Topology Optimization: An approach to light weight design, and manufacturing limitations

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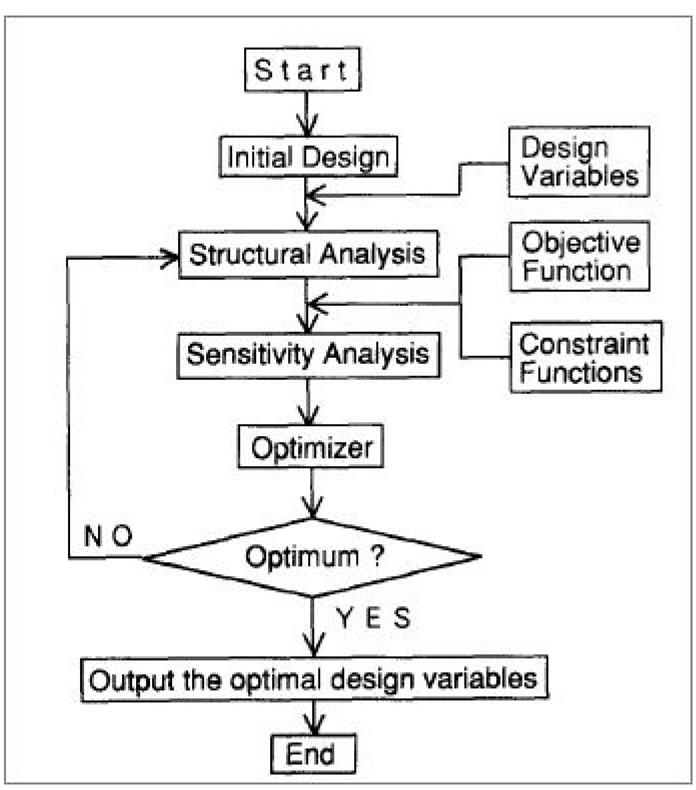
1 Introduction

Design is more than just an art, it is a philosophy of how things are meant to be. Its influences the direction of human progress and understanding. Human have ever longed to replicate nature. In achieving this, we have achieved something remarkable, harnessing the power of our technology, stumbling resembalances with the evolution itself have been made. Motivation for such a research has been propelled by the ever increase in population and demand of resources. So these technologies are a heart for light weight and yet robust components of our everyday things including cars, bridges, tables etc. These methods fall broadly under two categories, material substitution and material removal methods. The former has led to multiple active areas of research like programmable materials, microstructure enhancement. Lets take the automotive industry as a case study. The share of automotive industry in this sector would likely to increase from 30-70% by 2030[11].The later method gives control to the designers in the early product development stage, which is mostly experience driven, to start with an unconventional product design[10]. These techniques allow us to design automobiles of very low weight and gives the best for component weight to performance ratio. One of the most important method is called **Topology Optimization**. The scope of the present discussion is the principles involved and the applications.

2 Applications

Though these techniques are widely used in general in aerospace and other structural optimization applications, automotive industry is soon catching up to this technology, and several examples of its implementation is discussed here. In general the design methodology is illustrated from the below flow chart[6],



2.1 Vehicle body

This technique is most commonly applied with respect to light weighting of the chassis in automotive industry. Several industries have implemented the technique and have significantly cut down weight and corresponding material costs. This technique would give the designer an initial design point which bears the same loads as a conventional shell of the chassis but with optimal topology. This would give an enhanced performance without compromising on the safety of the vehicle[4].

2.2 Weld pattern design

Apart from the material distribution using density distribution as a parameter to optimize, other parameters like weld pattern and bead size can also be optimized for better design decisions. Apart from optimal design, topology optimization is recently also being used in deciding the optimal weld pattern, which would help in designing a robust system. In this context this method is being used to simulate optimal spot weld positions[5].

2.3 Design selection

Topology Optimization is a used as a tool by the designer to start the search for an optimal design to build upon before designing any component. Multiple designs can be analysed and the decision can be taken on which should be selected. A work done by D. Costi et. al., has implemented to compare the design benefits between coupe and spider type chassis[7]. The work illustrates search for optimal design by starting in a huge design space. Both the designs are compared under loading conditions and compared. They also implemented in reality and observed the coherence in the FEA vs practical application.

2.4 Automotive hood inner panel

Every car has a front bonnet to house the engine and other components. The covering and the support structure of the bonnet add to the mass of the bonnet. Work[8] has been done, to optimize the material distribution under automotive bonnet. In this study Altair Optistruct is used for optimization. Along with topology, topography and topometry optimizations are also done to find out the thickness and material density variations at various coordinates on the bonnet. They were able to achieve 12.4% of mass reduction.

2.5 Automotive component design

Most of the components are custom designed for particular group of cars. This technique can be used to design various components like upright or knuckle design, brake pedal design, pedal mount design etc. A study was done[9] to show the weight reduction achieved in a brake pedal design. Constraints like force applied and fixtures are given along with an initial design was given and a pedal with weight reduction of 22% obtained. Such a design though might not be feasible considering a passenger car and its manufacturing budget, but would have a significant influence on the performance of the car.

3 Manufacturing

There are many inherent manufacturing limitations to implement the method directly in the industry. A few of them are discussed here.

3.1 Additive Manufacturing

With the growth of research in the field of additive manufacturing, the potential to design complicated structures. Generally as the complexity of the product increases the cost of production increases, but in AM it remains constant and in some cases might actually decrease. Production processes like selective laser sintering, also called Direct Metal Laser Sintering, where layers of metal poweder are sintered selectively layer by layer and layers have a thickness of 20-100 μm. Such a manufacturing process can accommodate thin walls, deep cavities or some embedded channels deep inside. Such a process is critical for design of structurally optimized components. The comparison done between Traditional and AM in one of the studies is shown below[1].

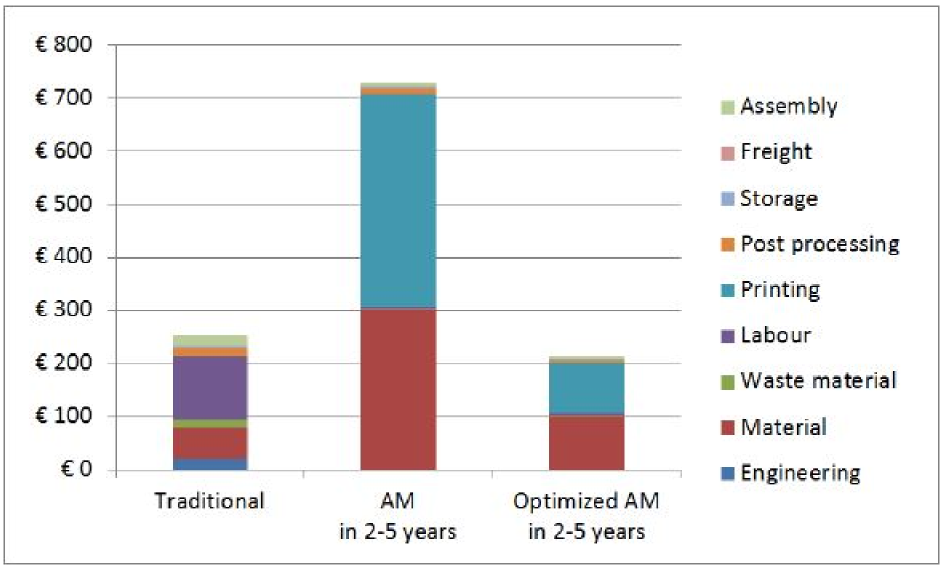


Figure.1: Cost of production vs manufacturing technique[1]

3.2 Hybrid Manufacturing

Hybrid machining processes takes advantage of the least wastage of material from the additive manufacturing and the precision and control of CNC machining to get the best out of them. With the growth of demand for manufacturing processes which can produce complicated components at a fast rate, hybrid additive manufacturing technology is growing at their conjunction[3]. Though research is being carried on in this field commercialization of Hybrid Manufacturing systems are still in their primitive stages.

The most common combination used is Direct Energy Deposition(DED) used along with the CNC. In this method the component to be manufactured is produced in a CNC machine by DED and the finishing is done using a CNC milling tool. Research is being done actively in automating the tool change process.

3.3 Limitations

Topology optimization often leads to a complicated contour and are often difficult to manufacture through conventional manufacturing techniques. Even through AM, it may demand a lot of overhangs and support material. The designs obtained are not manufacturable and are often start points of a product design development stages.

The suggested design is dependent on mesh and is computationally challenging to get the resolution required. The end design after optimization is not fully finished or it is hard to interpret and implement if additional constraints such as manufacturing and deployment are not considered. Thickness and tolerance suggested by the Optimization might not be physically feasible by the practical setup available[2].

From the perspective of automotive engineering, structures like chassis can be topologically optimized for light weighting, but while AM, the low weight components might develop heat residual areas and may undergo a large deformations and deflections which are inevitable. This is the major problem hindering their application from AM perspective.

4 Conclusion

This report consists of a technique for light weighting called topology optimization and discussed briefly the possibilities and avenues for manufacturing. A few applications have been discussed with the motivation of vehicle light weighting. With the ever in popularity of AM incorporated into industries and also with the rise of hybrid additive manufacturing processes to accommodate complex components have rose significantly. In the recent years a lot of bio-inspired models have also been developed which give an optimal solution based on bio-mimicry. This is a powerful tool for all the designers and augments the decision making process during development and guide towards an unconventional design thinking processes. Future work might be building much more robust algorithms to perform even within computationally challenging constraints. Development of such techniques would also help conserve material and energy and would help towards a sustainable growth. With the ever increase in pollution, material consumption and human demands, this is a great opportunity to implement and bring a change in the conventional design methodologies.It also augments the designers capabilities giving much deeper insights in design process.

5 References

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