PM500725

How can we design sustainability into Additive Manufacturing?

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Learning Objectives

- Identify applications where additive manufacturing provides a business and sustainability benefit and where it doesn't.
- Assess AM design trade-offs while avoiding common pitfalls
- Apply DfAM techniques such as generative design, latticing, and part consolidation
- Implement design workflows that drive more sustainable and higher performing part designs

Description

The additive manufacturing (AM) industry continues to grow, doubling in size roughly every five years. With this also comes an increasing environmental footprint. AM holds many promised environmental benefits. From lightweight parts for electric vehicles and reduced material consumption through optimized designs and flexible localized production, there's no shortage of potential. However, many caveats remain. How do you print parts that perform better and last longer? Is the lightest part necessarily the most sustainable? How can we design not just for the printing process, but also for post processing, shipping, and the entire product lifecycle? In this class, we'll look at design technology and case studies that will provide insight into these questions. We'll also cover how you can start putting these technologies and workflows into practice to turn promised sustainability ideas into reality—while avoiding common pitfalls.

Speaker(s)

Kieran Mak

Kieran is a Sr. Solutions Engineer at Autodesk. In his role, he provides technical expertise and thought leadership on additive and generative technologies that help customers improve their design and manufacturing processes and achieve their business goals. Prior to joining Autodesk, he served in a variety of application and design engineering roles in the additive manufacturing industry where he helped customers transform their industrial production processes using additive manufacturing. Kieran holds a bachelor's degree in Mechanical Engineering from McGill University and is based in Toronto, Canada.

Ryan Abel

Ryan has over 25 years of Design, Engineering and Manufacturing experience. Starting out in new product development, he focused on digital prototyping and upfront simulation to reduce physical testing and improve product performance with FEA, CFD and Moldflow. After joining a simulation startup, Ryan led Sales, Consulting and Training. At Autodesk, Ryan supported global growth by coaching new partners about sustainable simulation business models and detailed technical training for their staff. In his current role, Generative Design Specialist, he leverages his industry experience and passion to make every engineer better by adopting new ways to be creative and ideate effectively and achieve desired outcomes efficiently.

Introduction

Before determining how to design sustainability into additive manufacturing (also know as 3D printing) it is important to first ask the question: “Is Additive Manufacturing even something that is sustainable?”. Throughout this handout we will be attempting to address this question and identify ways to design sustainability into additive manufacturing.

To ward off the worst and most dramatic effects of climate change the IPCC has set the goal of limiting average global temperature rise to 1.5 deg C above pre-industrial levels. To do this, the solution proposed in 2015 is to reduce global emissions by 45% by 2030 and achieve net zero emissions by 2050. Something more tangible for designers and engineers is that approximately 80% of all product-related environmental impacts are determined during the design phase of a product.

How will we make upfront decisions that help the environment? Especially in a world where despite our need to reduce emissions, we are being asked to continue to grow businesses and produce more. Industries will only change by the hard work of many people doing the right thing, and not just the easy or profitable thing

Products go through a basic lifecycle, from raw materials to manufacture to use and eventual disposal – and it’s important to think of them in this larger context. There are environmental impacts at every stage of the lifecycle. Energy and waste are consumed and generated at each phase of the product lifecycle. These things cost money, and if we can work with less material, we’re already ahead of the game.

Enter the concept of Circularity or the Circular economy. Companies that consume their old product for parts and raw materials to build new product will lead in the circular economy. This included being Designed to be disassembled, products designed to come back to manufacturers and even paying the consumer for participating in the circular economy. This will create a 2-way marketplace and give the customer some skin in the game and brand loyalty.

Defining Sustainability

The 3 min pillars of sustainable development include economic growth, environmental protection, and social equality. To support the pillars the UN commission rally’s around Meeting the needs of the present without compromising the ability of future generations to meet their own needs.

In 2015 the United Nations Member States adopted the 2030 agenda for Sustainable Development.

At its heart are 17 sustainable development Goals, which are an urgent call for action by all countries in a global partnership. Today the division of Sustainable Development Goals plays a key role in evaluation of UN systemwide implementations of 2030 Agenda on advocacy and outreach activities to share best practices across industries. For the purpose of our talk today the most relevant Goals are #9 and #12.

#9 covers Industry, innovation and Infrastructure and specifically 9.4.1 covers CO2 Emission per unit of value added. This is just another product/performance matrix that is focused on impact of greenhouse gas venting to the environment.

#12 covers Responsible Consumption and Production. 2.1 covers material footprint per capita and material footprint per GDP. This help to right size decisions to the size of the market, this helps to compare impact between industries to ensure sustainable places to live. 4.3 covers hazardous waste, and some additive manufacturing methods generate more hazardous waste than others. Finally, one of our favorites, 5.1 tracks recycling rates.

Our Definition of Sustainability for this class will be "Use materials in the most productive way, use less, and reduce carbon footprint through the material lifecycle."

Assessing Tradeoffs: Avoiding AM sustainability pitfalls

Common AM sustainability claims

Before determining how to design sustainability into additive manufacturing, it is important to first address some of the common claims around sustainability and additive.

Many of the AM sustainability claims seem natural and intuitive. For example, because parts are created by addition, as opposed to subtraction, it is often assumed that additive only uses the amount of material contained within the end part. Another few other common claims are that the complex lightweight components that are possible can reduce the energy consumption of vehicles and that because AM allows for consolidating assemblies into single parts, it eliminates wasted material in the form of fasteners or adhesives.

While in some cases these claims can be true, there are also traps that one can easily fall into. It is important to know what these traps are so that they can be identified and avoided.

Waste Reduction

The reduction of wasted material in the manufacturing process is likely one of the most frequently mentioned additive manufacturing sustainability advantages. Generally, the claim is that the additive nature of 3D printing means that only the exact amount of material contained in the final part gets used during the manufacturing process.

While in some cases, this can be true, it firstly really only compares additive to a subtractive machining process. It does not typically mention or compare to other near net manufacturing processes such as injection molding or casting. Secondly, it ignores the waste that can occur in an additive process.

It is not uncommon that it takes several print iterations to get successful part. This can be caused by several factors such as hardware failures, material issues, and perhaps most commonly poor design for additive manufacturing (DfAM). Just like all manufacturing methods, it is important to design for the process. Too often a part that was designed for another process such as molding or machining is printed and leads to a failed print.

Regardless of how they occur, these failures may not necessarily be bad when they occur a few times in a larger production run of thousands of parts. However, for low volume production which remain one additive's biggest strengths and where volumes are sub one-hundred parts even a small number of failures can represent a significant impact to yield.

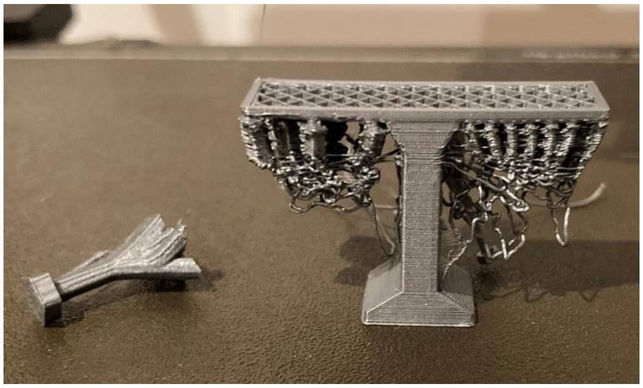

Figure 1 - A failed FFF 3D print

Figure 2 - A failed LPBF print

In addition to failed prints, it is also important to challenge the notion that additive is a no waste process. Many of the most common industrial 3D printing processes either rely on filament, powders, and resin as their material source. In the case of powder and liquid based processes, parts are created from vats of these materials either via thermal or chemical reactions such a laser melting or photopolymerization.

In the case of powder-based processes many of them rely on heating the bed of powder before melting it which over time degrades the powder. This means that even if the powder doesn't get used to create a final part, it must eventually be disposed of.

Similarly for liquids the resin that remains on the surface of the part in many cases must be removed via a physical or chemical process and this very frequently creates significant quantities of hazardous waste.

Figure 3 - Removing excess powder from a polymer print

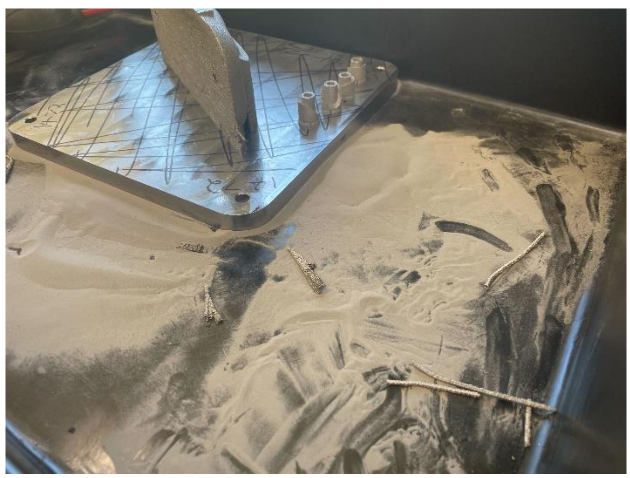

Figure 4 - Excess powder from a LPBF print

Finally, one must also consider waste in the form of support structures. Many additive processes and part geometries require support structures which are sacrificial parts whose sole purpose is to anchor and add structure to the part during the printing process. These structures need to be removed after printing and disposed of. It is not uncommon for these supports to represent a significant percent of the total print material.

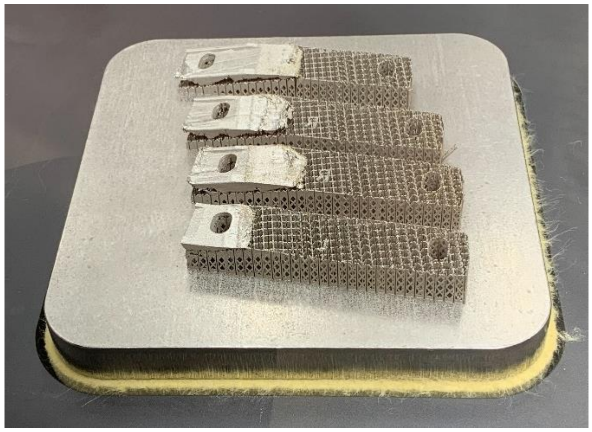

Figure 5 - Support structures from a failed metal print

Figure 6 - Support structures removed from a LPBF print

Energy Reduction

A second common additive sustainability claim is that it reduces energy consumption. This claim is generally two part. Firstly, that by leveraging the complex optimized structures that additive enables, lightweight parts can help save on weight and therefore emissions on vehicles like cars and aircraft. The second part is that additive is itself a more energy efficient manufacturing process.

One must however consider the energy that goes into enabling these complex designs. In the case of a metal additive part, raw metal has to be heated and atomized by blasting it with an inert gas in order to turn it into a fine metal powder. Next, that metal powder needs to be shipped from one specialized manufacturing facility to another. These facilities are specialized and may not necessarily be located in proximity to each other. This powder then needs to be heated generally to around 80C for the duration of a print while a high-powered laser traces out the contour and cross-section of the part over the course of several hours. Finally, these parts need to cool down and often need to be put into an oven in order to relieve the built up stresses.

All of this to say that this can be a highly energy intensive process which in turn comes with an energy cost.

The chart below compares the greenhouse gas emissions for various metal manufacturing processes such as machining, casting, and additive manufacturing on the basis of kilograms of CO2 equivalents emitted per kilogram of material processed.

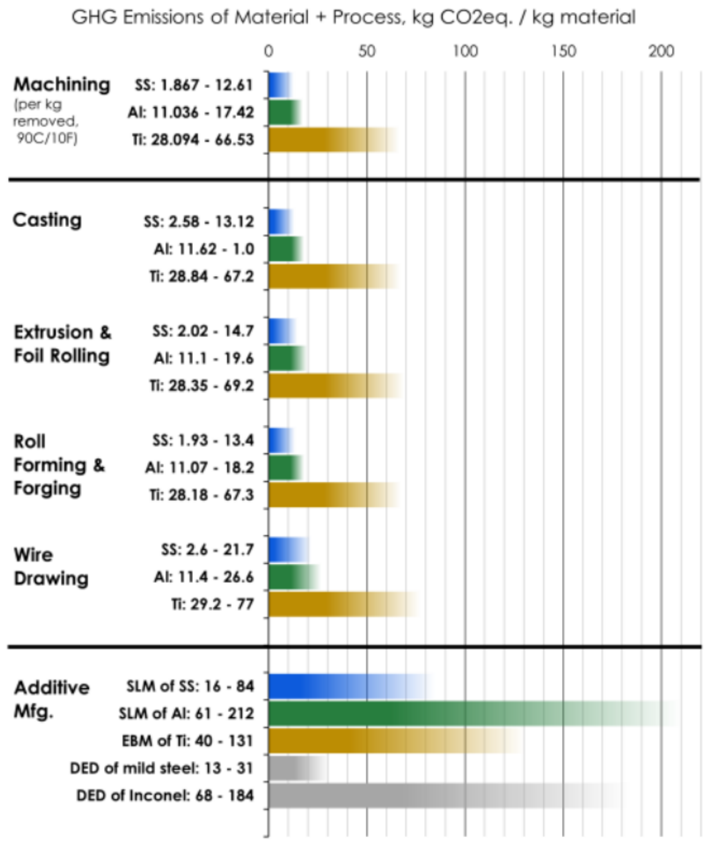

Figure 7 - GHG emissions of various metal manufacturing processes - Courtesy of J. Faludi

As can be seen in this chart the energy to print parts in stainless steel, aluminum or titanium are anywhere from 2x-14x higher than a conventional process.

As an example, let us consider the ultralightweight aluminum aircraft seat frame in the figure below that was designed and manufactured by our Autodesk research team. This part is 30% lighter than a conventional seat. On a large aircraft with hundreds of seats, this could shave over 100kg of weight ultimately saving close to 15 tonnes of fuel per year.

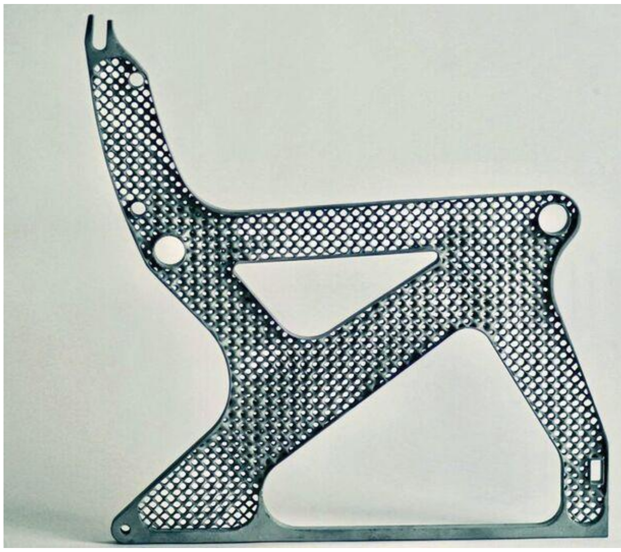

Figure 8 - Optimized Metal Additive Aircraft seat frame

However, had our teams decided to print this part in aluminum via an SLM process, it would have emitted 14x more CO2 per kilogram than had it been manufactured by casting. This choice in manufacturing process would have added 105 tonnes of CO2 emissions per aircraft. This may be a worthwhile trade-off if the part lasts the entire lifespan of the aircraft, however it is not uncommon for aircraft interiors to be refreshed every 5-7 years in which case, this part could be increasing the overall carbon footprint of the aircraft.

Part Consolidation

Part consolidation is another example of a common AM sustainability claim. This claim emphasizes that the reduction of fasteners, adhesives, and simplified supply chains is a more energy and material efficient approach.

Figure 9 - An example of part consolidation

However, one has to also consider the effect of part consolidation on the printing process. Often due to a combination of part geometry, and printing process, there are constraints on how a part can be oriented relative to the build direction. This limitation can often mean sub-optimal build packing, and in this case, this consolidated part only allows us to fit 8 parts into a single build. It also creates a relatively large amount of wasted space in between the parts. While this space can be filled with additional parts from a separate order, if the manufacturer does not have anything that will fit in this space and is on a deadline to produce these parts, they will go ahead and print them. This has the trade-off of lowering machine utilization and energy efficiency.

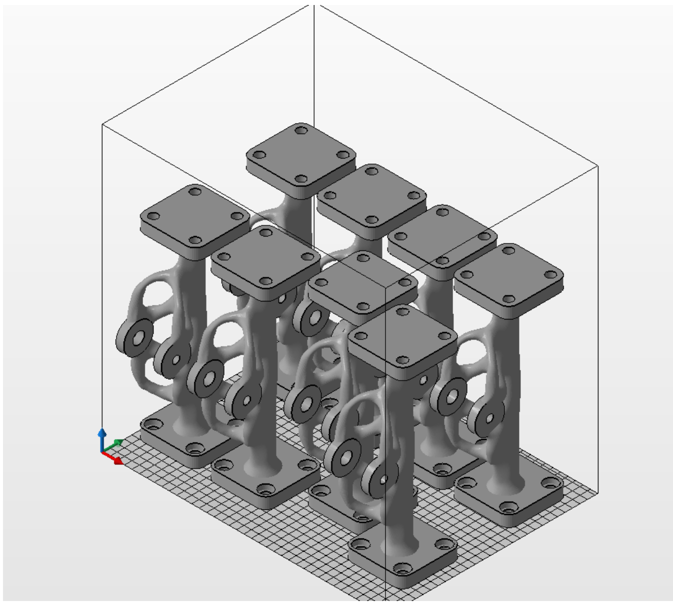

Figure 10 - Low Density 3D packing

All of this brings us to our first takeaway which is to not assume that by default additive manufacturing is sustainable.

Identifying Sustainable AM Applications: AM superpowers

Avoiding pitfalls

Despite the pitfalls reviewed in the previous section, there are many practical benefits that AM provides for achieving more sustainable outcomes.

Combining manufacturing methods – Printing & Casting

Let us consider the aircraft seat frame example from the previous section. We showed that had the team decided to print the part using an SLM process it could have increased the overall carbon footprint of the aircraft due to the high embodied energy in the manufacturing process. However, our team did not actually print this part in metal. The approach they took started by printing the part first in a polymer (see figures below).

This plastic part was then used to create a positive and coated in ceramic to make a mold. This mold finally allows the part to be cast in materials like aluminum and magnesium, the latter of which offers even greater weight savings than aluminum and therefore reduced CO2 emissions.

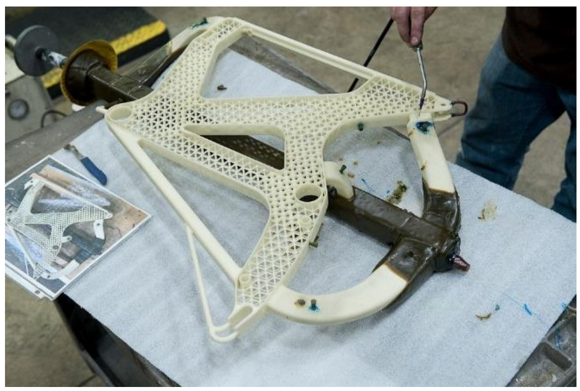

Figure 11 - Polymer print prior to casting

Figure 12 - Casting the metal part

Ultimately, this workflow allows for an efficient workflow that leverages a lower energy usage printing technology to define the complex optimized design while using an efficient casting process with a lower carbon footprint to actually manufacture the part in metal.

Part Consolidation workflows

Looking at the case of the consolidated part from the previous section, there are ways to improve the packing density and make for a more efficient printing process while still consolidating parts. For example, by splitting the single part into 3 separate bodies as opposed to one while designing in joining features to allow the part to assemble back together, the packing density can be increased from 10% to 15% and as opposed to 8 parts fitting into a build, 16 can now be printed at a time.

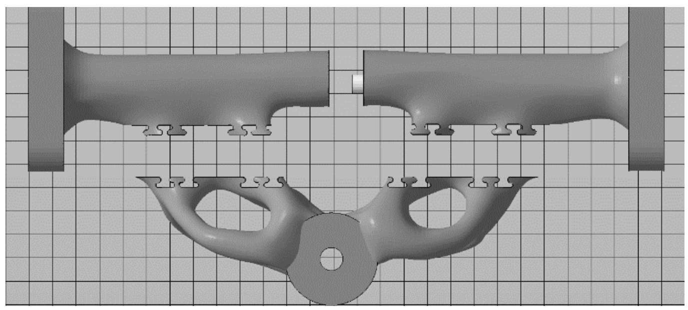

Figure 13 - Splitting the consolidated part from 1 piece to 3 with joining features

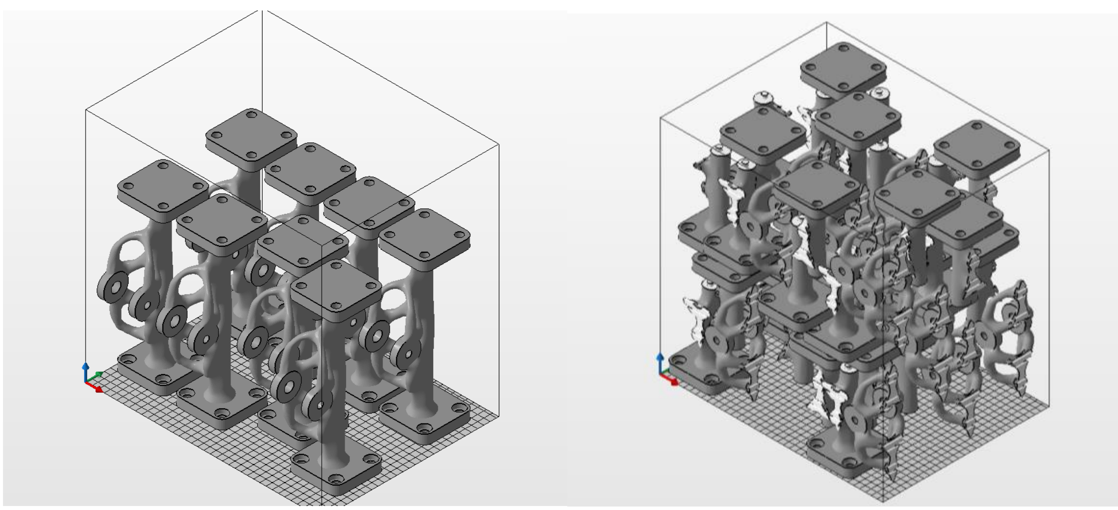

Figure 14 - Low density build (left) High density build (right)

With this simple change the part count is still reduced from 14 to 3 but can now be produced more efficiently. Furthermore, this approach also has the advantage that if one section of the part is damaged and needs to be replaced, only one portion of the part needs to be reprinted as opposed to replacing the entire assembly.

All of this to highlight that seemingly subtle design decisions can have a significant impact on the efficiency and sustainability of a particular part and additive manufacturing process.

Life Cycle Assessment

When determining whether a part or process is sustainable or not it is important to consider the entire life cycle of the product. This includes everything from the raw material extraction, manufacturing, use, and end of life phases. There is a methodology for assessing these phases and it is called life cycle assessment (LCA).

Until a full lifecycle assessment of the product is completed it cannot be definitively stated that one product is more or less sustainable than another.

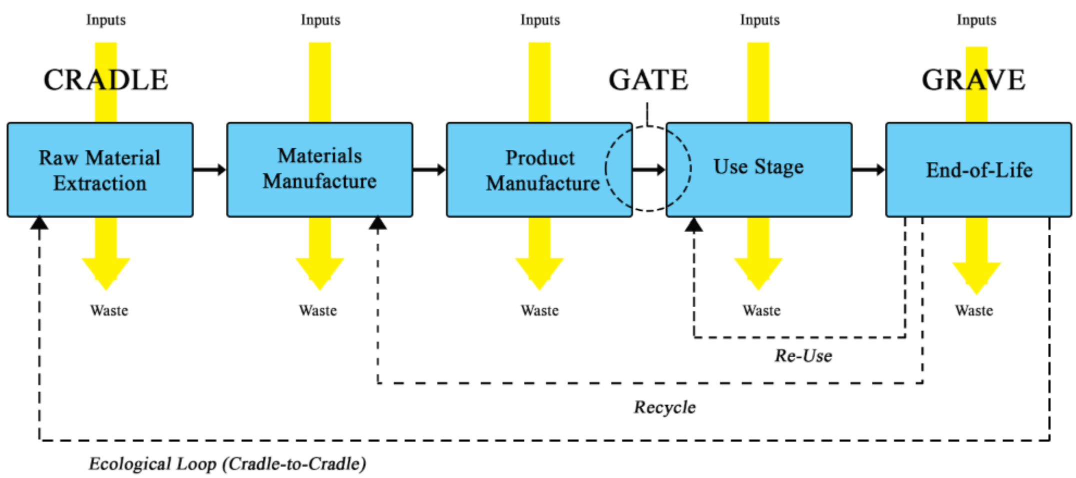

Figure 15 - Life Cycle Assessment Diagram

While there are several databases and tools for assessing the majority of common manufacturing methods, a challenge for the additive industry is that these databases have very limited information specific to AM. The fast changing nature of the industry and OEM's means that material suppliers often either don't have the information or can't easily make LCA data available to their customers and these databases.

In order to improve this and strive for a more sustainable industry, it is crucial that this data is available so that product designers and manufacturers can make more informed decisions regarding the sustainability of their products.

This now brings us to our second takeaway which is to advocate for better LCA data for additive manufacturing processes.

Identifying Sustainable AM Applications: AM Superpowers

Now that we have identified the primary pitfalls to avoid and reviewed a few examples of sustainable AM applications let's apply a more generalized approach. There are practical steps that can be taken today to achieve more sustainable outcomes.

It starts with going back to what additive manufacturing is good at. There needs to be some reason why printing a part is better than making it via another manufacturing method such as molding, machining, or casting. These strengths are fortunately well documented and established and they are:

- Improved product performance
- Accelerating time to market
- Low volume / high mix production
- Mass customization
- Flexible manufacturing
- Part consolidation

When considering these in a sustainability context, it is also important to refer back to the UN sustainable development indicators outlined earlier. These are things like:

- Reducing CO_2 emissions per unit of value added
- Reducing material footprints
- Reducing hazardous waste generation
- Increasing recycling rates

The overlap between these two areas is the space to operate within and find practical sustainable solutions.

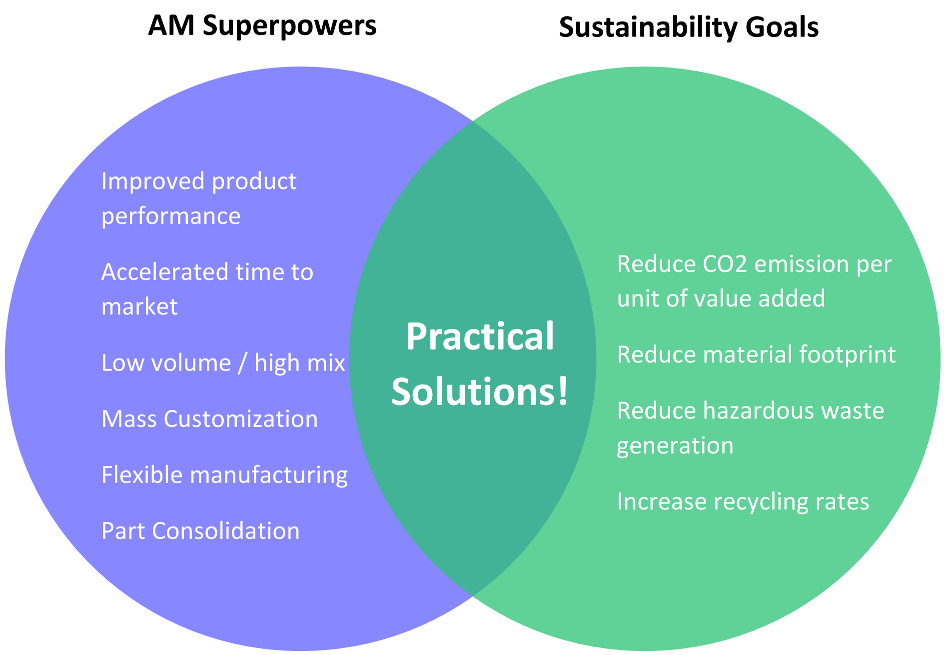

Figure 16 - AM Strengths and Sustainability Goals

Solution Categories

With these in mind, we can now use these strengths and goals to focus on specific areas which deliver both business benefits and more sustainable outcomes. They are summarized in the table below:

Sustainability Outcome	Additive Goal
Use materials in the most productive way	Improve product performance
Use less	Reduce waste during the manufacturing & product lifecycle
Reduce carbon footprint through material lifecycle	Shift to bio-based and recyclable materials

With these outcomes and goals established, we can now define five categories of practical solutions.

The intent is for internal advocates of additive manufacturing in industry to be able to use these as a starting point for identifying practical solutions for designing sustainability into additive manufacturing while avoiding pitfalls from the previous section.

Improve product performance of clean technologies

Removing mass of an aircraft component to improve the fuel efficiency of a jet engine or lightweighting a part to improve performance of an electric vehicle can have benefits but also come with potential embodied energy effects that can negate these benefits. Instead of just focusing on improved performance, look for opportunities where the performance improvement also becomes an enabling factor for a clean technology.

For example improving the efficiency of a hydrogen reactor for hydrogen powered vehicles, extending the range and increasing adoption of electric vehicles, or developing an optimized heat exchanger that enables carbon capture technology.

Furthermore, increasing the efficiency and performance of these technologies will have a business impact of increasing the output of the system per dollar spent.

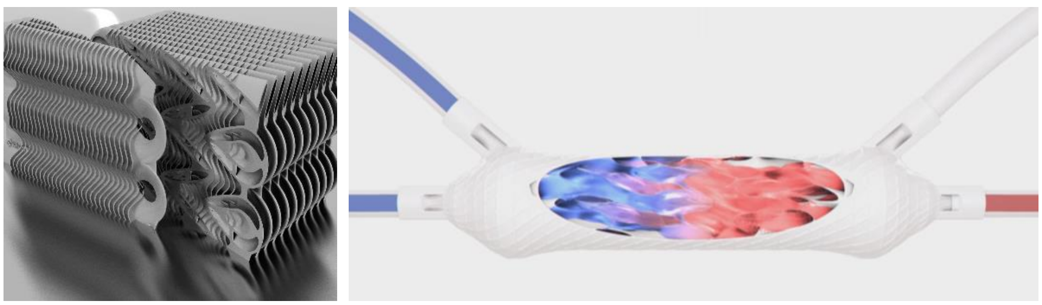

Figure 17- Example of optimized 3D printed heat exchangers - Right image courtesy of H2GO

AM Superpower	Design Complexity
Business Benefit	More output per dollar spent
Environmental Benefit	Reduced CO_2 emissions per unit of value added
Examples	Optimized heat exchangers

Simulate to reduce build failures

Failed builds can represent a significant waste stream for additive manufacturing as was highlighted earlier. However, just as one can run an FEA simulation to predict how a part will deform under load, or a injection molding simulation to predict how material will flow inside a mold before creating expensive tooling, it is also possible to simulate additive processes.

By running process simulation for metal powder bed printing, it is possible to predict areas of the part where supports or distortion could cause failures in the build.

Because AM is a highly digitized process, it’s easy to go back and make a change to the part geometry, support design, or process parameters so that these issues can be identified and corrected before they happen.

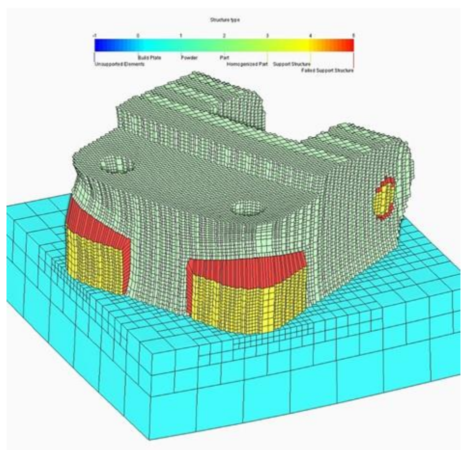

Figure 18 - Additive Build Simulation in Netfabb (figure courtesy of Dr Ed Demeter, Penn State University)

AM Superpower	Digitized manufacturing process
Business Benefit	Save cost of wasted powder & increase machine utilization
Environmental Benefit	Reduce hazardous waste emissions
Examples	Metal AM process simulation to detect support structure failure

Remanufacturing to extend part life

While some additive methods do require more material than just what goes into the final part, there are methods that can come close to near net material usage. Direct energy deposition (DED) is a process that is very comparable to the CO2 emissions per kg processed as conventional manufacturing methods while also being one of the fastest additive processes in terms of kilograms processed per hour.

This method can also allow for small amounts of material to be added back selectively onto precise areas of parts such as turbine blades, propellers or molds. This in turn has the business benefit of extending the service life of parts by making repair and remanufacturing a viable option. Furthermore, by extending the service life of a part it also increases the amount of time that the embodied carbon that went into these parts is amortized over.

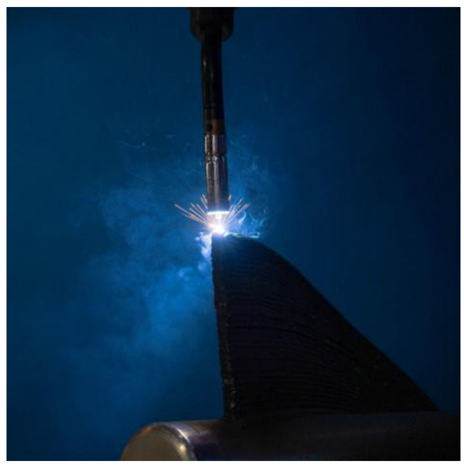

Figure 19 - DED Additive manufacturing (Image courtesy of RAMLAB)

AM Superpower	Selectively add material only where needed
Business Benefit	Save cost by extending service life of parts
Environmental Benefit	Increased amortization of embodied carbon
Examples	Remanufacturing of turbine blades, propellers, molds

Digital warehousing to produce parts on-demand

Flexible manufacturing is a strength of additive manufacturing. By removing the need for manufacturing tooling such as molds or fixtures additive enables cost effective production of parts at low and medium volumes. Furthermore, if the production demand is variable or unpredictable, it can be easy for additive to quickly adjust production volumes to scale up or scale down similar to how servers can be added or turned on in a data center to accommodate more web traffic.

This can reduce the need for business planners to accurately forecast production volumes, reduce underproduction which can result in lost sales, and reduce over-production with results in product waste.

Figure 20

AM Superpower	Flexible on demand production
Business Benefit	Eliminate product waste and lost sales
Environmental Benefit	Produce only what we need
Examples	On demand digital warehouse

Shifting production to bio-based & recyclable materials

The pace of new material development for additive manufacturing is rapid and increasingly material manufacturers are providing bio-based and recyclable materials. Examples include Rilsan Invent Natural PA 11 which is 100% castor bean oil based, Orgasol polyamide 12 which provides a high degree of powder recyclability, Recycled sawdust and bio-epoxy resin composites from Forust, or EPU 44 from Carbon which is a material that is 40% plant based.

Making the switch to a different material and process can be a challenge but with design exploration tools such as generative design, it is possible to easily redesign a part to meet it's functional requirements while considering the material properties of more sustainable materials.

Figure 21 - Image courtesy of Kartell and Phillipe Starck

AM Superpower	Rapid new material development
Business Benefit	Increase demand in an environmentally focused economy
Environmental Benefit	Extend material life cycle
Examples	Rilsan Invent Natural PA 11

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Sustainable DfAM workflows

Workflow #1: Generative design to shift to bio-based & recyclable materials

The design for sustainability challenge has in foundation in exploring different materials and optimising the amount of material used. To accomplish this, we are going to use Autodesk Generative Design in Fusion 360.

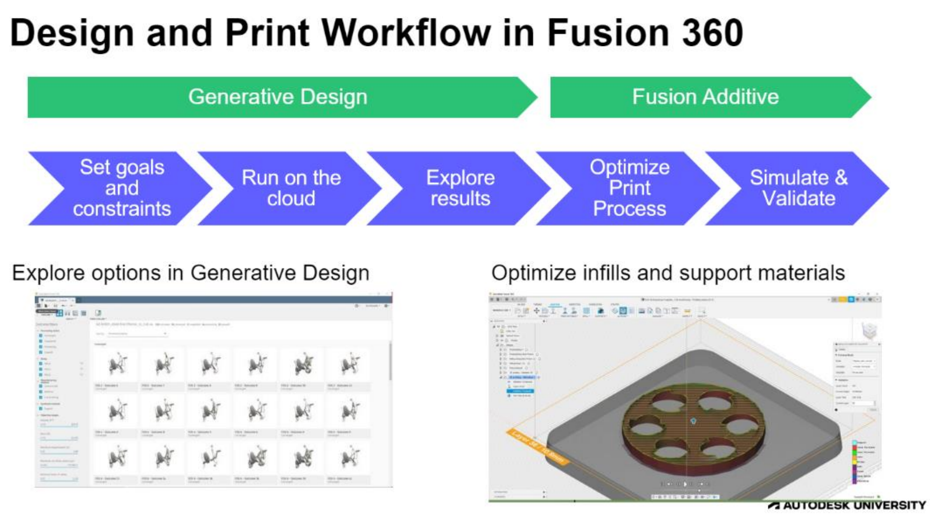


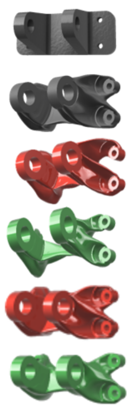
Figure 22 – Design to Print Workflow in Fusion 360

Material Properties

	Nylon - PA11	Orgasol – PA12	Rilsan – PA11	
Density kg/mm3	1.17E-6	9.6E-7	1.02E-6	**Lighter**
Young's GPa	2.6	1.68	1.5	**Elastic**
Ultimate MPa	46	48	54	**Stronger**

Figure 23 –Material Properties Change Recommended Shape Using Generative Design

Informed Design Decisions Performance vs Cost



Design	Material	FOS	Volume cm3	Material Saved	Δ1 (mm)	Δ2 (mm)	Mass (g)
Original	Nylon PA11	2	108	-	0.7	1.8	127
D1	Nylon PA11	2	93.3	14%	0.3	0.7	107
D2	Orgasol PA 12	2	50.2	54%	0.9	2.2	56
D3	Rilsan PA 11	2	54.8	49%	1.1	2.4	56
D4	Orgasol PA12	3.3	87.5	19%	0.6	1.8	84
D5	Rilsan PA 11	2.6	77.5	28%	0.8	1.8	79

Displacement Limited to Match Original Performance (D4, D5)

Figure 24 – Upfront Design Data from Generative Design

Workflow #2: Latticing to improve performance of clean technologies

In this workflow, we will be looking to apply design for additive manufacturing (DfAM) techniques to improve the product performance of electric vehicle battery cells.

Electric vehicle batteries have a relatively narrow band of temperatures at which they perform optimally and data has shown that exposure to heat and the use of fast charging promote battery degradation more than actual use. In many cases 35C is the maximum temperature a battery can withstand before it starts to degrade.

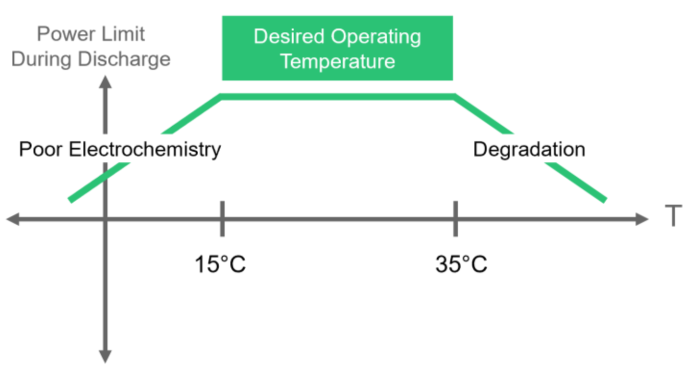


Figure 25 - Temperature vs Power Limit During Discharge for Electric Batteries

The objective of this workflow will be to see how we can redesign a heat sink that improves cooling performance and limits the maximum batter temperature below 35C by leveraging the design complexity that can be achieved via additive.

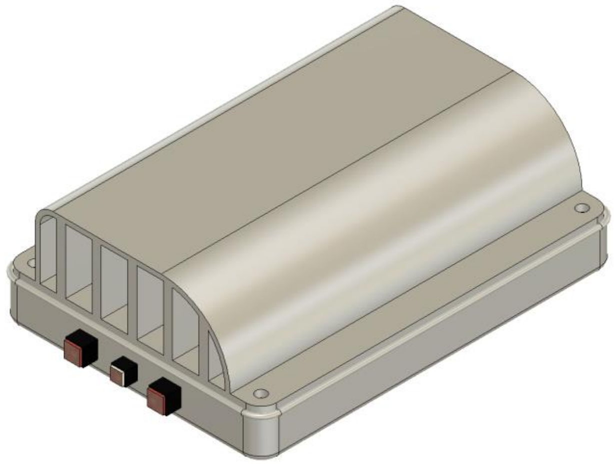


Figure 27 - Battery Module & Baseline Heatsink

1. Create a sketch offset from the outer profile of the heatsink and use it to create an extruded cut that removes the fins of the original heat sink.

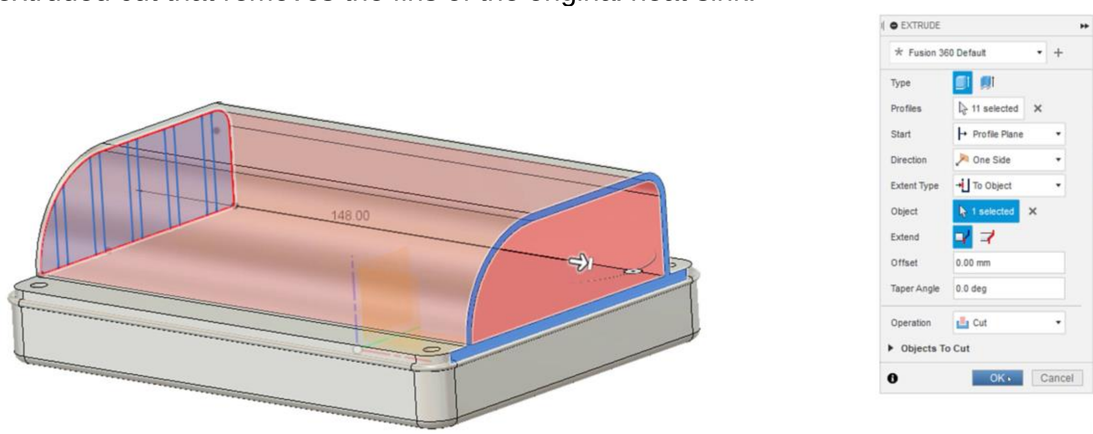


Figure 28 - Removing the fins via extrude cut

2. That same sketch is then used to extrude a second separate body. Make sure to select "New Body" as the operation type so that it does not merge to the existing geometry. This is body that will be used to generate the a lattice structure and eventually merged back to the original outer shell of the heat sink. Note that in this case, the body was only extruded to the midplane to take advantage of symmetry in the design.

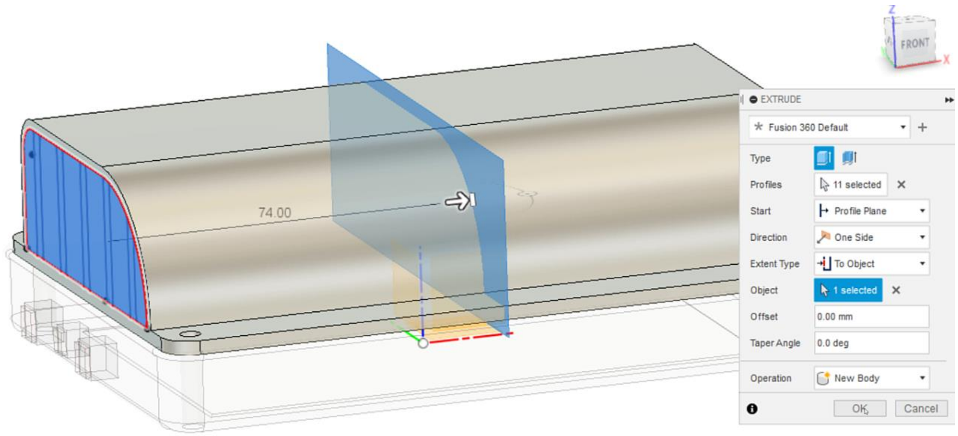


Figure 29 - Extruding a separate body to the midplane

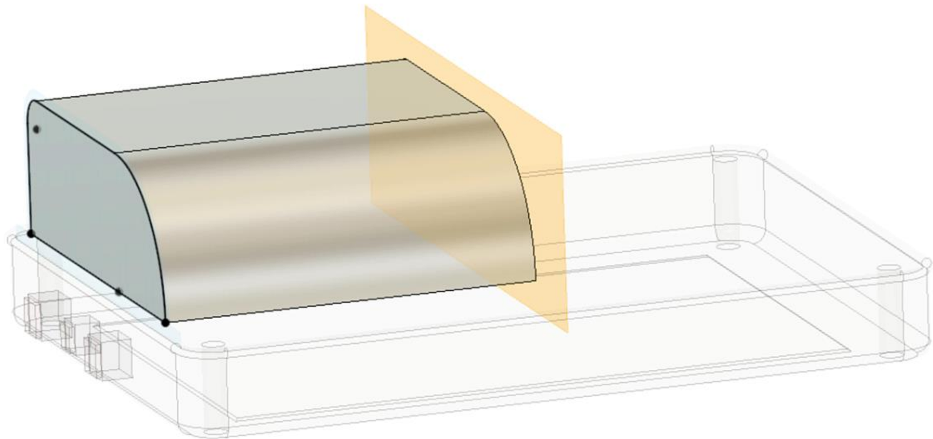


Figure 30 - Body to be latticed

3. Under the modify menu select the volumetric lattice feature. Note that this feature is a part of the product design extension and at the time of writing is a tech preview feature. More information on how to access and enable this feature can be found in the additional resources section.

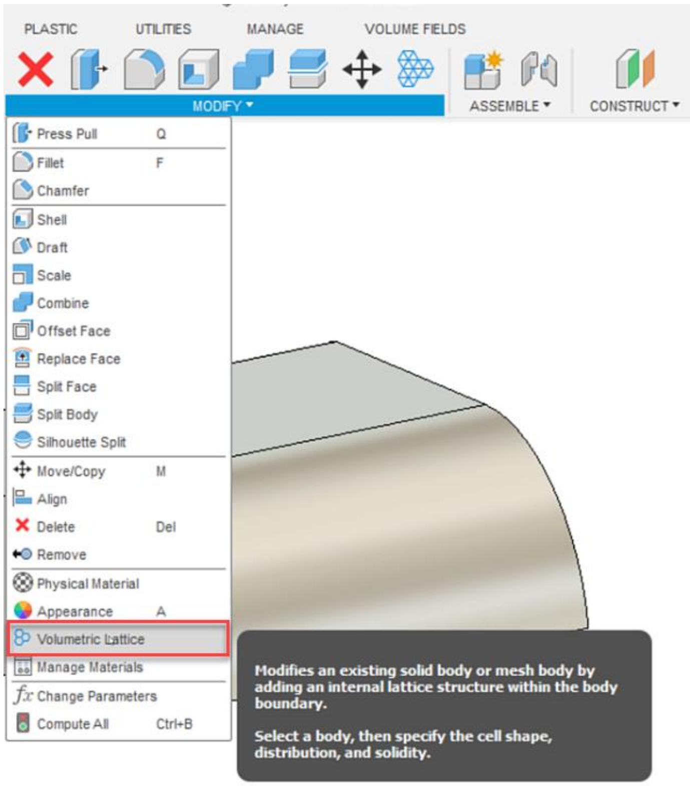


Figure 31 - Selecting the volumetric lattice feature

4. Select the body and assign gyroid structure with non uniform proportions (x=8mm, y=11mm, z=11mm). The lattice structure should also be set to a solidity of 0.25 or 25% volume fraction.

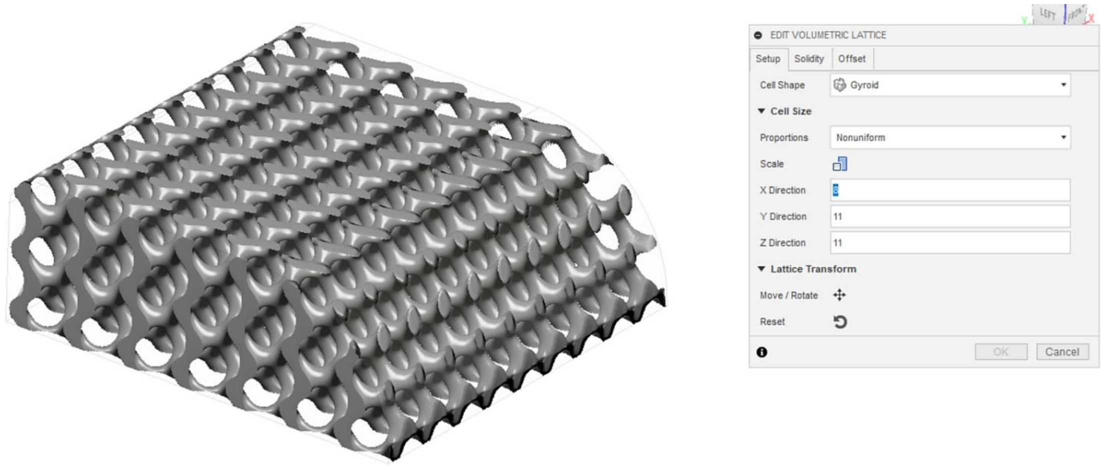


Figure 32 - Generating a volumetric gyroid lattice structure

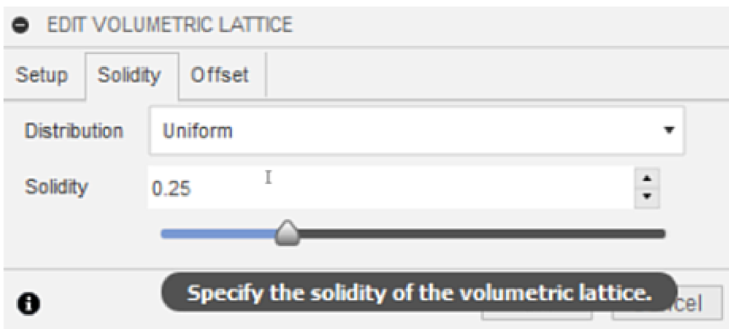


Figure 33 - Setting lattice solidity

5. In order to run a simulation and manufacture the part it will need to be converted to a mesh. To do this, right click on the body with the blue icon shown in the figure below, select “Volumetric Lattice Actions” and “Create Mesh”.

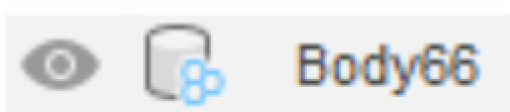


Figure 34 - Volumetric lattice body icon

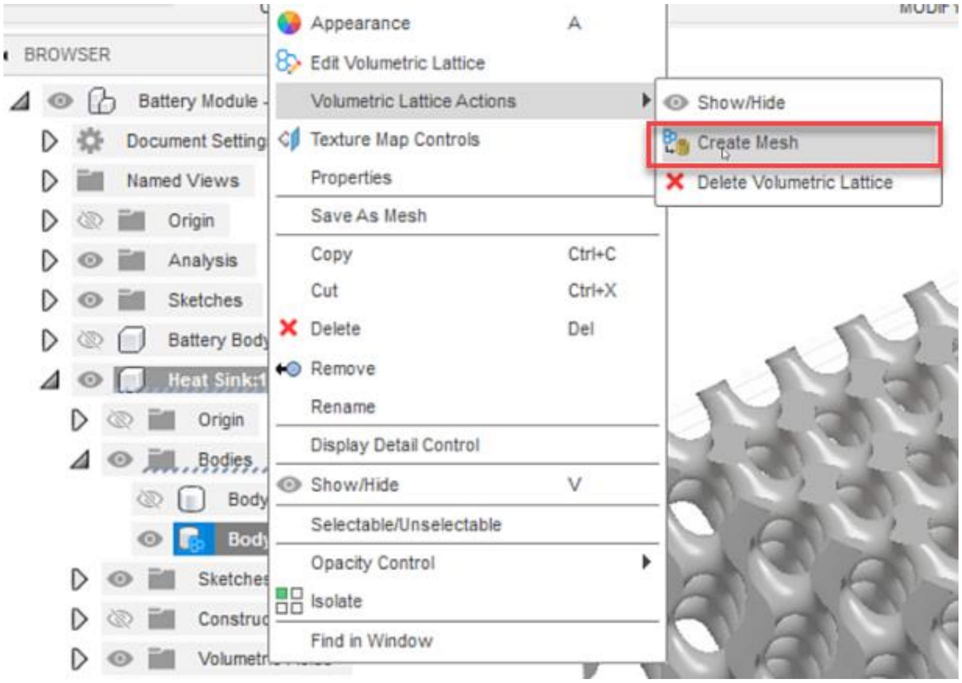


Figure 35 - converting the lattice to a mesh

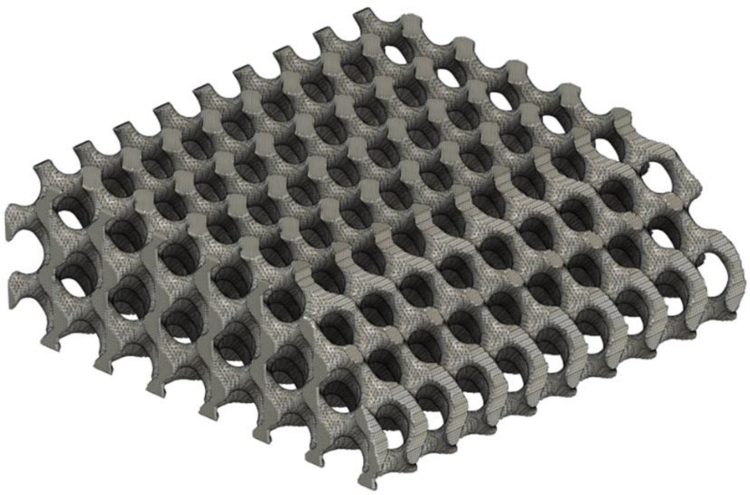


Figure 36 - The lattice converted to a mesh

6. In order to convert the mesh to a solid body, it will help accelerate the process if the number of mesh faces is reduced. This can be done using the reduce command in the mesh workspace. In this particular example, the face count was reduced uniformly to 80,000 faces.

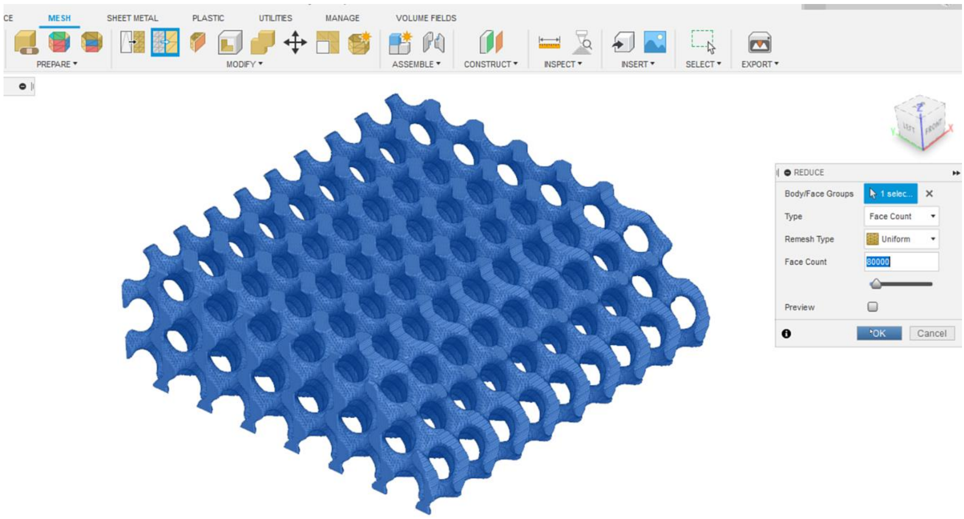


Figure 37 - Reducing the mesh

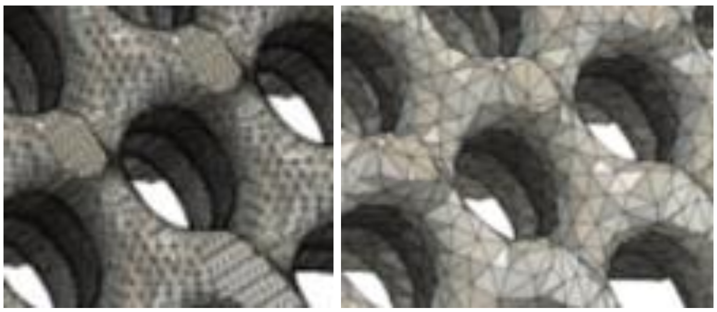


Figure 38 - High resolution mesh (left), reduced mesh (right)

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7. To convert the mesh to a solid body, select the “Convert Mesh” feature under the modify section of the mesh workspace.

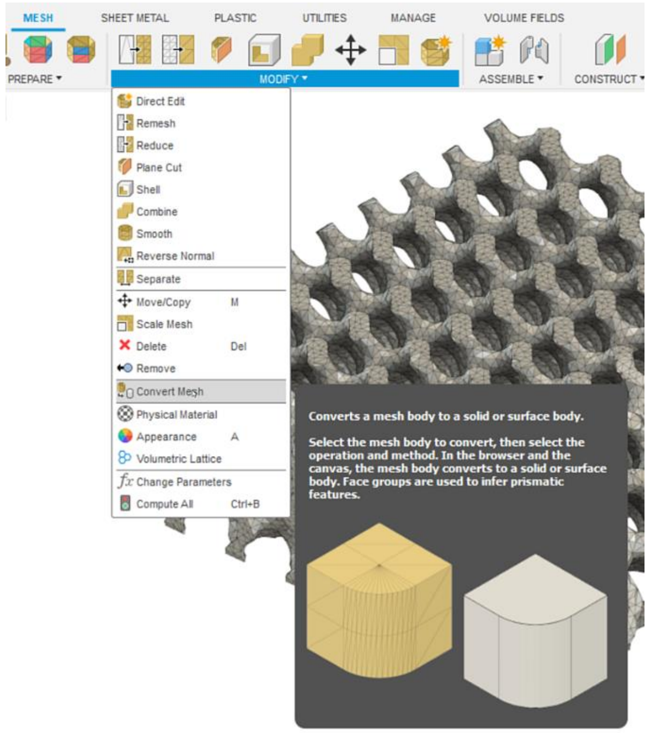

Figure 39 - Convert Mesh feature

8. In the case, the organic mesh conversion tool will be used as it is well suited to more complex organic structures like a lattice. Note: When using this feature on a mesh with more than 10,000 triangles you will receive a warning that the conversion calculation can take a considerable amount of time.

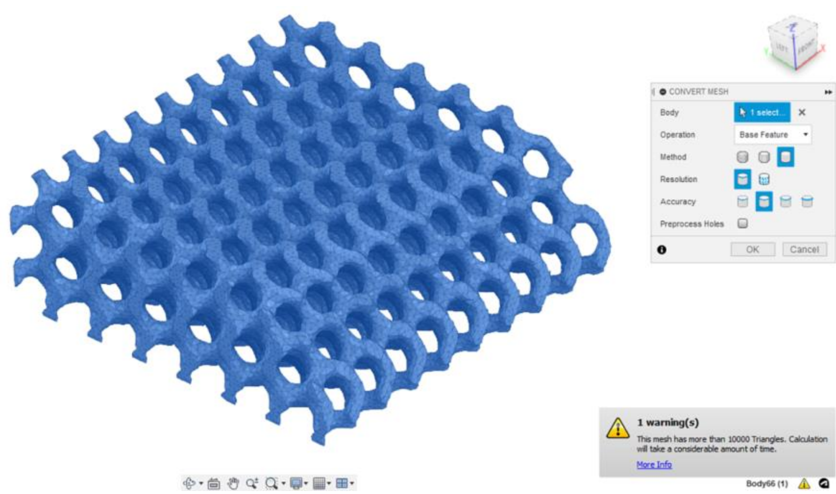

Figure 40 - Converting the mesh with the organic mesh conversion feature

9. The resulting part will be a solid body with faces much like would be seen output from T-Spline technology.

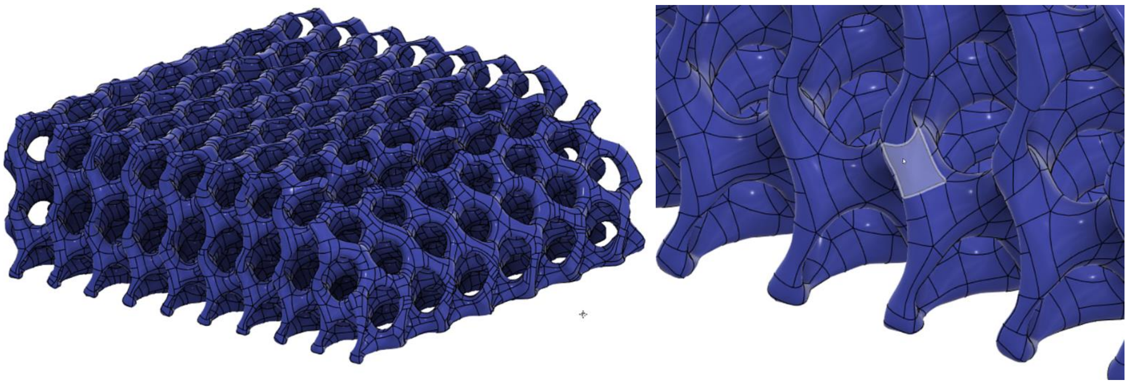

Figure 41 - A lattice as a solid body

10. The final step is to mirror the lattice solid body that has been created and use a combine operation to merge it back to the rest of the heat sink.

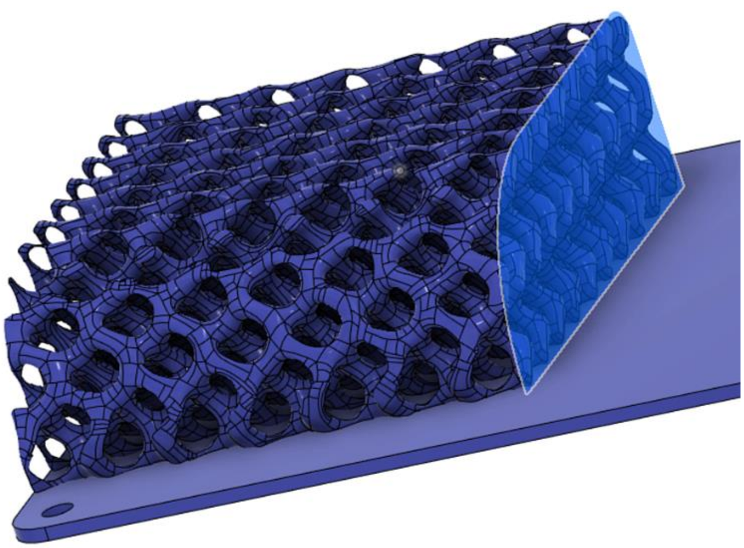

Figure 42 - Mirroring the lattice body

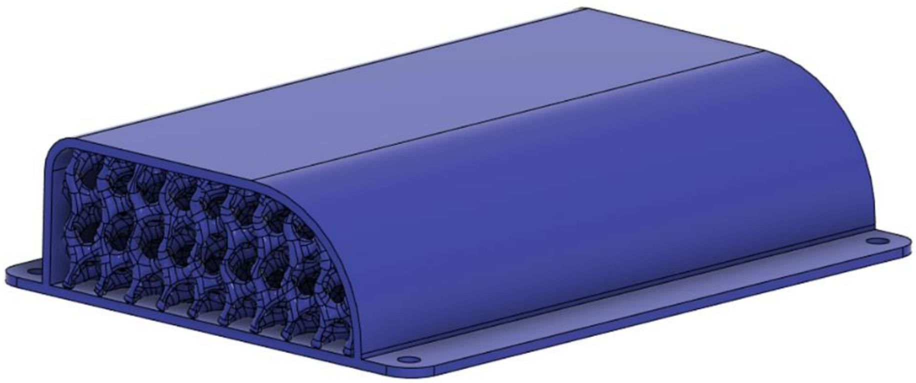

Figure 43 - The combined latticed heat sink design

Not only was the resulting part 8.3% lighter than the original design, but by running electronics cooling simulation in Fusion it was possible to verify that the gyroid structure also offered improved cooling performance and prevent the battery temperature from exceeding the critical limit or 35C.

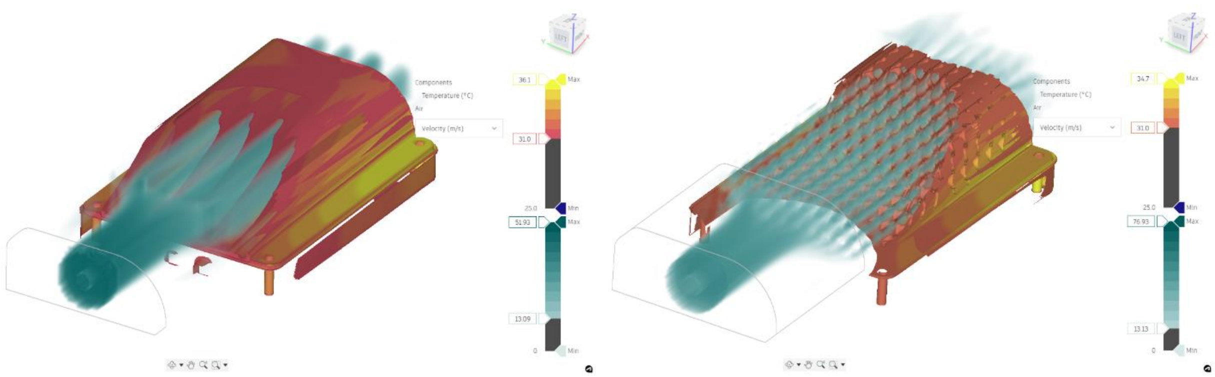

Figure 44 - Electronics cooling simulation for baseline design (left), latticed design (right)

	Fin Heat Sink	Gyroid Heat Sink	% Difference
Max Temp (C)	**35.9**	**34.6**	**-3.6%**
Surface Area (mm2)	**1.02E+05**	**1.43E+05**	**+40.2%**
Mass (g)	**420**	**385**	**-8.3%**

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Workflow #3: Simulating to reduce build failures

In the third workflow, we will be looking at how additive process simulation can be used to prevent build failures and reduce material waste. Here, Netfabb and Netfabb Local Simulation will be applied to simulate a laser powder bed fusion build, predict a failure before it happens and take action to redesign the support structures to prevent it.

1. To start, we will first import our model and run an orientation study by clicking on “Orient” to identify and evaluate trade-offs with different part orientations with regards to build height and support volume. Both factors can contribute to the energy and material usage of a print and an orientation study is an easy way to evaluate their impact.

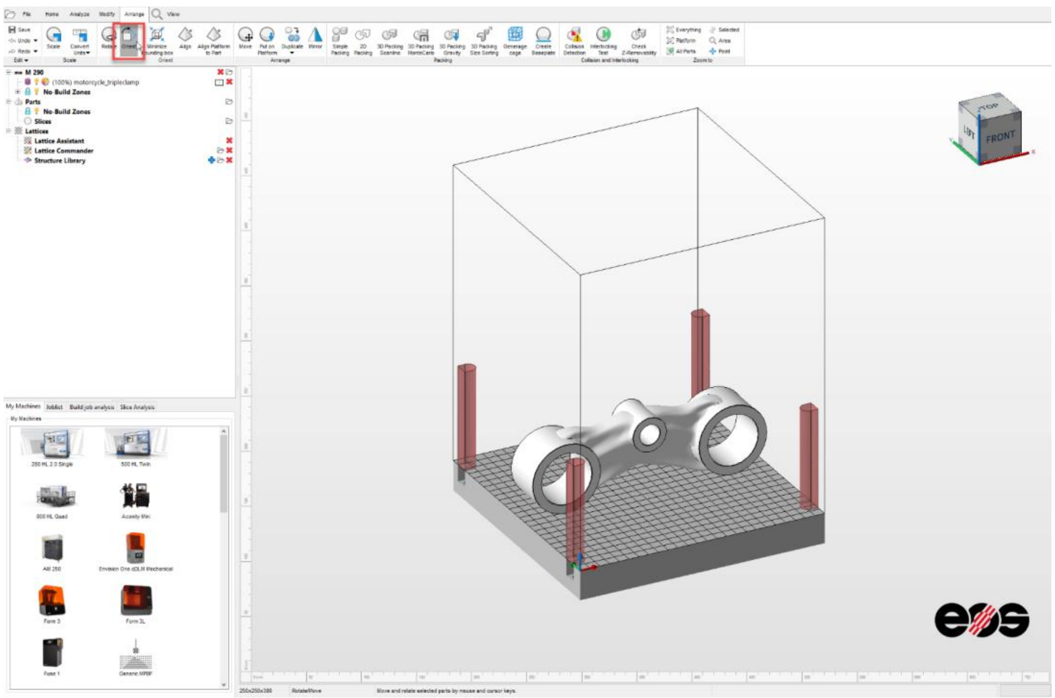

Figure 45 - Starting an orientation study in Netfabb

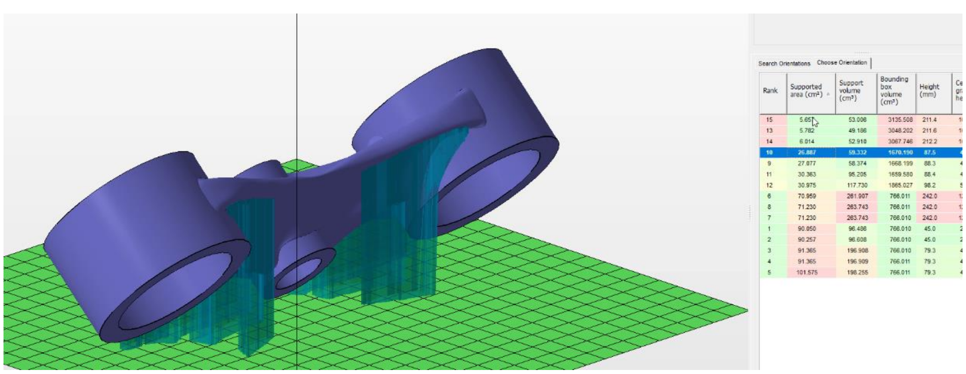

Figure 46 - Comparing orientations in Netfabb

2. Supports can then be generated using no-code support scripts which use customized parameters and rules to automate the tedious task of applying support structures. These save time and are repeatable which prevents operator errors such as leaving areas un-supported.

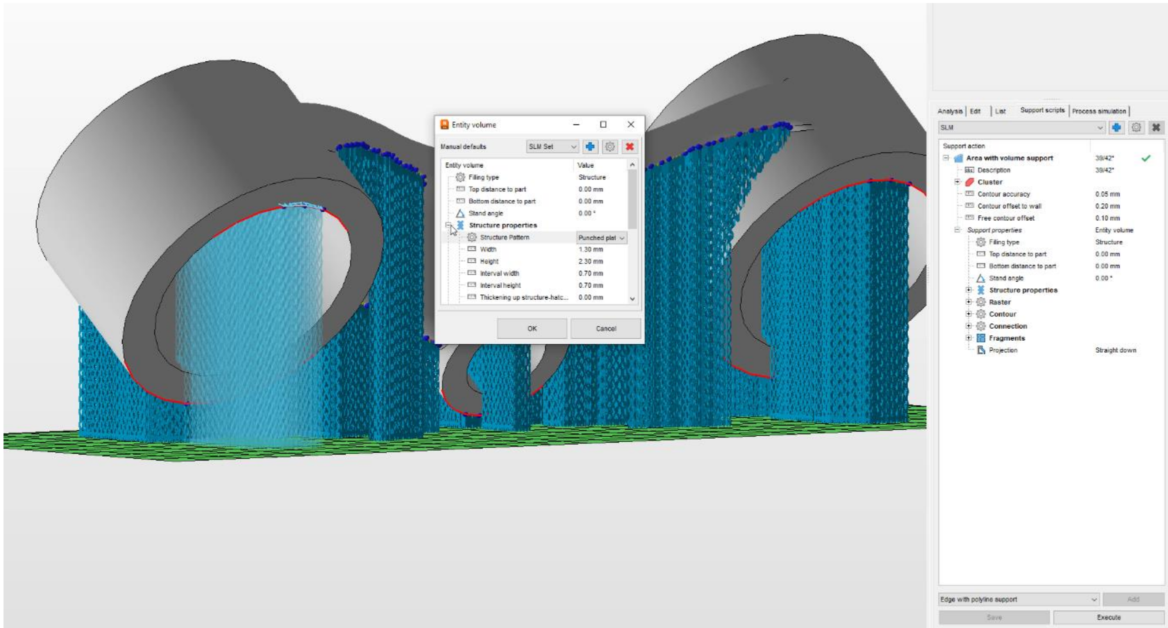

Figure 47 - Applying supports via a support script

3. With the supports applied and the part oriented in the machine workspace, the select “Start build simulation” from the current build dialog box and save the file.

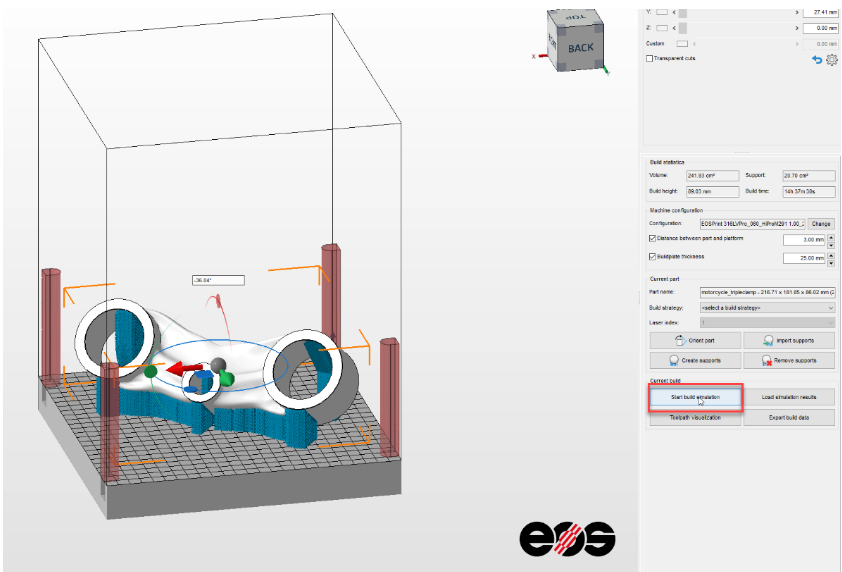

Figure 48 - Starting a build simulation

4. This will open Netfabb Local Simulation and allow you to set options such as the machine model, and processing parameters. In this case, we will be using AlSi10Mg on an EOS M290.

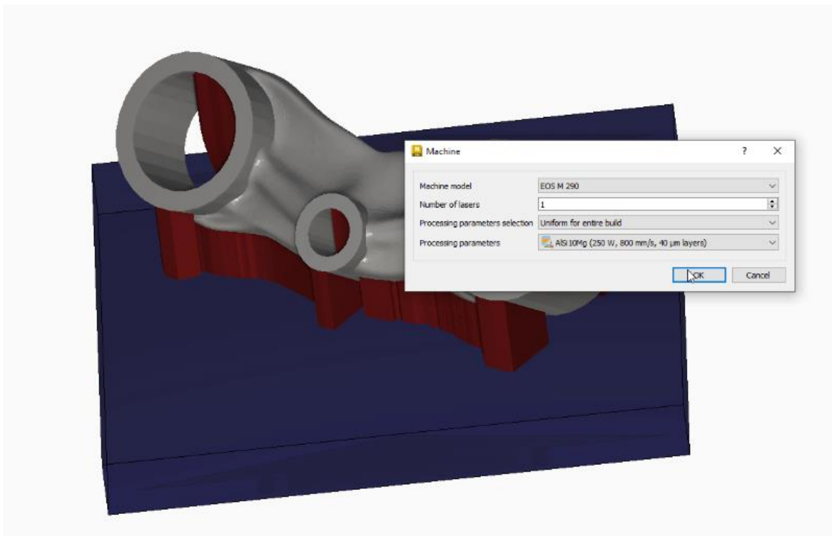

Figure 49 - Setting machine parameters in Netfabb Local Simulation

5. Moving along the top ribbon from left to right in Netfabb Local Simulation, the build plate settings should be assigned. In this case the build plate will also be in Aluminum, heated to 80C, and bolt release will be simulated.

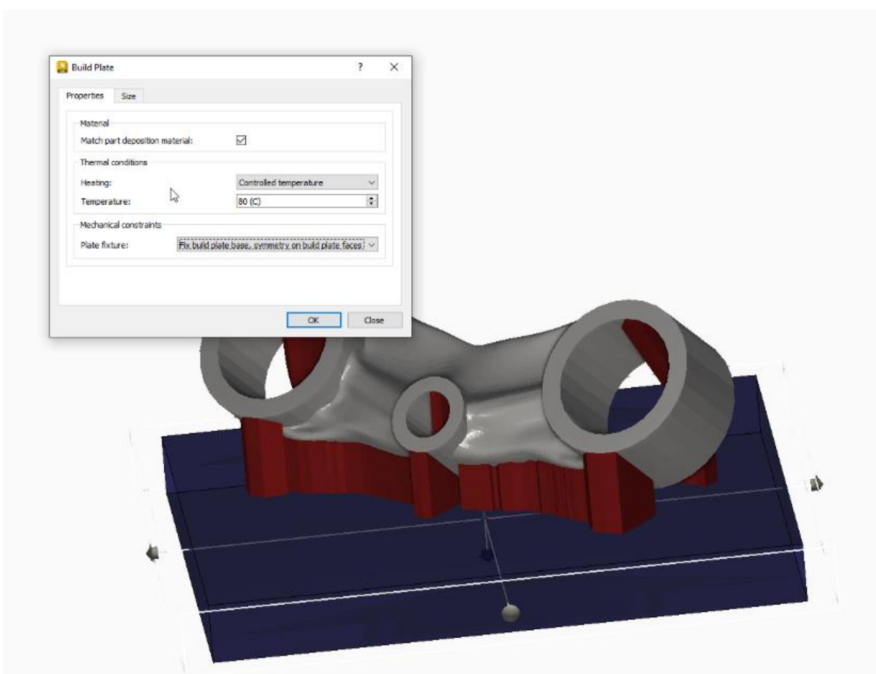

Figure 50 - Setting platform parameters

6. In order to run the simulation, a mesh must be generated. In this case the mesh will be set using the “Wall Thickness” based approach, with a minimum wall thickness of 1.6mm.

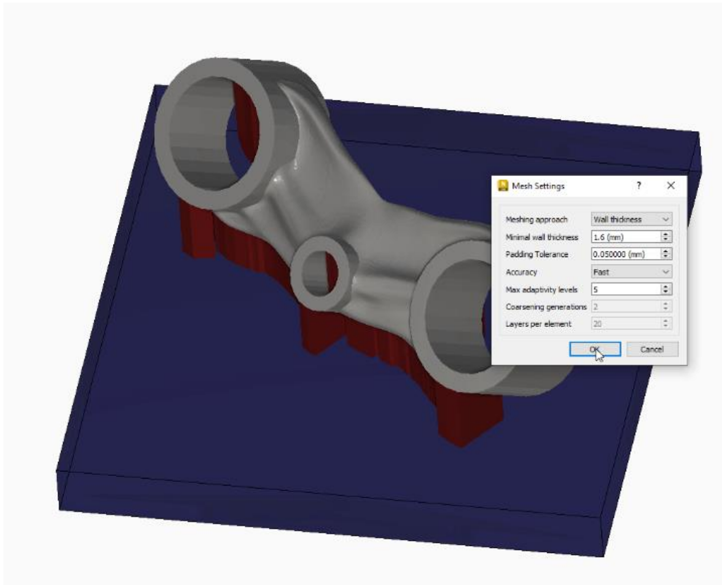

Figure 51 - Setting mesh parameters

7. Once the mesh has been generated, click “Solve” under the analysis pane to run the simulation.
8. By selecting the play button under the results tab, the various layer groups of the build can be visualized and analyzed for displacement, recoater clearance, stress, temperature, and more.

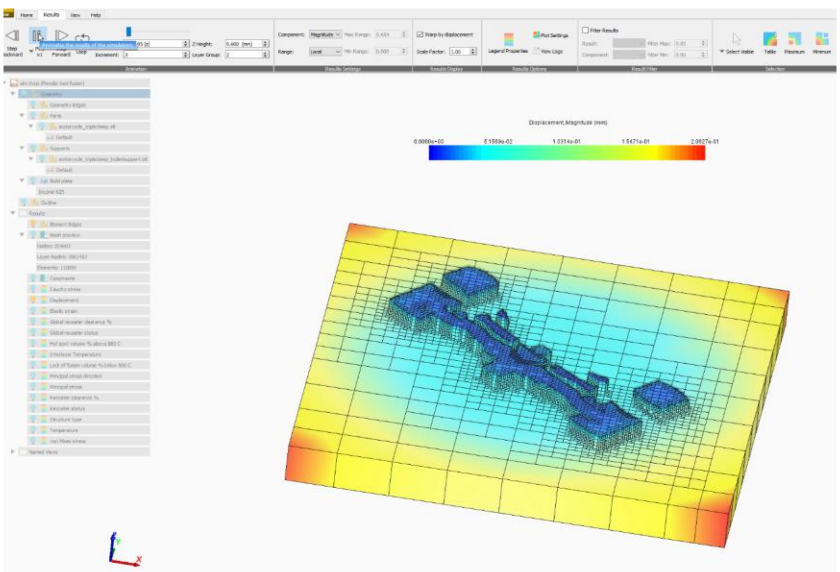

Figure 52 - Visualizing the simulation results

9. By selecting "Global Recoater Status" in the results, there are a few small areas highlighted in red where it is predicted that the recoater will interfere with the part and cause a build failure.

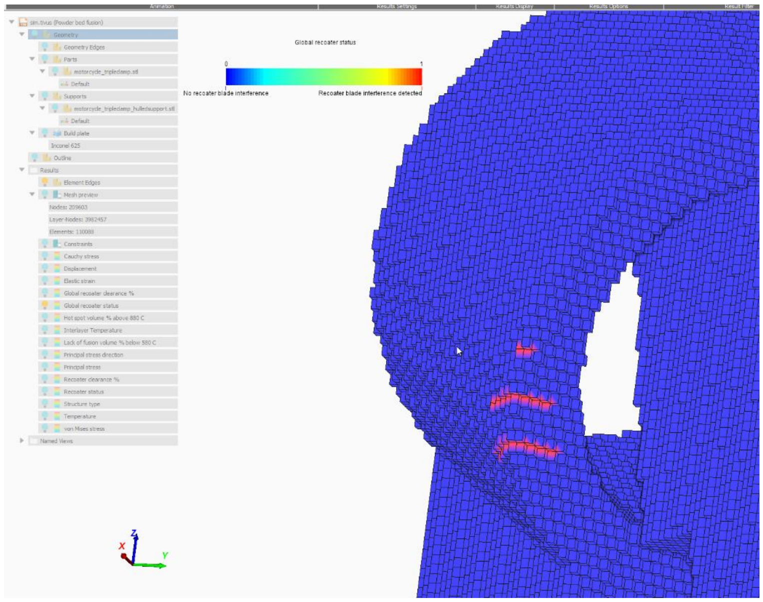

Figure 53 - Identifying areas of recoater interference

10. In Netfabb, select "Load simulation results" and load the mechanical results from the saved location and select "Display for support editing"

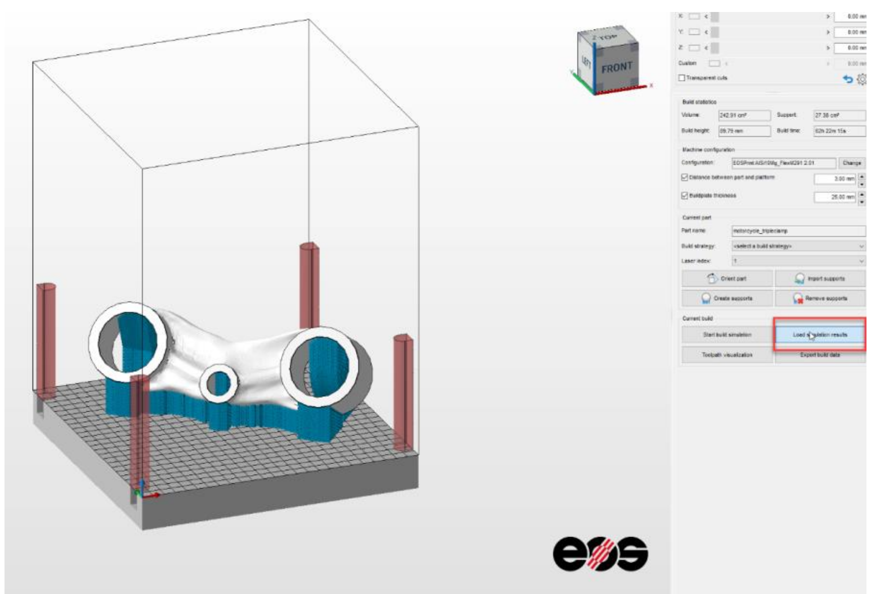

Figure 54 - Loading the simulation results into Netfabb

11. Now, back in the support editor, the simulation results can be displayed on top of the part and supports so that the problematic areas can be identified. By using the "Mark

clusters manually tool, the areas where additional support is required can be painted onto the model.

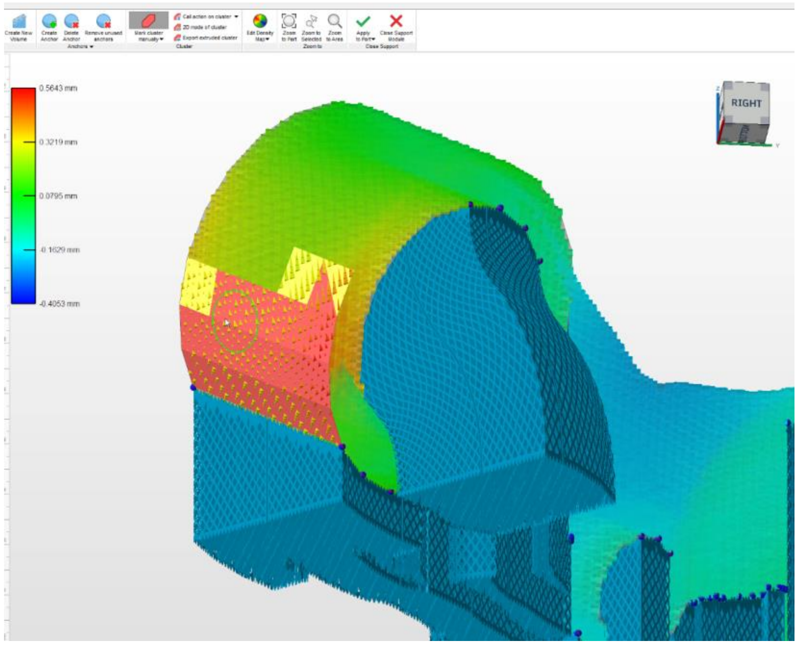

Figure 55 - Highlighting areas to add additional support

12. By right clicking on this new cluster, and selecting “Create volume support on cluster” the same script that was used to generate the original supports can be applied to the problematic area.

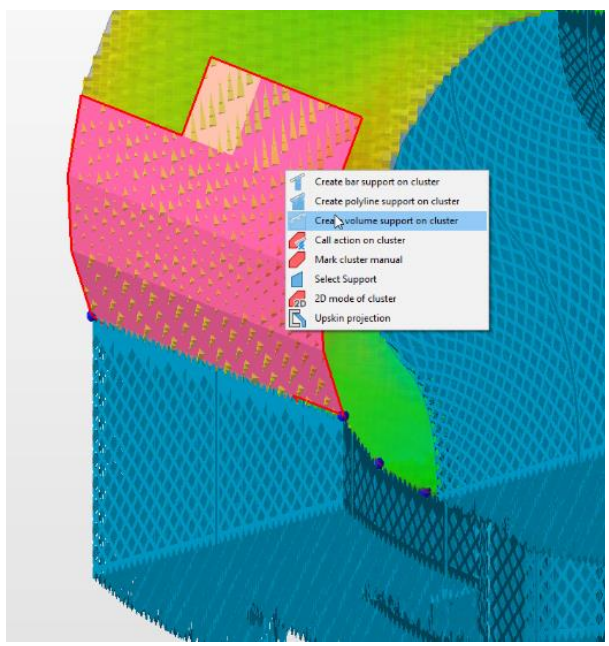

Figure 56 - Generating additional supports on cluster

13. The simulation can then be re-run and analyzed following steps 3-9 to confirm that this has resolved the areas of recoater interference.

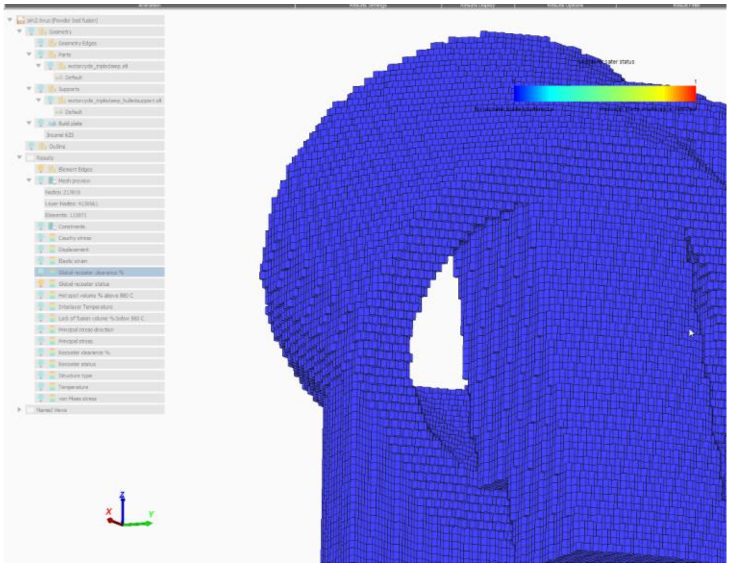

Figure 57 - Resolved recoater interference

14. The build can now be sent to the machine and printed successfully.

Conclusion

To recap, our key takeaways are:

1. Do not assume that AM by default = sustainable
2. Advocate for better LCA data for AM processes
3. Build a business case that aligns economic and environmental benefits to the unique strengths of AM

While there are still many challenges to address around sustainability and additive manufacturing, we hope that after this class, you feel more equipped with the tools and know-how for designing sustainability into additive manufacturing.

Additional Resources

Manufacturing & Sustainability

- United Nations Sustainable Development Goals
- Comparing Environmental impacts of metal additive manufacturing to conventional manufacturing – Corie Van Sice and Jeremy Faludi

Design for Additive

- How this light-weight airplane seat can save airlines $200,000,000 (and dramatically reduce carbon emissions)Generative Design
- Generative Design for Manufacturing With Fusion 360 | Autodesk
- Fusion 360 Product Design Extension | Autodesk
- Autodesk Fusion 360 | Creating Volumetric Lattice Structures in Fusion 360 - YouTube
- Autodesk Fusion 360 | Improve your mesh results with organic mesh conversion - YouTube
- 360 LIVE: Electronics e-cooling simulation - YouTube
- Netfabb: Software for additive manufacturing, design, and simulation

Partnerships & Additional Learning

- AM Forward
- The REMADE Institute
- 2022 Conference - World Remanufacturing Conference (worldremanconference.com)
- Additive Manufacturing for Innovative Design and Production | MIT xPRO