Carbon

DLS™ Design Guidelines

Overview

This guide will provide the basics for designing parts for Digital Light Synthesis (DLS™) using Carbon M Series printers.

Topics covered include:

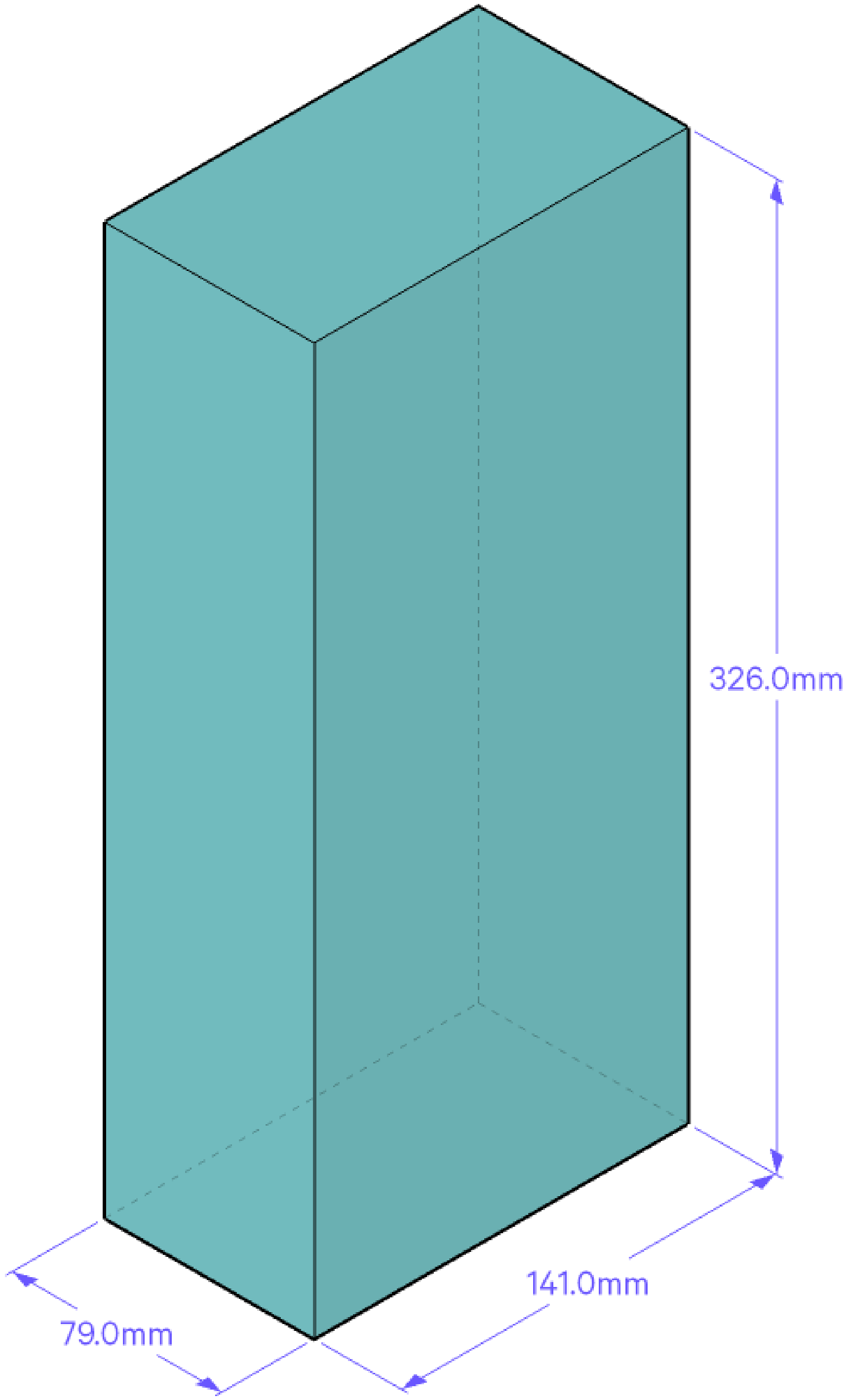
- Build envelope
- Resolution
- Optical effects
- Venting
- Design for additive
- Recommended feature sizes

Note: This course builds upon the information contained in **DLS™ Printer Dynamics.** Please refer to it as needed.

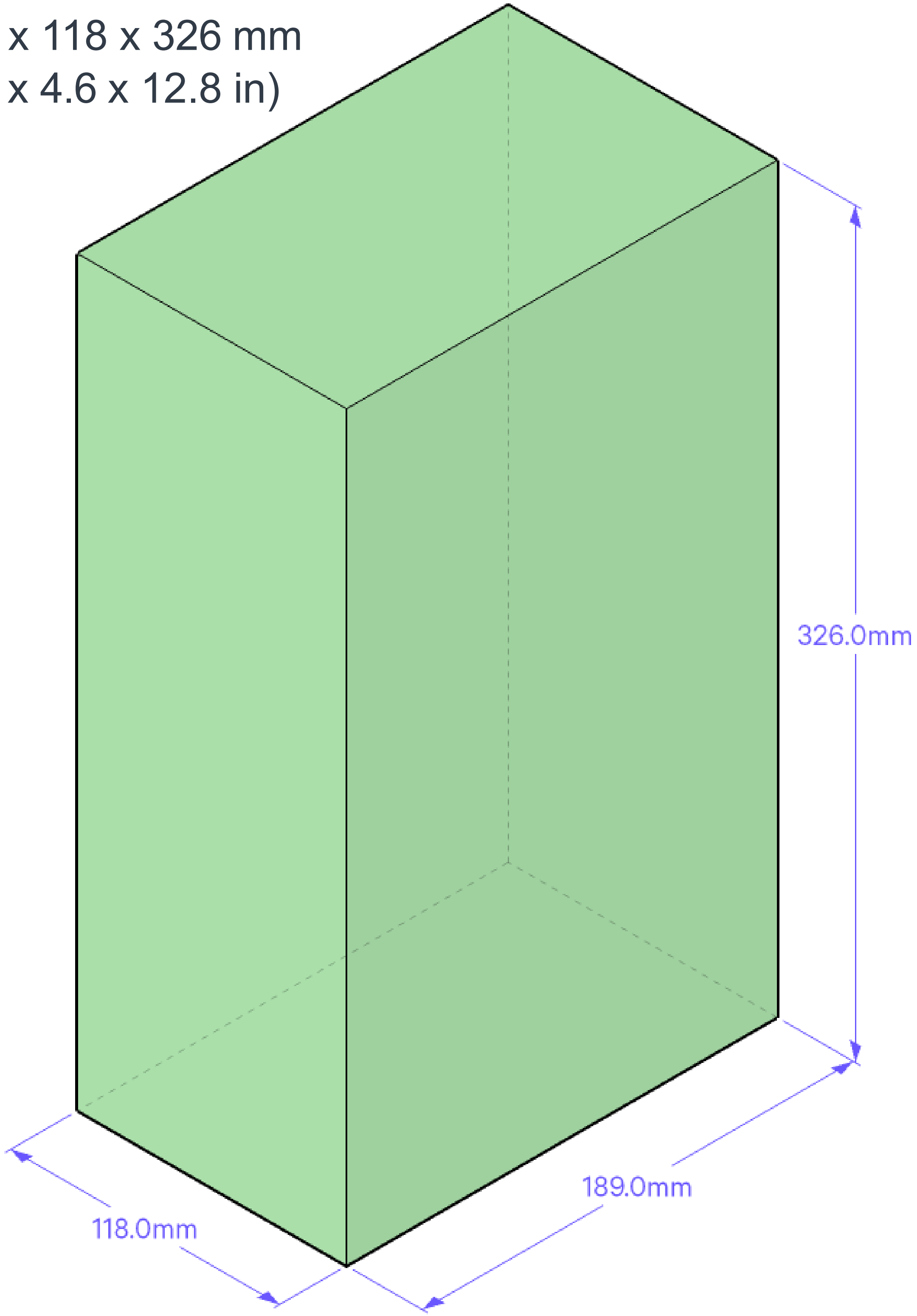
Build envelope

Our process can accommodate single or multiple parts as long as they fit within the build envelope.

M1
141 x 79 x 326 mm
(5.6 x 3.1 x 12.8 in)



M2
189 x 118 x 326 mm
(7.4 x 4.6 x 12.8 in)

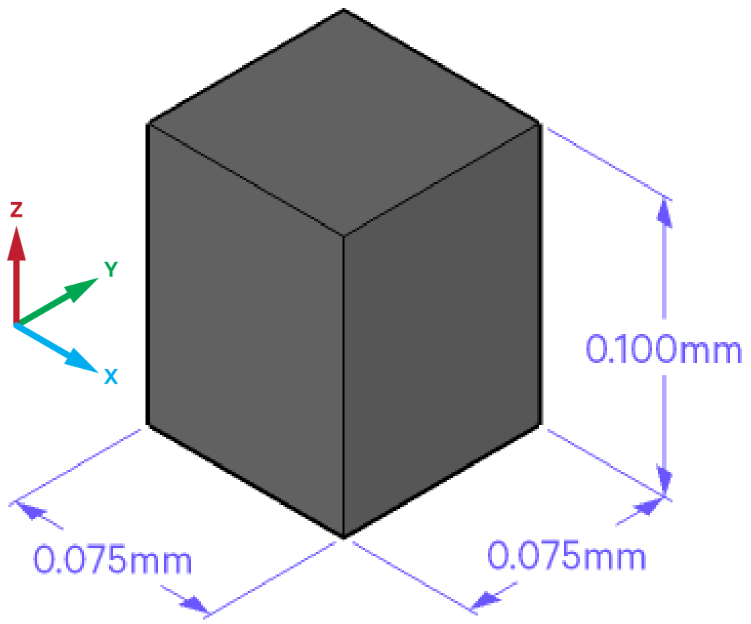


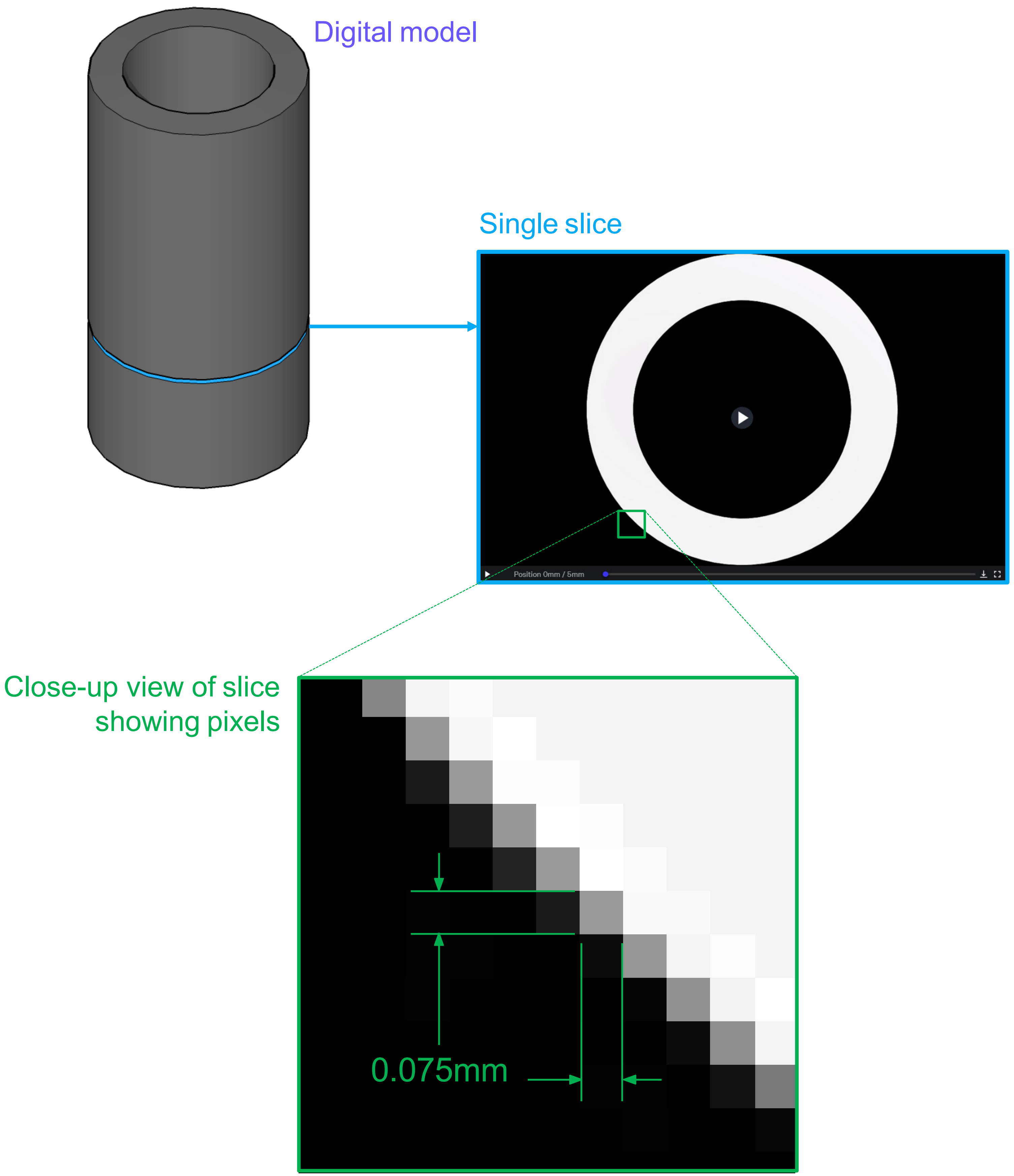
Printing resolution

Each printed part is made of consecutively printed **slices.** A slice is comprised of a field of **pixels** that are projected by the light engine and cure the liquid resin.

Each pixel is a **75 micron** (0.075mm/0.003 in) square. The height of the pixels is determined by the slice thickness, which is typically **100 microns** (0.100mm/0.004 in).

- **Pixel size = 0.075mm in X and Y axes**
- **Slice thickness = 0.100mm in Z axis**





Optical effects

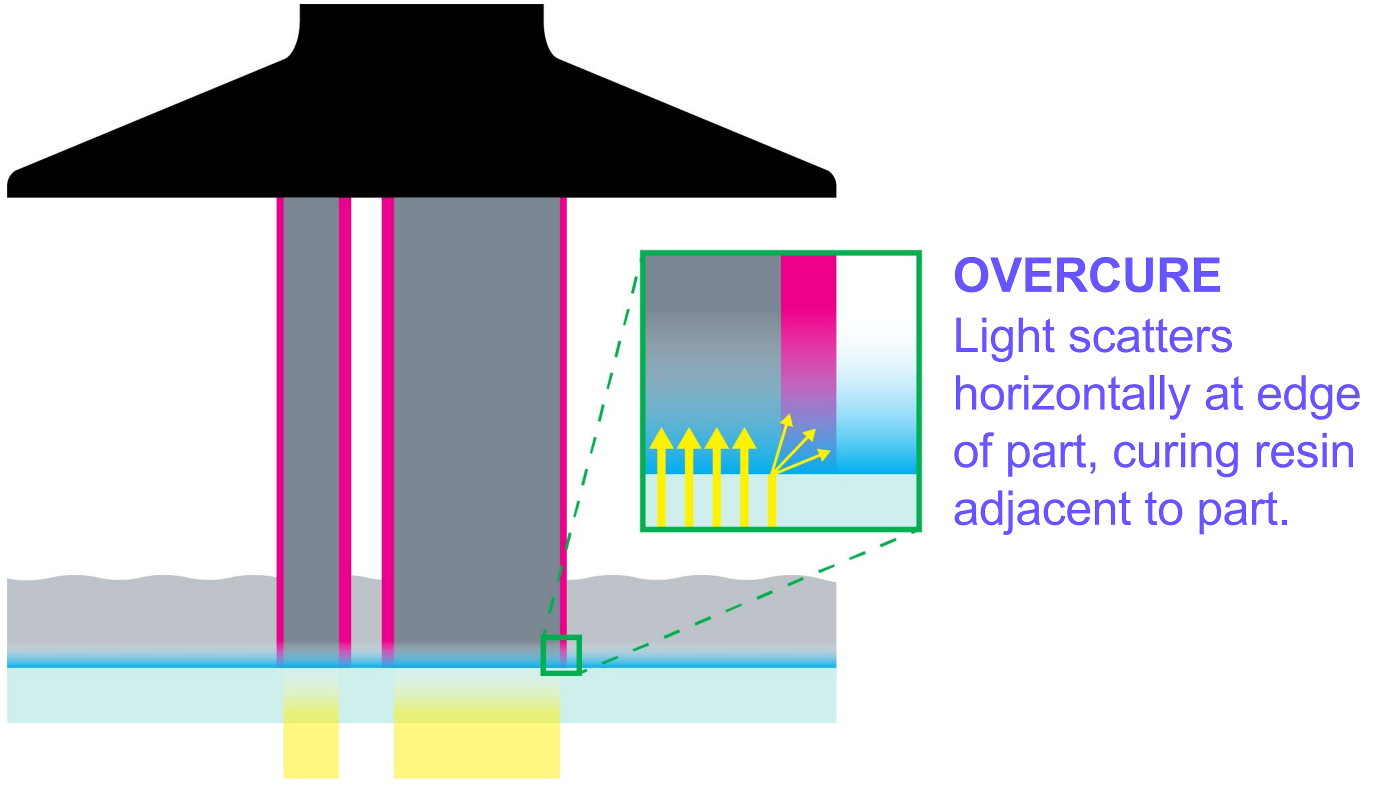
Because resin is not totally opaque to UV light, the light can penetrate through thin areas of material and cause inaccuracies.

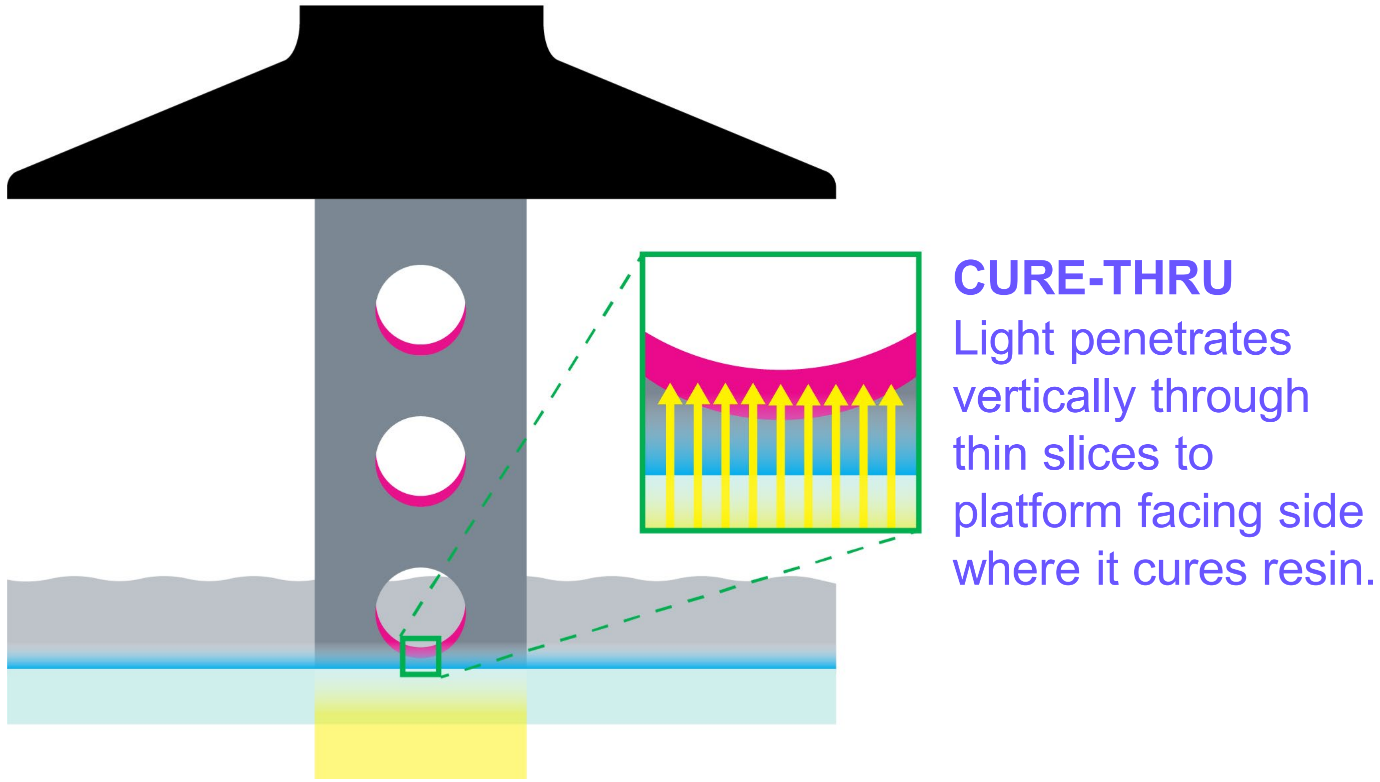
XY plane: Overcure

Overcure is an effect caused by light scattering horizontally at the edges of a slice, where the material is thinner and less opaque. This scattered light cures resin adjacent to the part and typically causes an additional **0.010 - 0.075mm** of part curing. This effect is greater in smaller cavities due to higher local temperatures.

Z axis: Cure-thru

Cure-thru occurs when light penetrates vertically through a thin slice of material and cures resin on the back side of the slice. It is essentially overcure in the Z axis. This phenomenon causes holes to be oblong and **0.050 - 0.200mm** smaller than nominal in the Z axis.

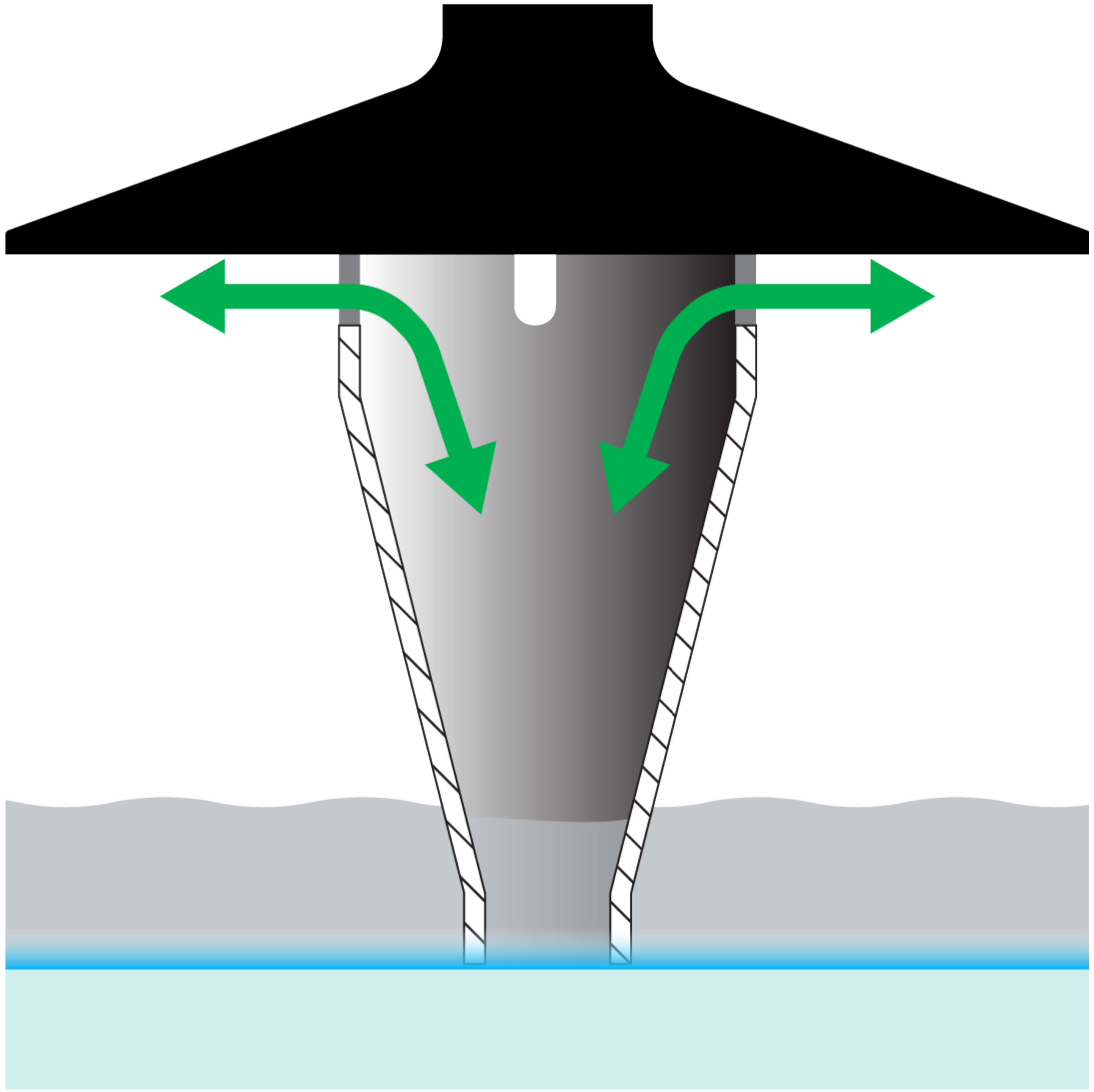




Venting with re-design

Parts can be vented through redesign.

- Add vents at or near the build platform.
- Vents should be a **minimum of 2 - 3mm wide.**



Design for additive

One of the greatest benefits of additive manufacturing is the absence of tooling, enabling designers to design parts that were impossible with traditional methods.

Software tools including **generative design** and **finite element analysis (FEA)** create geometries that are a perfect fit for DLS™ production.

Example of generative design which uses software to evolve parts over many generations to arrive at a highly efficient final design.

Lightweighting

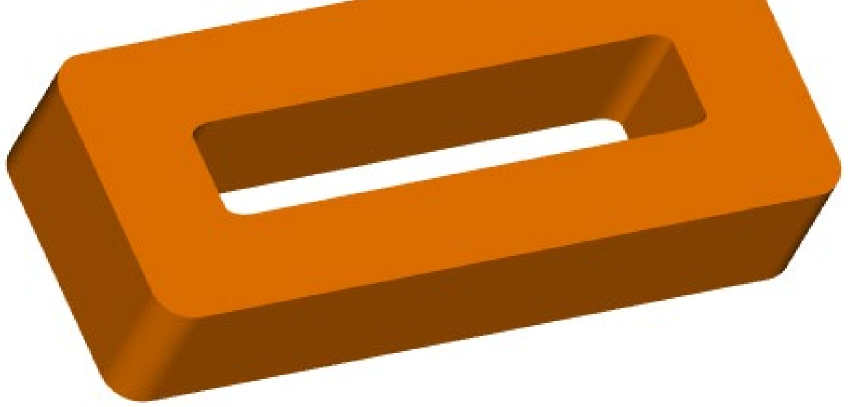
Lightweighting describes a process of removing material from a part or assembly to minimize weight without compromising mechanical performance.

Design modification can be done with powerful software or by a designer.

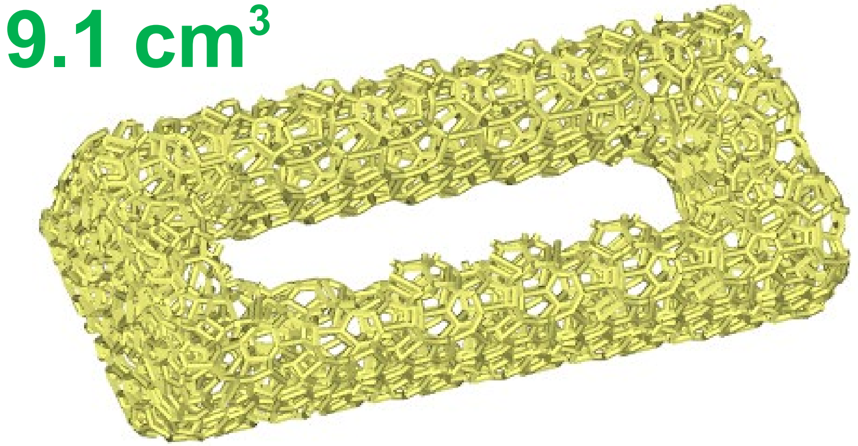
Lightweighted parts also benefit the printing process:

- Less massive parts have smaller cross sections so they print faster.
- Lightweighted parts cost less because they require less resin to achieve the same performance.

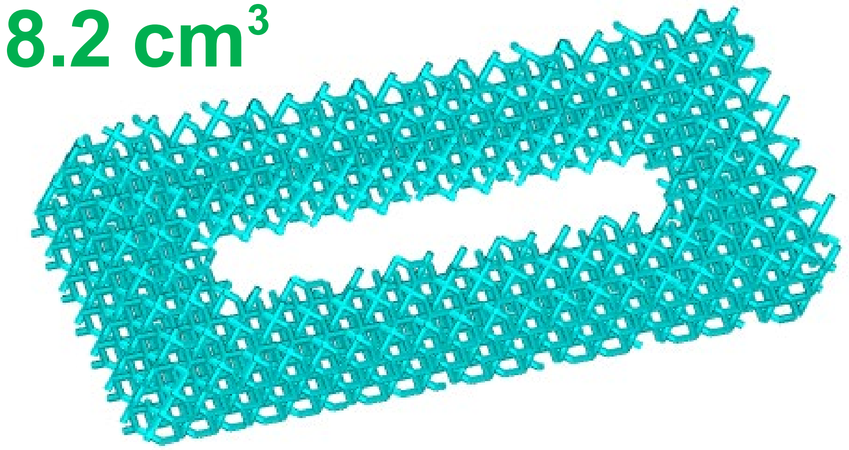
60.1 cm^3



9.1 cm^3



8.2 cm^3

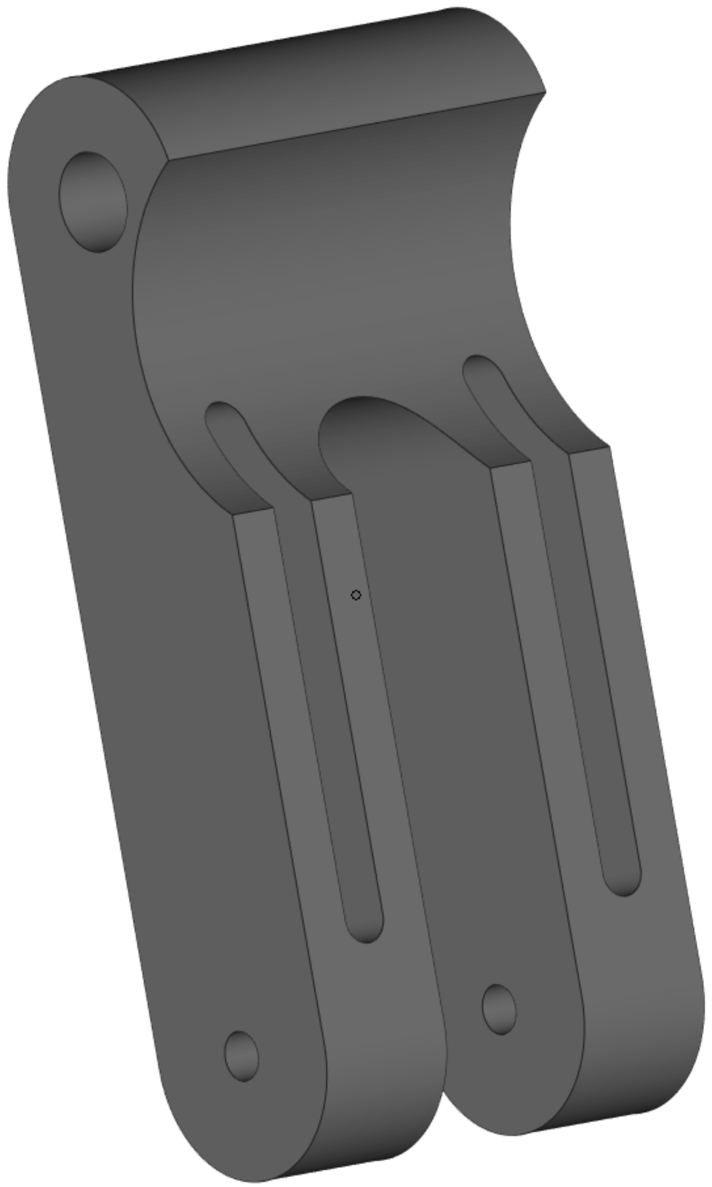


Topology optimization

Topology optimization (TO) modifies geometry within a design space, for a set of loads, boundary conditions and constraints with the goal of maximizing the performance of the system. TO leverages advances in hardware and software to erode or evolve parts. These optimized models printed with DLS™ provide some of the same benefits as lightweighting:

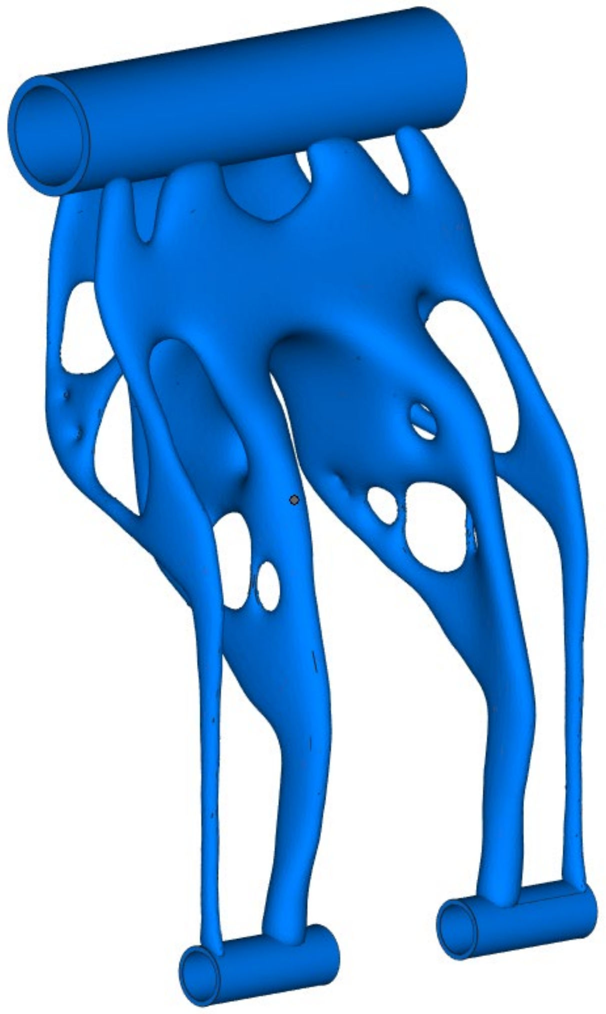
- High strength to weight ratio.
- Less massive parts have smaller cross sections so they print faster.
- Lower cost because they require less resin to achieve the same performance.

Version 1: Designed for milling



70.2 cm³

Version 2: Designed for DLS



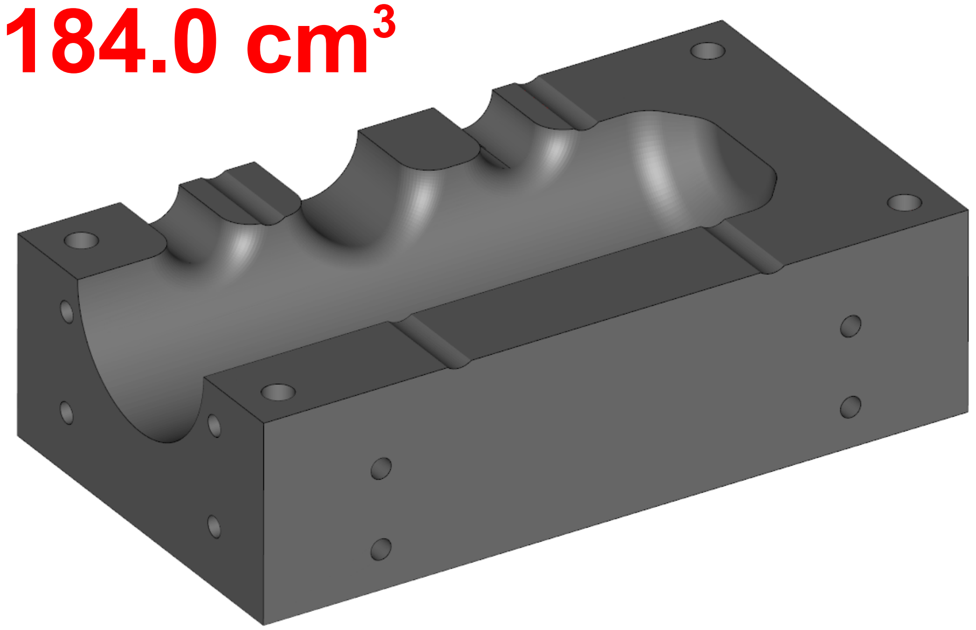
11.5 cm³

Lattices

Using DLS™ with the latest CAD tools enables the production of parts that are wholly or partially made of lattices. **Lattices** have a high strength to weight ratio so they can be used to make parts that are strong and light.

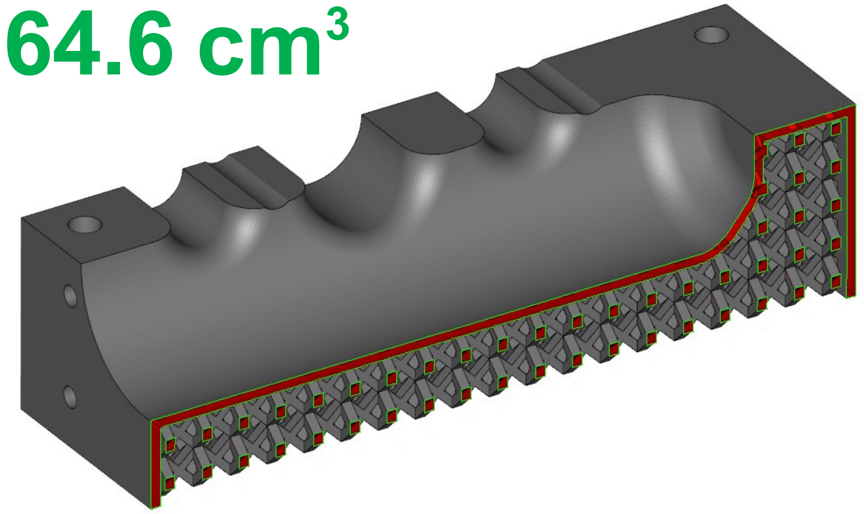
- Lattices can be designed for very specific conditions so that they can be stronger in one axis than another.
- When combined with Carbon's elastomers, lattices can be finely tuned to create durable cushions or pads.
- Traditionally massive fixtures and tooling like molds can be lightweighted when combined with lattices. In the example illustrated below, the latticed version of the mold uses only about one-third of the resin of the original design, resulting in a cheaper part.

184.0 cm^3



Version 1: Massive mold designed for milling.

64.6 cm^3



Version 2: Section through part showing interior filled with lattice and bottom skin eliminated to allow for drainage after printing.

Material properties

	RESIN	ULTIMATE TENSILE STRENGTH	ELONGATION AT BREAK	TENSILE MODULUS	SHORE HARDNESS	IMPACT STRENGTH *	HEAT DEFLECTION TEMP**	COMPARABLE THERMOPLASTIC	BIOCOMPATIBILITY: CYTOTOXICITY
2 PART	**CE 221**	**92 MPa**	3.3%	**3870 MPa**	92D	15 J/m	**231° C**	Glass filled nylon	✓
	EPU 40	7.7 MPa	>250%	N/A	68A	N/A	N/A	TPU	✓
	EPU 41	6.2 MPa	>130%	N/A	73A	N/A	N/A	TPU	✓
	EPX 82	82 MPa	5.9%	2800 MPa	89D	44 J/m	115° C	20% glass-filled PBT	✓
	FPU 50	22 MPa	>250%	690 MPa	71D	42 J/m	69° C	Polypropylene	✓
	MPU 100	37 MPa	>10%	1200 MPa	-	29 J/m	48° C	-	✓
	RPU 70	45 MPa	100%	1900 MPa	80D	22 J/m	70° C	ABS or PC ABS	✓
	RPU 130	35 MPa	>50%	920 MPa	**100D**	**76 J/m**	119° C	Nylon 6	-
	SIL 30	3.4 MPa	**330%**	N/A	35A	N/A	N/A	TPE	✓
1 PART	**DPR 10**	46 MPa	4%	1450 MPa	N/A	20 J/m	61° C	-	✓
	PR 25	46 MPa	4%	1450 MPa	N/A	20 J/m	61° C	-	✓
	UMA 90	46 MPa	17%	2000 MPa	86D	33 J/m	51° C	-	✓

Indicates the highest value in its category.

* NOTCHED IZOD, ASTM D256
** 0.455 MPA, ASTM D648

Accuracy

The DLS™ process is very reliable, but the parts it produces are susceptible to shrinkage and other sources of variation in the part. These sources include resin specific properties, print speed, quality of projected image due to cleanliness of light path (deck window, cassette window) and mechanical tolerances of the various components of each individual printer.

Accuracy and tolerances are dependent upon the material you select, and these values may change as we make improvements to our software.

As tolerances are tighter in the print plane (XY), features that require a higher degree of accuracy should be parallel to it.

Current accuracy for RPU 70 is 0.16% ±0.200mm.

We are continually working to characterize and improve upon the accuracy of our engineering resins.

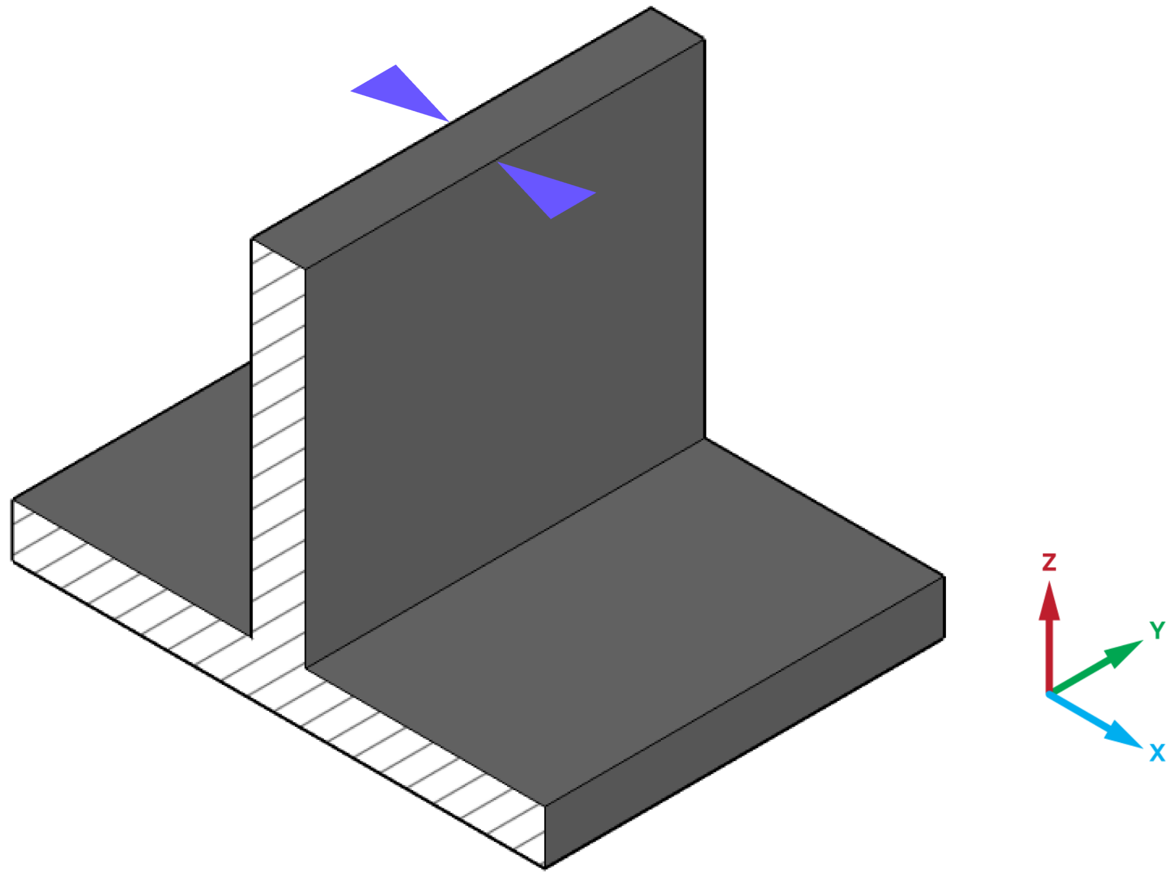
Recommended feature sizes

FEATURE	RPU 70	RPU 130	MPU 100	EPU 40 EPU41	FPU 50	CE 221	EPX 82	PR 25	UMA 90	SIL 30
Wall Thickness - Unsupported (mm)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Wall Thickness - Supported (mm)	1.0	1.5	1.0	1.0	1.0	1.0	1.5	1.0	1.0	1.5
Positive feature size XY (mm)	0.4	0.3	0.4	0.5	0.5	0.4	0.3	0.6	0.4	1.0
Minimum hole size XY (mm)	0.5	0.5	0.9	0.5	0.5	1.0	0.6	0.9	0.9	2.0
Positive feature size Z (mm)	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	1.0
Minimum hole size Z (mm)	0.6	0.5	0.8	0.5	0.5	0.7	0.9	0.6	0.8	2.0
Unsupported angle from horizontal (deg)	30	40	40	40	35	40	40	30	30	40
Clearance between mating parts (mm)	0.4	0.5	0.5	0.5	0.5	0.8	0.4	0.5	0.5	0.5
Engraving depth/Embossing height (mm)	0.3	0.3	0.3	0.3	0.3	0.4	0.3	0.3	0.3	0.5
Text size, engraved/embossed (mm)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.5
Overhangs (mm)	2.0	2.0	3.0	1.0	2.0	3.0	2.0	3.0	3.0	1.0

Unsupported wall thickness

An **unsupported wall** is supported along one edge.

- Walls can be printed thinner than our listed minimums if the user is prepared to iterate.
- When attempting walls at or below the minimum thickness, keep the walls as short as possible.
- Keeping in mind the minimum sizes, design walls to be as thin as possible for your application to keep resin costs down and accelerate print speeds.

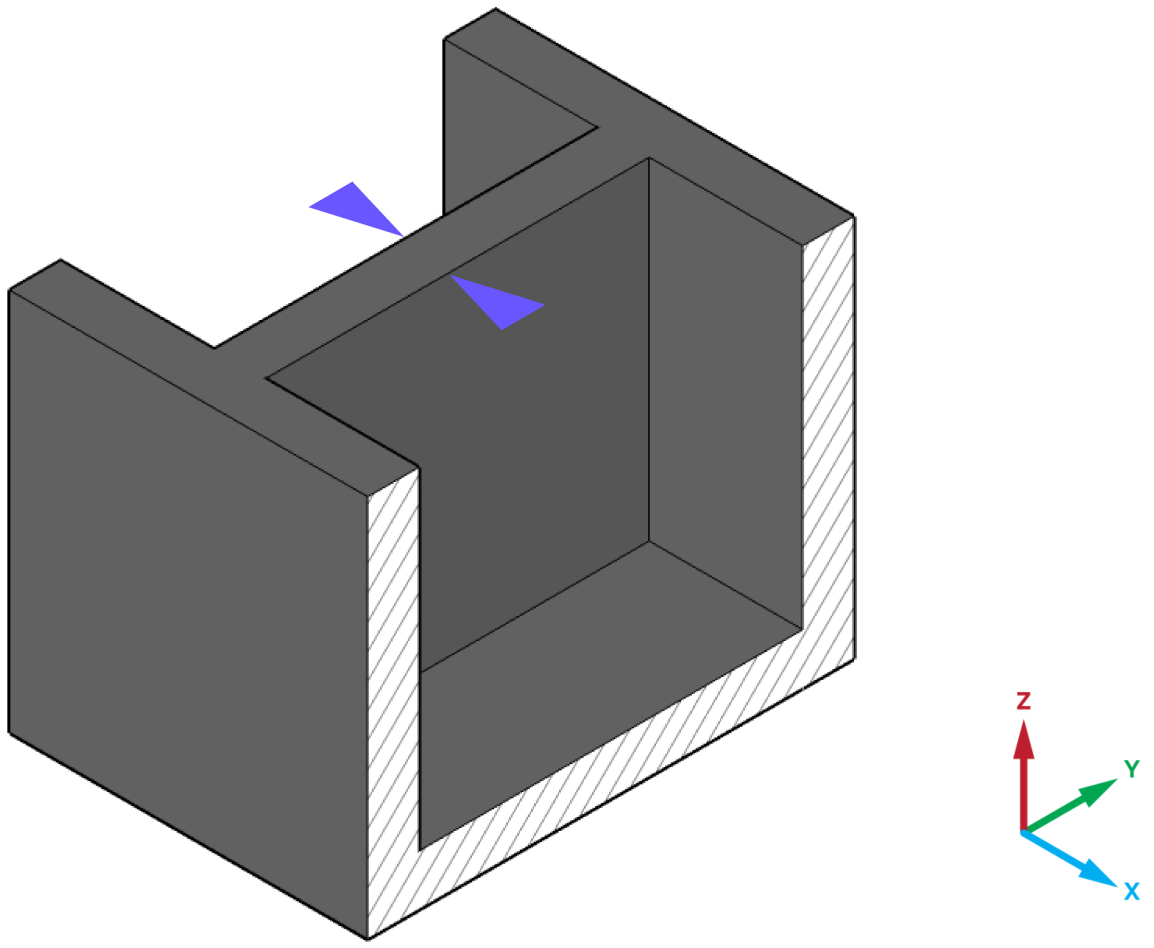


UNSUPPORTED WALL THICKNESS	RPU 70	RPU 130	MPU 100	EPU 40/41	FPU 50	CE 221	EPX 82	PR 25	UMA 90	SIL 30
Recommended (mm)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5

Supported wall thickness

A **supported wall** is a wall connected to other walls along two or more edges.

- Supported walls can be made thinner because they are more stable during printing and less likely to warp during the washing process.
- As with unsupported walls, when attempting walls at or below the minimum thickness, keep the walls as short as possible.
- Design walls to be as thin as possible for your application to keep resin costs down and accelerate print speeds.
- Non-uniform wall thicknesses can also create uneven shrinkage. Keeping walls a similar thickness can minimize warpage.

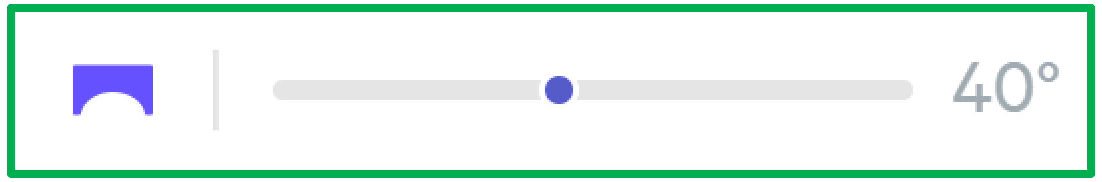


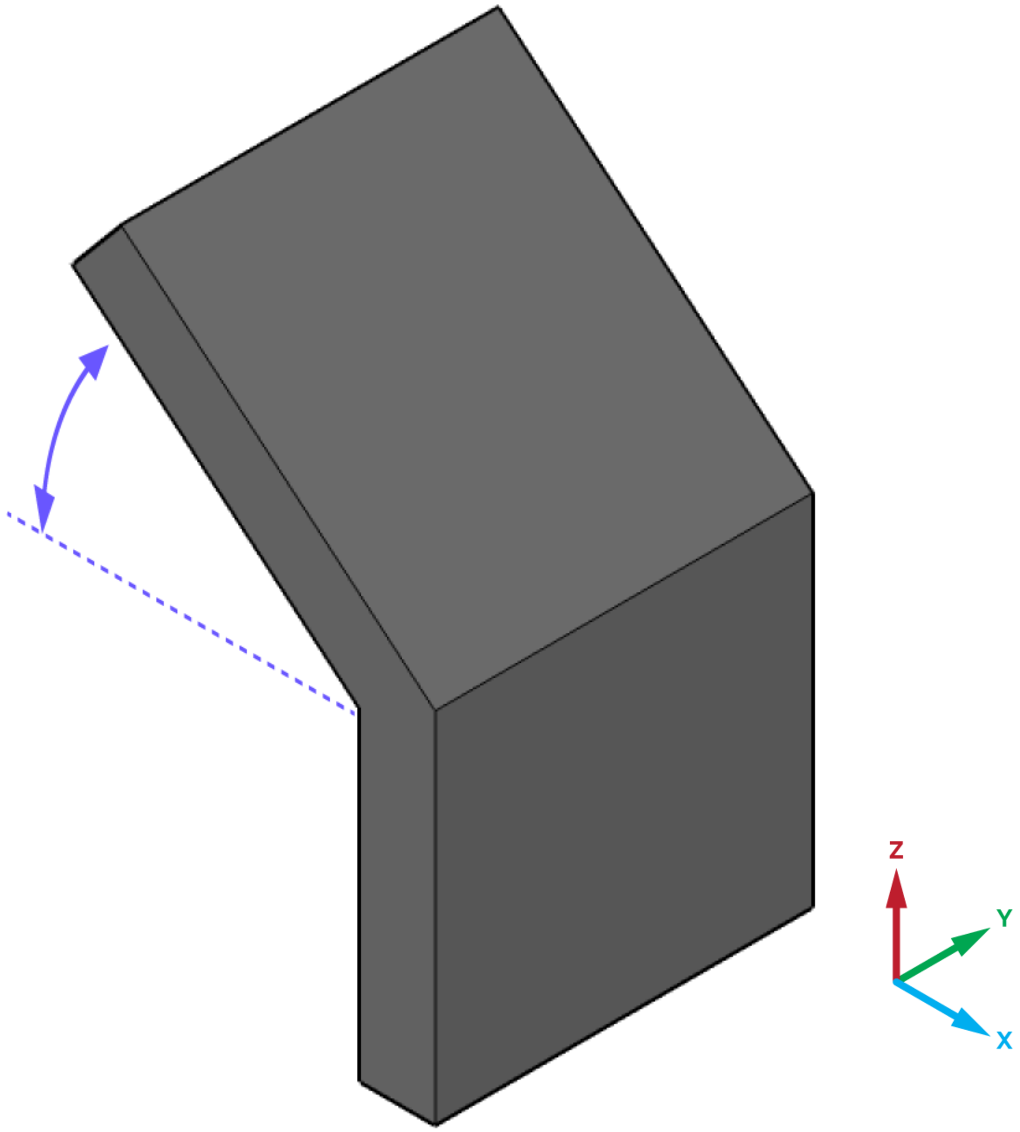
SUPPORTED WALL THICKNESS	RPU 70	RPU 130	MPU 100	EPU 40/41	FPU 50	CE 221	EPX 82	PR 25	UMA 90	SIL 30
Recommended (mm)	1.0	1.5	1.0	1.0	1.0	1.0	1.5	1.0	1.0	1.5

Unsupported angle

Unsupported angle refers to the angle that any unsupported feature is oriented relative to the platform (XY).

- The closer a feature is to being parallel with the platform, the greater the likelihood of failure. Conversely, the closer a feature is to vertical, the greater the likelihood of success.
- Thinner structures and more flexible materials may require more support or features oriented closer to vertical.
- Use the Overhang Detection tool in the printer software to find potential trouble spots.



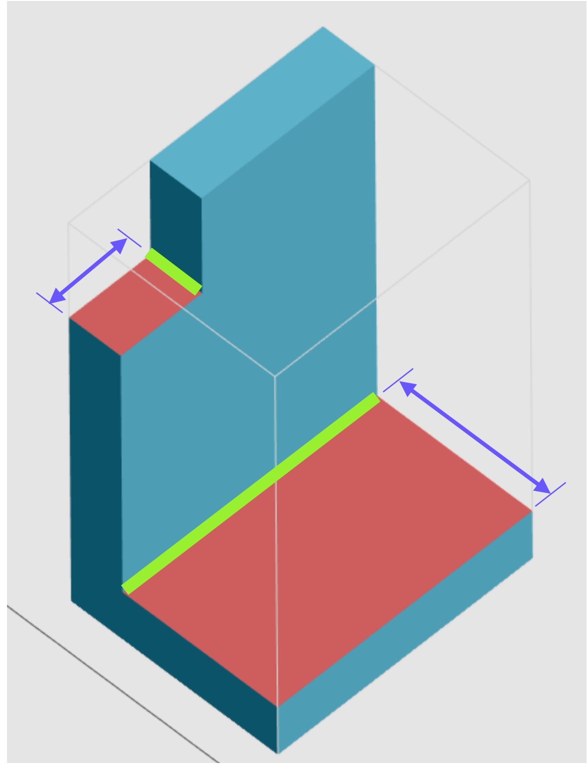


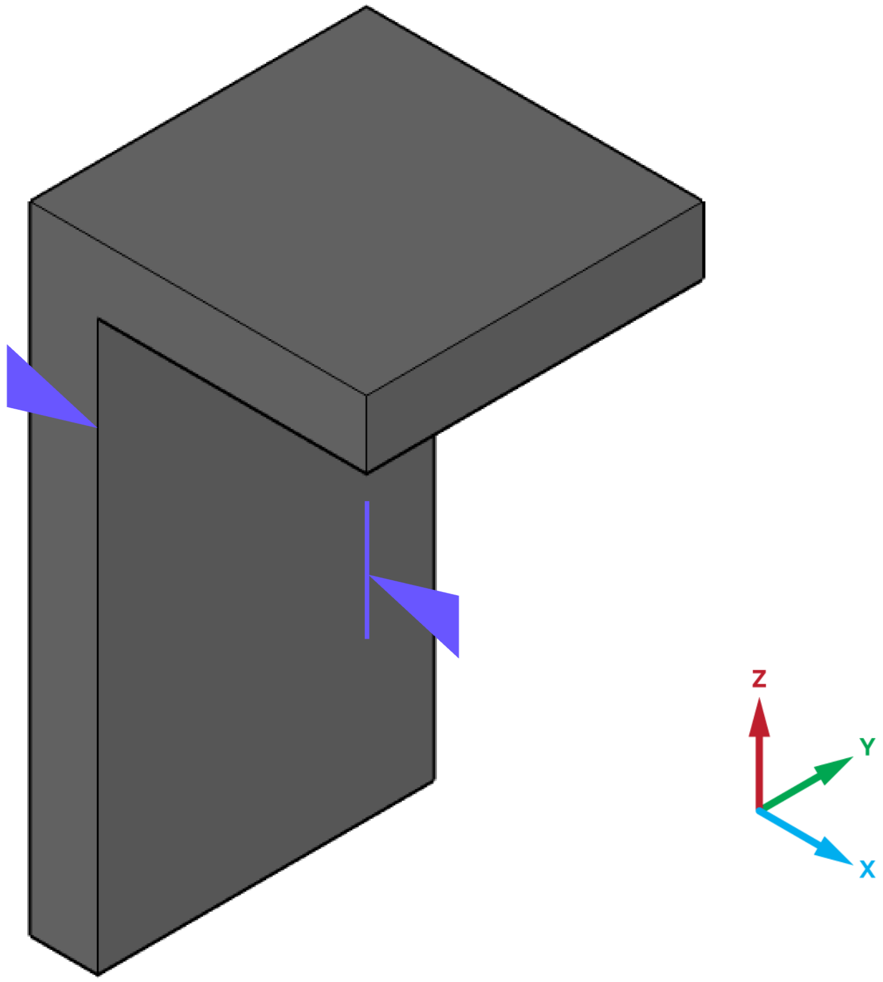
UNSUPPORTED ANGLE	RPU 70	RPU 130	MPU 100	EPU 40/41	FPU 50	CE 221	EPX 82	PR 25	UMA 90	SIL 30
Recommended (degrees)	30	40	40	40	35	40	40	30	30	40

Overhangs

An **overhang** is an unsupported feature that projects from the model during printing. DLS™ is able to create much larger overhangs than competing additive technologies.

- Overhangs that approach maximum values may not fully resolve or experience deflection during printing and may require redesign or supports.
- Measure overhangs from the **edge** that meets the rest of the model.



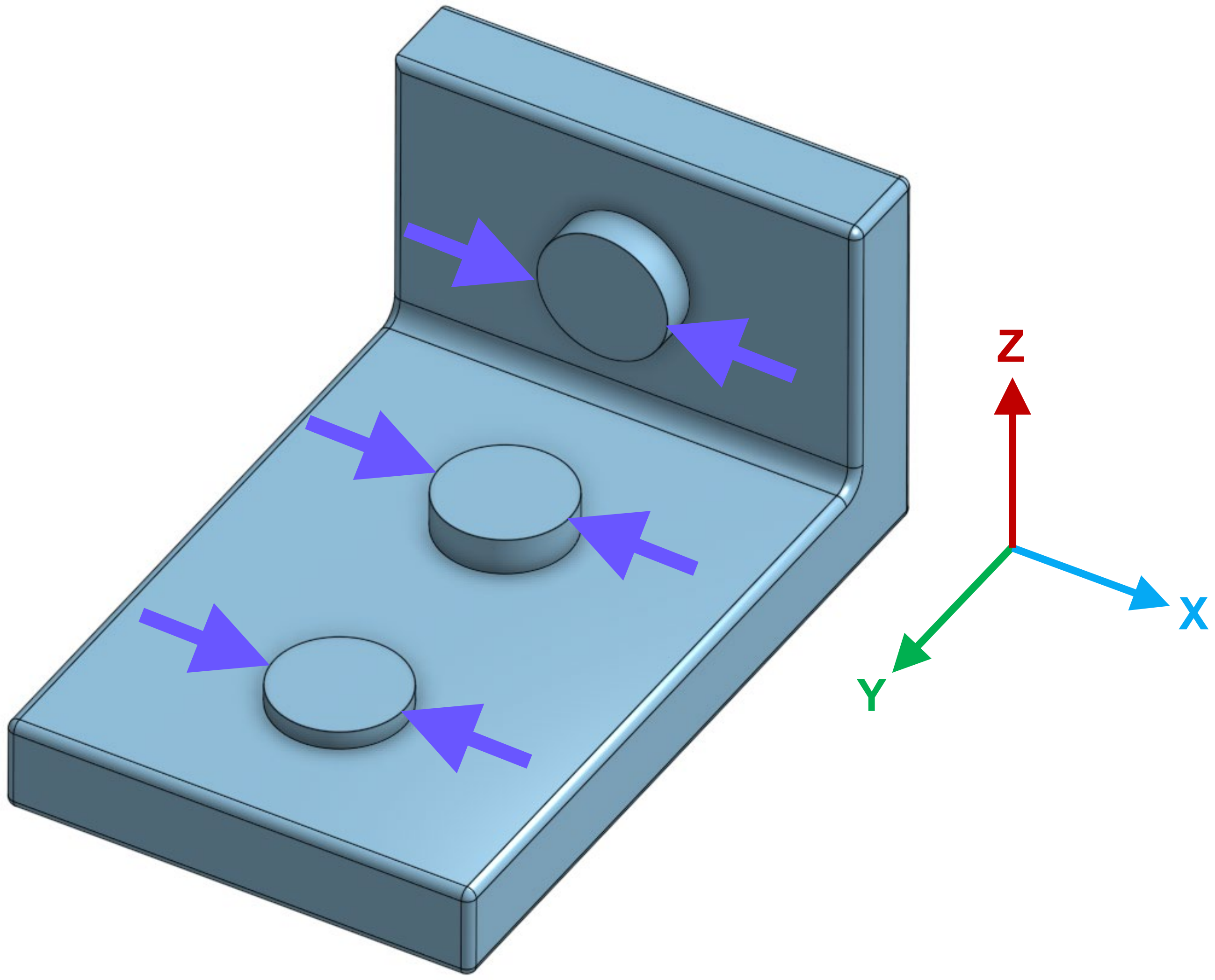


OVERHANG	RPU 70	RPU 130	MPU 100	EPU 40/41	FPU 50	CE 221	EPX 82	PR 25	UMA 90	SIL 30
Recommended (mm)	2.0	2.0	2.0	1.0	2.0	3.0	2.0	3.0	3.0	1.0

Positive features

Positive features protrude from the surface of a part.

- We provide size recommendations for positive features oriented horizontally in the XY print plane and vertically in the Z axis due to the different factors at play in each orientation.
- For feature orientations that differ significantly from either XY horizontal or Z vertical, use the XY values.
- Recommendations indicate how small the feature can be.
  - Features smaller than our listed minimums can be attempted if the user is prepared to iterate.

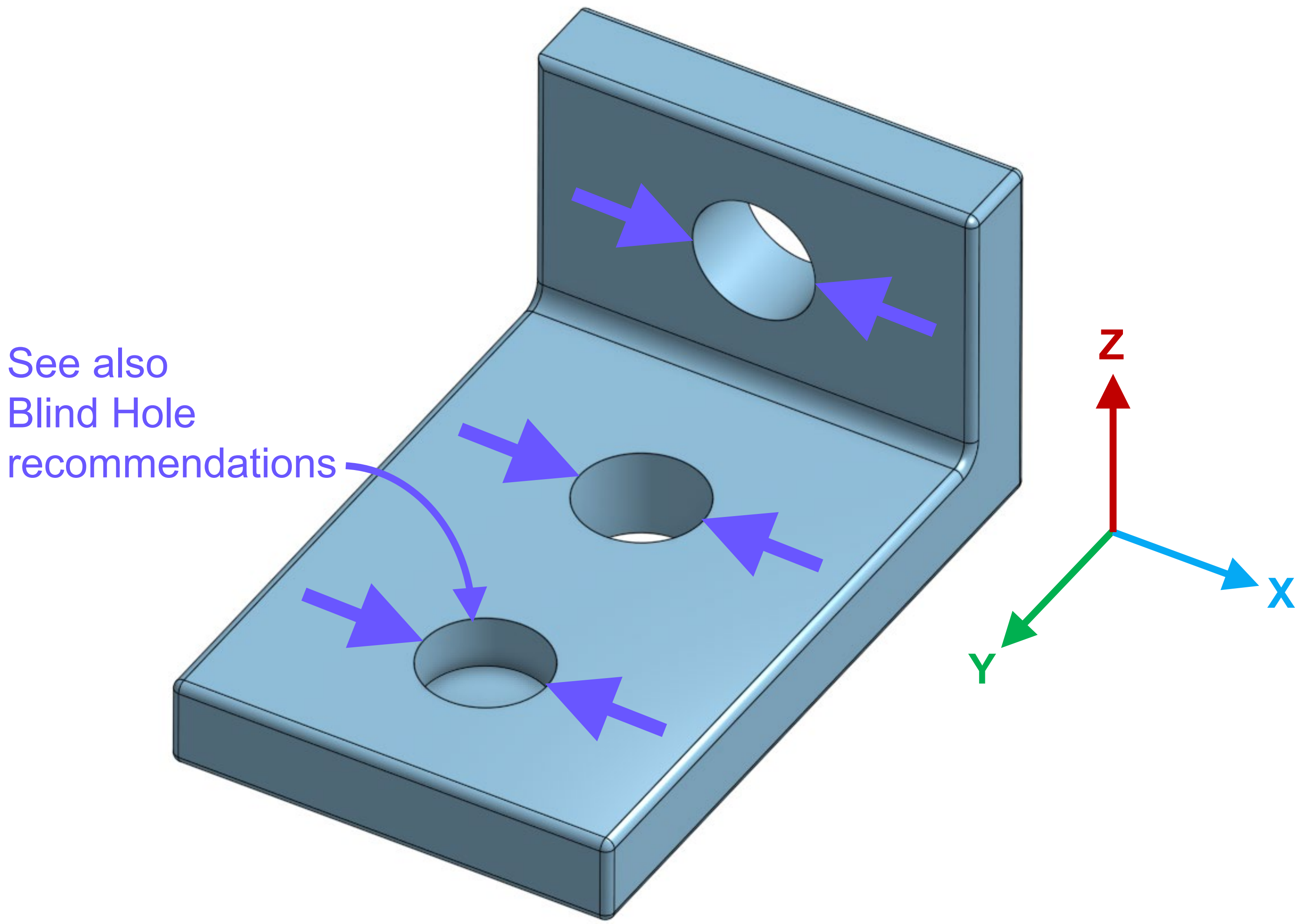


POSITIVE FEATURES	RPU 70	RPU 130	MPU 100	EPU 40/41	FPU 50	CE 221	EPX 82	PR 25	UMA 90	SIL 30
Horizontal XY										
Recommended (mm)	0.4	0.3	0.4	0.5	0.5	0.4	0.3	0.6	0.4	1.0
Vertical Z										
Recommended (mm)	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	1.0

Holes

Holes are openings in a part or features that pass completely through a part.

- We provide size recommendations for holes oriented horizontally in the XY print plane and vertically in the Z axis due to the different factors at play in each orientation.
- For hole orientations that differ significantly from either XY horizontal or Z vertical, use the XY values.
- To compensate for overcure, horizontal holes should be oversized by at least **0.04mm.**
- Recommendations indicate how small the holes can be.
  - Holes smaller than our listed minimums can be attempted if the user is prepared to iterate.



HOLES	RPU 70	RPU 130	MPU 100	EPU 40/41	FPU 50	CE 221	EPX 82	PR 25	UMA 90	SIL 30
Horizontal XY										
Recommended (mm)	0.5	0.5	0.9	0.5	0.5	1.0	0.6	0.9	0.9	2.0
Vertical Z										
Recommended (mm)	0.6	0.5	0.8	0.5	0.5	0.7	0.9	0.6	0.8	2.0

Blind holes

Blind holes only go to a specific depth and do not pass through the part. Bosses are a good example of a blind hole. **Avoid blind holes if possible.**

- Blind holes trap and hold resin during post-processing, requiring dedicated cleaning with swabs or other tools to remove liquid resin. In most cases, it is not possible to remove all of the uncured resin from the blind hole **(Fig. 1).**
- If a hole with a set depth is necessary, add an opening to properly vent the part during printing **(Fig. 2).**
  - Vent hole also provides a clear path for liquid resin, solvent and air to flow through during cleaning.

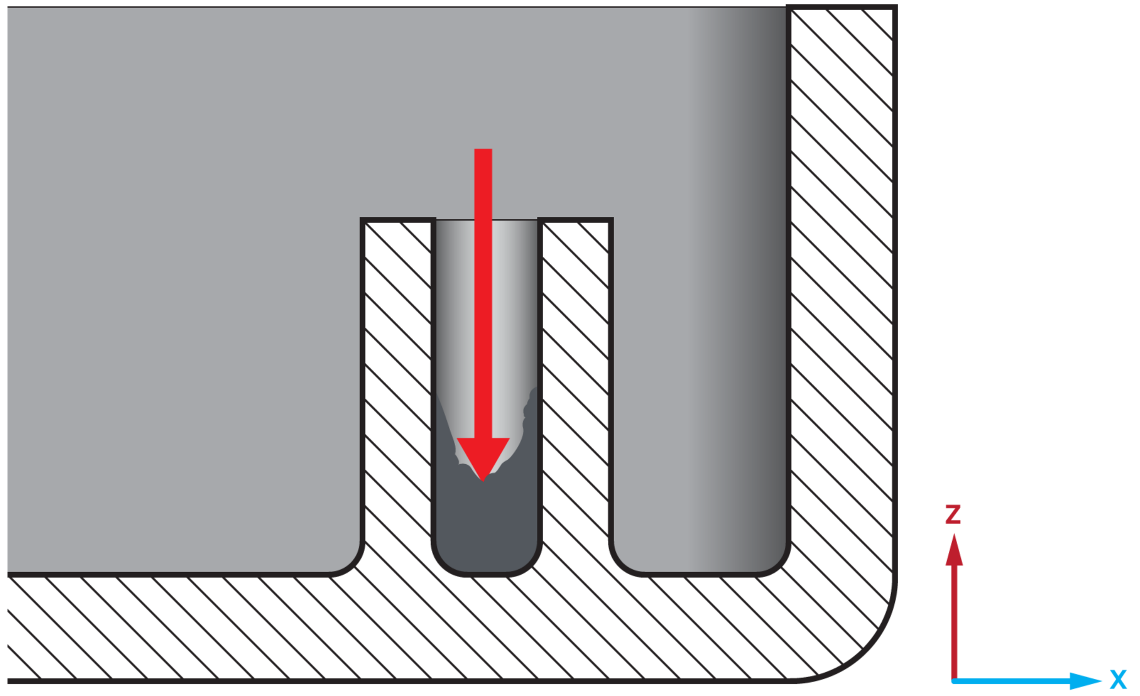


Fig. 1: Unvented boss traps liquid resin. Resin has no where to go when compressed air or IPA is applied from top of boss.

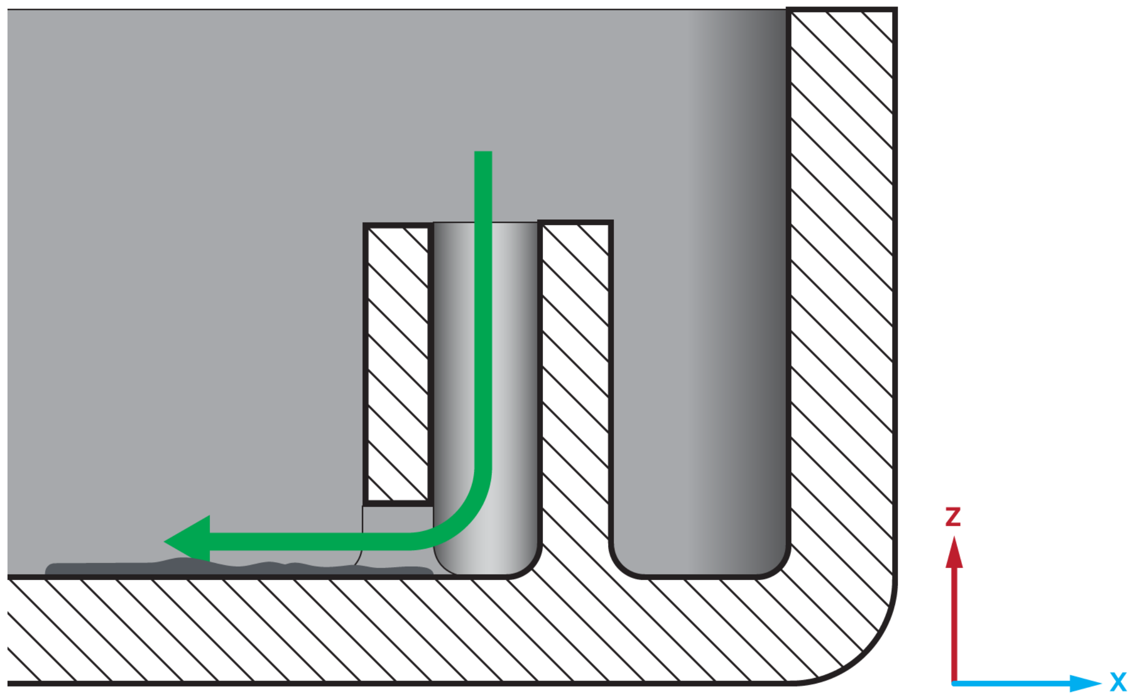


Fig. 2: Vent hole added at base of boss. Liquid resin easily flows through hole when IPA and/or compressed air is applied to top of boss.

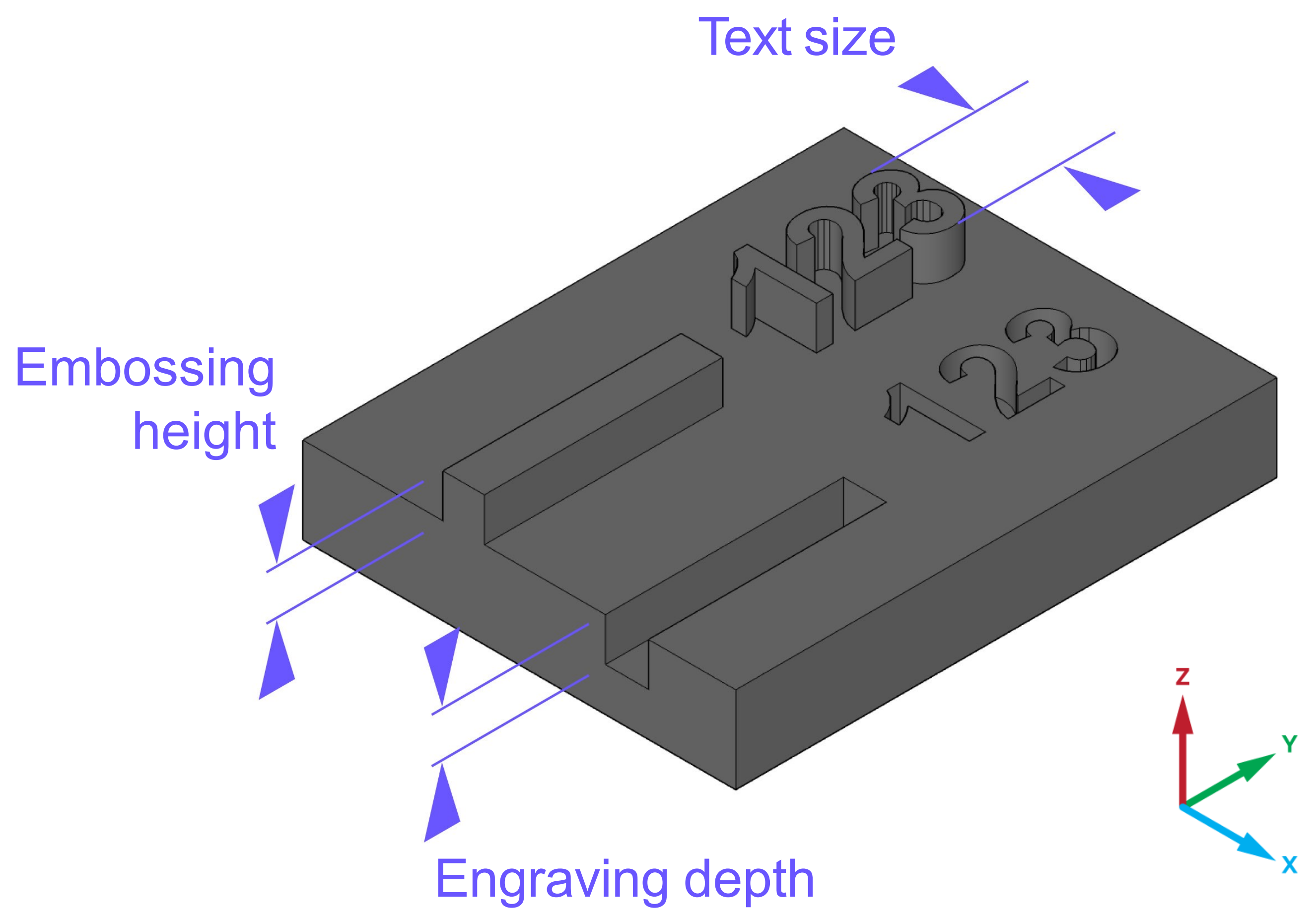
Engraving and embossing

Embossing refers to small details such as text protruding from the surface of the part.

Engraving refers to small details that are etched into the part's surface.

Text size refers to the height of the letter and is the same for both embossed and engraved text.

Note: Features should be window-facing for maximum quality.

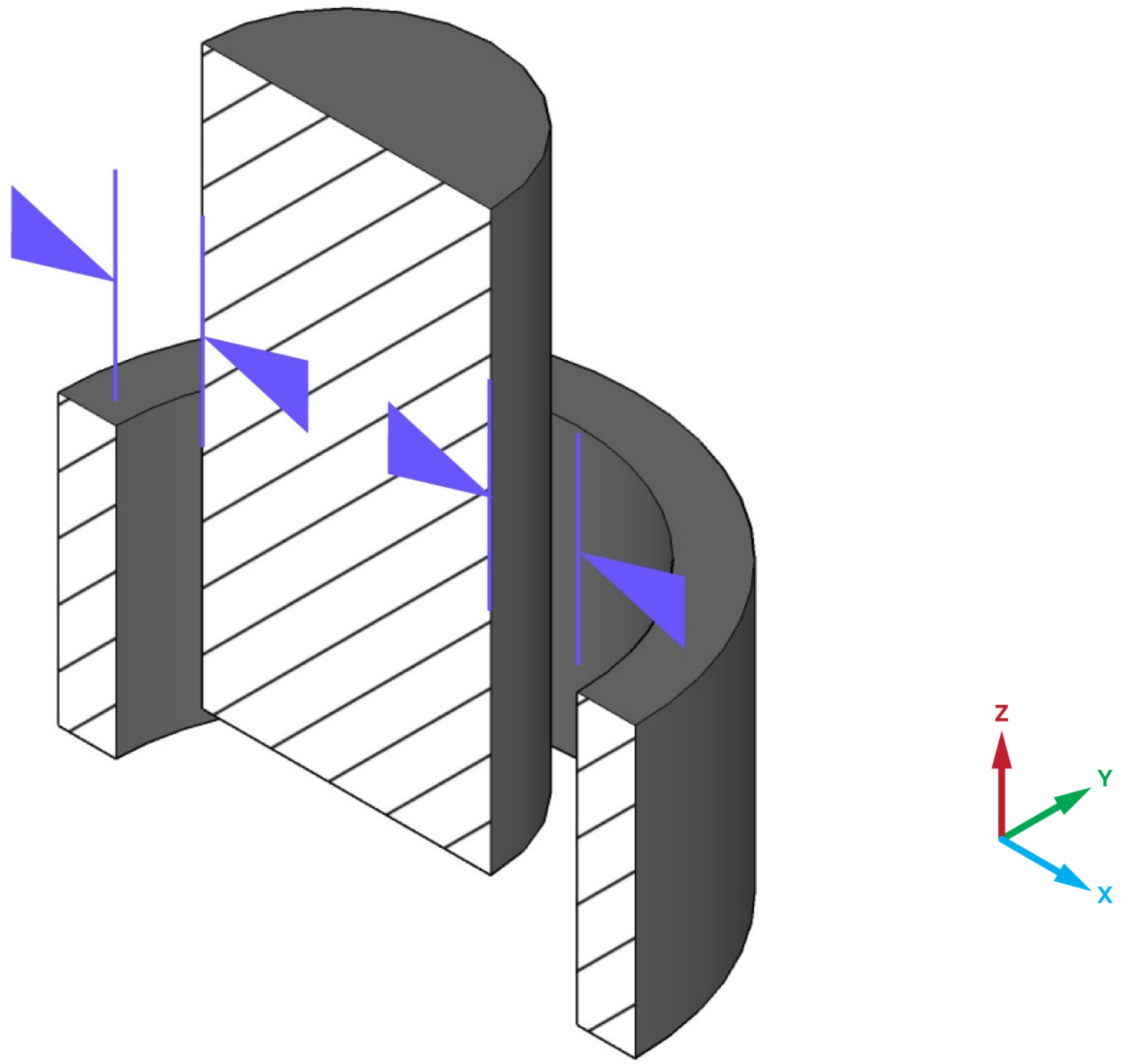


EMBOSSING AND ENGRAVING	RPU 70	RPU 130	MPU 100	EPU 40/41	FPU 50	CE 221	EPX 82	PR 25	UMA 90	SIL 30
Embossing height/Engraving depth										
Recommended (mm)	0.3	0.3	0.3	0.3	0.3	0.4	0.3	0.3	0.3	0.5
Text size										
Recommended (mm)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.5

Clearance

Clearance is the space required between parts that fit together, such as a post that fits into a hole. Clearance accounts for variance in the production process including printing and curing.

- Print mating parts in the same orientation that they will be assembled to get the best fit.



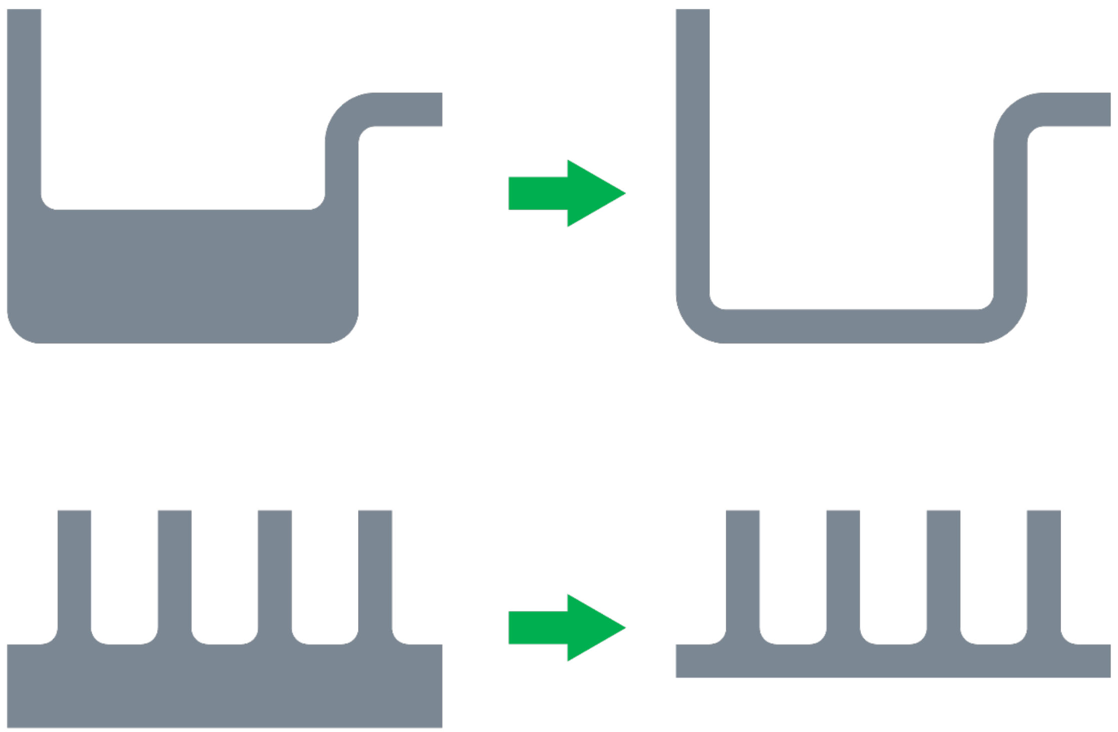
CLEARANCE	RPU 70	RPU 130	MPU 100	EPU 40/41	FPU 50	CE 221	EPX 82	PR 25	UMA 90	SIL 30
Recommended (mm)	0.4	0.5	0.5	0.5	0.5	0.8	0.4	0.5	0.5	0.5

Uniform wall thickness

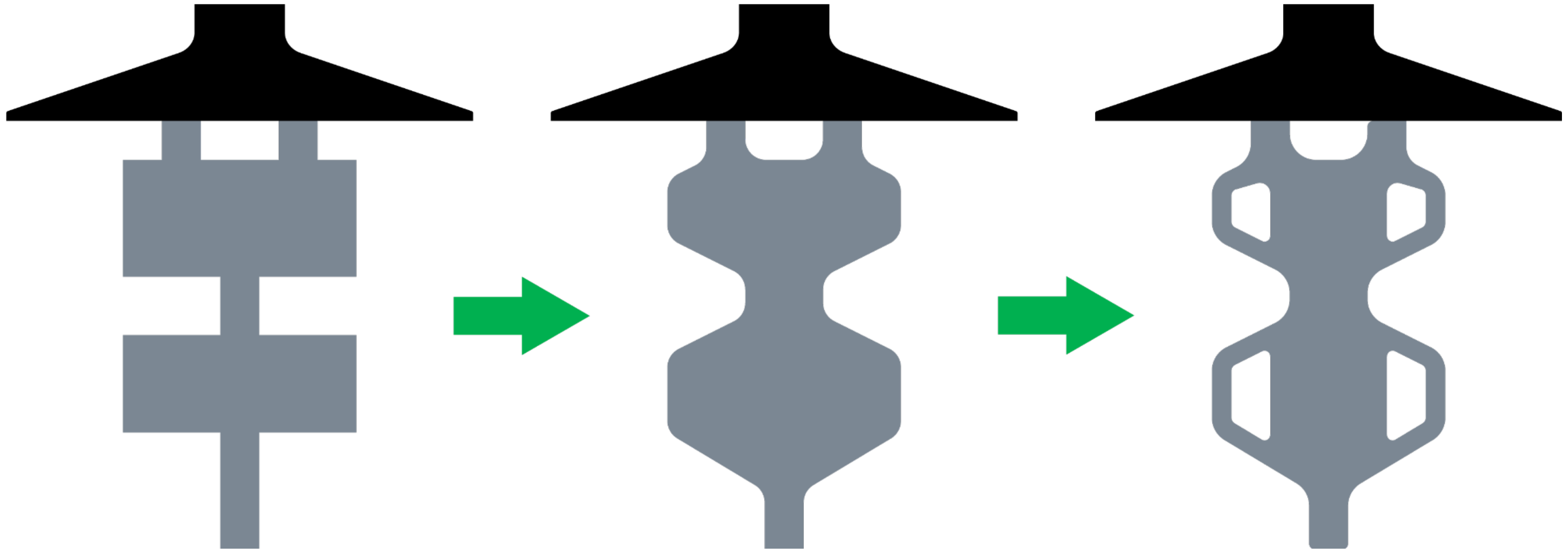
Design parts to minimize the effects of shrink and increase print success:

- Maintain uniform wall thickness to have equal shrinkage throughout the part.
- Avoid sudden changes in cross-section during printing.

Maintain consistent wall thickness.



Smooth sudden changes in cross-section.



Fillets and chamfers

Sharp internal corners and sudden changes in cross sectional area from slice to slice create areas of high internal stress that are the most likely locations for failure. In the case of CE 221, it may even cause cracking.

To lessen internal stresses:

- Use **fillets or chamfers** instead of sharp corners (Fig. 1).
- Create gradual transitions instead of steps (Fig. 2).

Recommendations (Fig. 3)

- **Minimum 0.5mm fillet on interior corners.**
- **Minimum 0.5mm + Wall Thickness for exterior corners.**

A **fillet** is the rounding of an interior or exterior corner. Where sharp corners tend to concentrate stresses, fillets distribute stresses over larger areas, leading to more durable parts.

Fig. 1: Add fillets or chamfers to corners.

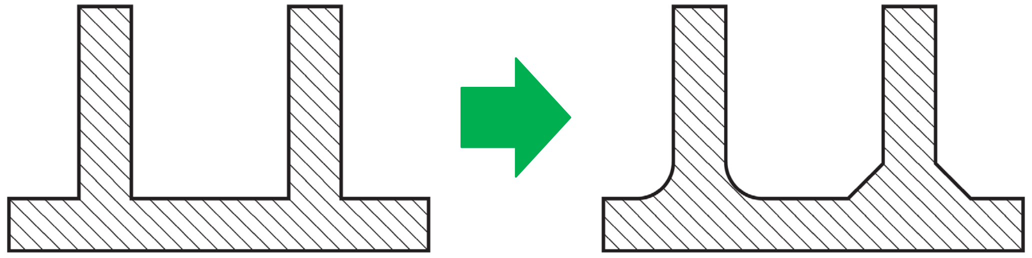


Fig. 2: Gradual transitions instead of steps.

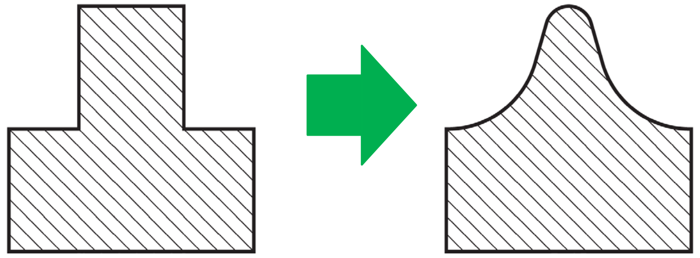
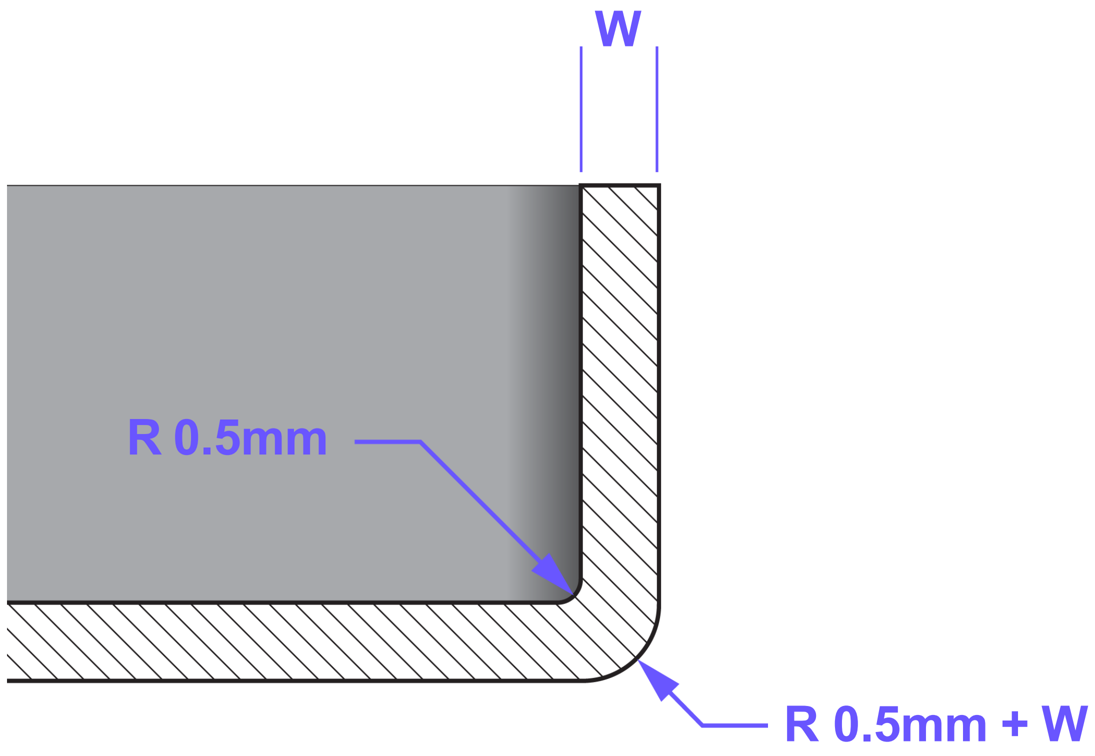


Fig. 3: Fillet radii



Gradual transitions

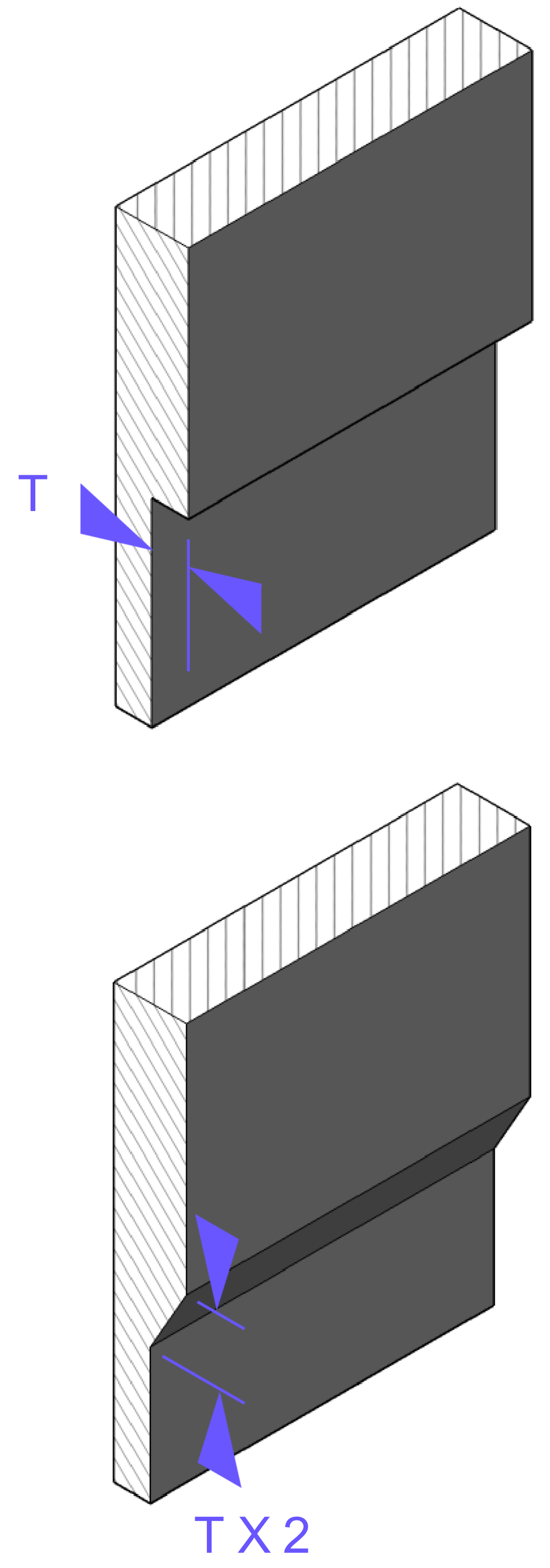
Minimizing the rate of change from slice to slice dramatically reduces stress on parts during printing and minimizes the chances of warping, witness lines and other defects.

Rather than steps, use ramps, fillets or curves to create changes in part geometry.

Recommendation

For a given rise T, the transition should run at least T x 2.

- Ex: A rise of 3.0 mm would require a 6.0mm run from the base level to the new level.
- More gradual transitions are even better.
- Keep the maximum overhang angle of 40 degrees in mind as it may come into play depending on part orientation.



Threaded holes

There are several ways of creating a threaded hole for DLS™ parts. Our recommendations are listed in order of preference:

1. Printed threads
2. Nut pocket
3. Helical inserts

Printed threads

Our high resolution process is capable of printing end use threads.

- We recommend printing threads no smaller than **M4 (0.7mm pitch).**
- Venting the hole is strongly encouraged to ensure the most accurate threads possible **(Fig 1).**
- Orient threads parallel to the platform for best accuracy.
- After baking, chase the threads with an appropriately sized tap.
- Match the hole with a machine screw, not self threading screws.

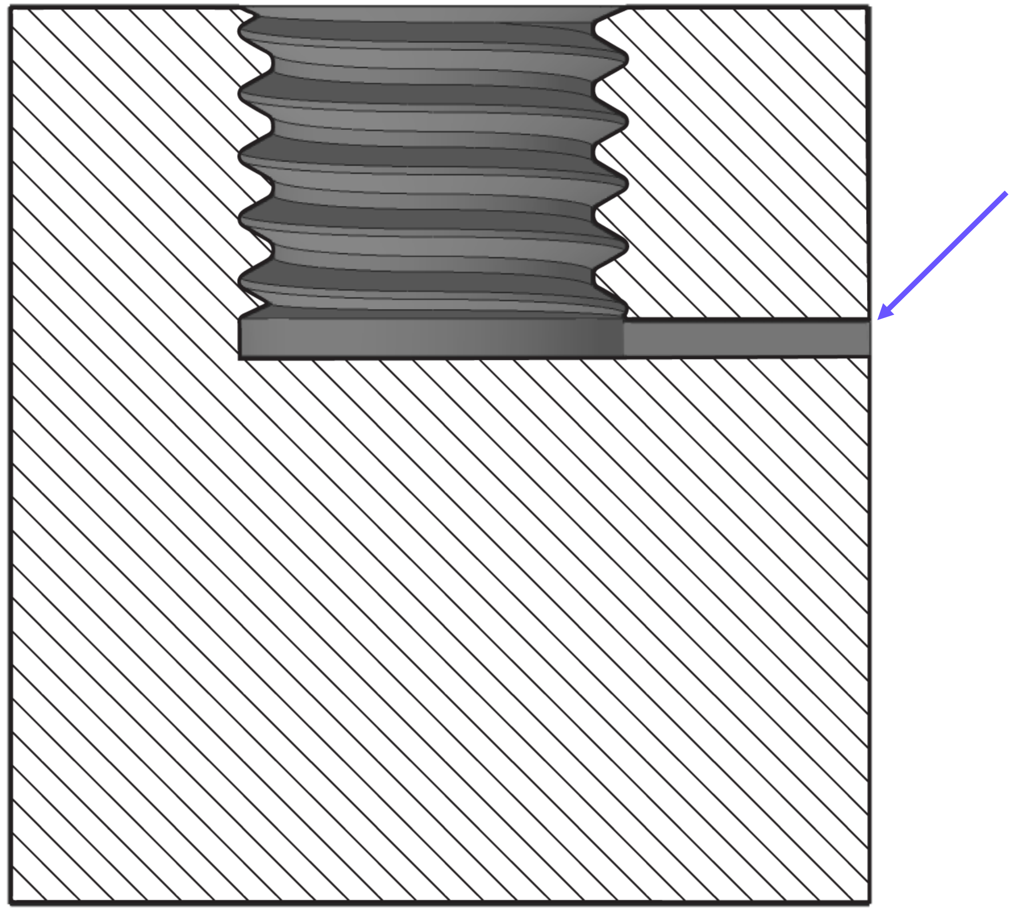


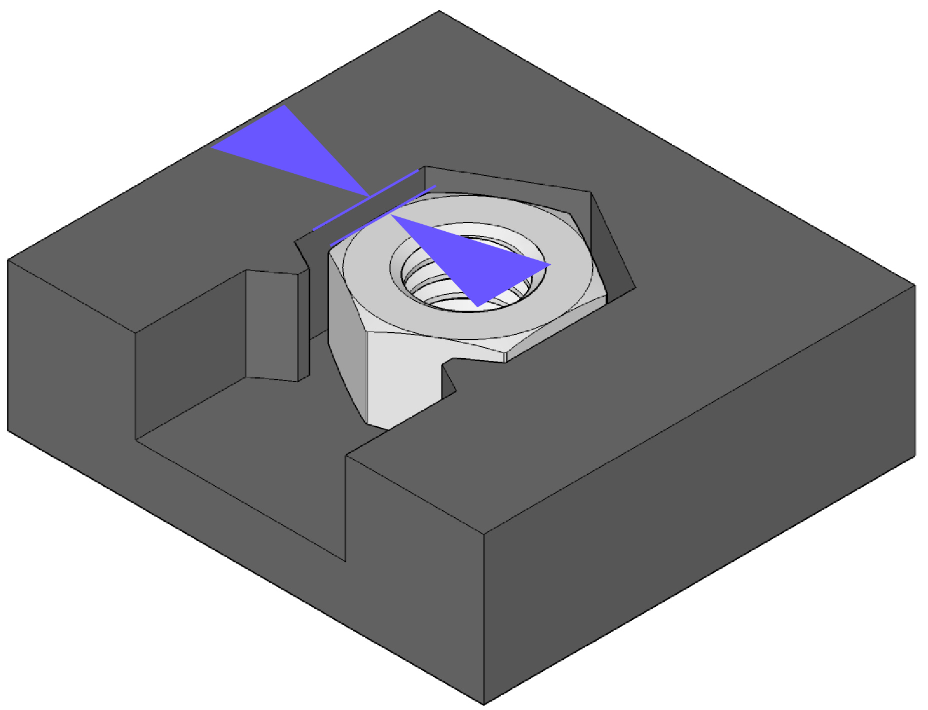
Fig 1

Threaded holes

Nut pocket

This is a cavity designed to hold a hexagonal nut. The pocket resists the rotation of the inserted nut so that the screw easily threads into the nut.

- Pocket should allow a small amount of play so that the screw can properly thread into nut without stripping.
- **Recommend 0.25mm clearance for nut.**



Helical inserts

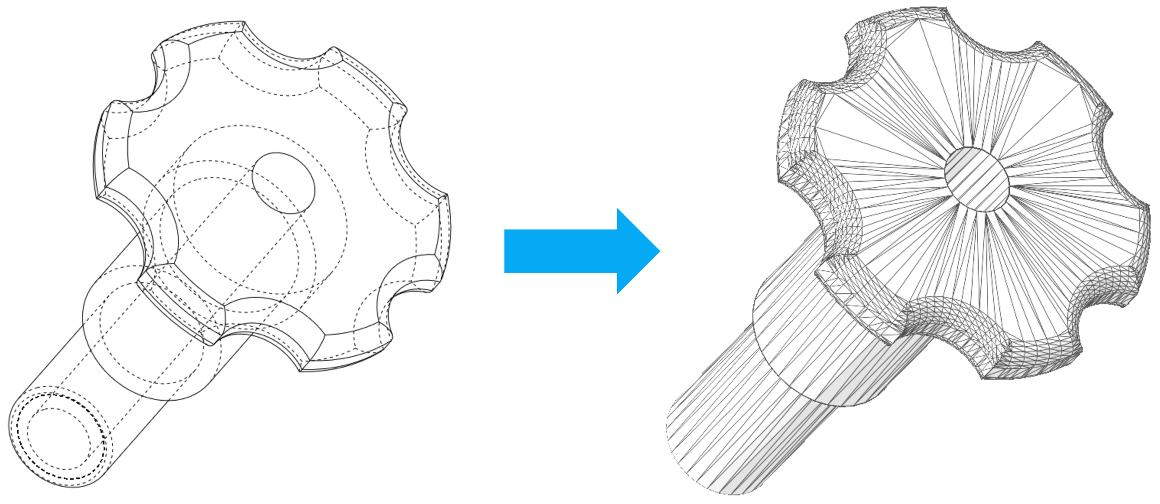
This is a coiled wire insert that is screwed directly into the part.

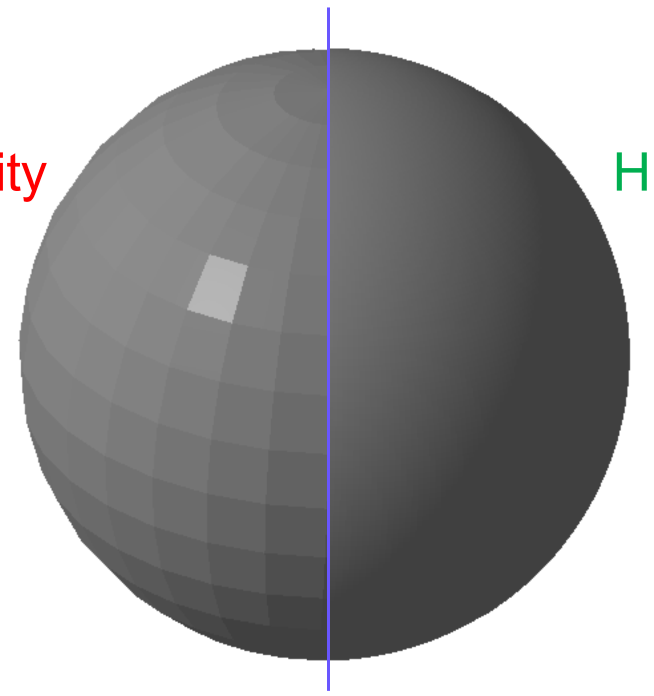
1. **Design a hole 0.25mm smaller than the manufacturer recommended plastic hole diameter.**
2. After printing, ream out the hole with drill bit the same size as the manufacturer recommended plastic hole diameter.
3. Carefully tap hole.
4. Insert helicoil.

Model tessellation

Before printing, digital models need to be exported from the CAD software where they were created to the .stl file format. The conversion process tessellates the model, converting it to an explicitly defined mesh of triangles usable by our printers. Proper tessellation will create a high quality model with smooth surfaces and well articulated features without **faceting.**

High quality digital models are necessary to maximize part quality. The DLS™ process is especially sensitive to the smoothness of digital models. Faceting that is not visible in other additive processes can be seen on DLS™ parts.





Exporting CAD models

Most CAD programs offer options to optimize the tessellation of parts before exporting. These options are typically surface deviation and angle. Smaller values create smoother geometry.

Recommended tessellation values:

- **Surface deviation = 0.01 mm**
- **Angle = 1.0 deg**

Exporting from Solidworks:

1. Select **File --> Save As...**
2. Select **STL (*.stl)** from the Save as type: pull down menu.
3. Click **Options...** and the Export Options window will pop up.
4. Leave **Binary** selected.
5. Under **Deviation,** set **Tolerance** to .01mm.
6. Under **Angle,** set **Tolerance** to 1 degree.
7. Click **OK.**
8. Enter the file name and click **Save.**