.

Experienced in helping businesses identify the scope for revolutionizing traditional manufacturing through Computer Aided Design and Manufacture, Josh's passion stems from a desire to help form a better world through technology.

Why 3D Print?

Whether you're already part way along your additive manufacturing journey, or just getting started, the insights and workflows covered provide a baseline to greater enable you to optimize for the 3D printing process, maximize efficiencies, minimize labour intensity and realize the strongest return on your investments.

In understanding the common motivations for 3D printing, we will cover the typical advantages, business benefits and value positions for 3D printing, so you can understand where additive manufacturing strategy might be applied within your business.

Through inception and market maturity, 3D printing was most often associated with rapid prototyping. However, in more recent years, there has been substantial developments in the field of functional and end use components through continually increased levels of automation. 3D printing offers opportunities for rapid, localized supply chains. An appropriate and timely example would be how the UK Additive Manufacturing community has responded to the requirement for localized production of Personal Protective Equipment, in masks, ventilators and the likes, in light of the current pandemic.

Figure 1: Toronto Technology Centre – Markforged Continuous Fibre Printing

Flexible Manufacturing

Flexible manufacturing through 3D printing enables the manufacture of designs that were previously considered impossible to produce through more traditional techniques. The process offers up added geometric design freedoms, with fewer limitations on part complexity, as designs are built from the ground up, layer by layer. This extended design freedom allows us to explore new aesthetics and envision designs that are not only visually attractive, but also more functional.

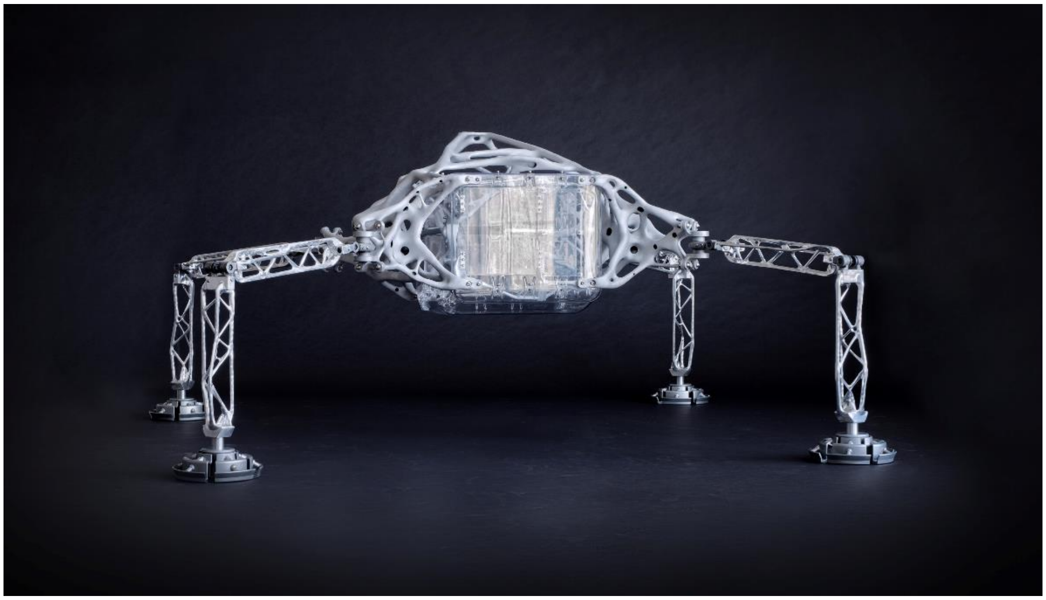

Figure 2: JPL Lander

Increased Performance

This example below is courtesy of General Motors who combined generative design and additive manufacturing techniques to prove concept in consolidating an 8-part assembly into a single component for a seat bracket. The resulting part was not only a consolidation of multiple initial components, removing assembly and reducing labour intensity, it was also 40% lighter and 20% stronger.

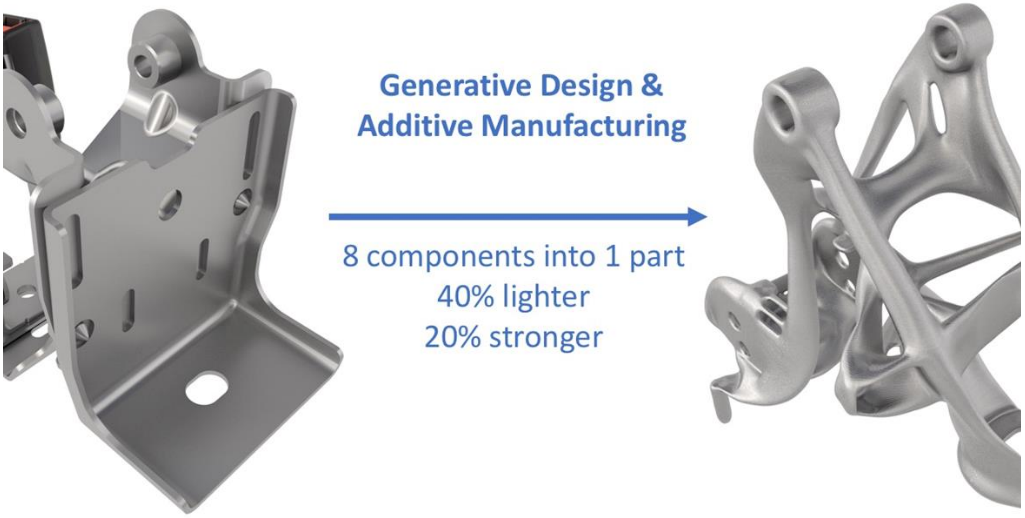

Figure 3: Seat Bracket Courtesy of General Motors

Impact on your Business

What does this potential mean in terms of value for your business. Often the case with 3D printing, time to market can be increased through increased levels of automation and added design freedom, as components can be manufactured locally with minimal manual setup. Printing on demand can often lead to reduced downtime in any manufacturing environment as you no longer have to wait days or weeks to receive a spare part for the assembly line for example.

Further cost savings are often achieved through reduced material usage. Moreover, lighter weight components can often result in further downstream cost savings such as shipping costs. In a manufacturing environment, a great starting point in building quick return on investment is looking at reducing inventories of spare parts, jigs, fixtures and tooling for example, by instead moving toward creating digital libraries of 3D data, that can be manufactured through 3D print on demand functionality.

Figure 4: Business Benefits – Generalized, Not Representative

Digital Strategy

Where restricted to a linear product development process such as seen along the bottom of figure 5, market differentiation and increasing innovation capacity can be a challenge.

For businesses that differentiate across of each of the pillars along an agile product development process, they often see greater market differentiation and ultimately increased product lifetime value. Fusion 360 is a really valuable tool that creates and connects all the data, processes and teams across all of these pillars, and the subsequent workflows cover aspects around mass customization, collaboration and flexible manufacturing through 3D printing in particular.

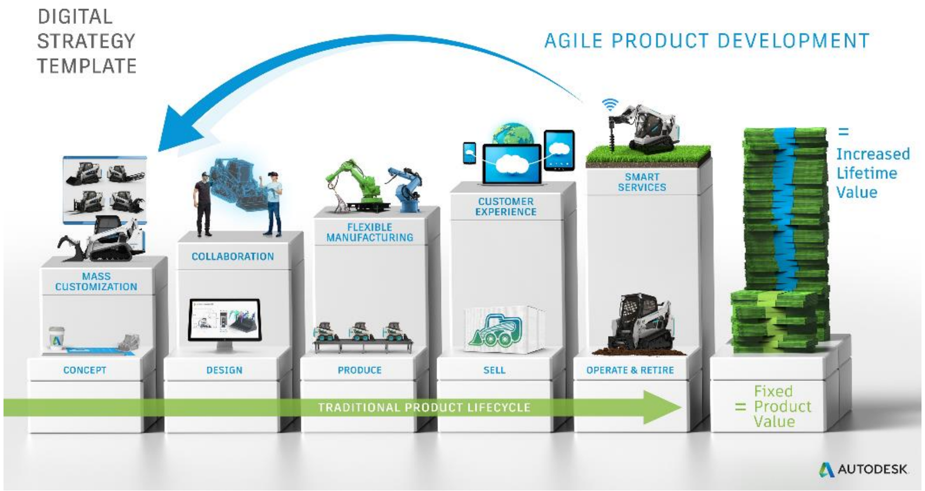

Figure 5: Digital Strategy Template

Key Challenges and Barriers to Adoption

Before we consider some of the common value propositions for 3D printing, it is first important to understand the common challenges and barriers to adoption.

Knowing the requirements is critical. There is still somewhat of a skills shortage in relation to 3D printing across segments of UK design and manufacturing. It is also not uncommon for pilot projects into 3D printing needing to justify a return on investment within 2 years, or sooner, for any capital expenditure. This means other than understanding the requirements, businesses need to understand the applicational scope for additive manufacturing. Other challenges that are commonplace include understanding what resources will need to be allocated in getting started, and the applicational feasibility across the various 3D printing technology platforms on the market.

The content of this class is most relevant to extrusion and vat photopolymerization printing processes where 3D printing functionality often incurs lower upfront investment in desktop systems and can be a good starting point for new endeavours. There is also an AU talk from 2019 covering more of the advanced additive manufacturing capabilities within Fusion 360.

Common Value Applications

The examples below are certainly not an exhaustive list, but cover some initial applications that might be worth exploring in relation to building a strong return on investment utilising additive manufacturing techniques.

Conceptual & Prototyping

3D printing is great for concept models and prototyping. Often it is as simple as providing a 3D physical representation and visualization of an idea, project or component. These types of models serve as great discussion points and enable ideation and collaboration on ideas.

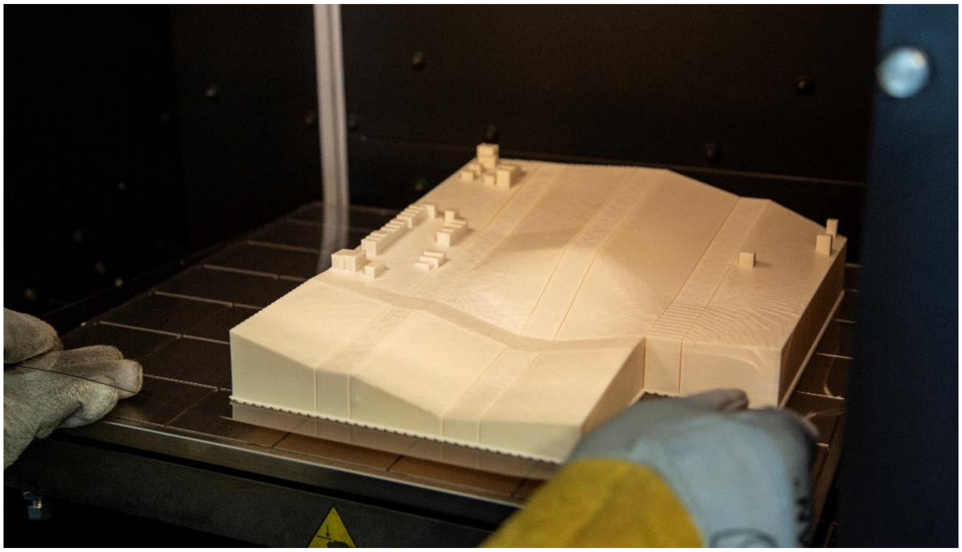

Figure 6: Conceptual & Prototyping – Architectural Model

Form, Fit & Function

The rapid prototyping of parts allows also for testing form, fit and function. Whether you're assessing dimensions and tolerances within the context of an assembly, checking the form and aesthetics of a part meet customer expectations, or plan to cycle test a part in a functional application before going to mass production, 3D printing offers value.

Prototyping can lead to increased confidence in functionality before going to production, improving reliability and decreasing costs associated to non-conformances. A great example of where this is applicable is within tooling.

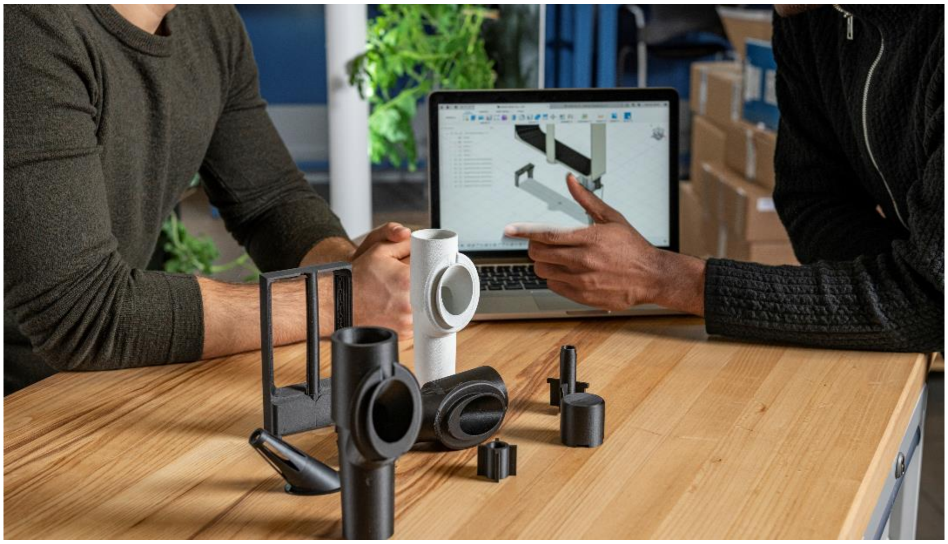

Figure 7: Form, Fit & Function

Tooling

Any manufacturer will appreciate tooling can incur significant costs, especially larger and more complex tooling. This can be in the region of hundreds, thousands, tens of thousands of pounds, even more. Non conformance or out of spec tooling can incur huge costs and delays to market. 3D printing can enable testing for form, fit and even function of tooling, comparatively cheap to increase confidence before going to final production. This of course depends on the sizes of parts, the materials and the printing technology as to how far the boundaries can be pushed

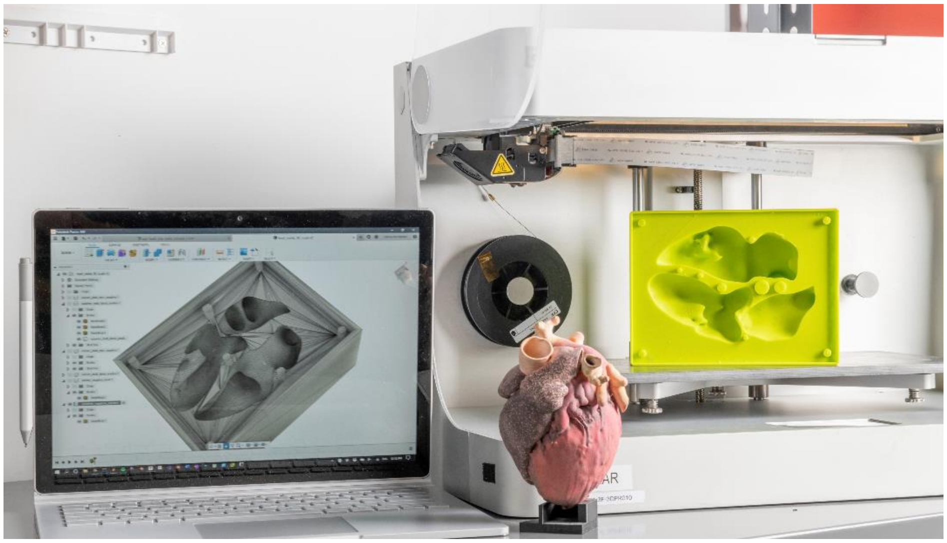

Figure 8: Printed Mould Tooling

Jigs and Fixtures

In addition to tooling, jigs and fixtures is often a suitable starting point where quicker return on investments can be achieved with additive manufacturing vs more traditional manufacturing methods. Perhaps the end customer facing product is still CNC machined, but you can decrease costs and labour intensity in the machine setup through printing the workholdings for example.

Typical value add applications for 3D printing include:

- Conformal soft jaws & vices
- Chucks
- Clamps & brackets
- Workholdings
- Legacy spares

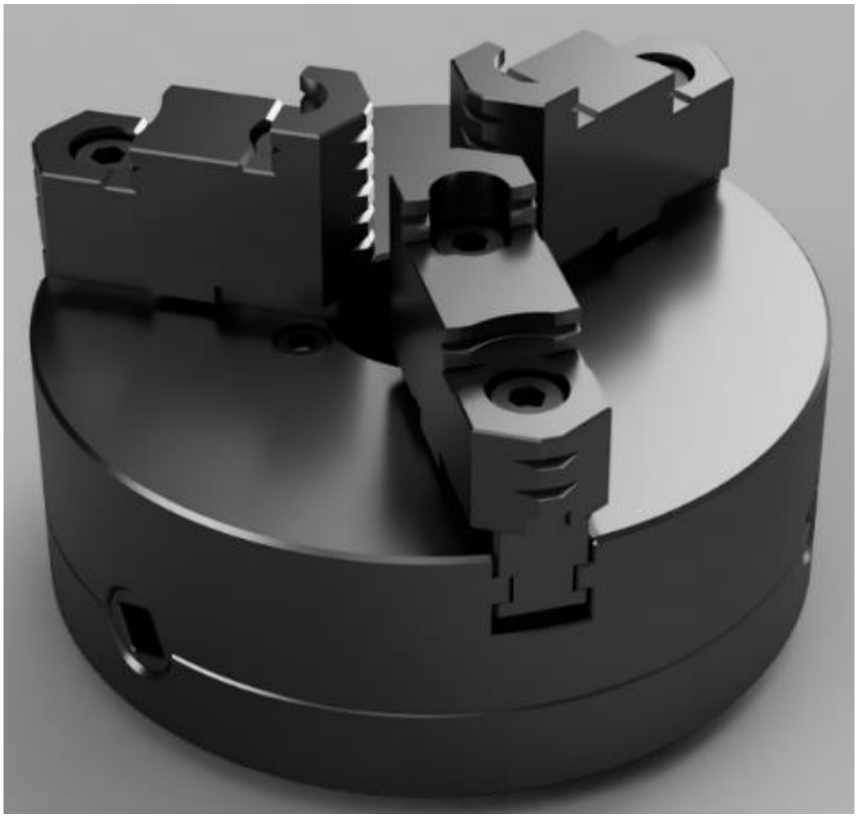

Figure 9: Jigs and Fixtures

Additive Manufacturing Workflows – Knowing the Requirements

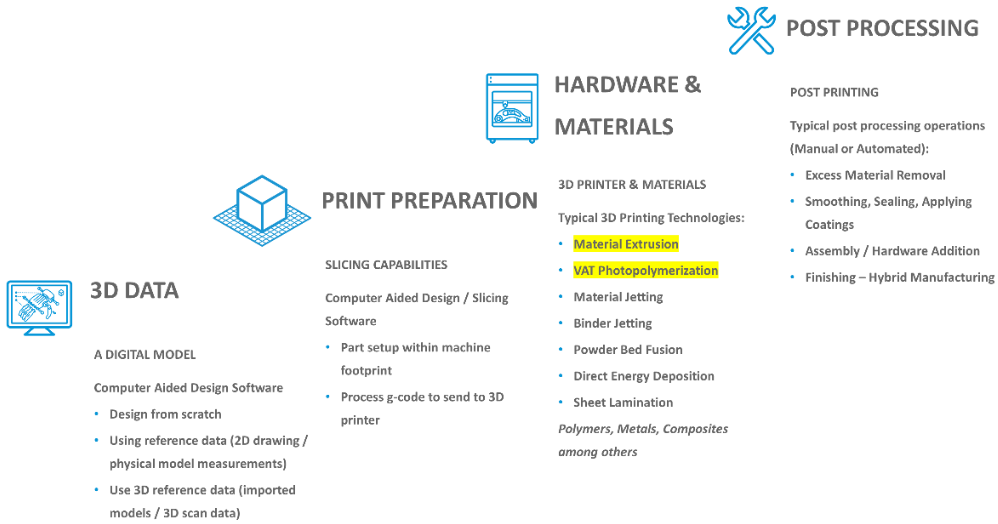

Figure 10: Knowing the Requirements

Whether you have hardware in house or outsource the printing itself, it all starts with 3D data, as 3D printers require 3D models. Whatever the scenario, you must have a digital, 3D representation of a model before going to manufacture and this takes place in Computer Aided Design Software.

Once, you have your 3D model, the next step is to prepare your model for printing. This step in the process is known as slicing your model. Here you will setup your part or parts, often within the virtual footprint of a specific machine. You will select your materials, your printing orientations and printing settings before sending to a 3D printer in the form of g-code.

At this point your 3D data is received by a 3D printer for printing. The industry is continually evolving and new technologies are always being added, but some of the most common subsets of additive manufacturing technologies are included on the list below:

- Material Extrusion
- Vat Photopolymerization
- Material Jetting
- Binder Jetting
- Powder Bed Fusion
- Direct Energy Deposition
- Sheet Lamination

Materials are also incredibly broad, but more common printing materials include plastics and polymers, metals, and composites. The Design for Additive Manufacturing (DfAM) principles covered here are most specific to typical material extrusion and vat photopolymerization processes. Once printed, there may be additional post processing steps you may want to consider; this often includes processes such as excess material removal, finishing or assembly for example.

DfAM – The Starting State

As per the image below, the workflows covered here address the first two stages in the additive manufacturing process. In applying some general best practices through design for additive manufacturing, we'll take a look at how Fusion 360, as a design and manufacturing solution, can be used to model designs and prepare them for additive manufacture.

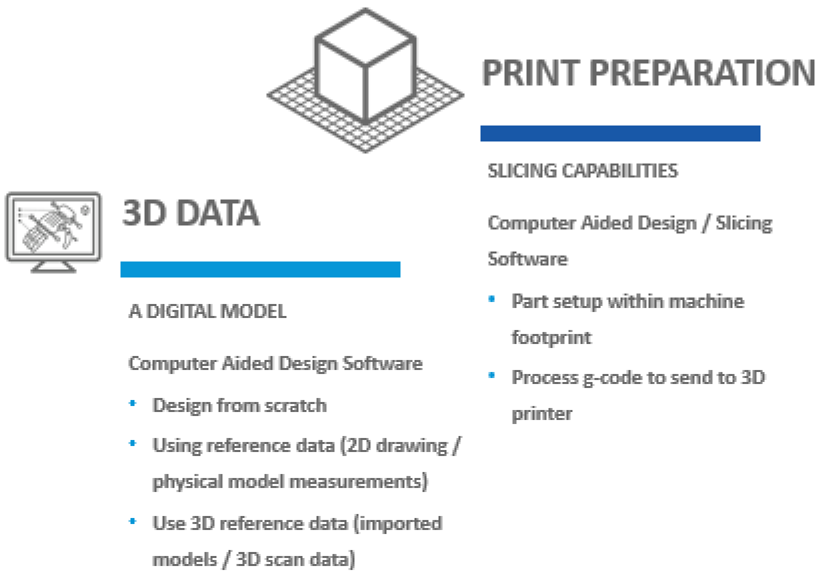

Figure 11: Additive Manufacturing Workflows within Computer Aided Design Software

Using 2D Reference Data (Drawings)

Some typical scenarios involved in designing and modelling a component may utilize reference data, perhaps from a 2D engineering drawing that has been supplied in paper or digital form. Here we need to use modelling tools to convert that 2D data to 3D data.

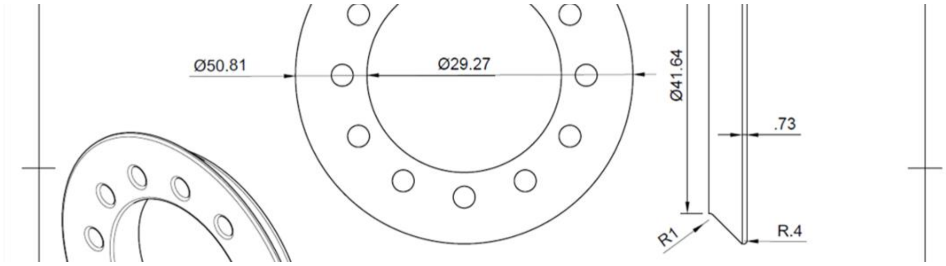

Figure 12: 2D Engineering Drawing

Using Reference Data in the form of a Physical Model

Similar to how we may use 2D engineering drawings to build a model, we might take measurements from a physical model and replicate its form in computer aided design software.

Figure 13: Using Calipers to Measure a Part

Using 3D Imported Data

Scenarios also arise where someone else has modelled a part and you have downloaded, imported or need to make amends to a part before 3D printing. This is applicable for parts that are developed by other team members, within the supply chain, customer generated, or downloaded from parts catalogues for example.

Reverse Engineering from Scan Data

A more complex reverse engineering scenario is through the use of 3D scan data to reverse engineer a part. Working with Mesh data in typical reverse engineering workflows involves:

- Using mesh data as is
- Mesh repair, manipulation & conversion to manifold geometry

Figure 14: Reverse Engineering with Scan Data – Example Courtesy of PrintCity

Design Inspiration – Generative Design

The final scenario we might consider is one in which the function of a desired component is known, along with constraints and possible manufacturing method, but the actual form of said design doesn't yet have definition.

With this type of information, Generative Design can be incredibly valuable in converging design and manufacturing techniques to automate shape generation and functional componentry. Whilst we will not cover generative design for additive manufacturing in detail in this session, it is definitely worth exploring further once you have the knowledge and capabilities to scale, and you can find further content at the end of this handout.

Figure 15: Generative Design Outcomes

Fusion 360 Overview

With Fusion 360, we are able to streamline the design and manufacture process, via a connected, integrated, and automated platform. This means teams have the tools to automate mundane tasks, the agility and connectivity to manage supply networks, and access to the latest manufacturing technologies to realize previously impossible outcomes. Fusion 360 is not just Computer Aided Design, Computer Aided Manufacture, simulation, documentation, rendering or electronics, it is all of these things and it is available on any device, anywhere, anytime. Simply put, it is for anyone involved in a product development process, as it's the product innovation platform which streamlines this process.

Figure 16: Fusion 360 Functionality Snapshot

Additive Manufacturing Specific Functionalities

Specific to additive manufacturing, the major benefits include:

- Flexibility and adaptability to change
- Simple creation of controlled surfaces and models
- A fast learning curve

Some of the key capabilities include:

- **Parametric Modelling** – To create adaptive models using functions. The parameters table is accessible within the Design workspace
- **Direct Modelling** – Achievable through AnyCAD, allows you to easily make changes to non-native file formats
- **Mesh Tools** – Useful in working with scan data, accessible through Fusion 360 profile preferences
- **Freeform Modelling** – T-Spline technology provides sculpting tools similar to working with clay, only digitally. This is ideal for more organic surfaces
- **Manufacturing** – Including integrated printing workflows, printing simulation, and support for plastic and metal machines, with an extensive and customizable machines library for posting g-code
- **Collaboration** – The streamlined ability to collaborate on designs and projects with data accessible through a web browser, leveraging cloud technology
- **Generative Design** – Accessible through its own workspace, Generative Design truly revolutionizes the way products are design and manufactured and converges these workflows.

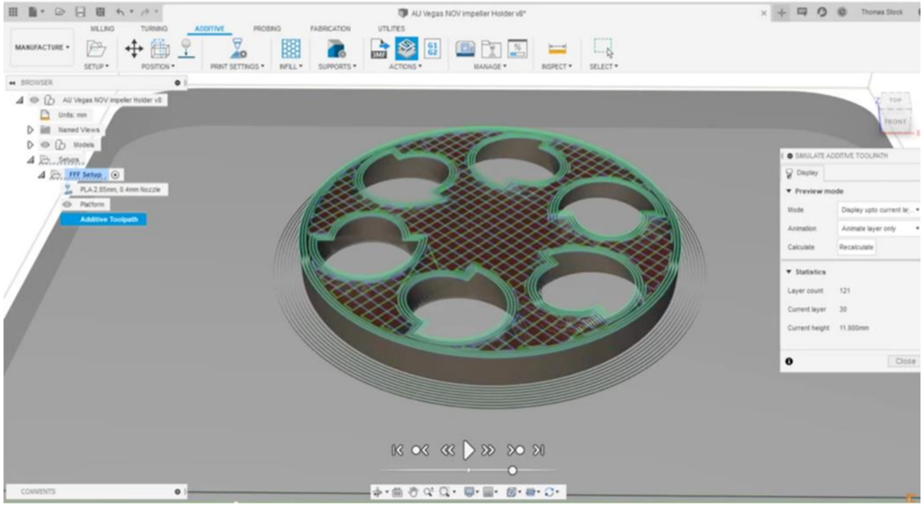

Figure 17: Printing Simulation in Fusion 360

DfAM – Optimize for Manufacturing

If you're not familiar with the material extrusion 3D printing process, you can check out some videos in the resources at the end of this handout. In considering some top-level typical design optimizations for this process we'll take a look at a scenario for a simple bracket where someone else has designed the part and we have downloaded/imported that model to make changes.

Direct Modelling

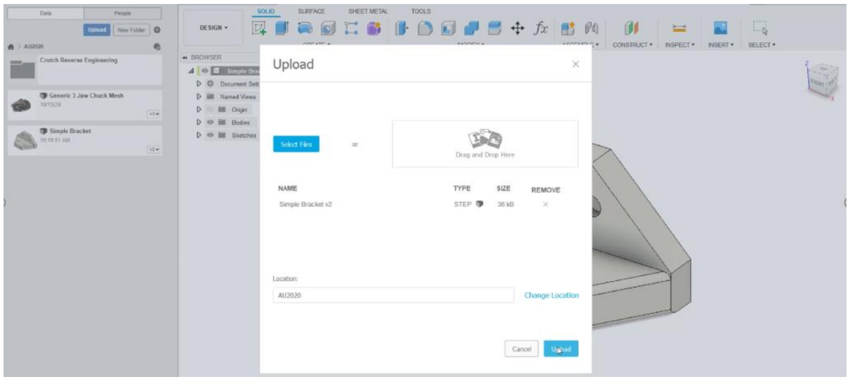

Figure 18: Uploading Files in the Data Panel

- Having opened the data panel, **upload** a model and choose your file, in this case a step file
- Once the upload is complete we can open our model
- Through direct modelling we are able to make direct edits to this model even without a complete feature tree

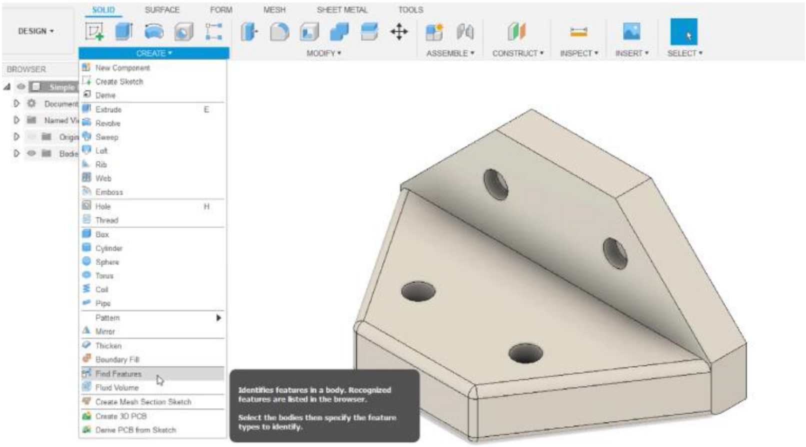

Figure 19: Find Features

- We might use the **find features** command to identify modeled features
- This can make it easier and quicker for us to delete features we might not want, or want to change to optimize for 3D printing

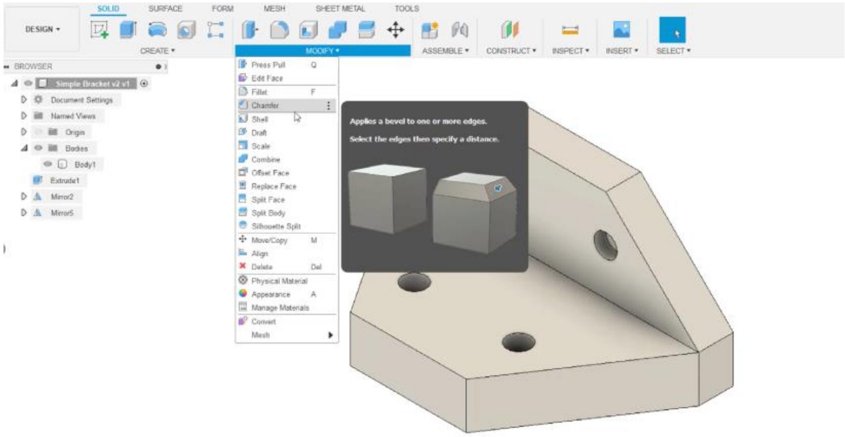

Figure 20: Applying a Chamfer

- We can delete the **fillets** and instead reapply **chamfers** to the bottom edges, as this will ultimately aid in extrusion printing scenarios

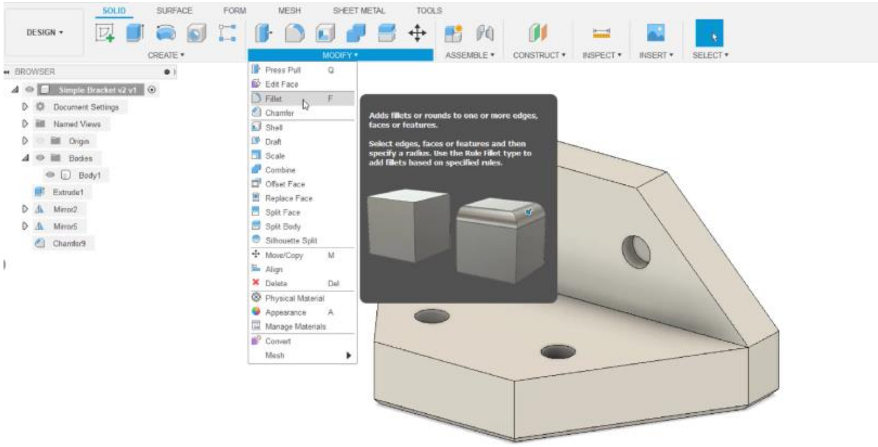

Figure 21: Applying a Fillet

- We can then reapply our fillets to the edges we want, as it is still advisable to remove sharp edges where possible, to minimize stress concentrations during printing
- Following this we can simply select any features we don't want and hit delete, such as the holes which can be remodeled in this instance

McMaster Carr Part Catalogue

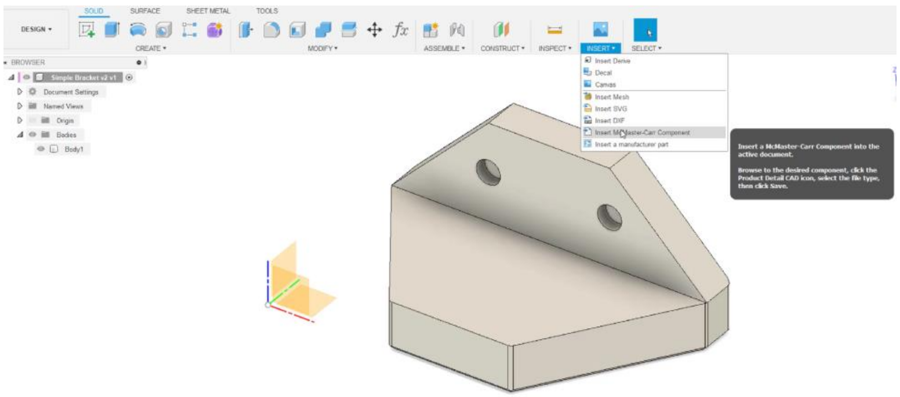

Figure 22: Accessing Part Catalogue

If hardware needs to be added into a design for assembly, as with this example and is often the case with jigs and fixtures for example, then rather than creating and maintaining a library of common hardware, Fusion has partnered with a standard part catalogue in McMaster Carr.

This means you can browse, search and eventually order, parts that are inserted directly into Fusion 360 without having to take an extra step of downloading and importing, or creating your own library of common hardware, which is often a common question in the industry.

Once in Fusion, these components are just like any other component. In this scenario, we take a look at an instance whereby a hex nut is embedded and captivated within a 3D printed part, rather than press-fitting the insert in after printing. This is made possible by scheduling a pause in a print job, in order to insert a nut flush in the cavity, before resuming the print – applicable for certain extrusion printing machines and is a useful technique to employ across 3D printed jigs, fixtures and tooling.

Through the in-bult parts catalogue, a 3D model of a hex nut was useful in measuring the dimensions for a cavity. That being said, taking physical measurements from any hardware is considered best practice in order to ensure tolerances in the design are correct.

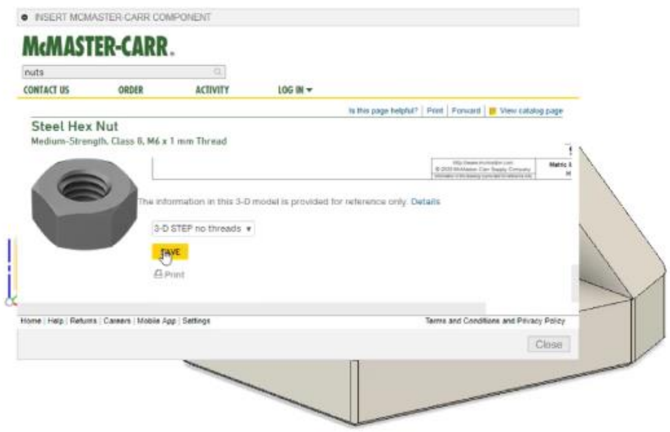

Figure 23: Inserting Components from the McMaster Carr Catalogue

Solid Modelling

Once the Hex nut is inserted in the design workspace, it is possible to take the necessary measurements for creating a cavity, or alternatively most of the needed dimensions are within the product details in the McMaster Carr catalogue.

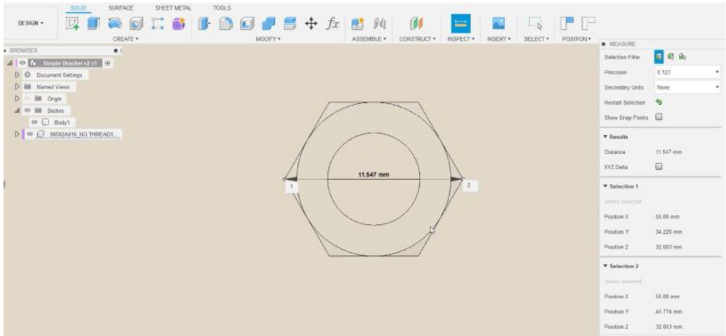

Figure 24: Inspect and Measure Tools

Determine the depth of the base of the bracket and the height of the nut, which in this case was 20mm and 5mm + or – a tolerance respectively. To center the cavity in the base, offset from the plane by 12.5mm and create and extruded cut to a depth of 5mm + the tolerance.

Analysis tools such as section analysis can be used to check that the operation has created the intended hex cavity within the centre of the base of the bracket.

Repeat for the hole and select through **All** for distance. Or alternatively edit the original sketch.

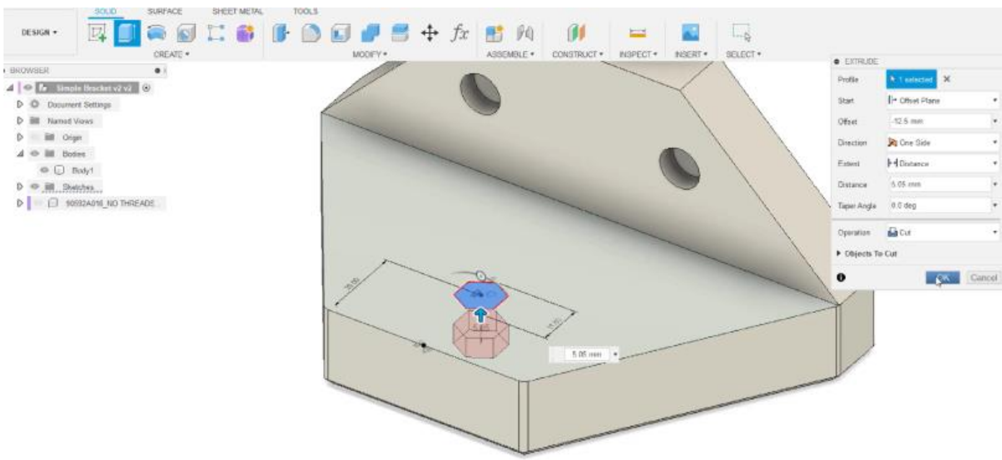

Figure 25: Extruded Cut to Create Cavity

Adaptive Modeling for Extrusion Printing

Designing parametrically in Fusion 360 using adaptive modelling techniques can enable greater customization early on in the design process. Using a basic slew bearing as an example, there are a number of rollers internally and the aim is to be able to adapt an entire model based on set parameters and functions referenced within sketches.

A single master **sketch** can be used to create revolved features for example, and a number of dimensions can reference functions in Fusion 360's parameters table. This is denoted by **fx** and is where you may add in tolerances.

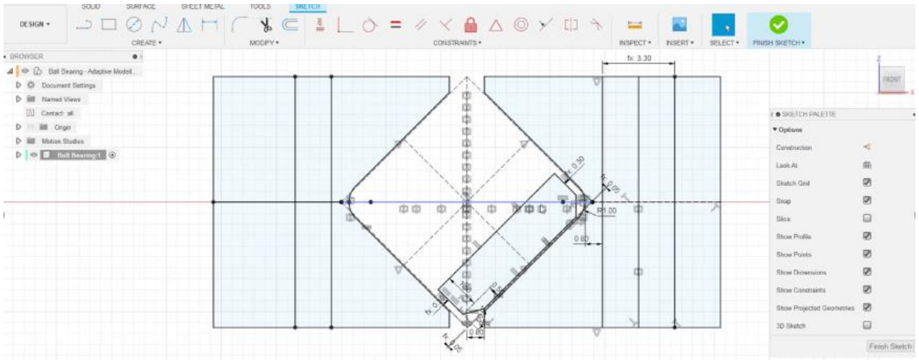

Figure 26: Advanced Sketching

Bringing up the parameters table within Fusion 360 via the top toolbar, here is where you can add functions which the master sketch can reference. **Adding New** (+) enables creating a new parameter and in this case, we can add parameters such as tolerances, diameters and number of rollers for example.

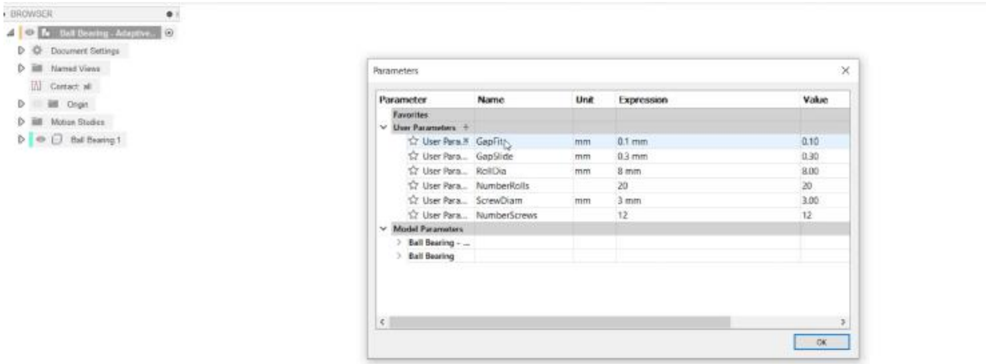

Figure 27: Parameters Table in Fusion 360

Using a single sketch to create multiple features increases design efficiency and can be used to create a series of 3D features. In this instance, each component has been created using the **revolve** command and selecting the appropriate sketch profiles and centerline axis, using a **circular pattern** command to create multiple instances.

Before progressing to print preparation, or slicing, for a part such as this, we may want to add some motion to simulate parts virtually in application and make sure everything fits and moves as it would in real life. **Revolute joints** can be added between the outer race and inner rollers by selecting **joint**, selecting components, choosing joint type (revolute), and simulating the movement.

We can also apply a motion link to link the motion of various components, in this instance the motion of both sets of internal rollers. You can find this under **Assemble – Motion Link.**

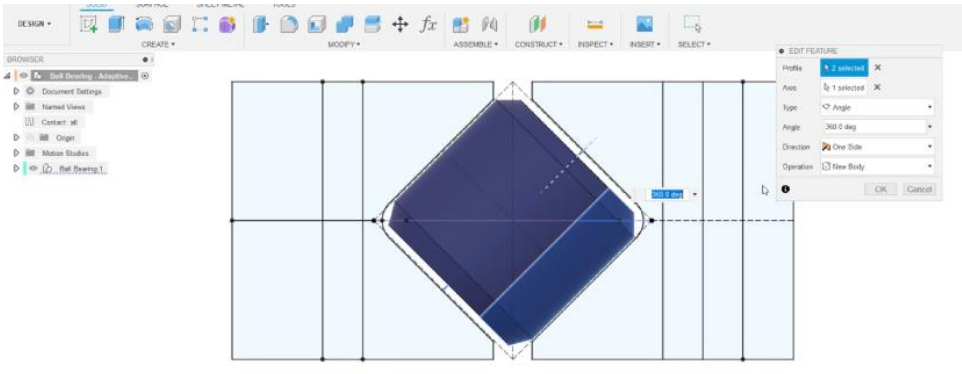

Figure 28: Revolved Features

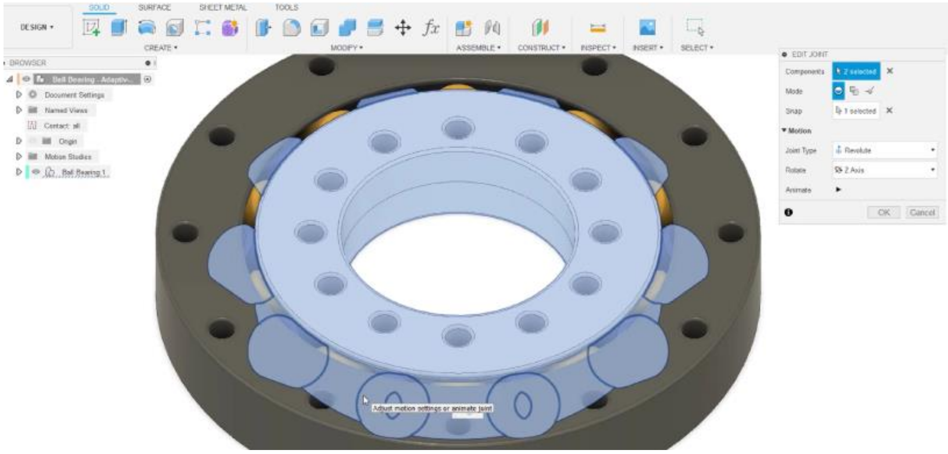

Figure 29: Applying Joints

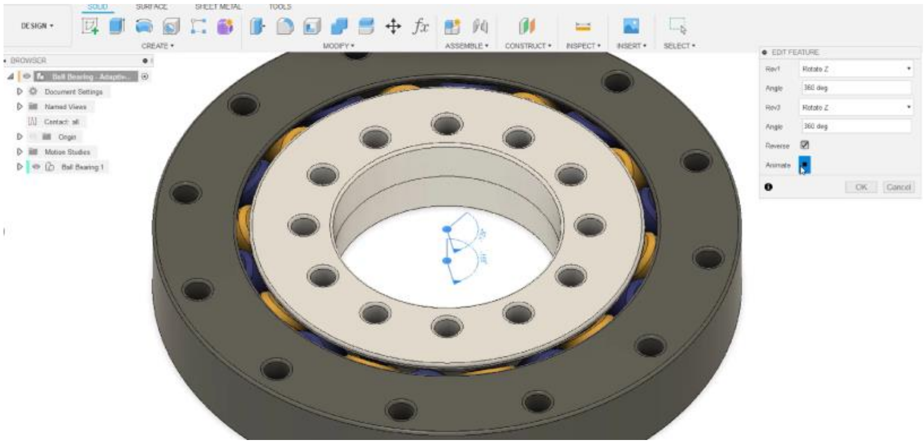

Figure 30: Adding a Motion Link

You can add appearances to various components to help with distinguishing between different components. You can also toggle **Component Colour Swatch** under **Settings** (bottom right of the screen). To bring up the appearances dialogue, click **'a'** on your keyboard.

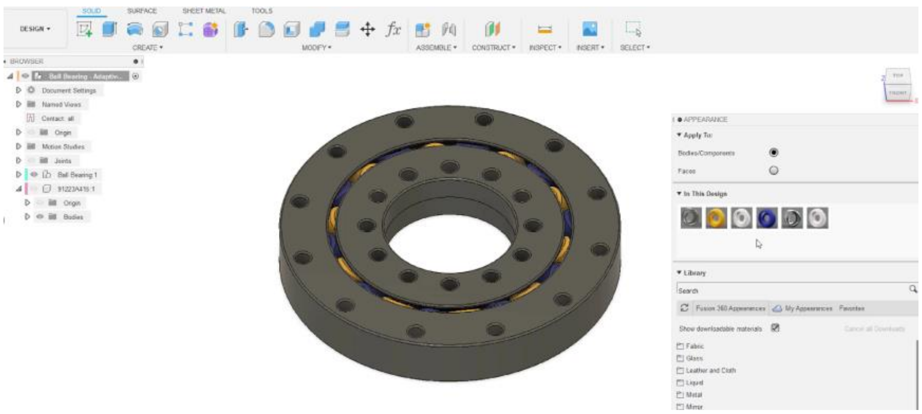

Figure 31: Adding Appearances

To add hardware such as nuts and bolts, you would access the McMaster Carr parts library as referenced above. With a design in a completed state in the design workspace, you can easily and quickly navigate to the manufacture workspace to slice parts and prepare them for printing.

Preparing your Parts for Printing (Slicing)

First create a new setup and select a machine. Fusion 360 has an extensible machines library for additive manufacturing which is also customizable so if you can't find your machine you can always create/download a [custom configuration](). Under setup, with machine selected, first select your models for printing.

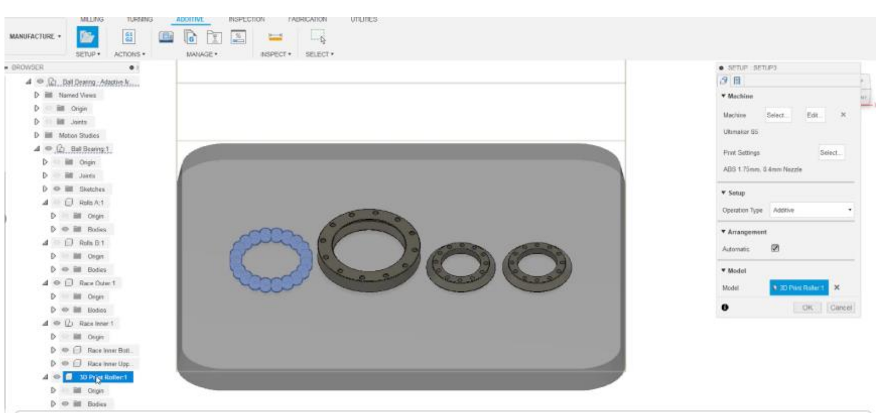

Figure 32: Creating a Setup

The next thing to consider is orientation and layout on our build platform. If models are raised off the bed for any reason, we can select **place parts on platform** and allow Fusion to **auto arrange**. We also have manual position tools to move components.

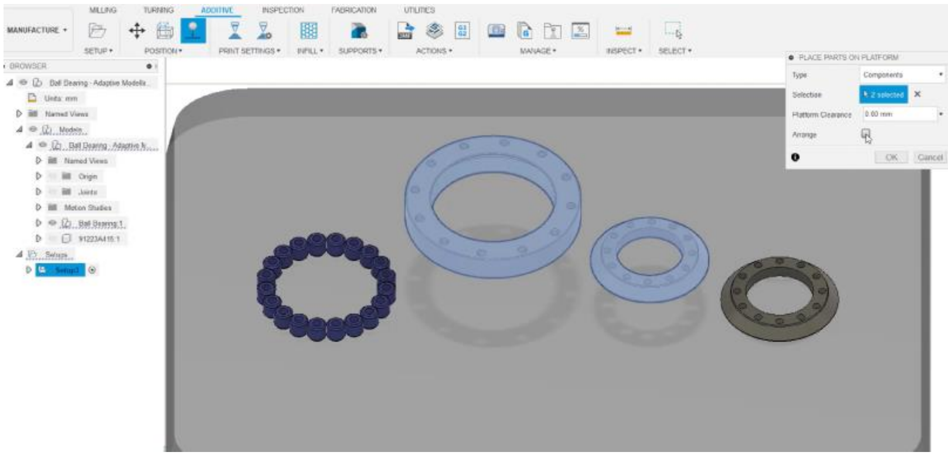

Figure 33: Arranging Parts on the Build Platform

Accessing the **Print Settings** from the top toolbar, or the initial setup menu, cycle through all the various print settings associated with the selected machine. There is a multitude of settings you will likely need to consider in setting up your machine configuration. Default configurations are loaded for a machine profile available in Fusion 360's machine library.

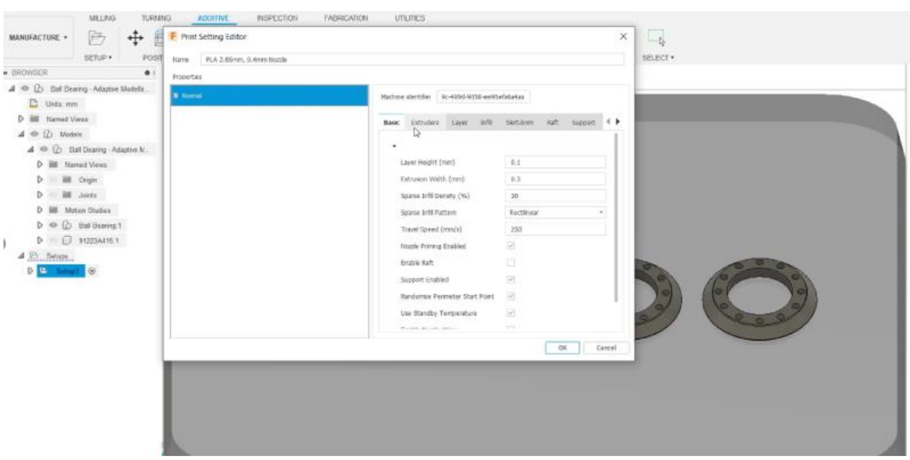

Figure 34: Accessing Print Settings

Individual **Print Settings** are also accessible from the top toolbar, such as infill settings and support settings.

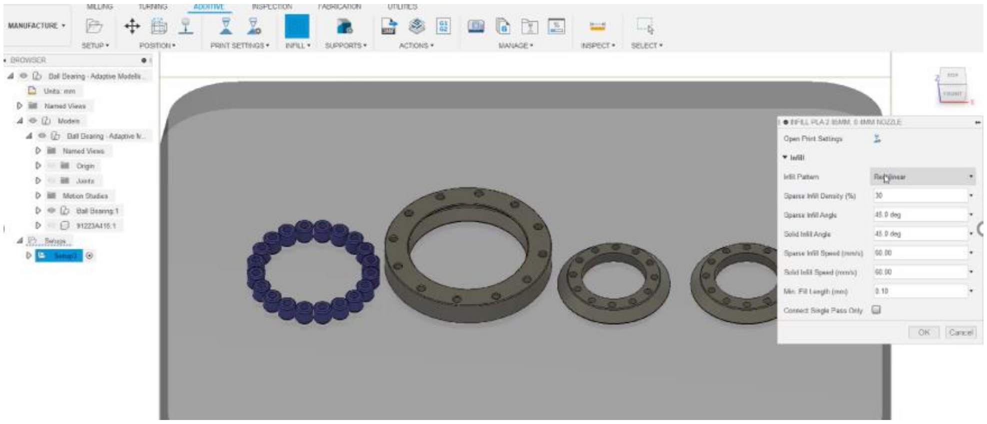

Figure 35: Infill Settings

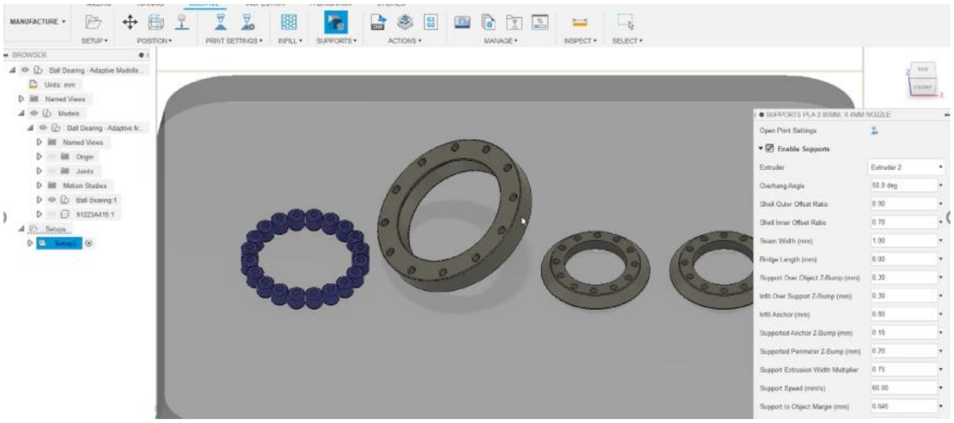

Figure 36: Support Settings

Regarding supports, this only becomes applicable for models that require supports for overhanging geometry. Models designed with angles no greater than 45 degrees from the horizontal wouldn’t ordinarily need support material on a typical material extrusion printer.

Once happy with print settings, navigate to the **setup** and right click **Additive Toolpath** and **Generate**. This enables simulation of the print setup.

Once confirmed, navigate to **Post** from the top toolbar and post the gcode which can be uploaded to a 3D printer.

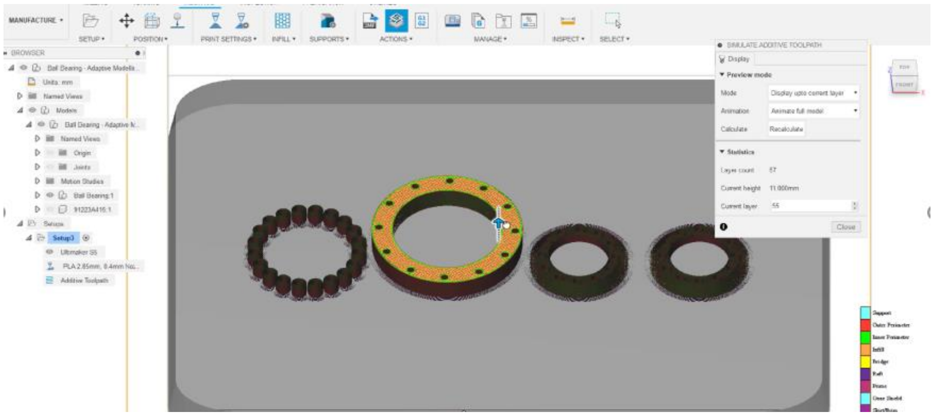

Figure 37: Simulating Print Setups

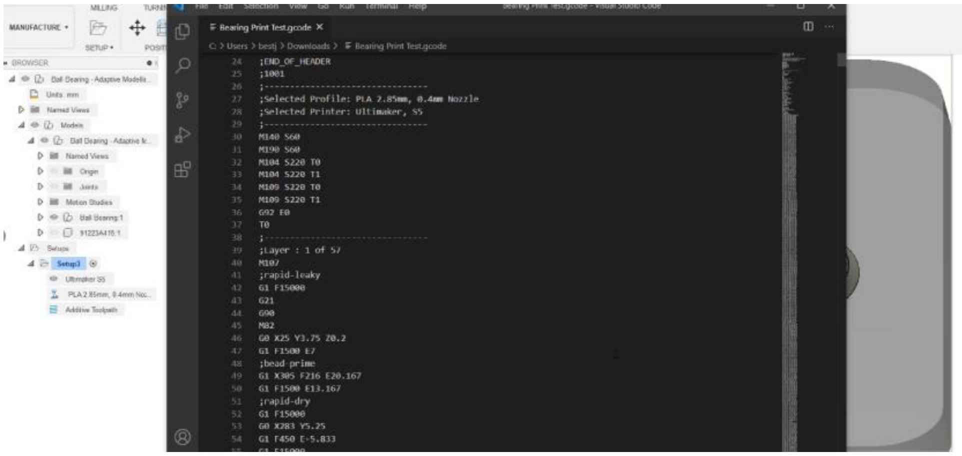

Figure 38: Posting Gcode

The steps of slicing and preparing parts for 3D printing can also take place within other slicing software, 3rd party, or specific to individual machine Manufacturers. The links here navigate to Ultimaker's Cura slicing software, Markforged's Eiger slicing software, Formlabs' Preform slicing software and Autodesk's Netfabb software. Associated design guides for extrusion printing can be found here for Ultimaker and Markforged machine specifically for example.

DfAM Principles for Vat Photopolymerization

In considering some best practices for optimizing models for this process, some similar principles apply as per material extrusion. But as with any process, there are intricacies specific to this type of printing that you'll want to be aware of when modelling your parts See link to Formlabs stereolithography 3D printing process and the associated design guide for more information on this 3D printing process. The principles below demonstrate how to apply DfAM to align with typical process constraints with Stereolithography/VAT photopolymerization processes.

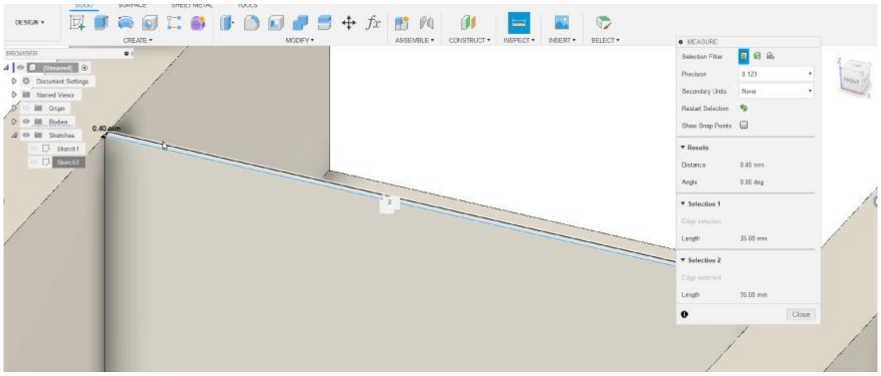

Figure 39: Minimum Supported Wall Thickness

A supported wall is one is that is connected to other walls on two or more sides. The typical recommend unsupported wall thickness for this type of printing process is around 0.4mm as anything lower may suffer some warpage during printing.

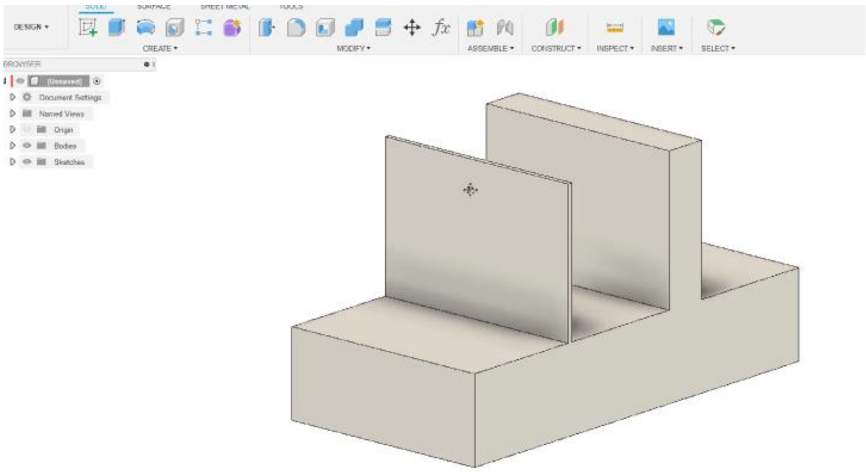

Figure 40: Minimum Unsupported Wall Thickness

A similar minimum recommendation applies to unsupported walls, one that is connected to others walls on fewer than two sides. It is recommended for this manufacturing process that this is not lower than 0.6mm to prevent warping or detachment from your model during printing.

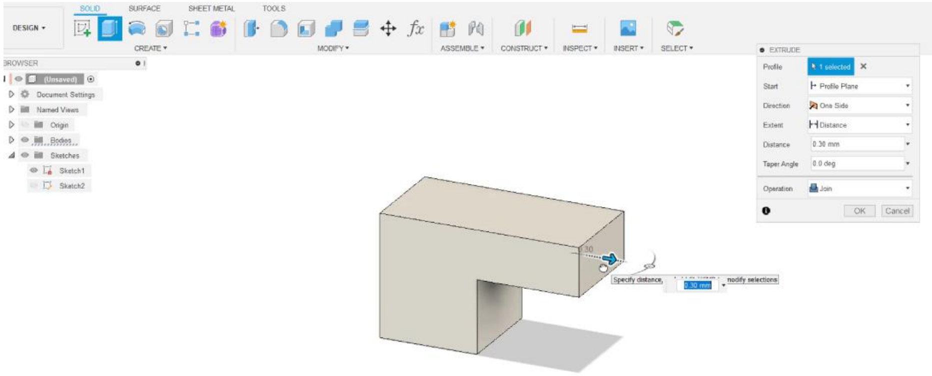

Figure 41: Minimum Unsupported Overhang Length

An overhang refers to a part of a model that sticks out horizontally, parallel to the printing platform. For a typical stereolithography printing process, this value should not be above a maximum of 1mm so as to retain structural integrity in printing. We can use the push pull command under modify in the design workspace to manipulate overhangs to bring them into specification for printing.

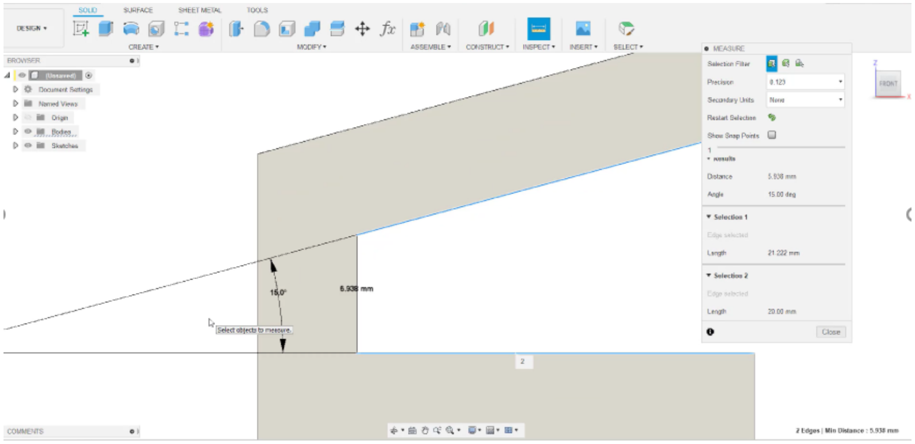

Figure 42: Minimum Unsupported Overhang Angles

Whether we are modifying our models within sketches and dimensions, or through direct modelling, another thing to be aware of is minimum unsupported overhang angles. 3D printing build parts up layer by layer and as such support material is required in some instances to support geometry that would otherwise be printing in thin air. The minimum recommended is around 15-20 degrees from the horizontal for Stereolithography printing, or 45 degrees for a material extrusion process.

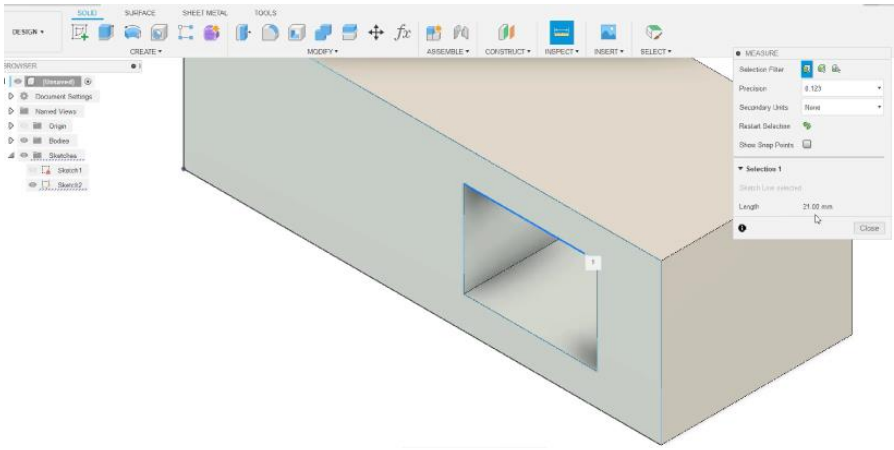

Figure 43: Maximum Unsupported Support Span/Bridge

Another aspect to be aware of is maximum unsupported spans or bridges. The minimum recommended span or bridge, unsupported, would be around 20mm. Anything larger will begin to suffer sagging during printing if unsupported.

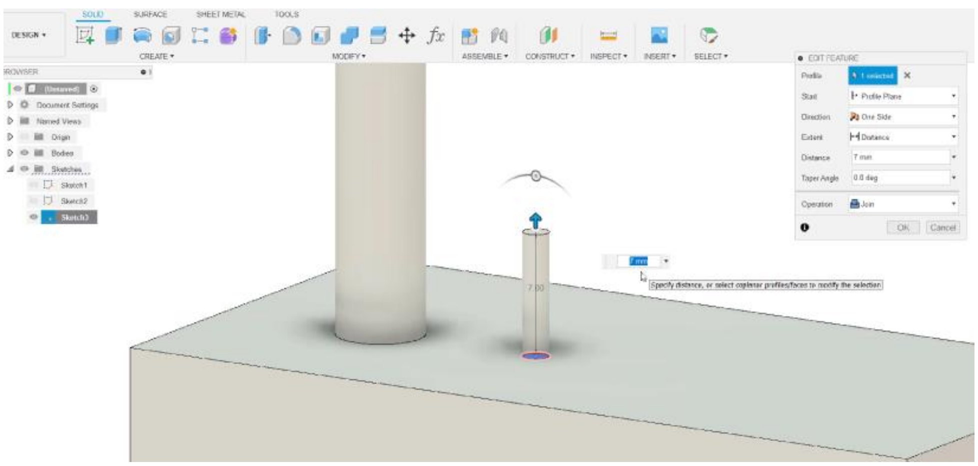

Figure 44: Maximum Vertical Pillar Diameters/Lengths

When considering the finer details on a printed part, we also need to be aware of manufacturing constraints. For vertical wire detail, the recommended minimum diameter for such a printing process would be around 0.3mm for up to 7mm tall, or 1.5mm diameter for up to 30mm tall. Such features can be modelled and altered simply by changing the dimension for the diameters. Extrude, push pull and inspect and measure commands enable the designer to get this right early in the design process.

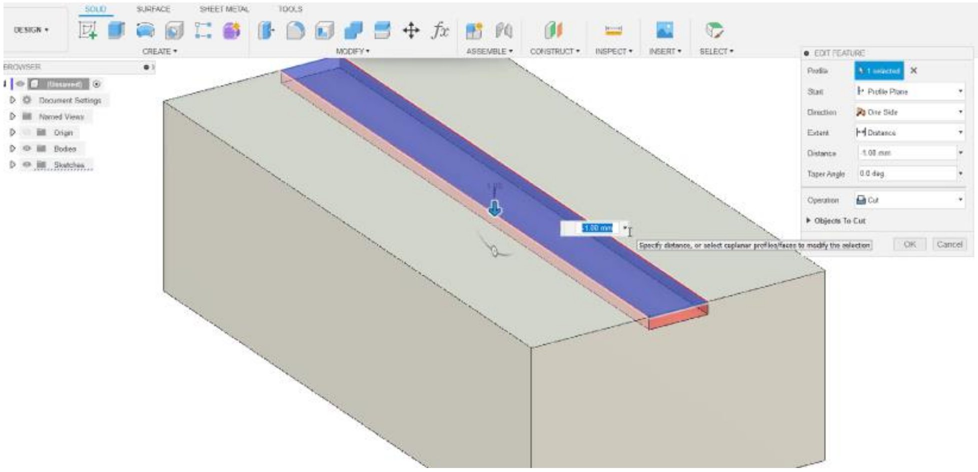

Figure 45: Embossed/Engraved Detail

Minimum embossing detail typically relates to the minimum layer height achievable on a 3D printer, and could be as low as around 100 microns in thickness, even lower. To change a sketch profile from emboss to engraved, we simply edit the extrude command in the parametric timeline, bottom of the screen, and change the command setting from join, to cut. The same principle applies for adding minimum hole diameters, which for this type of 3D printing technology is generally around 0.5mm in the x, y and z axes. Anything lower may close off during printing.

Reverse Engineering from Scan Data

For reverse engineering workflows there is generally multiple steps:

- Data collection - This could be completed with a laser scanner or through photogrammetry for example, where point cloud data is captured
- Mesh Repair and Manipulation - Working point cloud data into a workable Mesh. The processes of Mesh repair, manipulation and conversion can take place in Fusion 360, other complimentary Autodesk software including Netfabb and Recap Pro, and also within the scanning software itself.
- Slicing and export the g-code to 3D print

These workflows can vary, but the following example considers Fusion 360 as the primary tool for working with mesh data.

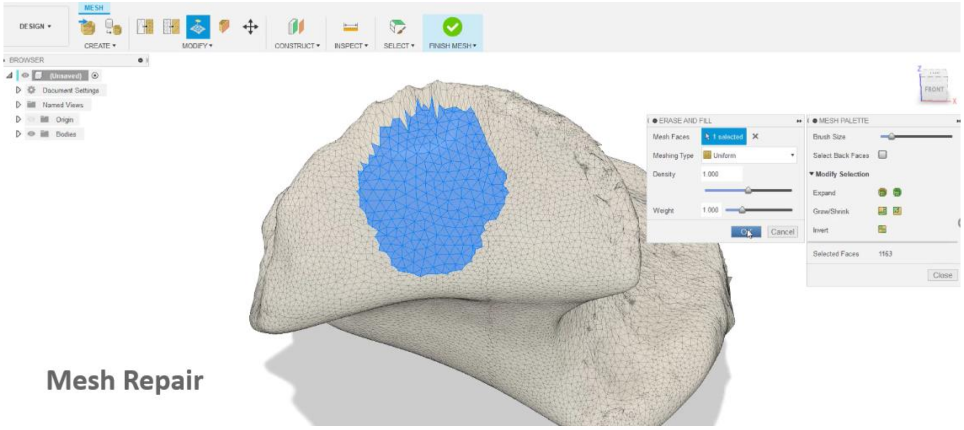

Figure 46: Mesh Repair, Erase and Fill – Model Courtesy of [PrintCity]

Assuming we have an open mesh which has been exported from scanning software, we can import this into Fusion 360 (**insert Mesh**). After positioning within our workspace we can use the orbit command to navigate around our part and identify areas that require repair. **Right click and edit the Mesh**, this takes us into the Mesh workspace to bring up repair tools.

You can access **selection tools and filter**s including window select, or perhaps more relevant here, the **paint selection** tool, to select only areas of the Mesh you want to repair. Holding left mouse click we select the areas we wish to remove, followed by the **erase and fill** command. Following this, we may want to smooth the mesh in certain areas as any rough geometry and remaining facets in the Mesh geometry will likely propagate through to the 3D printed part. So, still using the paint selection command, we can smooth areas using the **smooth command**.

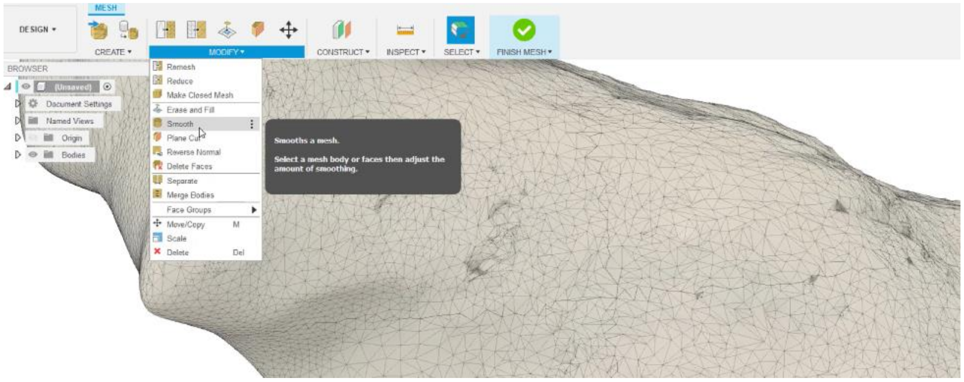

Figure 47: Smoothing Mesh Geometry

Following some basic mesh repair, we will want to make a closed mesh if not done already in other software for example. By selecting our Mesh and selecting **Make Closed Mesh**, we can form a watertight Mesh and create manifold geometry that can undergo further manipulation or be 3D printed. With our solid closed Mesh, we can apply repair operations at this stage also.

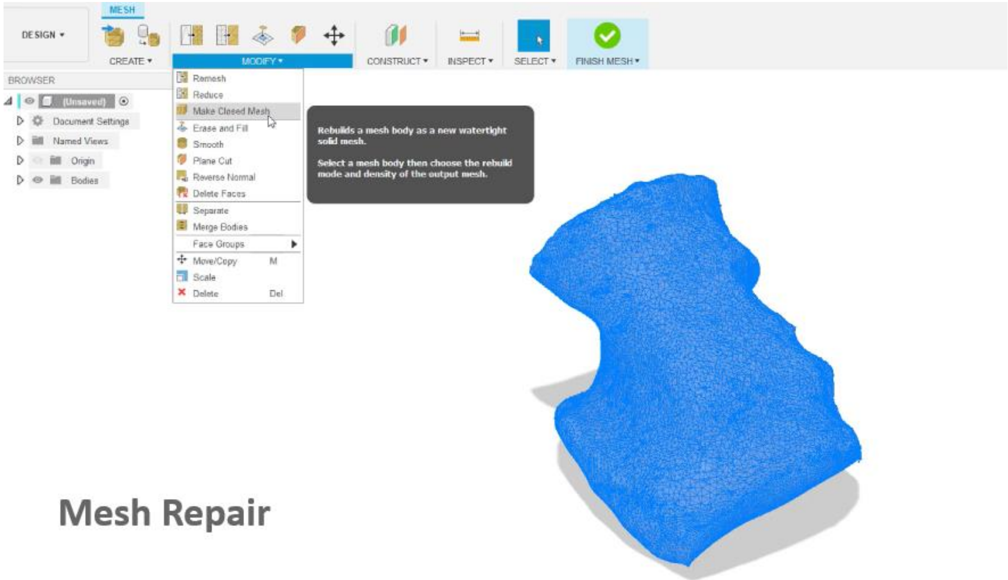

Figure 48: Make Closed Mesh

At this stage our Mesh data is in the form of a tri-mesh, so if you zoomed in you would see a series of individual triangles making up the body. This is relevant when we move onto the next phase of manipulation. So save the file as a tri-mesh and move on.

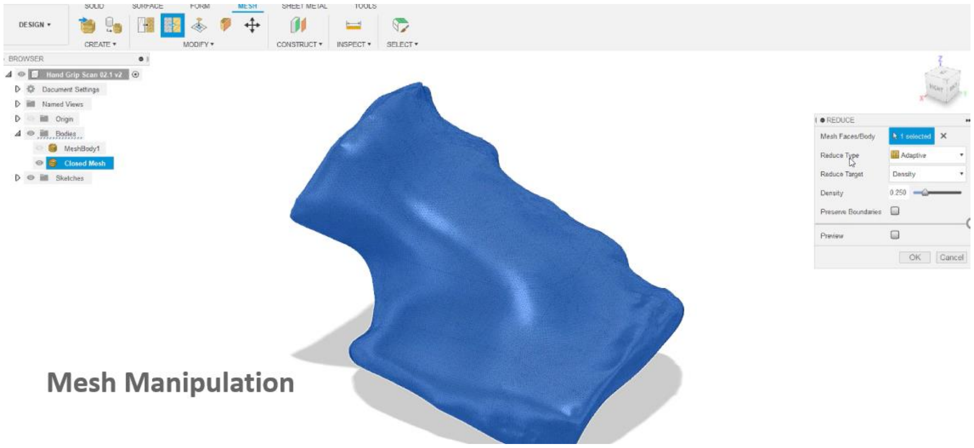

Figure 49: Re-Meshing

At this point it might seem sensible to try and convert the mesh to a BRep (boundary representation) to progress towards a more 3D printable file. However, if we try to convert as in figure 49, we are sometimes faced with a warning or the conversion aborts all together as the number of facets is too large to convert. Therefore, you might then use remeshing tools in Fusion 360 to reduce the mesh density, achievable uniformly or adaptively, to reduce meshes by density, face count or tolerance.

Once we have done this and sacrificed a little quality to enable conversion, which is a trade-off, we can convert. The maximum facet count Fusion will handle is around 40,000.

A further step to manipulating Mesh data easier is to convert a Triangulated Mesh to a Quad Mesh. This is achievable in Autodesk Netfabb or Recap Photo. Whilst Fusion 360 has reasonable Mesh repair tools, Autodesk's Netfabb has more advanced capabilities in mesh repair and manipulation. You would also have the ability to convert a tri-mesh to a quad mesh simply, in order to enable t-spline modification in Fusion 360

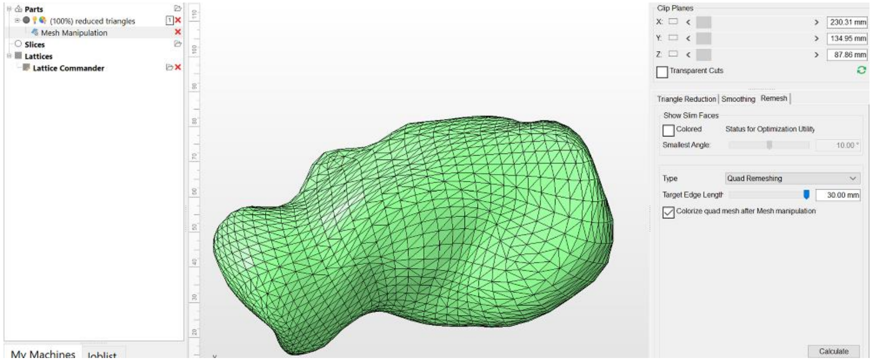

Figure 50: Converting Tri-Mesh to Quad Mesh in Autodesk Netfabb

Exporting a Quad Mesh from either software will enable us to bring the quad mesh into Fusion 360 for further conversion to a t-spline body. This means we can enter the form workspace and convert the model form **quad mesh to t-spline body**, under **utilities**.

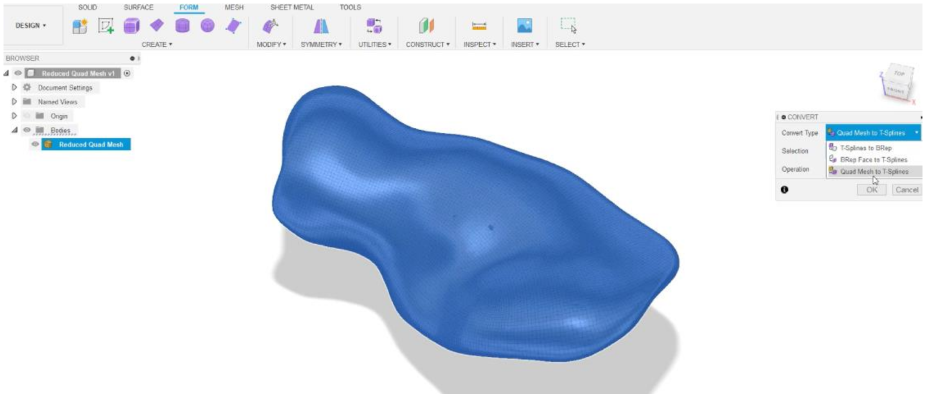

Figure 51: Converting Quad-Mesh to T-Spline body in Fusion 360

Within the form environment we can use a variety of selection tools to select individual faces, edges and vertices. T-Splines technology allows us to easily manipulate models with a triad, simply pushing and pulling geometry, rotating or scaling it and changing its position. With regards to reverse engineering workflows it is incredibly useful to manipulate surfaces in a controlled manner and eliminate any rough areas of a model resulting from scan data. Using **soft modifications** we can extend the affecting zone of any form manipulation, to make transitions more gradual for example.

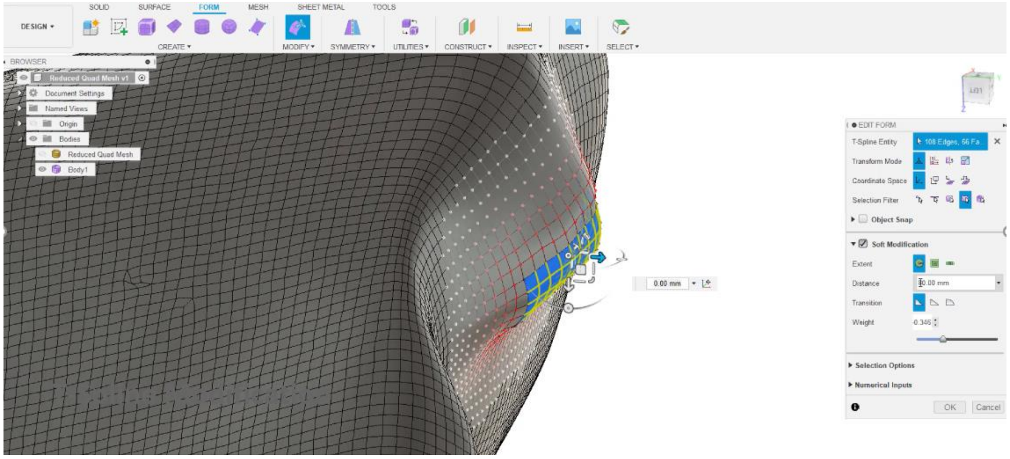

Figure 52: T-Spline Manipulation in Fusion 360

Following edits to groups of faces, we can alter the position of individual edges and vertices.

In order to progress toward 3D printing, and make final amendments using solid modelling commands, we convert to what’s called manifold geometry in the form of a BRep model.

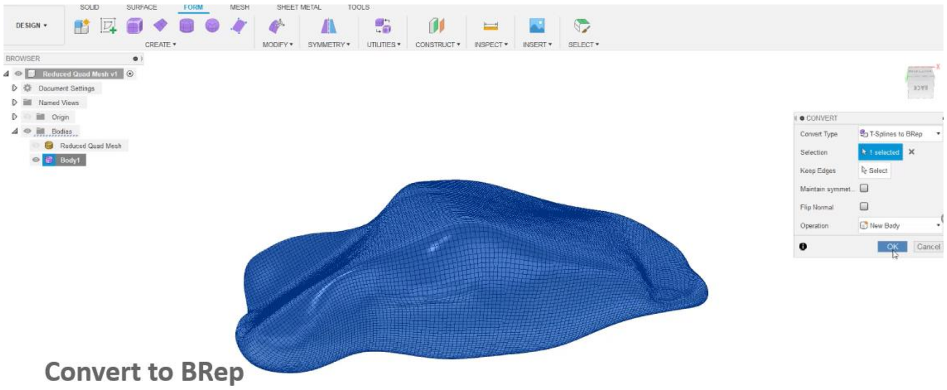

Figure 53: T-Spline Manipulation in Fusion 360

This workflow example is courtesy of PrintCity, whereby it was set out to achieve a high impact, low cost and attainable solution within the design and manufacture of customised daily living aids.

3D scanning was achieved with minimal labour intensity on an industrial scanner in a time of around 10 minutes with minimal skill level. The mesh repair and manipulation as shown is a semi-automated process and took around 10 minutes from good scan data from an industrial laser scanner. This type of part would print in around 10 hours on a desktop extrusion printer with a material cost of less than £5.

The advantages in such a workflow is a cost effective sub 24 hour turn around for a product where mass customisation and customer experience has been placed at the core.

Figure 54: Workflow Application – Case Study Courtesy of [PrintCity]

Generative Design with Fusion 360

Whilst the core of the accompanying presentation to this handout focuses on a baseline for designing for additive manufacture within Fusion 360 for extrusion printing and vat photopolymerization processes, as discussed, Generative Design can offer significant further value within the field of additive manufacture.

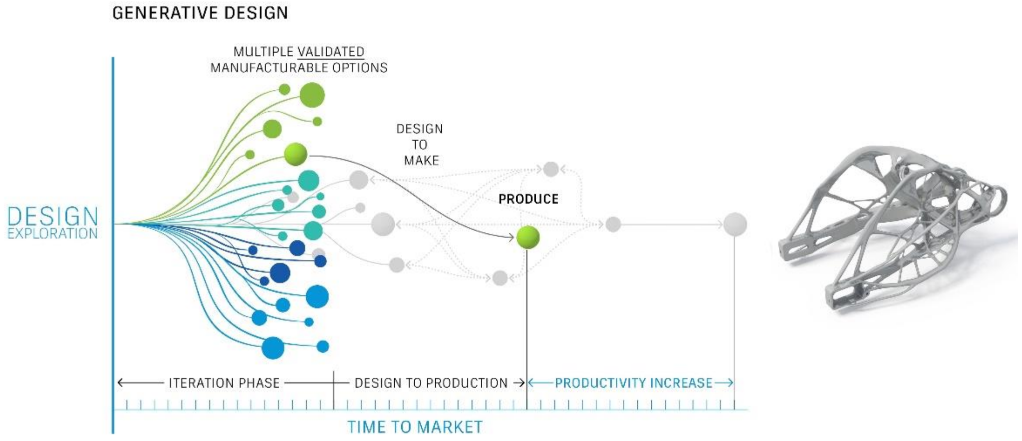

Figure 55: Generative Design Workflow

Autodesk Generative Design is a design exploration technology. It enables the simultaneous generation of multiple CAD-ready solutions based on product performance requirements as well as real-world manufacturing constraints.

The ultimate goal for any engineering activity is to strike the right balance between performance and cost to produce for a given design challenge or market opportunity. Engineers are limited in the time and energy they can spend on any design problem to fully explore the options that encompass the design space. Therefore the benefits in Generative Design is in enabling the rapid creation and exploration of design options, empowering design teams to determine the trade-offs they want to make along the price/performance curve.

Generative Design technology inspires and enables a revolutionized way to design and manufacture, using Artificial Intelligence and Cloud computing to generate many outcomes to a specified problem. It therefore requires a different mindset in defining a problem that a particular design must meet.

Figure 56: Generative Design Target – Simple Shelf Bracket

If we were to consider a simple scenario for designing shelf brackets, for the above shelf, then with Generative Design we might setup the problem similar to below.

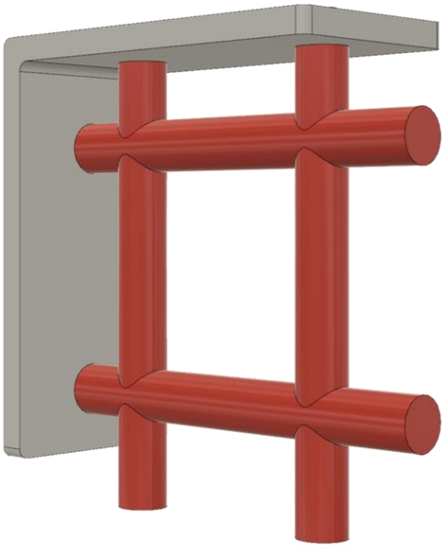

Figure 57: Generative Design Setup – Preserves & Obstacle Geometry

Rather than defining the shape of this product, we can instead first define preserve and obstacle regions. A preserve is where material needs to be kept such as at points of fastening or assembly, and an obstacle region would indicate where material can't be added (red), such as allowing for tool clearance and installation for example.

Figure 58: Generative Design Result

In applying load conditions, materials, and manufacturing constraints in Autodesk's Fusion 360, cloud computing and AI then generates many validated concepts, similar to the one seen above for this particular problem.

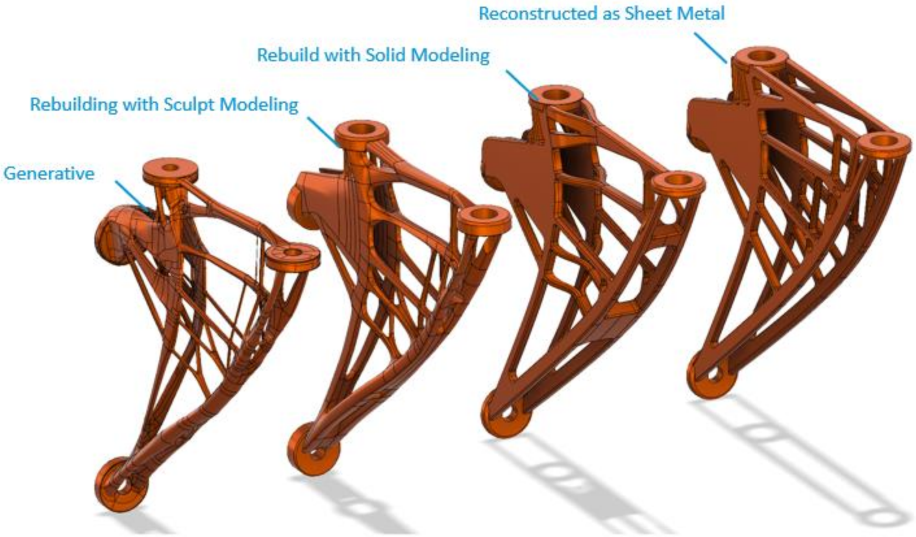

Figure 59: Generative Design Result

Using various modelling techniques in Fusion 360, a particular output could be sent directly to manufacture, further optimised, or re-worked to suit other manufacturing methods such as sheet metal forming.

Generative Design offers shape inspiration, design optimisation, and manufacturing specific optimisations. To learn more, check out the case studies, tutorials and courses below to see how you can adopt and leverage this ground-breaking technology.

What is Generative Design

- https://www.youtube.com/watch?reload=9&v=nFy4i6a9Bwk&feature=emb_rel_end

Self-paced learning

- Generative Design for Additive

Hyundai Motor Group Drives New Mobility Innovation with Generative Design

- https://www.youtube.com/watch?v=N6xrdx1sfaQ&feature=emb_logo

Sign up for a Generative Design Workshop

- https://www.autodesk.com/training/generative-design-customer-workshop

Additional Resources

Extrusion Printing Process

- Case Study
- Ultimaker Design Guide
- Markforged Design Guide

Stereolithography Printing (Vat Photopolymerization)

- Formlabs Technology Overview
- Formlabs Design Guide

Software – Download a Free Trial Today

- Fusion 360
- Netfabb
- Recap Photo

Advanced Manufacturing for Additive in Fusion 360

- Advanced Manufacturing for Additive in Fusion 360 – AU2019

AU 2020 Related On Demand Content

- Generative Design and Additive Manufacturing for Work—and Play
- 3D Printing PPE: A Three-Minute Face Shield Solution
- 'Barriers to Entry' for Large-Format Additive Manufacturing
- Additive Manufacturing: Understanding and Applying Key Design Considerations
- Fusion 360 and 3D Printing—Tips and Tricks for a Successful Workflow
- Design Focused for Additive Manufacturing
- Generative Design in Fusion 360: A Year in Review and a Look Ahead
- Generative Design Masterclass