A1. Appendix: Design Optimization Strategies

Decreasing the overall mass and wall thickness of printed parts helps to reduce the amount of material used, which has an associated cost reduction. Furthermore, thinner sections accumulate and re-radiate less heat, improving the dimensional accuracy and general look and feel of the parts. The most obvious re-design route is to alter the CAD manually, trying to remove any unnecessary features and sections, as it is done for other manufacturing technologies. However, Additive Manufacturing allows the designer to create more complex structures than ever before, enabling substantial savings in time, material, and assembly time.

Semi-automatic re-design routes can be followed to achieve similar or even greater part optimizations, such as hollowing the objects, inserting internal lattices in them or applying topology optimization algorithms. These strategies are summarized in **Figure 9** and are briefly described in the following sections, but for a deeper explanation of their use in Multi Jet Fusion, see *Design Optimization Strategies* [8]. Please note that they can be combined for even more significant mass reduction.

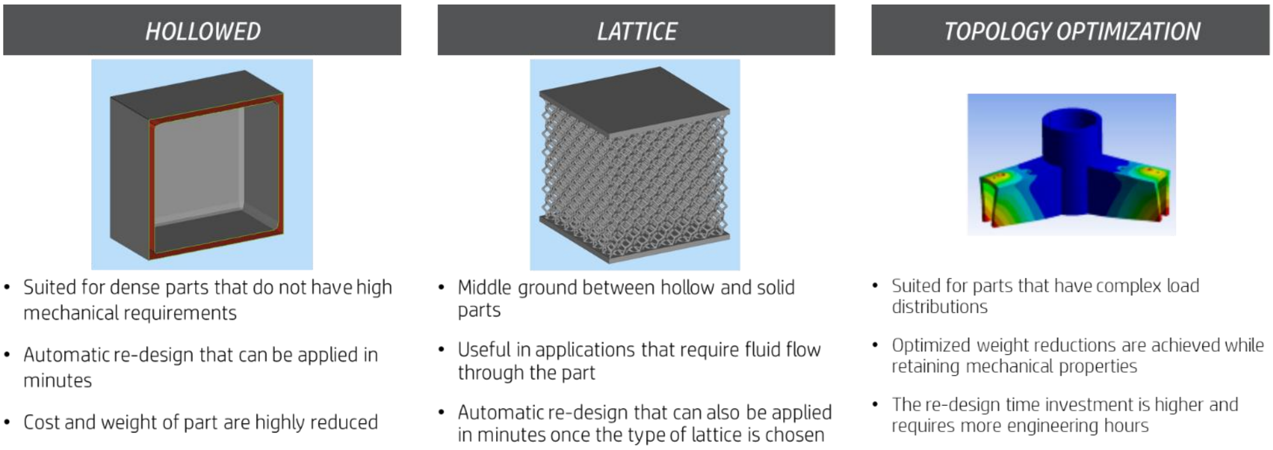

Figure 9: Description of the main semi-automatic re-design approaches for parts printed with Multi Jet Fusion.

Hollowing

This method consists of hollowing the CAD file through an automatic process. This is very fast and simple, reducing the mass of a part significantly, but at the expense of its mechanical integrity, as the amount of melted material is diminished. However, the performance of the part compared with the fully solid design is ultimately linked to the remaining wall thickness and the amount of unfused powder left within the part.

- The minimum recommended **wall thickness** is 2 mm, but higher mechanical properties are achieved with thicker walls. The optimum choice is application dependent.
- At least two **drain holes** with a minimum diameter of 5 mm in opposite faces of the part are recommended for efficient powder removal, which is critical to obtaining the highest weight reduction.
- **Trapped unfused powder** can be left within the part if no drain holes are included. This results in heavier and more resistant parts compared with the fully hollow option, however. While the part is still light, it is weaker than the non-hollowed version. The difference in weight stems from the different density of

fused and unfused material. Leaving the powder trapped within a part also saves post-processing time, since no powder extraction is required.

Lattice Structures

This approach consists of hollowing a part and replacing the internal solid mass by a lattice structure that provides mechanical integrity via the collective action of many rigid cells. The advantage of this method is that it allows to modify the overall behavior of the part despite using the same material. This re-design is also a fast process that can be automated with professional software. The main design parameters in these cases are the type of lattice cell (see Figure 10 for some common examples), distribution of the lattice cells, beam thickness, wall thickness for enclosed lattices, and the presence of unfused powder.

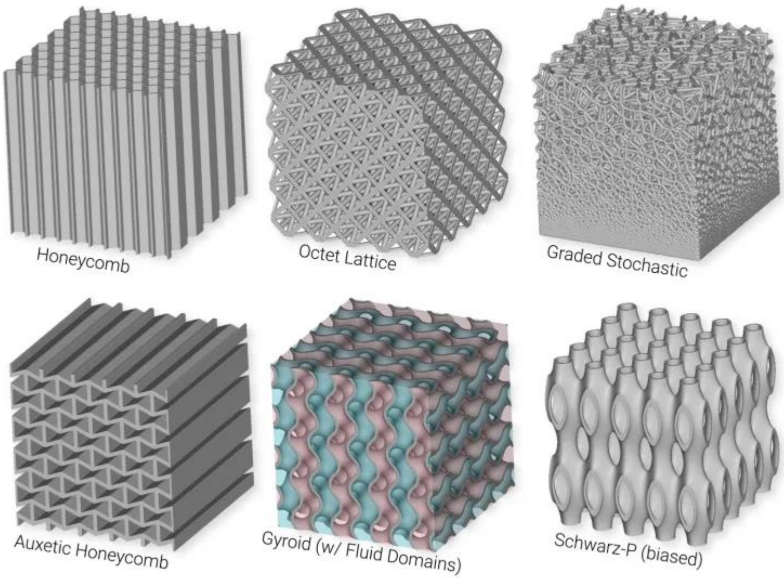

Figure 10: Examples of structure cells that can be used to tune the mechanical properties and weight of a printed part. Image from nTopology documentation [9].

- The **geometry** of each cell of the lattice defines the load distribution. Lattice geometries can be isotropic or anisotropic. This choice of geometry allows designers to introduce different local properties on the final part.
    - Lattices increase the file size of the parts considerably, requiring more computational powder. It is recommended to use lattice cells as simple as possible, so consider reducing the number of triangles per cell.
    - Simple cells with open channels are easier to clean that those with convoluted shapes.
- The **point distribution** determines the size of each lattice cell. The higher the cell size given a specific geometry, the fewer cells in the same volume, leading to a higher cost/weight reduction, but also to a greater mechanical trade-off.
    - It is recommended to avoid broken patterns when adding a lattice (see Figure 11), especially

if no external wall is added. Thus, select a cell size that is a multiple of the total length to cover (for parallelepiped volumes), for instance, use 10 cells of 10 mm to cover a part of a 100 mm.

- The thicker the beams, the higher deformation resistance of the parts. However, at some point the structure is so rigid that increasing the thickness does not vary noticeably the haptic properties of the part. Thus, a beam thickness of 1 – 1.5 mm is recommended.
- The wall thickness surrounding a lattice would add weight and mechanical robustness to the part, so the thicker the wall, the higher the resistance to deformation under the same load.
    - Pay attention to the joining section of the lattice to the wall, since it is possible to have triangulation and connectivity problems. To minimize these issues, avoid broken patterns and connect the lattice to the wall on the widest point (see Figure 11). If the beams have constant cross-section, consider increasing it gradually on the connection points.
- Unfused powder can be difficult to remove from a part through drain holes when a part has a lattice structure inside it. Therefore, it is recommended to leave the powder trapped within it or to leave the lattice partially open. A minimum separation of 5 mm between lattice beams is recommended in order to facilitate powder removal.

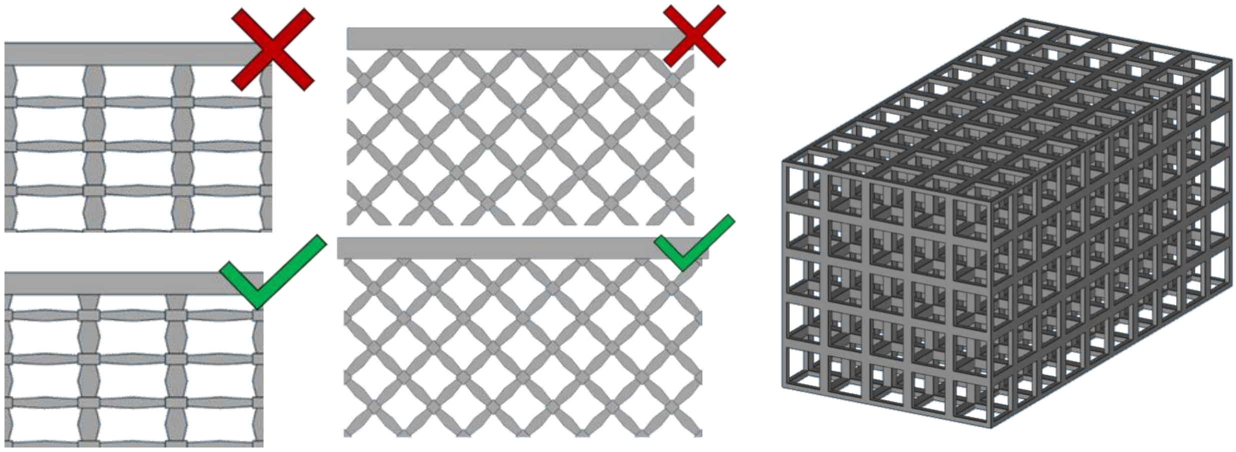

Figure 11: (Left) Examples of lattice-wall joints where the option maximizing beam cross-section on the connection point is preferred. (Middle) Example of a broke pattern and its solution by selecting the appropriate cell size for the available space. (Right) Example of a lattice following the recommendations, that is a simple cell, closed pattern, gap size of 6 mm, and a beam thickness of 1.5 mm.

A2. Appendix: Minimum Features

Each geometry and application present a unique set of factors that define the minimum features that can successfully being produced with BASF Ultrasint™ TPU01 and the Multi Jet Fusion 5200/5210 series. Some of these factors and the effect that they have on the outcome are:

- **Accumulated heat**, which is related to the delivered energy by the system, the mass of the part and the local packing density. Hotter parts are more likely to grow, which increases the size of the pins and walls and closes holes and gaps. Thus, allow higher tolerances for massive movable parts.
- In MJF the non-fused powder acts as a support during printing but needs to be removed later on. Assemblies with clear **powder escape routes** are more likely to move with tighter tolerances.
- **Cleaning and post-process** influence the final parts. For instance, a feature can be printed correctly but broken later during cleaning, gaps and holes are reduced with coatings, tumbling decreases and rounds most features, and beads used during blasting can get stuck in gaps or text with a similar size.

Thus, the reader is given the values of **Table 2** as a starting point for the use of BASF Ultrasint™ TPU01, but iterative experimentation is encouraged to achieve optimum results.

Table 2: Recommended size for various features

Feature	Recommended size
Wall thickness	
Min. vertical walls	0.5 mm
Min. Horizontal walls	0.5 mm
Most recommended wall thickness	2.0 mm
Max wall thickness	7.0 mm
Features sizes	
Min. hole diameter at 1 mm thickness	0.5 mm
Min. shaft diameter 10 mm high	0.5 mm
Min. clearance at 1 mm depth	0.5 mm
Min. slit between walls 1 mm thick	0.5 mm
Min. feature size width	0.1 mm
Printable Letters and Labels	
Min. printable font size (letter height)	12 pt = 4.2 mm
Min. deboss depth	1 mm
Min. emboss height	1 mm
Cleaning Features	
Min. diameter escaping holes	5 mm
Most recommended diameter	10 mm

Lattices	
Min. strut thickness	1 mm
Min. lattice hole (gap)	5 mm (may be insufficient for long latticed parts)

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