WHITE PAPER

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Leveraging DfAM for Enhanced FDM Post-Printing Efficiencies

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goengineer
www.goengineer.com

POST PROCESS SALES
marketing@goengineer.com
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supplies@goengineer.com
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I. INTRODUCTION TO DESIGN FOR ADDITIVE MANUFACTURING

Additive manufacturing (AM) is a powerful technology that lends itself to producing organic geometries, and building parts in short timeframes. Additive technologies are capable of printing shapes that cannot be created by any other means. One of the most salient factors in successfully building these unique designs is the utilization of soluble support material.

As is well-known by anyone who has worked with additive technology, 3D-printed end use parts and prototypes do not come off of the printer "customer-ready." Virtually every printed part, regardless of print technology, requires some sort of post-printing, whether that be support removal, resin removal, surface finish, or all the above.

As the additive production process has been classically categorized into three separate silos; design, build/print, and post-print, the final step is all too often an afterthought. Rather than considering the additive process a linear, sequential one, PostProcess Technologies embraces the ideology that efficiencies and end part results can be dramatically improved when all of the steps are conceptualized as interdependent.This integrated approach is an advanced ideology that will be necessary to scale additive's impact, and eventually usher in Industry 4.0.

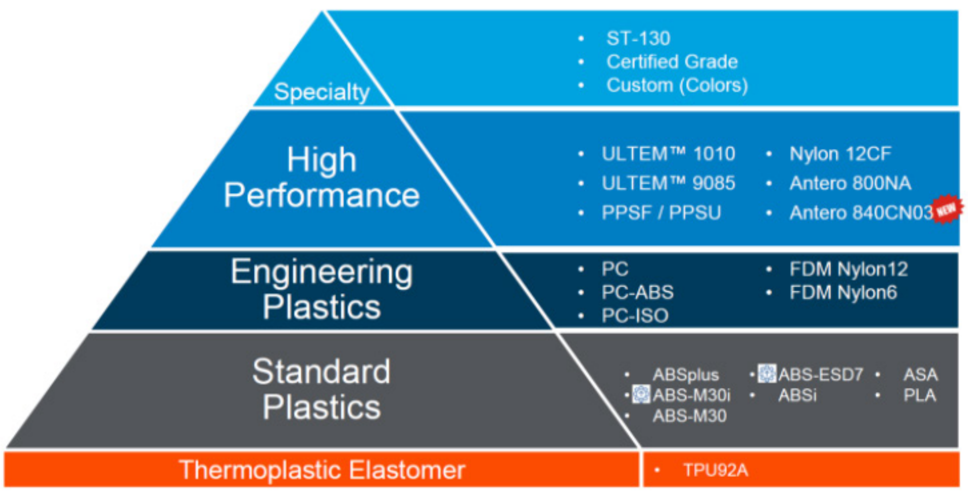
This paper will identify the ways in which designing for additive manufacturing (DfAM) can affect efficiencies, cost, and support material usage in Fused Deposition Modeling (FDM) printing. Print orientation, support settings within the slicing software, and part design are all aspects which can be leveraged to streamline additive workflows, and facilitate faster, more cost-effective post-printing. It should be noted that while some of these DfAM for FDM techniques can be applied to other print technologies, this is not the case universally (e.g. self-supporting angles are also useful in DfAM for stereolithography (SLA), but not selective laser sintering (SLS) or PolyJet).

DfAM: Design for Additive Manufacturing

As a rule of thumb, DfAM will have a greater effect in circumstances where there is a higher level of design freedom. While DfAM will have a minimal impact on rapid prototyping or tooling applications (situations with the lowest allowance for design freedom) manufacturing aides and end-use production parts allow for more unique designs, thus making DfAM more significant. The more design principles that are considered upfront, the less time must be later allotted to redesign, or the removal of unnecessary support structures later in the process.

II. FDM BACKGROUND

To comprehend the DfAM techniques that will streamline an FDM workflow, it is vital to comprehend the advantages and limitations of the print technology, and why it is one of the most popular 3D printing technologies available today. The process starts with a thermoplastic filament wound in spools. This filament could be ABS, Polycarbonate, or Ultem™*, for example (see the image below for a complete list of Stratasys thermoplastic materials available for use with the brand's FDM printers). Strength requirements, the temperature that the part will be exposed to, its performance expectations, and the sort of chemical resistance that it requires are all factors that may impact material selection.



Source: Stratasys

The filament is extruded through a heater block, then a nozzle, and computer-controlled motion is used to deposit the melted thermoplastic. As the deposited plastic cools, the z-stage build platform is lowered to create the 3D part. While this layer-by-layer deposition process is ideal for parts with low heights, FDM printers can face challenges printing complex geometries with tall and thin walls. Virtually anywhere there is an overhang on an FDM part, support material will likely be required to prevent build failure, leading to high support material usage. Consequently, FDM processes involve tedious support removal steps, which traditionally involve dissolving support material by using detergents or breaking the supports away manually, depending on the support material used.

*Trademark owned by SABIC

As reported by the PostProcess Technologies' 2020 Annual Additive Post-Printing Trends Report, material extrusion printing methods (e.g. FFF, FDM, MEM) are utilized by 71% of additive manufacturing users, making them the most popular print technology. The top challenge of material extrusion technology was found to be the length of time to finish parts, while the runner-up answer was damaged parts, both issues that DfAM can help mitigate. That being said, additional research has found that 23% of the average part cost for polymer 3D printing is attributed to the post-printing step alone (Source: 2019 Wohler's Report). Finally, keeping support material to a minimum is ideal in lowering the build time required for a part, the material cost of a part, as well as the time and resources which must be allocated to the post-printing step.

III. DFAM STRATEGIES

Orientation

Depending on the geometry of your part, orientation may play a paramount role in DfAM. Usually a sole aspect like part strength, support structures, print speed, or surface quality must be prioritized to determine the best orientation of the part. Strength is most often the driving factor for orientations, though priorities may change depending on print materials used, or time restraints. Considerations regarding part orientation should be explored during the design phase to proactively ensure minimal support material requirements, as well as printing and post-printing speeds.

Figure 1 shows a L-bracket printed on its end and Figure 2 shows the same L-bracket printed flat on its side. Utilizing GrabCAD Print software, the green represents the model material of the part and the orange represents the support material required to print the part in that orientation. This change in build orientation accounted for a 58% reduction in build time, and a 91% reduction in support material usage, equating to cost, material, and time savings.

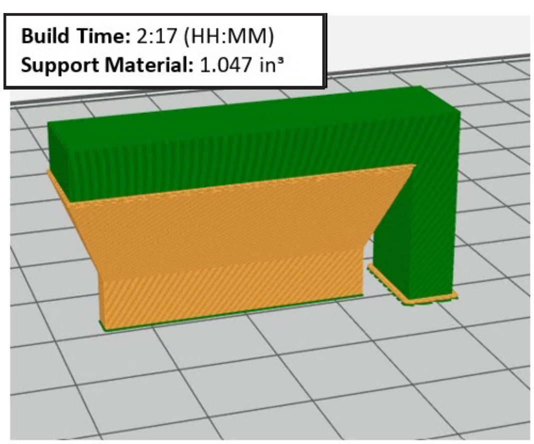


FIGURE 1: End Orientation

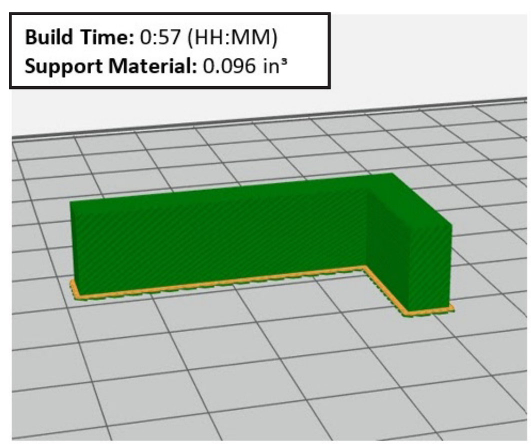


FIGURE 2: Side Orientation

Part Design

Knowing the advantages (and limitations) of a print technology is vital in designing the most efficient, structurally-sound part possible.

Self-Supporting Angles

FDM is one of the only technologies that leverages self-supporting angles. Typically, as long as there is at least a 45° overhang to the build platform, support materials will not be needed. This strategy can also come into play by implementing chamfers and/or fillets, for example see Figures 3 and 4. Also by using the SMART support settings within GrabCAD Print or Insight on Stratasys printers, the software will automatically utilize self-supporting angles when developing support structures, which will help to reduce the amount of support material needed in comparison to other support styles.The actual self supporting angle value will vary based on the printed model material and the slice height that the printer is set at. For example, on a Stratasys Fortus 450mc, loaded with ASA material and printing at a slice height of 0.010" will have a self-supporting angle of 43°, whereas Nylon 12CF is 50°.

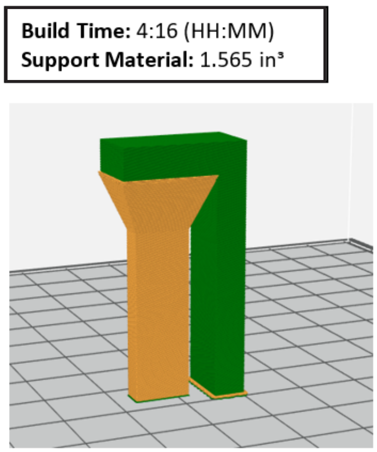


FIGURE 3: Overhanging Geometry Example

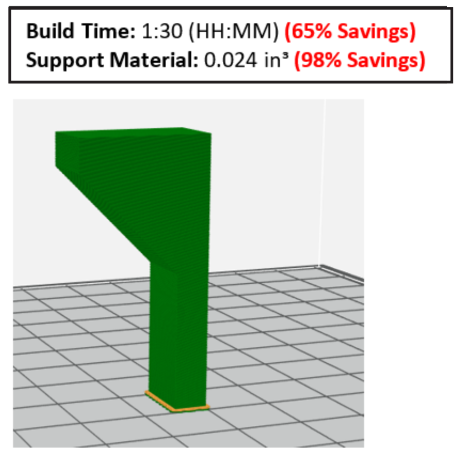
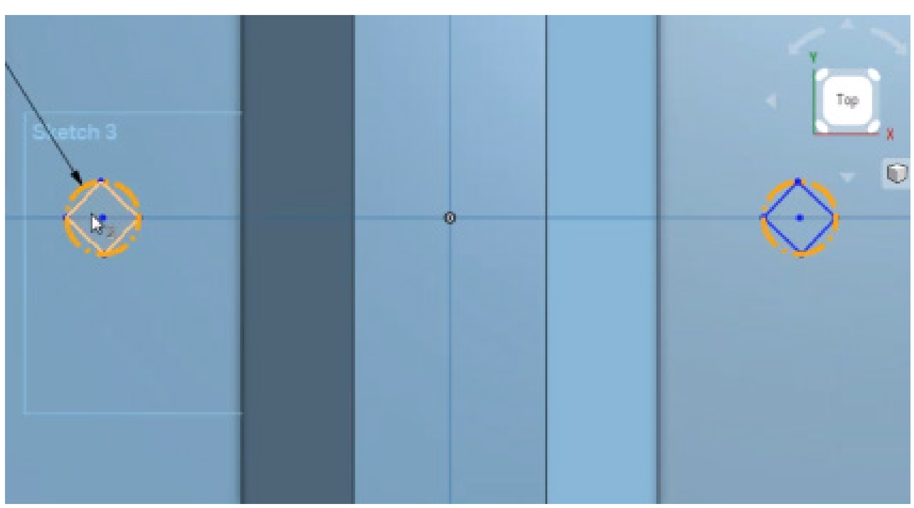


FIGURE 4: Self Supporting Geometry Example

Implementing Strategic Holes

Designing vertical, non-critical holes as diamond or teardrop-shaped instead of round will reduce the amount of support material required (see bearing block image below). Critical diameter holes should be printed in the XY plane if possible. If the vertical holes require tighter accuracy, they may be drilled out in a post-printing step. When using an automated support removal system it is best practice to reduce the amount of blind holes and cavities. Rather, when possible implement through holes and open cavities, allowing the support removal detergent to flow through those areas more freely, and remove support material faster.



Material Usage

In certain circumstances, utilizing model material as support material can decrease build time, specifically by reducing wait time caused by the printer switching between model and support material. However, this time reduction is only realized if the entire layer's support material can be changed to model. Whenever you slice a part in GrabCAD Print or generate support material in Insight, the software automatically generates support material and will interface directly with the model material, giving it a good foundation to build model material on. When changing the support material to model material, you will want to leave the three or four support material interface layers, or the layers below where the model material starts, as support material. Otherwise, the model support may end up fused to the finished part, subsequently causing damage to your overall part.

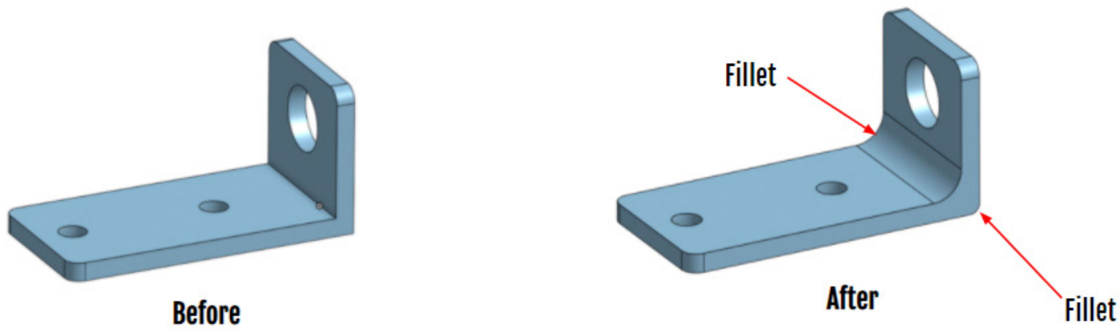
Surface Finishing

Orientation can also impact the surface finish of a part. Exterior contour toolpaths will result in a better surface finish than exposed raster toolpaths, as rasters are more likely to cause air gaps, which can prove difficult to remove. While flat orientations may print faster, particularly with FDM, horizontal orientations with exterior contour paths will take significantly less time to post-print (see example in image below). FDM parts will also always have a "seam", which is the start/stop point of each build layer. Utilizing the slicing software to determine where a seam should be placed can help reduce surface finishing time on specific part areas.

IV. RESULTS

As a result of implementing the various DfAM techniques that this white paper covers, small-scale FDM parts were able to achieve significant build time and material savings, thus streamlining the entire additive process. Below is a step-by-step explanation of what part features were changed in the CAD modeling software, and what settings were changed in GrabCAD Print to achieve the desired results, reducing build time and support material usage.

Sensor Bracket Part



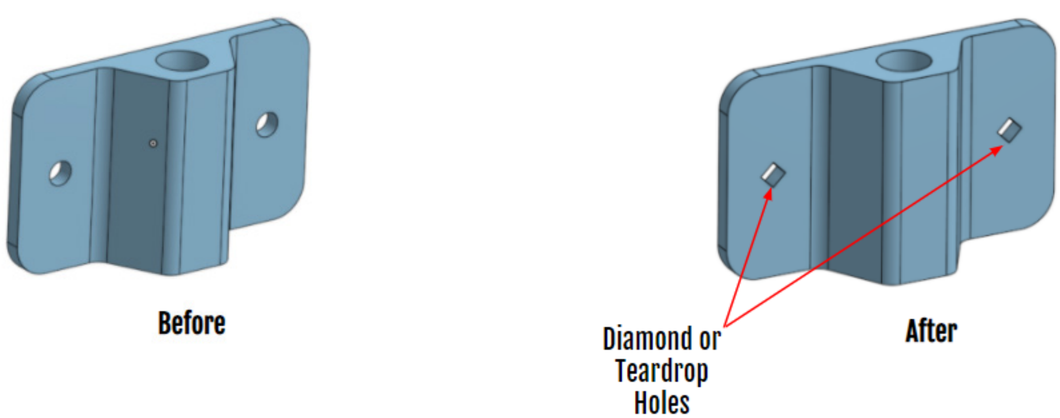
Part features added:

- Interior and exterior fillets added to increase the strength of the bracket.

GrabCAD Print Settings:

- Orientate the part with the "L" profile in the XY plane of the build platform (see picture below).
- Reduce the amount of support material required by selecting "Do not grow supports" in the Support Settings.

Bearing Block Part



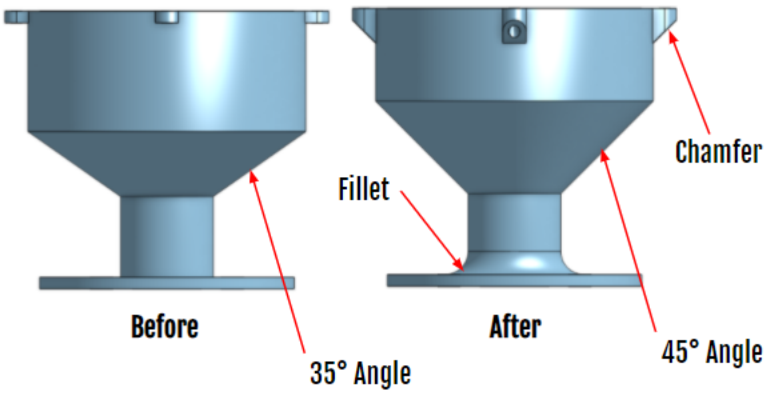
Part features added:

- Modified the mounting holes from round to diamond shaped, making the geometry self-supporting.

GrabCAD Print Settings:

- Orientate the part with the diameter of the large vertical hole in the XY plane of the build platform (see picture below).
- To place the layer seams on the back of the part (a noncritical surface) select the surfaces where you don't want the seam placed (critical surfaces), and select "Avoid Seams" in the Model Setting section. This will help to reduce surface finishing time on critical surfaces. This feature only works for parasolid part files that are imported into GrabCAD Print, and will not work with STL files.

Coupling Part



Part features added:

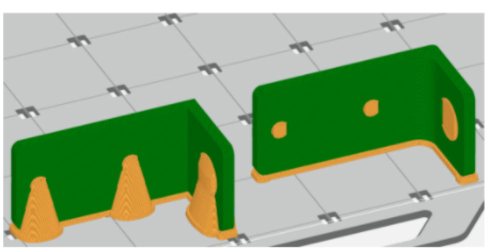
- Changed the angle of the coupling from 35° to 45° to make the geometry self-supporting.
- Added a fillet between the base of the part and the vertical cylinder to help strengthen that area.
- Added a chamber under the top tabs to make the geometry self-supporting.

GrabCAD Print Settings:

- Orientate the part with the round base in the XY plane, as shown below.

Before and After Printing Results

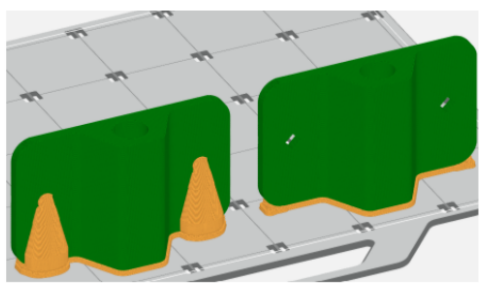
The below picture illustrates the reduction in build time and support material used by making the small design changes and printer setting changes listed above.



Sensor Bracket

Before	**After**
Build Time: 2:51	Build Time: 2:25
Model: 3.008	Model: 3.107
Support: 0.658	Support: 0.321

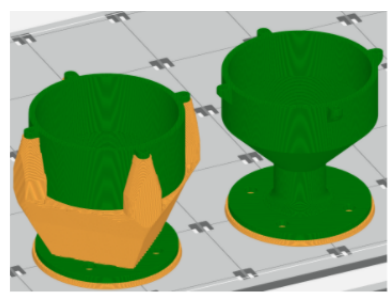
Difference
Build Time: -26 minutes
Model: +0.01 in^3
Support: -0.34 in^3



Bearing Block

Before	**After**
Build Time: 5:05	Build Time: 4:18
Model: 7.544	Model: 7.709
Support: 0.742	Support: 0.219

Difference
Build Time: -47 minutes
Model: +0.17 in^3
Support: -0.52 in^3



Coupling

Before	**After**
Build Time: 4:16	Build Time: 2:47
Model: 3.694	Model: 3.833
Support: 2.092	Support: 0.312

Difference
Build Time: -89 minutes
Model: +0.14 in^3
Support: -1.78 in^3

V. Conclusions

» To utilize additive to the best of its ability, it is essential to recognize that the design, build, and post-print steps are heavily integrated. It is most strategic to consider support removal and surface finishing during the design phase.

» When designing an FDM part for optimized post-printing, factoring in material selection, part orientation, self-supporting angles, contour toolpaths, as well as chamfers and fillets as needed, can contribute to time, cost, and materials savings.

» Automated post-printing solutions from PostProcess Technologies can further enable efficiencies within additive workflows, and cut down on overall time and money spent on the AM process. The proprietary Volumetric Velocity Dispersion technology for soluble support and Suspended Rotational Force for surface finishing both leverage various chemical and mechanical energy sources for optimal post-printing for FDM.

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POSTPROCESS TECHNOLOGIES INC.
2495 Main Street, Suite 615
Buffalo NY 14214, USA
+1.866.430.5354

POSTPROCESS TECHNOLOGIES INTERNATIONAL
Les Aqueducs B3, 535 Route des Lucioles
06560 Sophia Antipolis, France
+33 (0)4 22 32 68 13

info@postprocess.com
www.postprocess.com