White paper

Design optimization strategies: Transitioning from traditional manufacturing technologies to HP Multi Jet Fusion technology

Data courtesy of KINBOSHI

Executive summary

The highest value for Additive Manufacturing is achieved when 3D printing is introduced into the very early stages of the product life cycle. At these stages, designers can consider designs that are only possible through Additive Manufacturing, the combination of assemblies, and the optimization of the designs for the specific manufacturing process. The role that design plays in the process changes depending on where the product is in its development cycle.

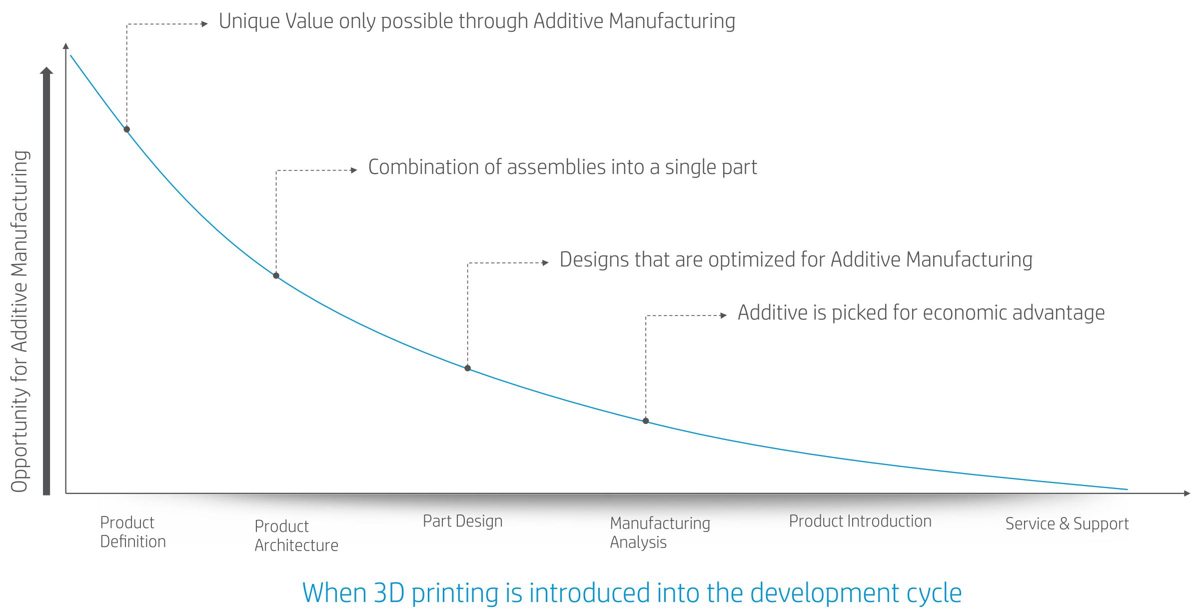


Figure 1: The value of Additive Manufacturing in the development cycle.

In many cases, however, it is easier to start the adoption journey with an **existing product**. This paper presents several automatic design optimization methods that can help you take full advantage of Additive Manufacturing when moving production from traditional manufacturing methods to those that involve HP Multi Jet Fusion (MJF) technology for parts that have already been designed.

The **re-design decision trees** presented in this paper will help your teams filter through the possible parts that can be 3D printed and assess the recommended re-design strategy for each part. The **factors** that affect that decision include how solid the part is, its size, the desired production volume, and mechanical requirements.

There are **three re-design strategies** that can be used when a part has already been designed for another manufacturing method: **hollowing, internal lattice structures, and topology optimization.**

Big, solid parts are great candidates for applying re-design strategies.

Considering the small time investment required to apply the re-design, hollowing parts or creating internal lattice structures results in **high weight/cost reductions vs. invested re-design time**. However, these strategies can only be applied to dense parts.

Lattice structures are applied when dense parts require high mechanical performance but have a very similar cost reduction as hollow parts, which makes them a **recommendable re-design strategy to maintain sufficient mechanical properties and obtain high cost reductions.**

Topology optimization methods provide the most **optimized cost/weight reductions while maximizing the mechanical performance of a part** but require a significantly greater time investment.

For thin parts, topology optimization or manual re-design are the only re-design strategies that can be used, and the time investment must be justified by the production volume (business case) or by the performance increase that can be obtained.

Wall thicknesses less than 2 to 2.5 mm are not recommended when hollowing parts. The recommended wall thickness will depend on the specific function and size of each part and will need to be tested.

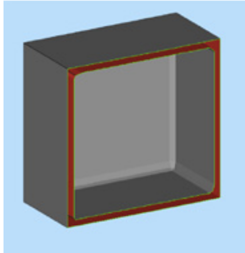
To achieve the best balance between cost/weight reduction and mechanical performance, the recommended geometry is the **hexahedron-based pyramid (Geometry 3) with a cell size of 8 mm and a beam thickness of 1.2 mm.**

Although there are no printing limitations for the parameters analyzed (i.e., dense parts), it is wise to re-design the parts to **achieve the best part quality and maximize the consistency and repeatability of your production.** The throughput when printing massive parts can be **limited by the packing density limit.** Thus, these re-design strategies will also help maximize the productivity of your printer.

Automatic product parametric design can help to automate a re-design and adapt the resulting outcome to a series of input parameters.

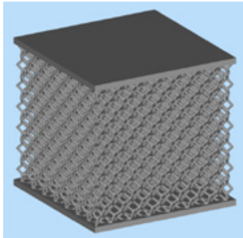
HOLLOW

- Especially suited for solid parts that do not have high mechanical requirements.
- Automatic re-design that can be applied in minutes.
- Cost and weight of part are highly reduced.



LATTICE STRUCTURES

- Especially suited for solid parts that require mechanical properties.
- Automatic re-design that can be applied in minutes once the type of lattice needed for the specific part is chosen.



TOPOLOGY OPTIMIZATION

- Especially suited for thin parts or parts that have complex load distributions.
- The re-design time investment is higher an requires more engineering hours.
- Optimized weight reductions are achieved given the computational nature of the process while maximizing mechanical properties of the part.

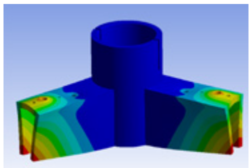


Figure 2:
Main characteristics of the three re-design strategies.

Part assessment

Starting from a list of potential candidates, the flow chart below will help you decide which parts make the most sense to re-design first. The three key aspects to consider are:

1. **Solidness of the part:** In the case of very dense parts, the potential weight and cost reductions are very relevant when taking advantage of the design freedom of 3D printing and, therefore, these are the most suitable parts to which to apply the re-design strategies presented above. For parts that are not dense, the first two re-design strategies do not apply and the time invested in applying topological optimization strategies must be justified by other parameters such as the size of the part or its production volume.

2. **Part size:** Reducing the cost and weight by a given percentage will always have a higher absolute for big parts, whether in terms of cost or performance increase (lightness in weight). In the case of small parts, the impact of the change must be evaluated in terms of production volume to justify the time invested in the re-design.

3. **Production volume:** High production volumes can make a re-design with lower cost/weight reductions result in a significant impact and, therefore, re-designs must be evaluated in these cases.

The following decision tree provides a systematic approach to deciding what parts should be re-designed.

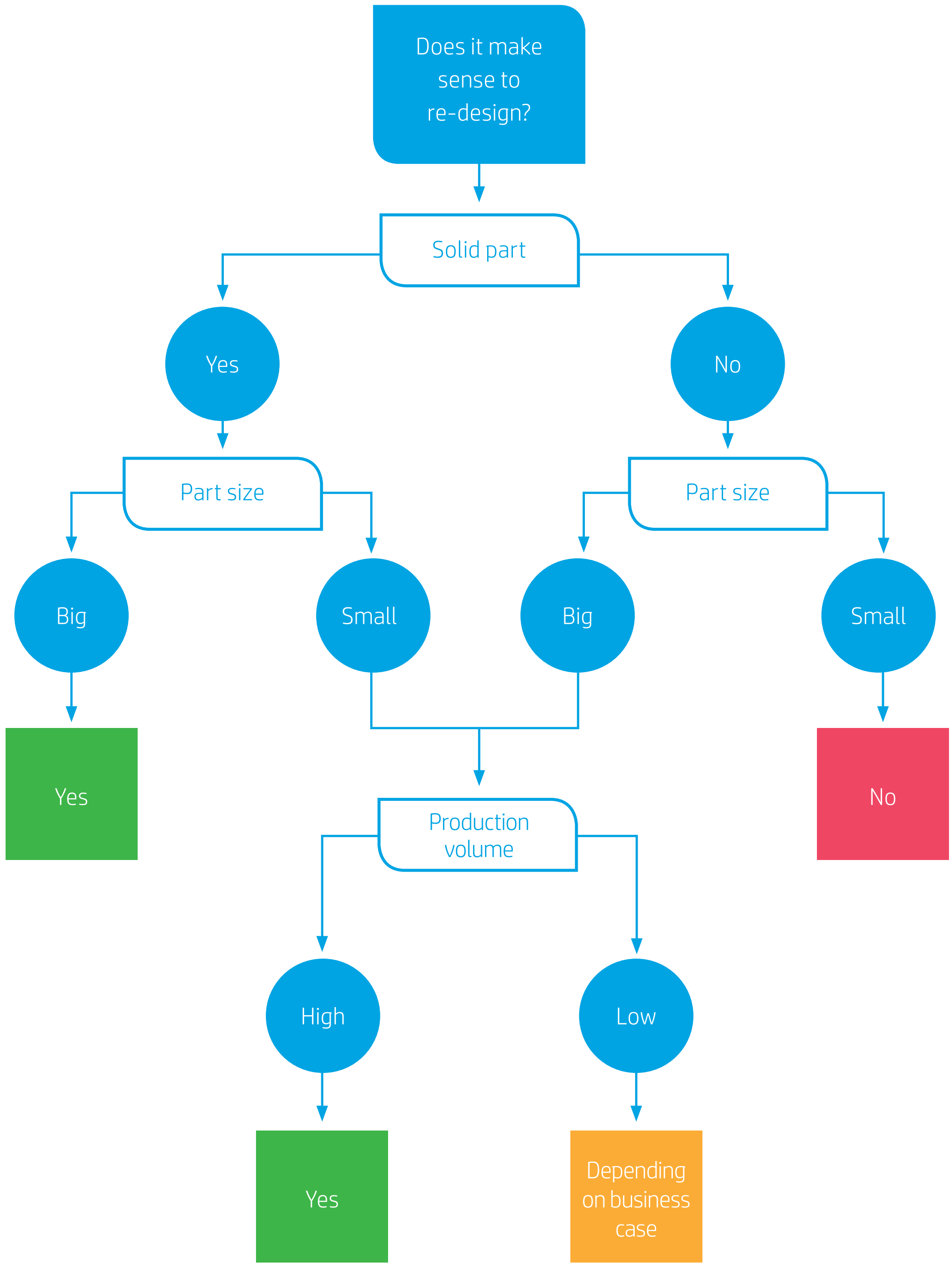


Figure 3: Decision tree for deciding whether to re-design a part.

Re-design strategies

Hollowed parts

The advantages of this method are that the re-design is very fast and simple and that it can significantly reduce the mass of the part, but it can also reduce the mechanical properties to the point that the part no longer meets its requirements. Therefore, solid parts that do not have high mechanical requirements are great candidates for this re-design strategy. Generally, parts with a thickness greater than 15 mm can be considered solid parts, although the analysis should be done on a case-by-case basis.

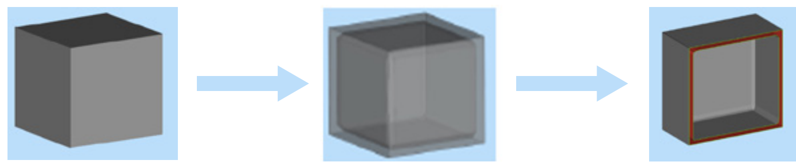


Figure 4: Step-by-step process for hollowing parts.

In general, the minimum **recommended wall thickness is 2 mm**, but for big parts, a thickness of 2.5 mm will result in better performance. It is necessary to determine the optimal value considering the characteristics of each case. We recommend considering lattice structures when the required wall thickness to meet the functional requirements exceeds 15 mm.

When applying this re-design strategy, cost reduction is achieved by using less of the agent given the smaller area to fuse, thus less powder is fused, which can allow for bigger packing densities and, therefore, more parts in a build. For example, when hollowing these cubes, the use of agent was reduced by approximately 80%.

Lattice structures

This method involves hollowing the part and replacing the solid mass of the area inside it with a lattice structure. The advantages of this method versus simply hollowing the part is that it retains most of the mechanical properties of the original solid part while reducing its mass and, therefore, its cost. Also, this re-design is a fast process that can be automated, but the cost and weight reductions are not as significant as in the previous method.

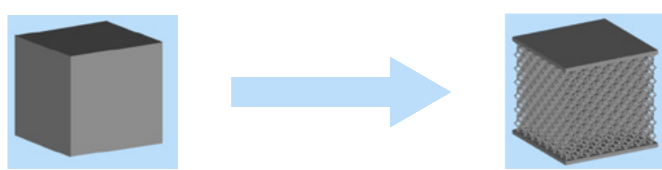


Figure 5: A solid part and one with lattice structures.

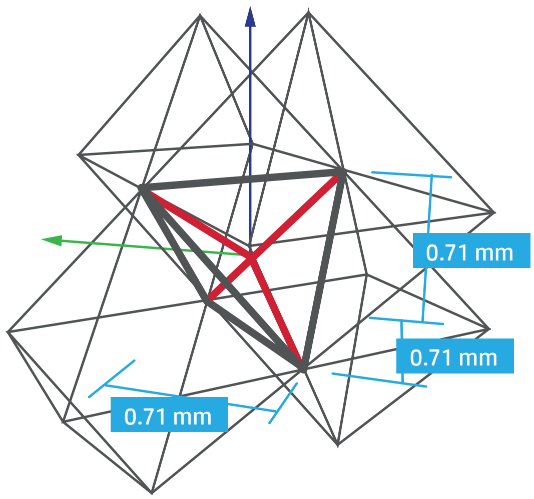
There are **two parameters** by which designers can fine-tune to meet the mechanical requirements of the re-designed part: **wall thickness** and **the type of lattice structure used.**

To choose the right type of lattice structure, there are **three parameters** to consider:

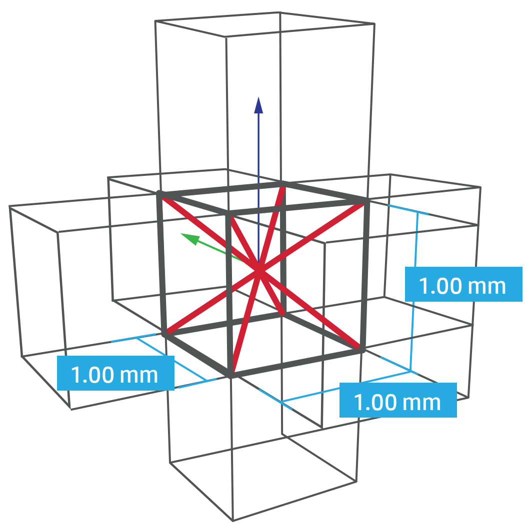
1. **Geometry:** The geometry of each cell of the lattice defines the load distribution. Lattice geometries can be isotropic or anisotropic. This allows the designer to introduce different local properties to the final part, depending on its desired performance.

2. **Point distribution or cell size:** Point distribution determines the size of each lattice cell: The bigger the given cell size for a specific geometry, the lower the number of cells needed for the same volume and, thus, the higher the weight/cost reductions, but also the higher the reduction in mechanical properties.

3. **Beam thickness:** The thicker the beams within the lattice structure, the better the mechanical properties, but the lower the cost/weight reductions.



	Geometry 1					
Cell size (mm)	5			8		
Beam thickness (mm)	0.8	1	1.2	0.8	1	1.2
Volume reduction	89%	62%	47%	87%	84%	82%
Deformation to compression	MEDIUM	LOW	LOW	HIGH	MEDIUM	MEDIUM



	Geometry 2					
Cell size (mm)	5			8		
Beam thickness (mm)	0.8	1	1.2	0.8	1	1.2
Volume reduction	86%	78%	69%	86%	83%	80%
Deformation to compression	MEDIUM	LOW	LOW	HIGH	MEDIUM	MEDIUM

Table 1: Study of the different lattice structure geometries

Therefore, given the weight reductions and mechanical performances of the geometries tested, we recommend a **hexahedron-based pyramidal geometry (Geometry 2) with a cell size of 8 mm and a beam thickness of 1.2 mm** as the general lattice structure dimensions that should be applied. However, each part needs to be studied specifically to determine the type of lattice that will better meet the performance of the part.

Regarding the cost reduction achieved when applying lattice structures, the use of agent typically reduces the cost by 60% to 70%. Thus, **lattice structures are the recommended re-design for solid parts**, as it is possible to achieve a better mechanical performance with a very similar cost reduction compared with hollowed parts.

The following table and chart qualitatively compare the three re-design strategies based on the criteria described at the beginning of the chapter.

Criteria / Re-design strategy	Hollow	Internal lattice structure	Topological optimizations
Manufacturing cost reduction	High	High	Very high
Time required for design optimization	Minutes	Minutes	Hours
Part performance knowledge	Basic	Basic	High
SW required	CAD or STL-management	CAD or STL-management	CAD + FEM
Weight reduction	High-very high (depending on keeping the unfused powder inside or not)	Medium high	Very high

Table 2: Summary of the different re-design methods.

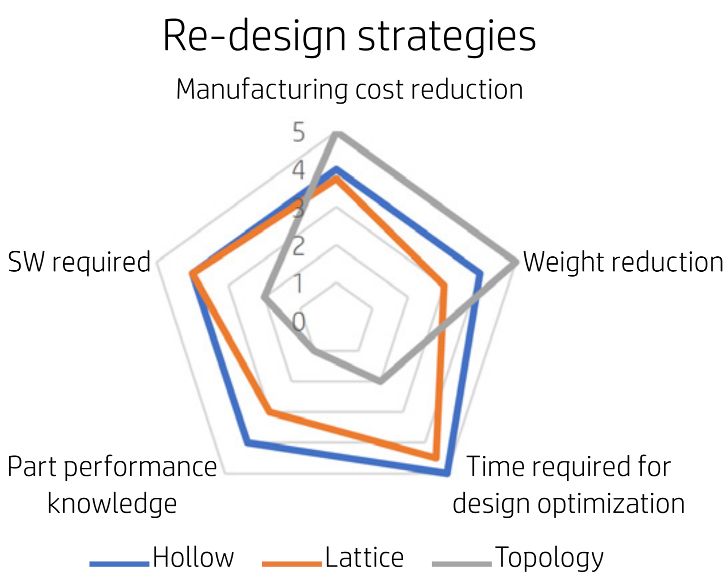


Figure 6: Radar chart comparing the different attributes of each re-design strategy.

For parts that are worth re-designing, the **four key aspects** that will help you choose the best strategy are:

1. **Mechanical properties:** Hollowing strategies will most likely not be suitable when parts need to resist mechanical stresses. Therefore, it is important to understand the need (or lack thereof) for those requirements from the beginning.
2. **Performance complexity:** Performance complexity refers to the complexity of the loads applied to a part and, thus, it only applies for parts that require mechanical properties in the first place. In cases where load distribution is simple, it does not always make sense to apply topological optimization strategies because a manual re-design or an automatic lattice structure could be even easier and faster to apply and may result in the same levels of cost/weight reduction. However, each case needs to be analyzed. Optimizing topology is recommended when the complexity of a part is such that it is not trivial for the designer to find the best re-design of the part.
3. **Solidness of the part:** Sometimes the solidness of the part will determine the recommended re-design method. In the case of very dense parts, applying a lattice structure to or hollowing them will bring about the best cost/weight reductions, but it will not make sense to apply lattice structures or hollow parts when they are not dense. In these cases, a manual re-design or a topological optimization are the best re-design strategies.
4. **Production volumes:** The time invested in the parts' re-design must be justified when analyzing the business case. Therefore, it is important to take this parameter into account as well when choosing the re-design strategy.

The following decision tree will help you decide which re-design strategy is best suited for each type of part.

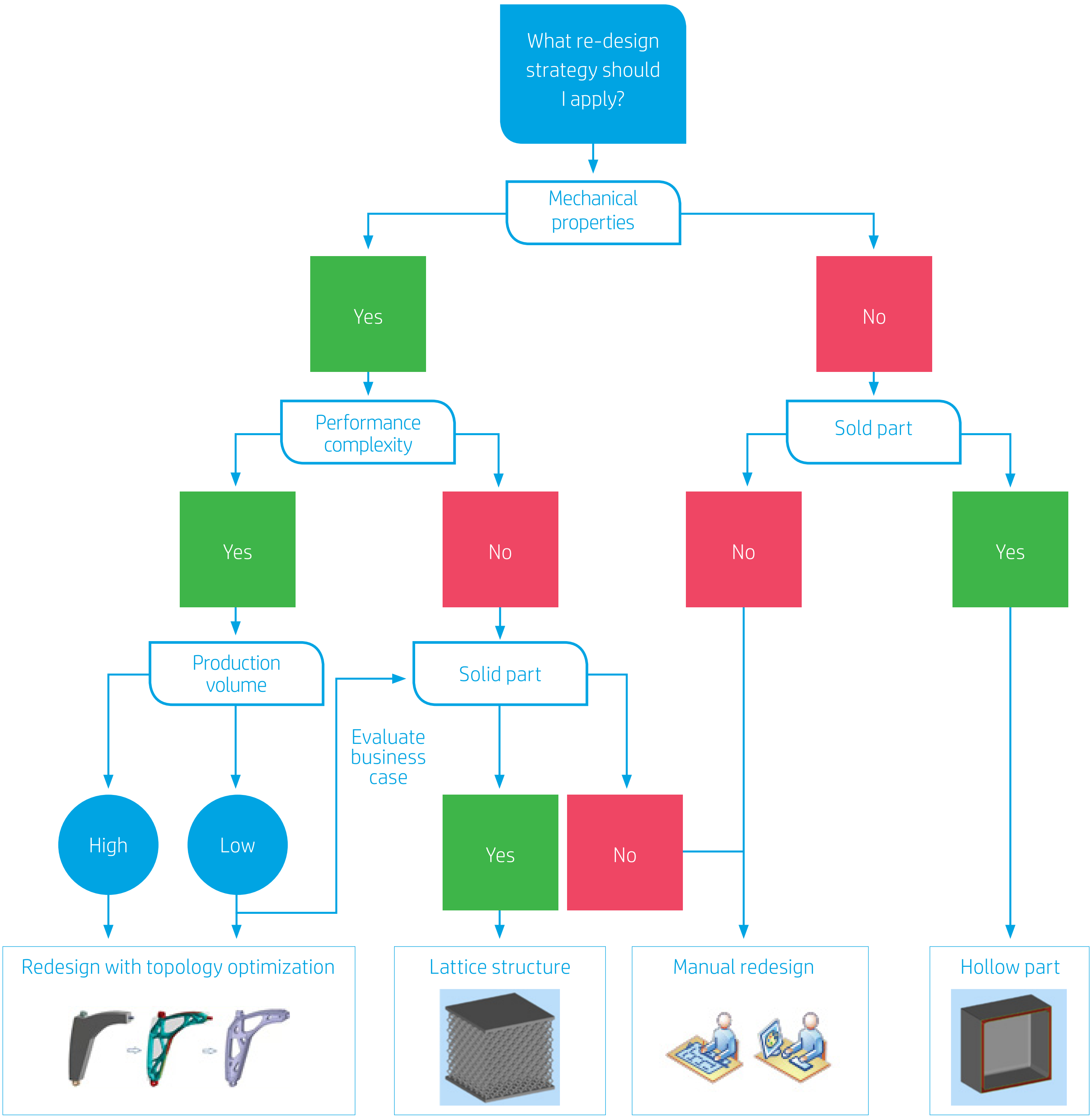


Figure 7: Decision tree for deciding on the best suited re-design strategy for each type of part.

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