WHITE PAPER

# An Engineering Services Framework for Additive Manufacturing

## Abstract

Additive manufacturing is now mature and is becoming a mainstream production technique for various industries. It is important that engineering services organizations equip themselves to provide a new range of services in this sector. This paper presents an engineering process framework for evaluating and adopting additive manufacturing. It describes tools developed to improve engineering services for additive manufacturing. The paper also demonstrates the developed engineering process through a practical example of re-engineering a mechanical component, from conventional manufacturing to additive manufacturing along with the cost-benefit analysis.

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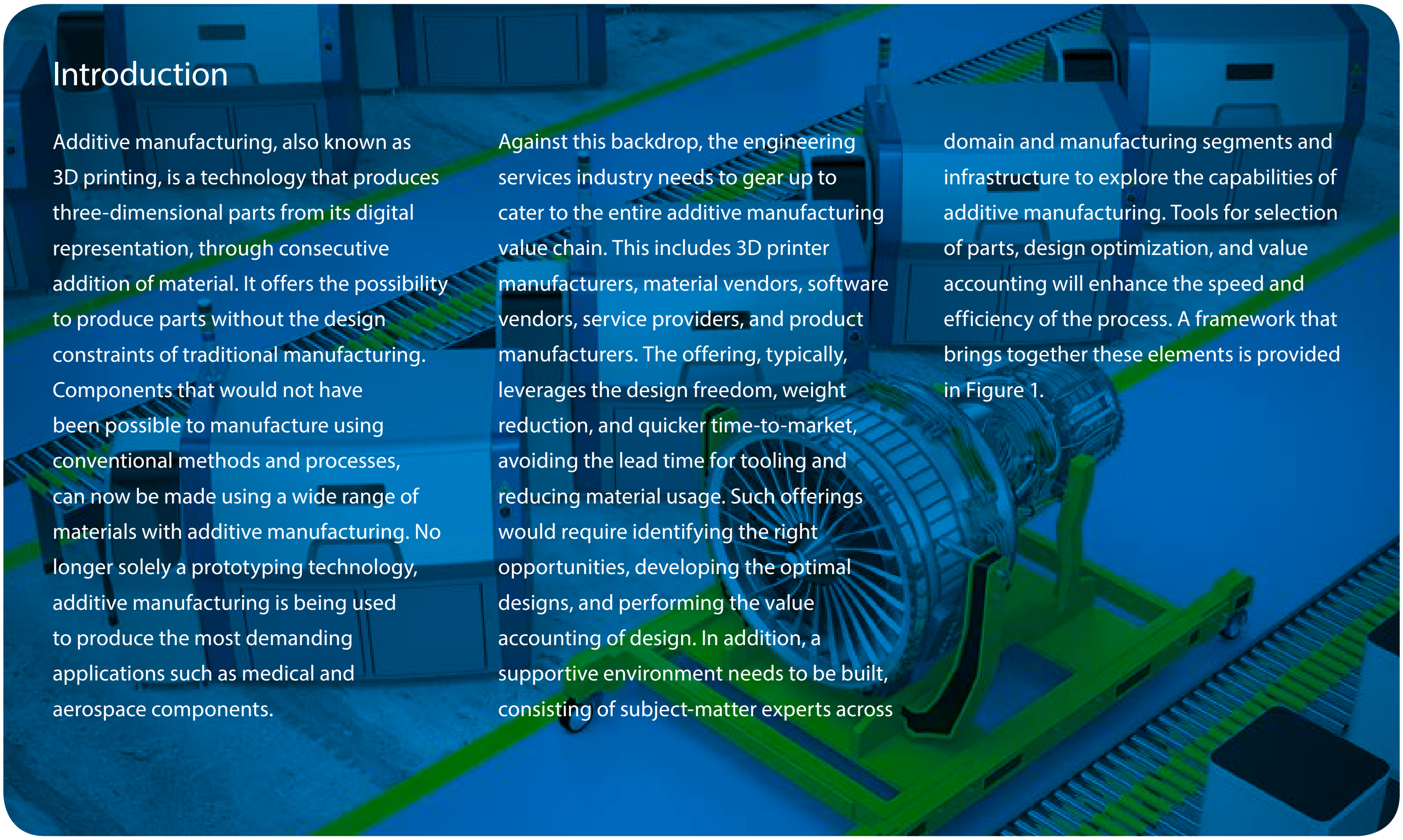
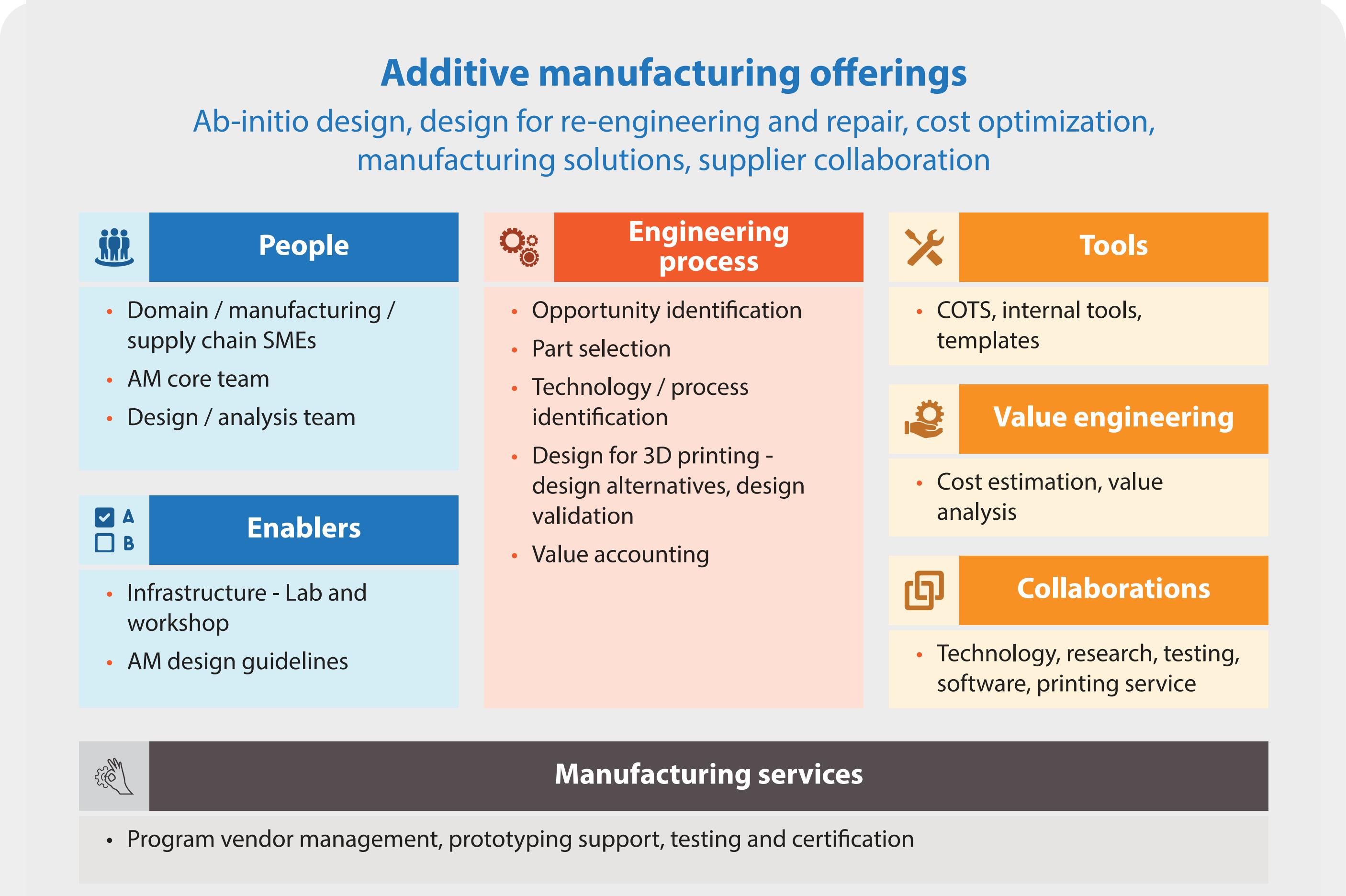


## Introduction

Additive manufacturing, also known as 3D printing, is a technology that produces three-dimensional parts from its digital representation, through consecutive addition of material. It offers the possibility to produce parts without the design constraints of traditional manufacturing. Components that would not have been possible to manufacture using conventional methods and processes, can now be made using a wide range of materials with additive manufacturing. No longer solely a prototyping technology, additive manufacturing is being used to produce the most demanding applications such as medical and aerospace components.

Against this backdrop, the engineering services industry needs to gear up to cater to the entire additive manufacturing value chain. This includes 3D printer manufacturers, material vendors, software vendors, service providers, and product manufacturers. The offering, typically, leverages the design freedom, weight reduction, and quicker time-to-market, avoiding the lead time for tooling and reducing material usage. Such offerings would require identifying the right opportunities, developing the optimal designs, and performing the value accounting of design. In addition, a supportive environment needs to be built, consisting of subject-matter experts across domain and manufacturing segments and infrastructure to explore the capabilities of additive manufacturing. Tools for selection of parts, design optimization, and value accounting will enhance the speed and efficiency of the process. A framework that brings together these elements is provided in Figure 1.



**Additive manufacturing offerings**

Ab-initio design, design for re-engineering and repair, cost optimization, manufacturing solutions, supplier collaboration

**People**

- Domain / manufacturing / supply chain SMEs
- AM core team
- Design / analysis team

**Enablers**

- Infrastructure - Lab and workshop
- AM design guidelines

**Engineering process**

- Opportunity identification
- Part selection
- Technology / process identification
- Design for 3D printing - design alternatives, design validation
- Value accounting

**Tools**

- COTS, internal tools, templates

**Value engineering**

- Cost estimation, value analysis

**Collaborations**

- Technology, research, testing, software, printing service

**Manufacturing services**

- Program vendor management, prototyping support, testing and certification

*Figure 1: Additive manufacturing framework*

## The engineering process for additive manufacturing

A business, while analyzing the suitability of additive manufacturing, typically, encounters the questions as below:

- Which parts are best suited for additive manufacturing?
- What is the applicability in the context of the existing design as well as ab initio design?
- How can the design freedom, offered by additive manufacturing, be best leveraged?
- Which of the multiple technologies are best suited?
- Will the part be cost-effective? Is there a business case in using additive manufacturing?

First, the decision on whether the business can take advantage of additive manufacturing needs to be made. Once the decision is made to use additive manufacturing, the engineering process involves identifying the right components, the right technologies, and the optimized design offering the best value. A structured framework enables making these choices with fewer iterations. A typical engineering process is depicted in Figure 2.

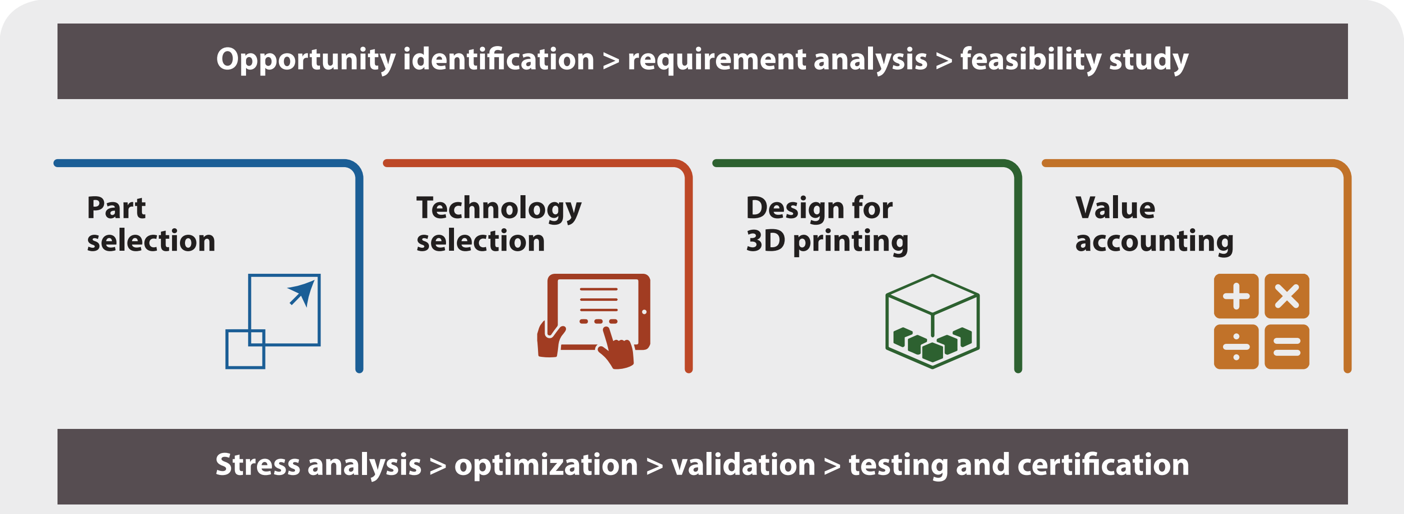


*Figure 2: Typical engineering process*

### Part selection

The characteristic advantages of additive manufacturing that is best leveraged, varies with the industry. Here are some examples:

- The capability to have lattices, replacing internal volumes, provides a great potential for weight optimization in aerospace
- Customization of individual parts achieved through CAD allows medical requirements to be met for individual patients
- The need to print at site to minimize logistical requirements of spare parts reaching remote locations, can help industries such as mining

The selection process is effective when some of the key benefits (Figure 3: Key benefits) of additive manufacturing result in a major improvement. Parameters need to be defined such that it guides the engineer in accurate parts selection.

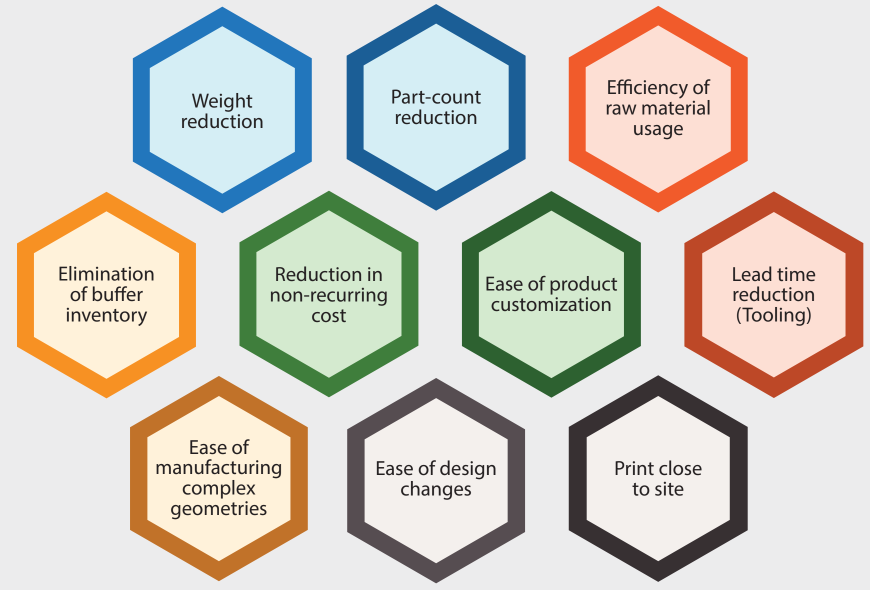


*Figure 3: Key benefits*

The analysis of an existing product typically begins with a study of the visualization models comprising the entire product parts. The required data is captured to enable the application of selection parameters to filter parts that are best suited for additive manufacturing. Then, a review of the functional requirements is performed to ensure that the design meets the requirements. A preliminary impact on the cost is also studied. The results are studied further in an expert group that identifies a short-listed set of parts.

The requirements vary based on the life cycle stage of the product for which additive manufacturing is proposed. For a new product, additive manufacturing could be considered as a prototype, limited production, or series production process. For prototype and limited production, the freedom that additive manufacturing offers to build parts of very high complexity without the lead time for tooling is a huge advantage.

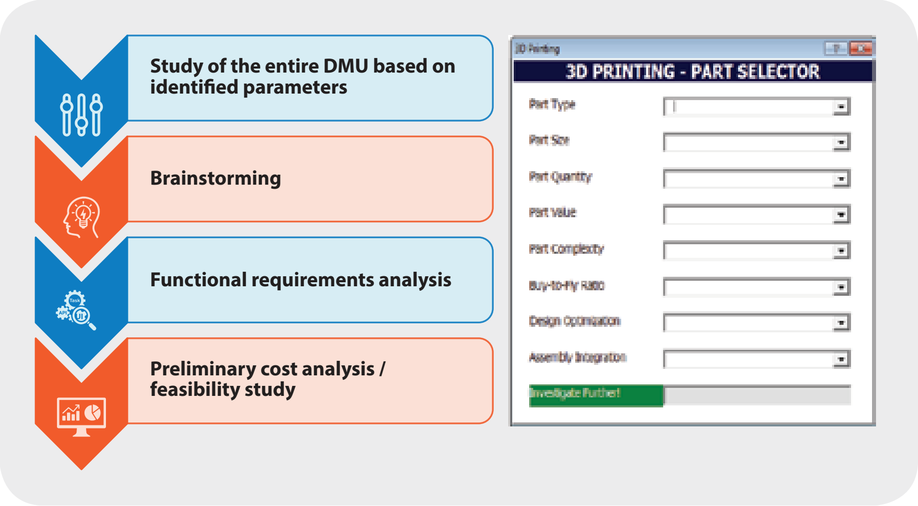


*Figure 4: Part selection*

Infosys has developed a tool (Figure 4) to analyze parts based on a set of parameters and establish the feasibility of the part for additive manufacturing. This is performed by analyzing the part attributes (type, size, quantity, value), complexity of the part, manufacturing limitations, opportunity for weight-reduction, and design optimization to reduce raw material requirement. Specific requirements of the industry are also analyzed such as the buy-to-fly ratio in aerospace. The tool provides a comparative score that can guide the engineer in preliminary parts short-listing.

## Technology identification

Additive manufacturing technology is fast evolving, providing better opportunities as well as reducing the cost and time for fabrication. A large number of technologies are grouped under the realm of additive manufacturing. An indicative list of various technologies and characteristics influencing the selection of technology are provided in Table 1 below.

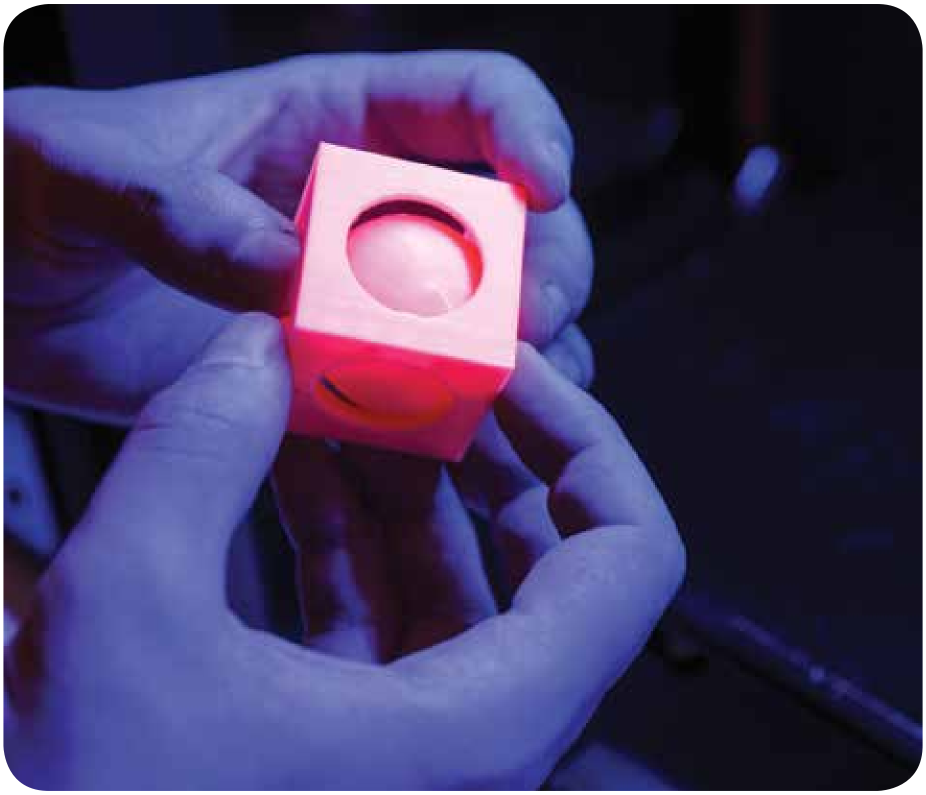
Table 1: Comparison of various technologies

| Material | Process | Material source | Heating method | Volume capacity | Resolution | Deposition rate |
|---|---|---|---|---|---|---|
| Plastic | Selective Laser Sintering (SLS) | Powder bed | Laser | V. Low | High | V. Low |
| | Fused Deposition Modeling (FDM) | Heated Nozzle | Heated Nozzle | Low | Medium | V. Low |
| Metal | Direct Metal Laser Sintering (DMLS) | Powder bed | Laser | V. Low | High | V. Low |
| | Selective Laser Melting (SLM) | Powder bed | Laser | Low | High | V. Low |
| | Electron Beam Melting (EBM) | Powder bed | Electron Beam | Low | High | Low |
| | Laser Metal Deposition (LMD) | Powder feed via nozzle | Laser | Medium | Medium | Medium |
| | Direct Metal Deposition (DMD) | Metal wire | Plasma Arc | High | Low | V. High |
| | Electron Beam Additive Manufacturing (EBAM) | Metal wire | Electron Beam | High | Low | V. High |

The following are the major parameters in identifying the right technology for the selected part:

- Material
- Size of the part
- Complexity of the component
- Quantity / production rate
- Material deposition rate
- Mechanical properties
- Resolution, post processing, and finish

Technology selection has a large impact on the part properties and quality. Therefore, conflicting aspects need to be thoroughly reviewed before selecting the technology. For instance, direct metal deposition can be extensively used for repair as it allows building up on the most substrate material using different metals. However, this will introduce thermal stresses as the process creates local melt pools for deposition.



## Design for additive manufacturing

Additive manufacturing offers enormous freedom to the designers as highlighted in the examples below:

- Capability to print very complex geometries including internal lattice structures and other intricate features
- Ease of fabrication using hard-to-machine materials
- Capability to combine multiple components of an assembly into a single sophisticated part
- Graded material combinations seamlessly varying within a part
- Objects such as sensors embedded as parts get printed

The parts are typically designed considering the limitations of conventional manufacturing processes. Once a part is identified for additive manufacturing, the design can be enhanced, leveraging the freedom offered by additive manufacturing.

A typical design process for additive manufacturing is shown in Figure 5.

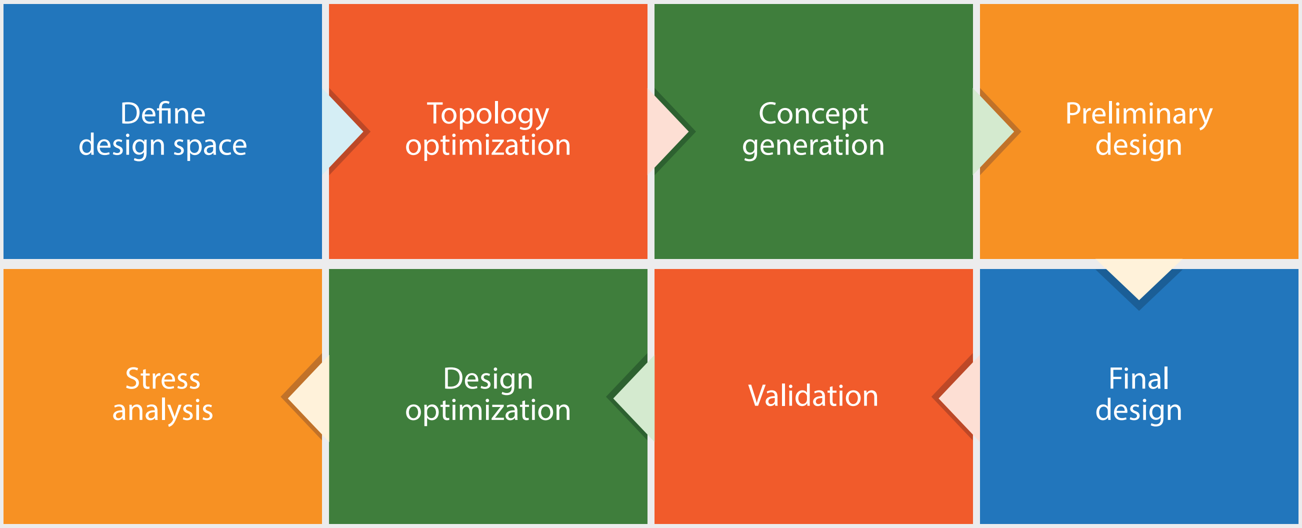


*Figure 5: Typical design process*

Take for example structural components where the designer can aim for the mathematically optimized topology, while exploring the complete design space. Optimization tools such as OptiStruct allow the designer to set the optimization parameters. For example, the designer can target weight-reduction while specifying constraints such as interface geometry, strength, and stiffness. The optimized material layout, considering the target parameters and constraints is provided by the tool. This result is used by the designer to generate concept designs in line with the optimized material layout.

The designer, however, needs to follow the design rules and understand the limitations of the selected additive manufacturing technology. Typical design considerations include: optimum orientation for manufacturing, overhangs, abrupt changes in thicknesses, minimum feature size, internal surface finish, aspect ratio, and mechanical properties, which vary with technology.

3D printing of a prototype closes the gap between design and manufacturing. Infosys has a lab fully equipped with an internally developed printer – Vismay, a Stratasys printer, required software applications, hardware tools, and measuring instruments.

## In-house 3D printer – Vismay

Most 3D printers available in the market are very expensive. Hence, a group of creative and innovative engineers conceptualized, designed, and developed an affordable 3D printer, 'Vismay' (Figure 6).

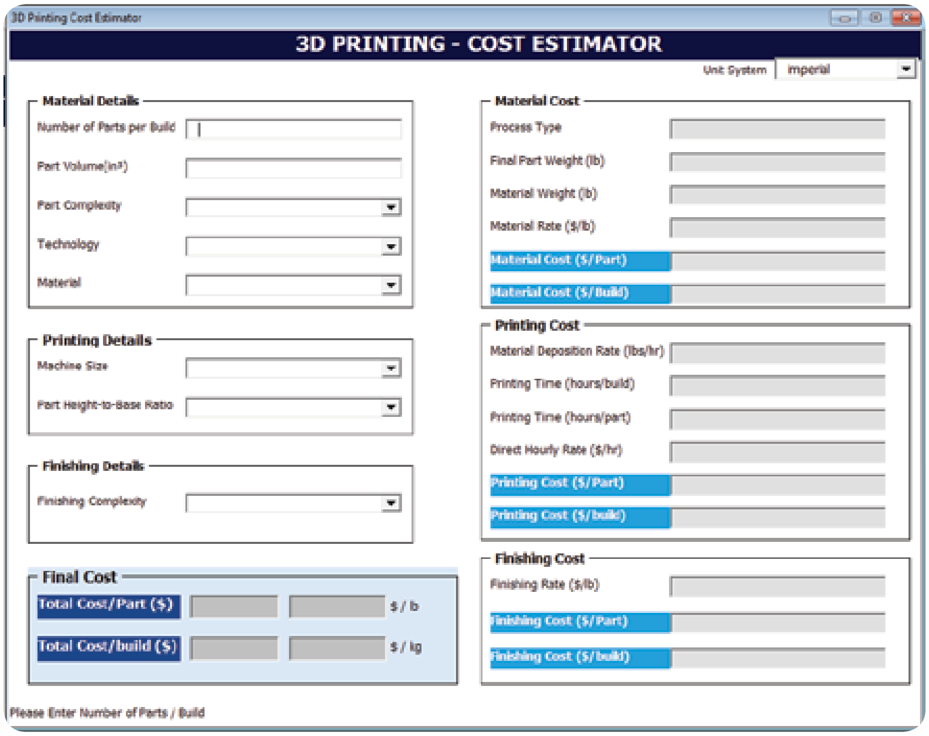
Vismay, is fabricated using electrical and electronic waste and the post processing applications are customized by using open source software. Vismay produces parts with good accuracy and it can process many plastic materials such as PLA, ABS, Nylon, and Flex-PLA.

## Value accounting

Considering the large variation in cost structure for the manufacture of 3D printed parts based on the technology and in comparison to conventional manufacturing, a detailed value accounting needs to be performed. The following are the major cost drivers considered for value accounting:

- Batch quantity
- Defect rate
- Complexity
- Material
- Volume / weight
- Additive manufacturing technology
- Post-processing requirements

*Figure 6: Vismay*



3D Printing Cost Estimator

3D PRINTING - COST ESTIMATOR

Unit System: imperial

**Material Details**
Number of Parts per Build
Part Volume(in³)
Part Complexity
Technology
Material

**Printing Details**
Machine Size
Part Height-to-Base Ratio

**Finishing Details**
Finishing Complexity

**Final Cost**
Total Cost/Part ($) $ / lb
Total Cost/build ($) $ / kg

**Material Cost**
Process Type
Final Part Weight (lb)
Material Weight (lb)
Material Rate ($/lb)
Material Cost ($/Part)
Material Cost ($/Build)

**Printing Cost**
Material Deposition Rate (lbs/hr)
Printing Time (hours/build)
Printing Time (hours/part)
Direct Hourly Rate ($/hr)
Printing Cost ($/Part)
Printing Cost ($/build)

**Finishing Cost**
Finishing Rate ($/lb)
Finishing Cost ($/Part)
Finishing Cost ($/build)

Please Enter Number of Parts / Build

*Figure 7: Cost estimation tool*

Infosys has built a tool for the cost estimation of 3D printing, as shown in Figure 7. The tool guides the user in selecting compatible inputs with respect to technology and material type. Some of the other parameters considered are the part specification, category of the printer, post processing requirements, and production rate. Based on these parameters, the material deposition rate and printing time are calculated to arrive at the printing cost.

# Technical demonstration

Here is a technical demonstration, which details the implementation of this framework in the aerospace industry.

## Part selection

A study of parts was performed to shortlist and identify the part for proof of concept creation. Titanium parts belonging to secondary structures and systems were found to be the most suitable for additive manufacturing. Components belonging to primary structures were avoided, considering the criticality for aerospace certification. A few criteria used in the selection of suitable parts are as below:

- Buy-to-fly ratio
- Size
- Cost of the component by conventional manufacturing
- Modifiability for additive manufacturing
- Larger quantity per ship set
- Machinability

It was found that titanium parts with high buy-to-fly ratios were most suitable for additive manufacturing. High material cost, wastage, and low machinability of titanium were leading to high part costs as seen from figure 8.

| Sl | Part Number | Description | Key consideration | Material | Part Weigt (Kg) | Buy to Fly | Size (mm) | No of fasteners used | Modifiability | Cost ($) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Shroud | Weldment from titanium sheet | High rejection rate | Ti-6Al-4V, Annealed | 1.92 | 2.2 | Dia. - 307 H 260 | 0 | Low | 5K |
| 2 | Duct support bracket | Formed titanium sheet metal assembly | Large number of fasteners and weight optimization opportunity | Ti-6Al-4V, Hot Formed | 1.35 | NA | 275 X 226 X 220 | 34 | Medium | 2.5K |
| 3 | Fitting | Machined fitting | High buy to fly ratio with complex features | Al 2124-T851 | 0.72 | 3 | 304 X 177 X 127 | 0 | Medium | 1K |
| 4 | Bracket Assembly | Assembly of machined components | High buy to fly ratio and integration opportunity | Ti-6Al-4V, Annealed | 1.1 | 15 | 179 X 157 X 90 186 X 69 X 40 | 6 | High | 2K |
| 5 | Door Fitting | Machined from thick block | High buy to fly ratio and weight reduction opportunity | Ti-6Al-4V, Annealed | 0.51 | 5.8 | 88 X 86 X 86 | 0 | High | 1K |

*Figure 8: Part selection study*

The door fitting part was short-listed for further study. The existing component is machined from a titanium alloy stock (Figure 9). It has a high buy-to-fly ratio of 6:1 and the quantity per ship set is about 50.

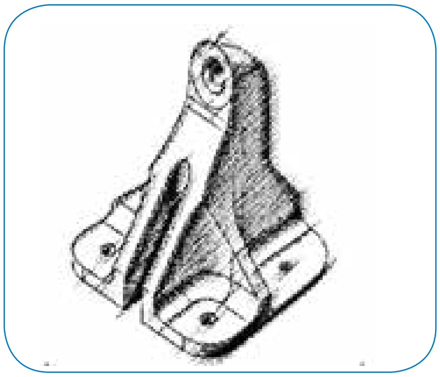


*Figure 9: Initial design*

The function of the component is to act as a door stop at the passenger entry doors. Hence, the part should be designed considering the stiffness, maximum deflection, and maximum interface force. The component has four fastener locations and a bearing pin is attached at its interface with the passenger door. As the number of similar fittings per aircraft is high, improvement in weight and cost per part has a large saving per ship set.

## Technology identification

The part is made of titanium alloy and the same material is considered for the additive manufacturing. As optimization of topology using OptiStruct is considered, the final geometry is expected to be complex. The geometry of the part fits in to a 100mm cube that can be printed in commonly available Direct Metal Laser Sintering (DMLS) machines. Though deposition rate would be very low, considering the complexity, DMLS can produce a near final component with very minimal support structures and hence, minimal post processing requirements. These characteristics make DMLS the most suitable technology for additive manufacturing.

## Design for additive manufacturing

Topology optimization is carried out using OptiStruct with a cube model. The fastener locations and the bearing pin location are defined as non-design spaces. The rest of the model is defined as design space for optimization. Boundary conditions are defined and load is applied at the bearing pin location. The resultant OptiStruct model shows material removed at locations where the loads are observed to be less. The below figure (Figure 10) shows the initial cube model, a representation of load with boundary conditions and the optimized result from OptiStruct.

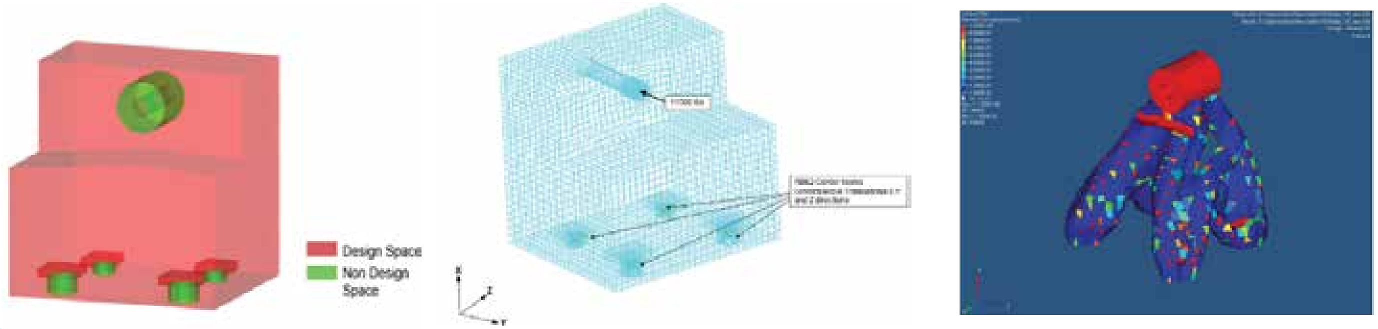


*Figure 10: Topology optimization study*

## Design concepts

Based on the OptiStruct result, different concept designs are created for the door fitting model using CATIA as shown in Figure 11.

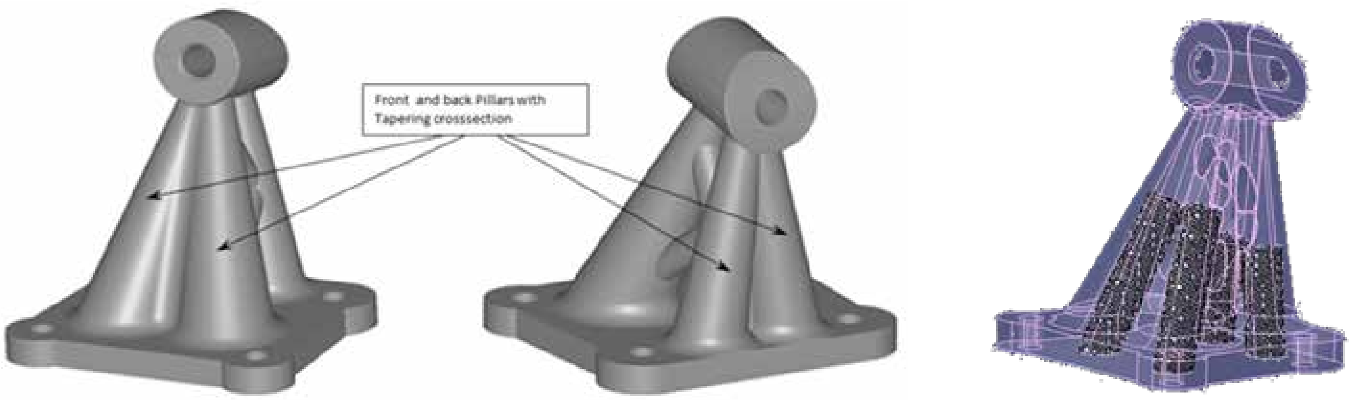


*Figure 11: Design Concepts*

A design similar to truss structure with tapering pillars fusing in to the head at the top and with side bridges is created to ensure structural integrity. The possibility of introducing a lattice structure is also explored for the pillars. The designs are iterated based on optimization opportunities and stress analysis result, to arrive at the optimized design.

This design is analyzed with the given loads and appropriate boundary conditions. Comparison between the current and the optimized designs are shown in Figure 12. The optimized design shows better performance on all parameters such as weight, maximum stress, stiffness, maximum deflection, and maximum interface force.

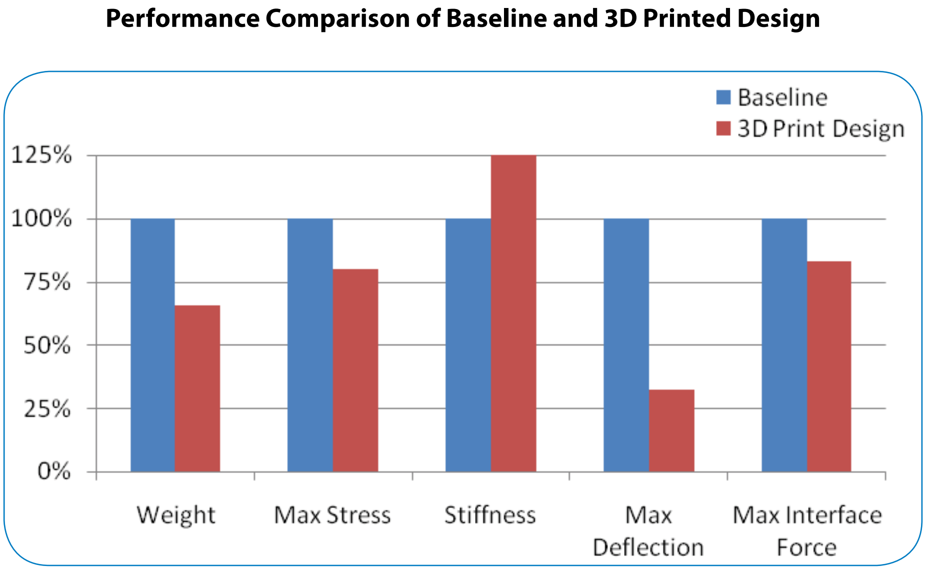


*Figure 12: Comparison between current and optimized design*

Conventional manufacturing of the proposed geometry would be difficult to achieve. Also, lattice structures provide an optimal design configuration with minimum weight. Such optimization is not achievable using conventional manufacturing methods. The design does not take into account the fatigue aspect which requires further study. However, the current work demonstrates the first-level concept of a door fitting for additive manufacturing.

## Value accounting

Value accounting is performed considering only 50 door fittings per ship set. The details are presented in Figure 13. The current cost of the fitting is arrived at by cost estimation considering the material, manufacturing, and processing costs. The 3D printing cost is based on printing service provider quotes for similar parts and technology.

| Sl | Part Description | Snapshot | Quanty per ship set | Current cost (US$) | 3D printing cost (US$) | Savings per part (US$) | Average ship set savings (US$) | Average annual savings (US$) | Total program savings (US$)SS |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Door fitting |  | 50 | 450 | 300 | 150 | **7,500** | **750,000** | **5,250,000** |

*Figure 13: Value accounting*

The cost of additive manufacturing is currently high due to the high cost of printer and raw material. However, these costs are reducing at a significant rate, which will contribute to a lower 3D printed part cost in the near future.

# In conclusion

This paper presents a holistic engineering services framework for additive manufacturing. The engineering process for additive manufacturing has been detailed out and is demonstrated through a practical design problem. A door fitting has been conceptualized for additive manufacturing. The proposed concept model for 3D-printed door fitting performs better than conventional door fitting in terms of weight, strength, and stiffness. The part can be manufactured using the direct metal laser sintering (DMLS) process. This can reduce the weight of the component and provide a cost saving of about 35% each. It also reduces machining and eliminates scrap.

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