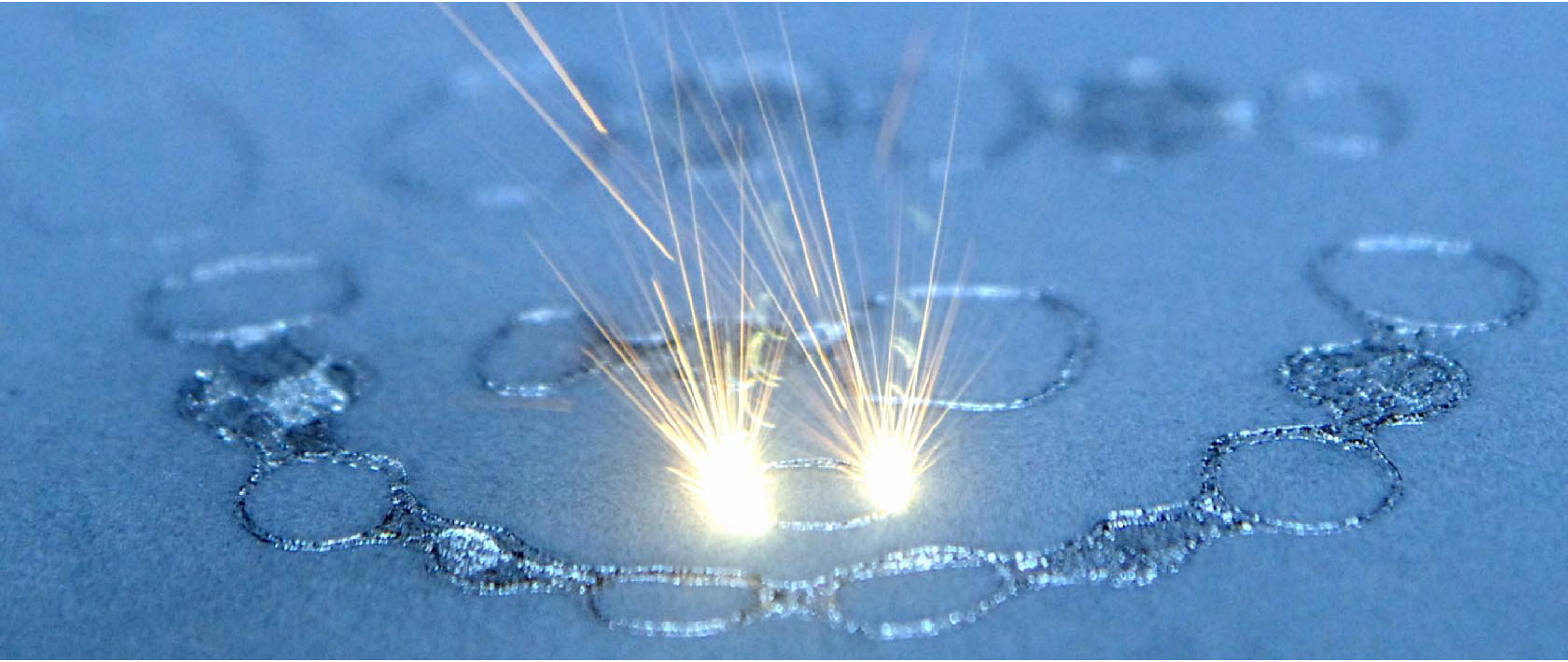
LAMP

- LASER ADDITIVE MANUFACTURING & PROTOTYPING -



10th CYCLE
ALTA SCUOLA POLITECNICA
POLITECNICO DI MILANO | POLITECNICO DI TORINO

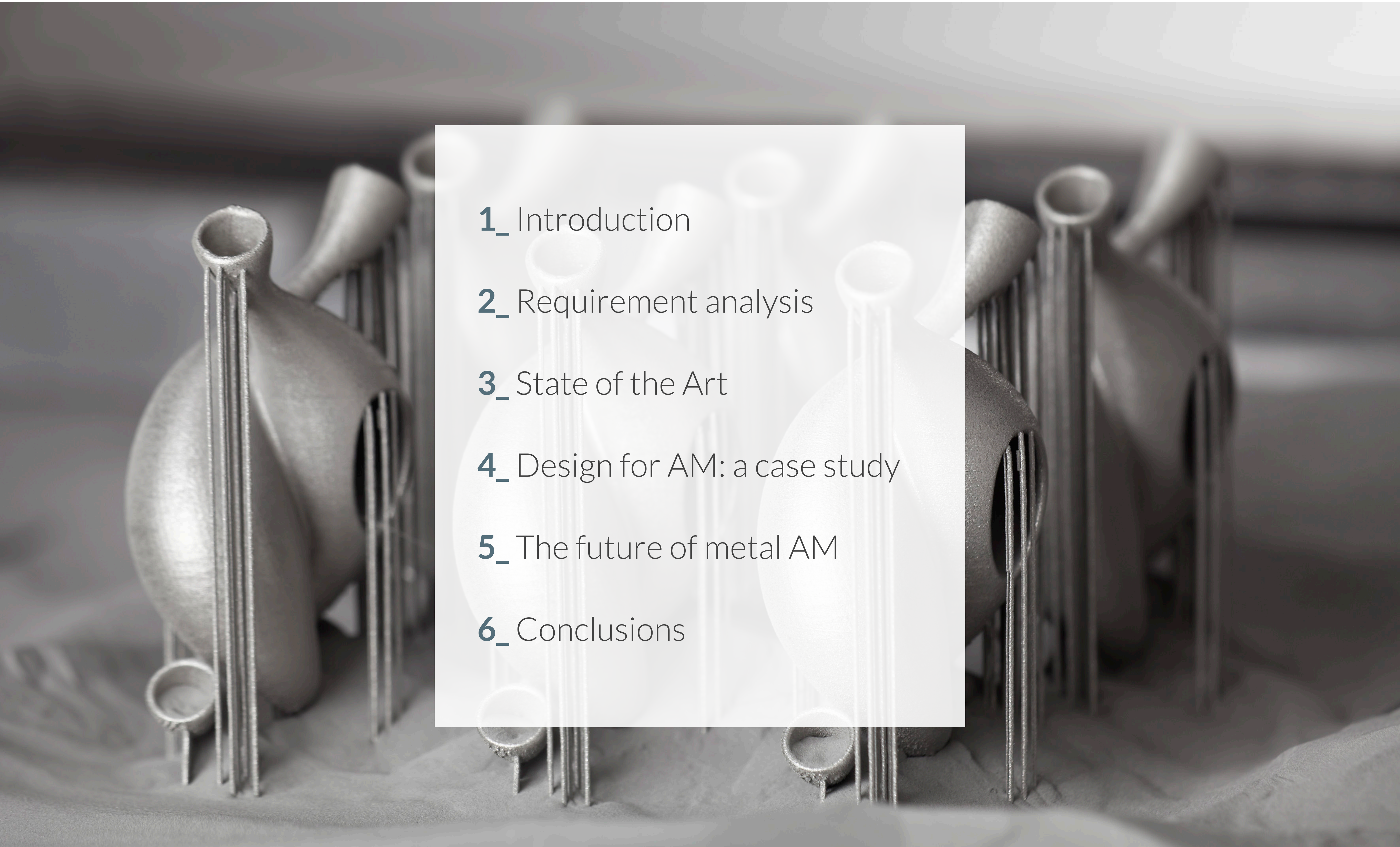
INTRODUCTION

Additive Manufacturing (AM) is based on the idea that any object can be created adding layers of raw material one on top of the other

PURPOSE

Identify and report the present state and future trends of the AM sector, providing a technical insight of the State of the Art of the technology and highlighting the key features that the next AM machine should have.

OUTLINE



1_ Introduction

2_ Requirement analysis

3_ State of the Art

4_ Design for AM: a case study

5_ The future of metal AM

6_ Conclusions

REQUIREMENT ANALYSIS

STAKEHOLDERS

1 END USERS

Biomedical sector
Aerospace sector
Automotive sector
Other sectors
AM service providers

2 DIRECT COMPETITORS

EOS
Renishaw
Trumpf
SLM Technologies
Arcam
3D Systems
OptoMec
POM Group

3 INDIRECT COMPETITORS

Companies in the metal supply chain

4 SUPPLIERS

Metal powder suppliers
Printing software suppliers
Component suppliers

5 PUBLIC INSTITUTIONS

European Union
Italian Government
Universities
PPP Lab
IIT
Trade unions
Local communities

6 STANDARD-SETTING BODIES

ISO TC261
ASTM F42

USERS' REQUIREMENTS

	REQUIREMENTS			
Stakeholder	**Human-Based**	**Functional**	**Corporate**	**Regulatory**
End users	Usability, reduced operator's work burden	Design freedom, capability of manufacturing functionally graded parts, production of lightweight components, surface finishing, low residual stresses, higher building volumes, reduced tolerances, improved mechanical properties, extended range of alloys	Short pay-back period, NPV>0, reduced material waste, economical feasibility also for short-runs, reduced time-to-market	
Direct competitors			Preservation of the competitive gap	
Indirect competitors		Integration of AM into traditional machining centers	Preservation of the market share	
Suppliers		Standardization	High profitability, customer lock-in	
Public institutions	Environmental sustainability, creation of highly-skilled jobs		Increase of firms' competitiveness	Preservation of the competitive gap

STATE OF THE ART

THE 8 STEPS IN AM PROCESS

1_ CAD modelling and FEM analysis

2_ Conversion to STL (external geometry model)

3_ Manipulation of STL file and transfer to AM machine

4_ Machine setup according to material powder — VIRTUAL

5_ Build — **REAL**

6_ Part removal and cleanup

7_ Part post-processing

8_ Application

THE 8 STEPS IN AM PROCESS

1_ CAD modelling and FEM analysis

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4_ Machine setup according to material powder

SOFTWARE / VIRTUAL

5_ Build

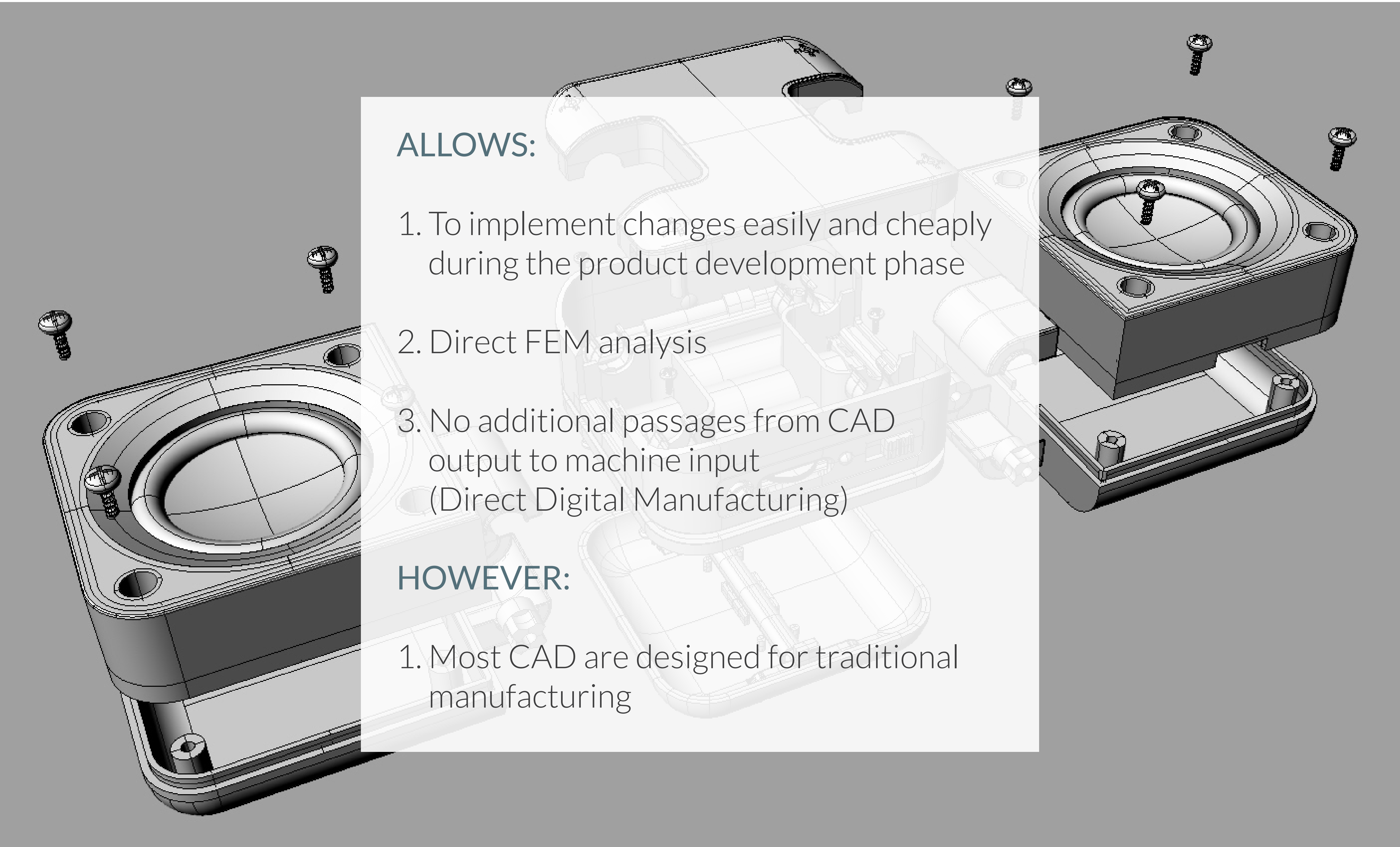
REAL

6_ Part removal and cleanup

7_ Part post-processing

8_ Application

SOFTWARE



ALLOWS:

1. To implement changes easily and cheaply during the product development phase

2. Direct FEM analysis

3. No additional passages from CAD output to machine input (Direct Digital Manufacturing)

HOWEVER:

1. Most CAD are designed for traditional manufacturing

THE 8 STEPS IN AM PROCESS

1_ CAD modelling and FEM analysis

2_ Conversion to STL (external geometry model)

3_ Manipulation of STL file and transfer to AM machine

4_ Machine setup according to material powder **MATERIALS / VIRTUAL**

5_ Build **REAL**

6_ Part removal and cleanup

7_ Part post-processing

8_ Application

THE 8 STEPS IN AM PROCESS

1_ CAD modelling and FEM analysis

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4_ Machine setup according to material powder **VIRTUAL**

5_ Build **PROCESS / REAL**

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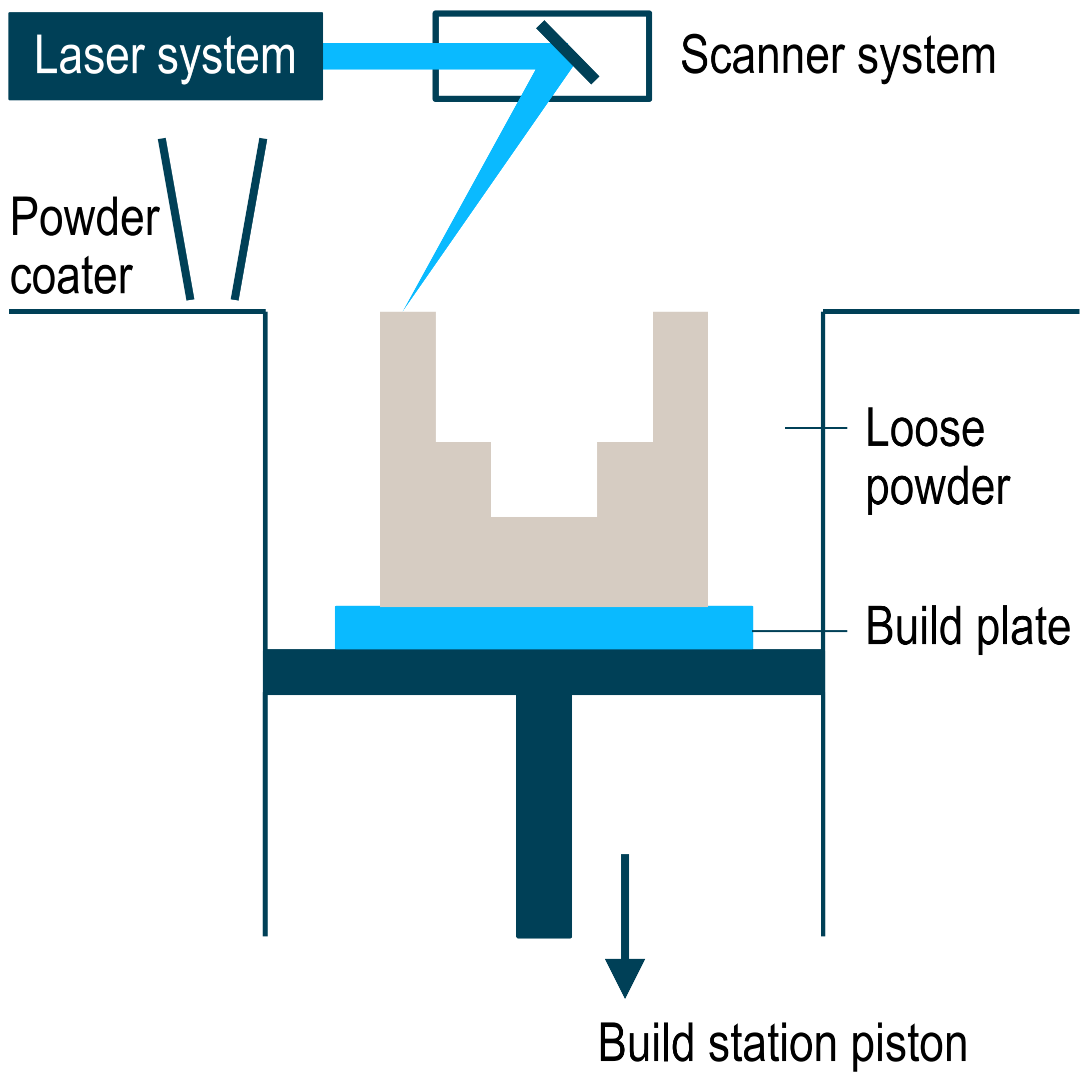
Processes: Powder Bed Fusion (PBF)

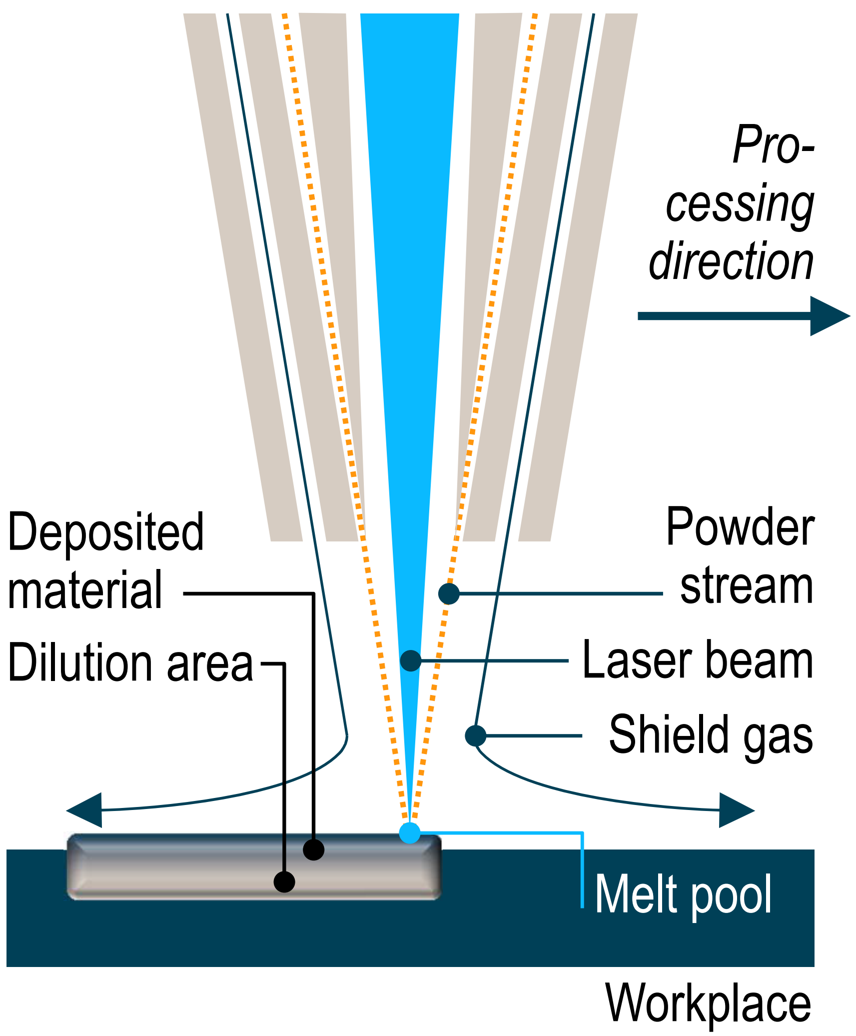


Process by which thermal energy selectively fuses regions of a powder bed

- Solid-state sintering
- Chemically-induced binding
- Liquid-phase sintering
- Full melting

Energy source: laser or electron beam

Processes: Direct Energy Deposition (DED)



Focused thermal energy is used to fuse materials by melting them as they are being deposited.

- Higher cost
- More flexibility

THE 8 STEPS IN AM PROCESS

1_ CAD modelling and FEM analysis

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VIRTUAL

5_ Build

APPLICATION / REAL

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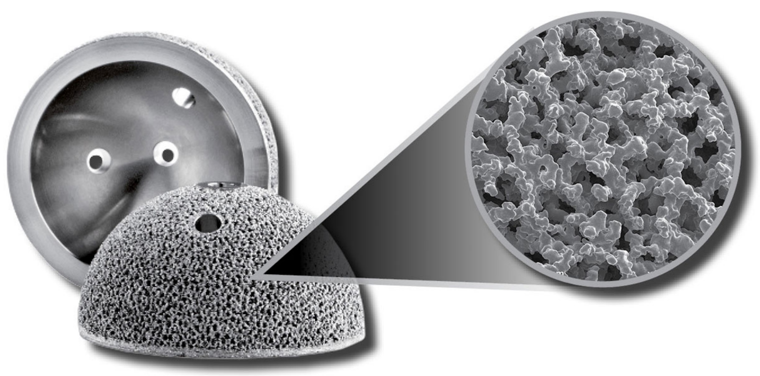
APPLICATIONS

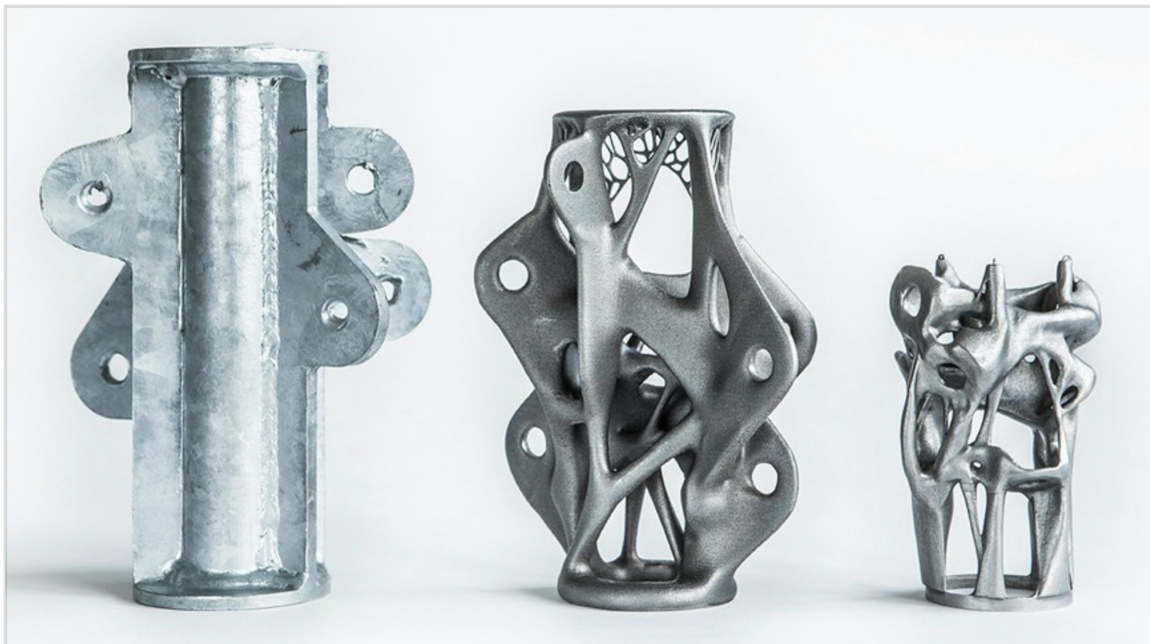


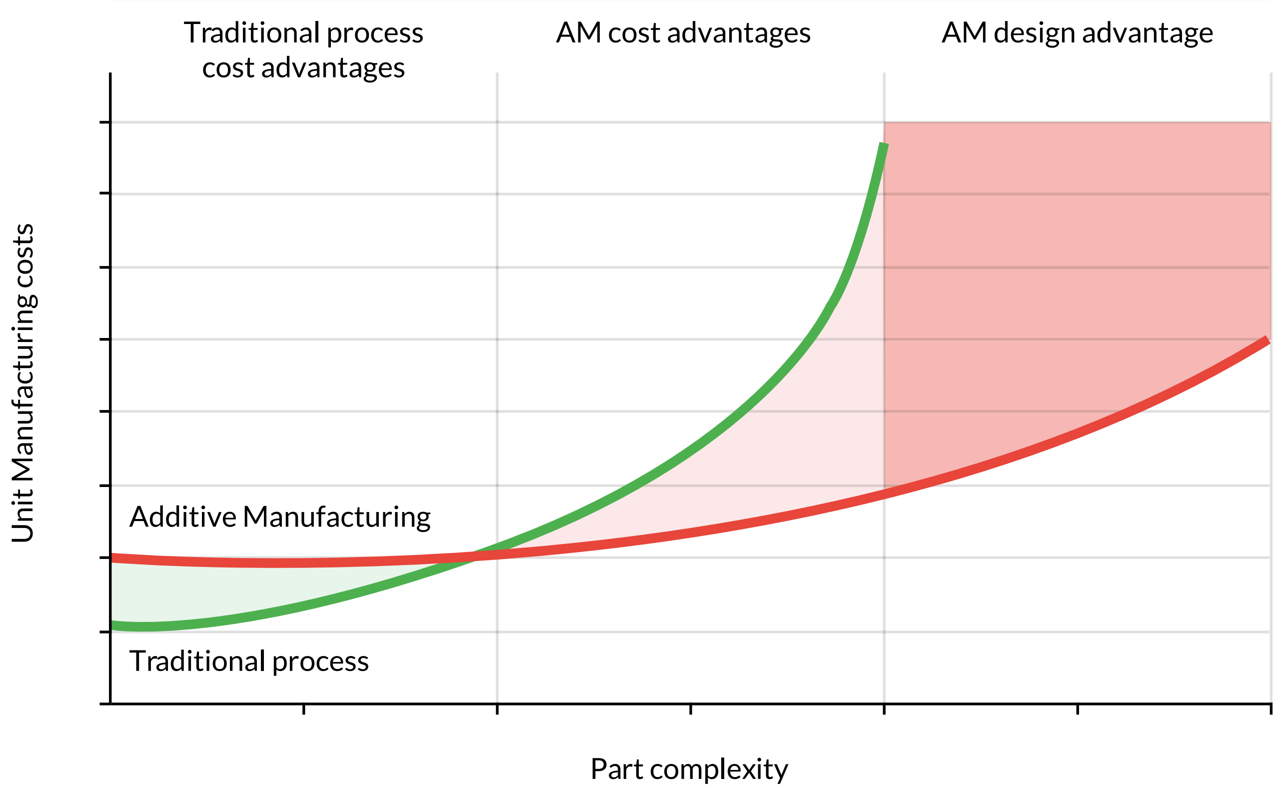
- Acetabular cup
- Lattice structures for better osseointegration

- Fuel injection system
- From 20 components to 1 part
- Weight reduction of 25%

- Freeform design

COST ANALYSIS & ECONOMICS





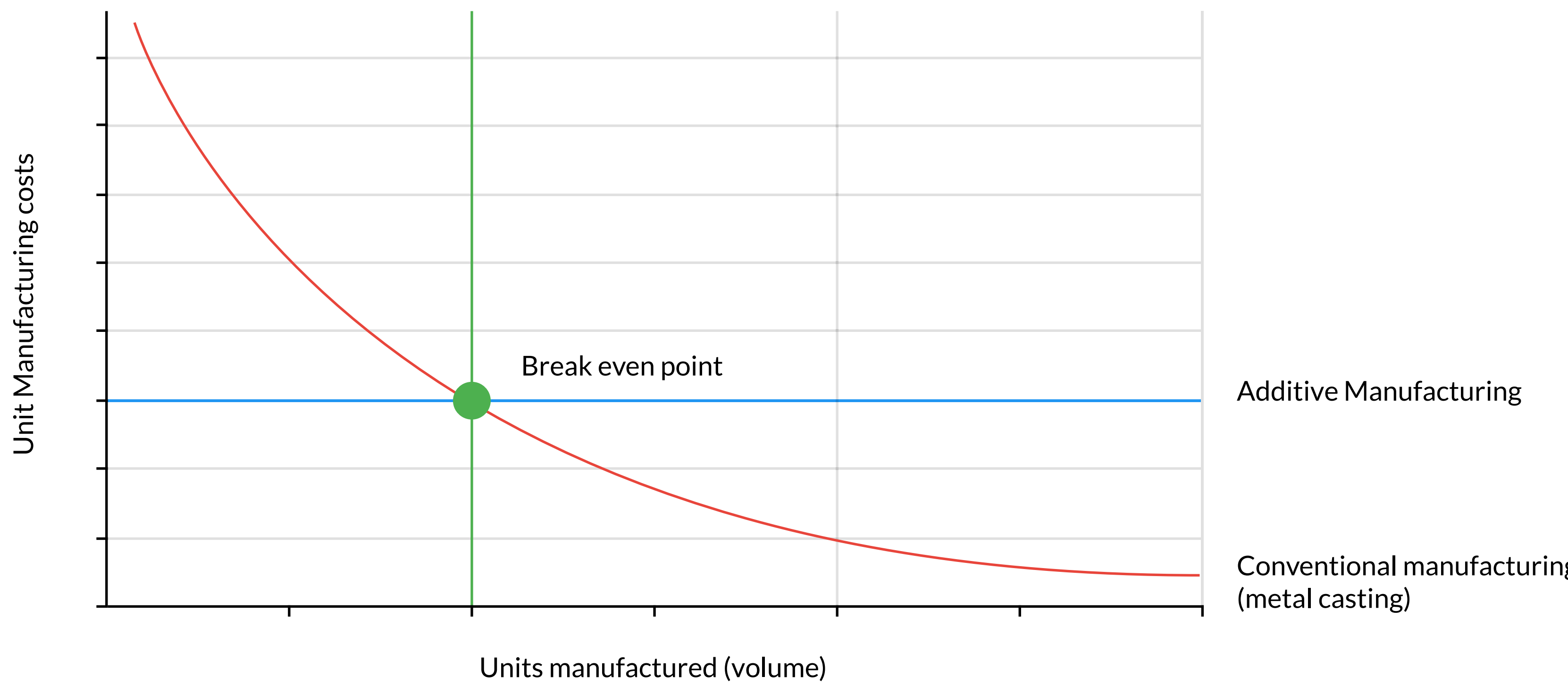
Sources: Interviews with experts; Bain analysis

- Lightweight
- Less material
- Improved mechanical properties
- More durable

As the geometric complexity of a component increases, it can prevent a part from being fabricated as a single piece, while AM multi-functionality design can reduce part count

COST ANALYSIS & ECONOMICS

AM used for low-medium batch sizes of production is capable of being highly economical, while traditional methods still prevail for very large volumes.

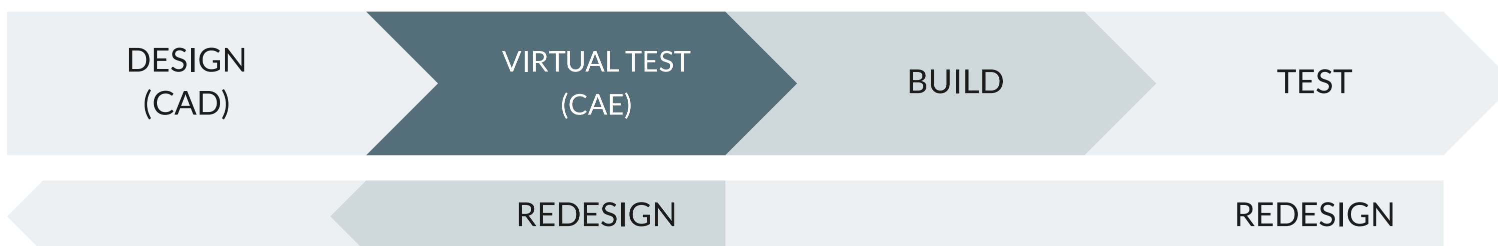


Source: Mark Cotteleer and Jim Joyce, 3D Opportunity: Additive Mmanufacturing paths to performance, innovation and growth, Deloitte University Press

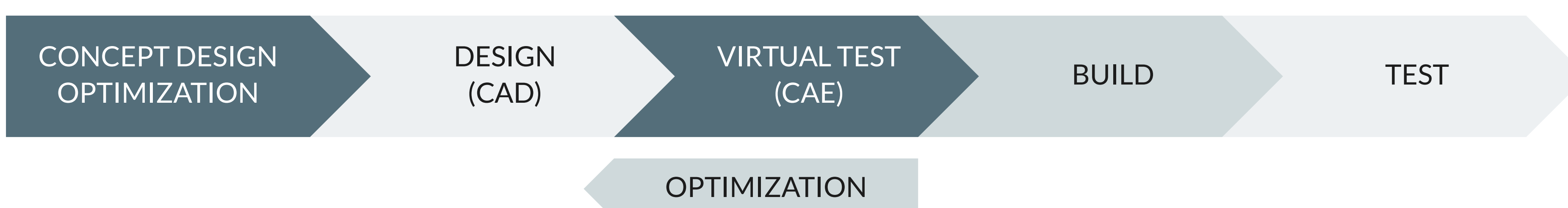
Design for AM
A case study

DESIGN FOR AM

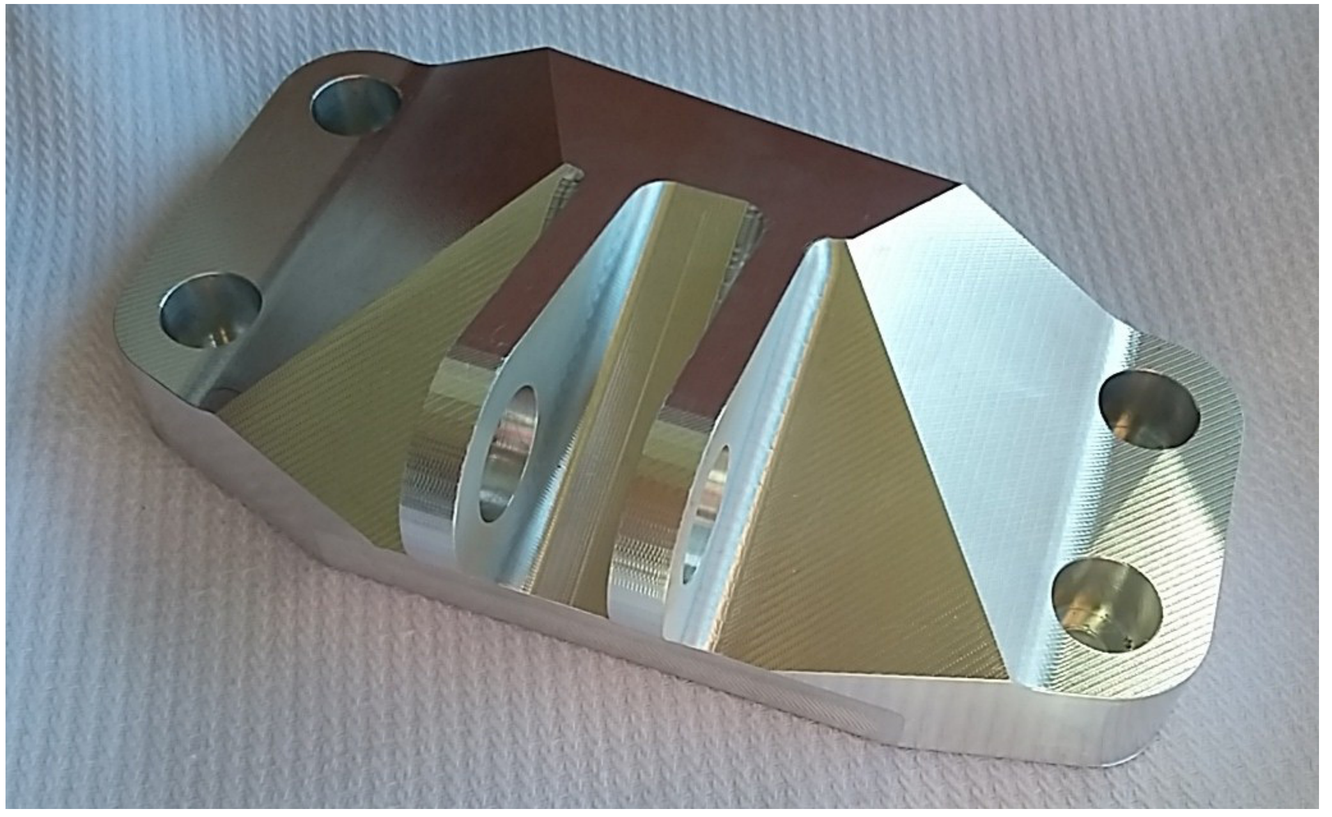
Traditional Design approach



New Design approach for AM



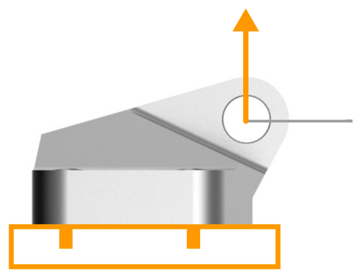
CASE STUDY



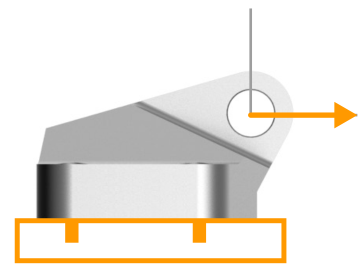
JET ENGINE LOADING BRACKET

- Huge interest of the aerospace industry in AM:
  - Less weight
  - Less fuel consumption
  - Less CO_2 emissions

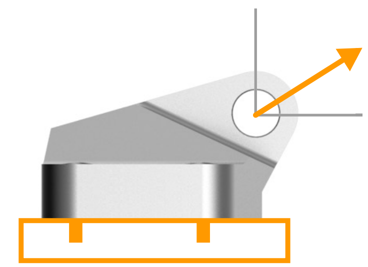
CASE STUDY



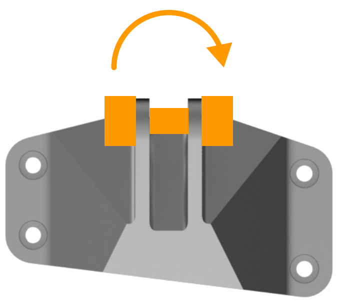
LOAD CONDITION 1
Static
Vertical
35.6 kN



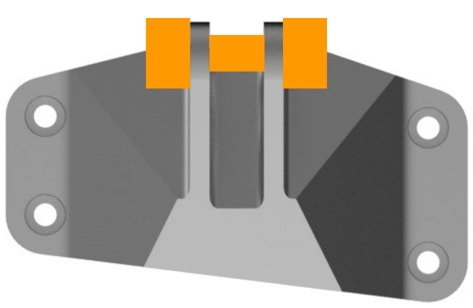
LOAD CONDITION 2
Static
Horizontal
37.8 kN



LOAD CONDITION 3
Static
42° from Vertical
42.3 kN



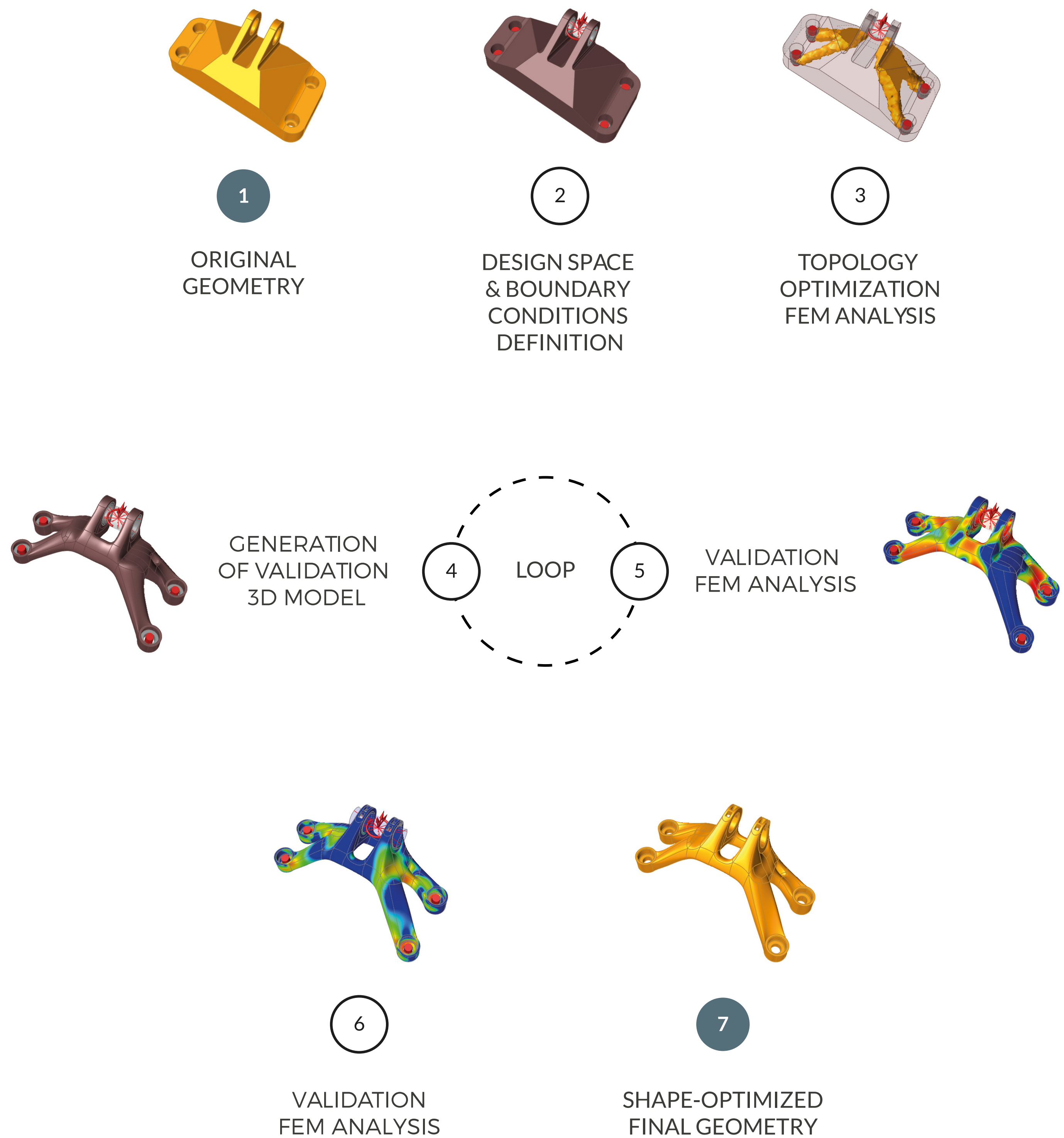
LOAD CONDITION 4
Static Torsional
Horizontal plane
565 kN mm



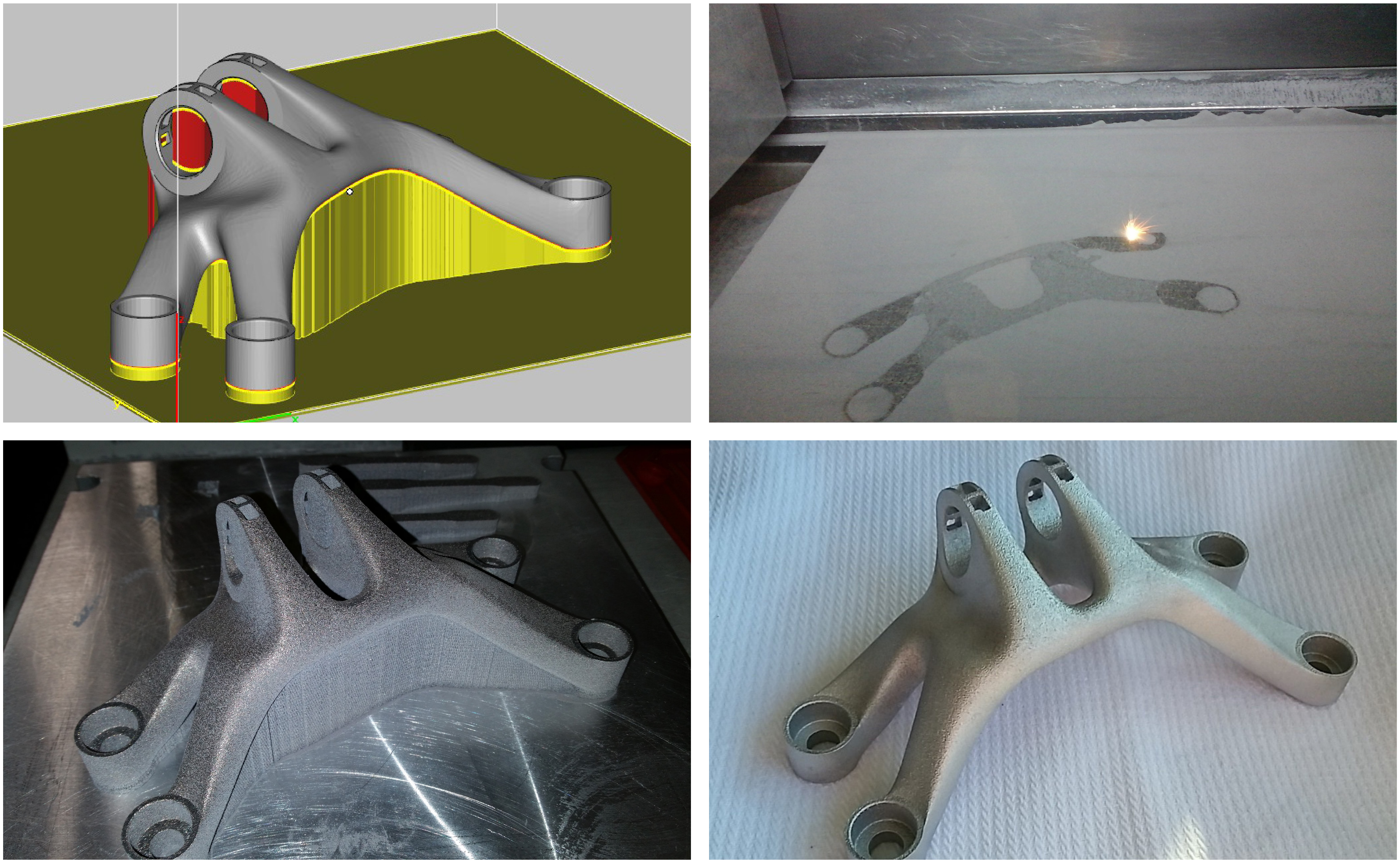
JET ENGINE LOADING BRACKET

- Strict requirements on:
    Static and dynamic performances
    Total weight

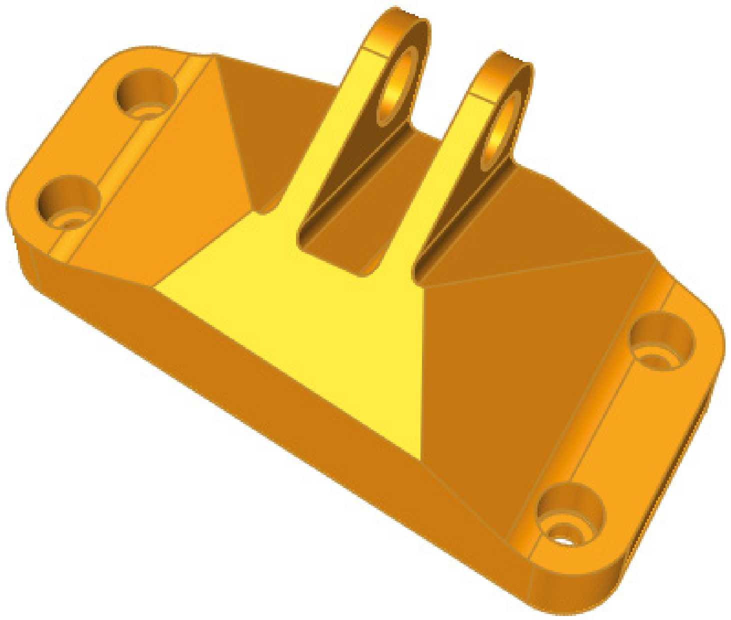
TOPOLOGY OPTIMIZATION PROCESS



FROM 3D MODEL TO REAL PART



FINAL RESULT



Mass reduction **-76.5%**

- **Decrease of almost 70 tons in CO_2 emission over 20-years lifespan**

The future of metal AM

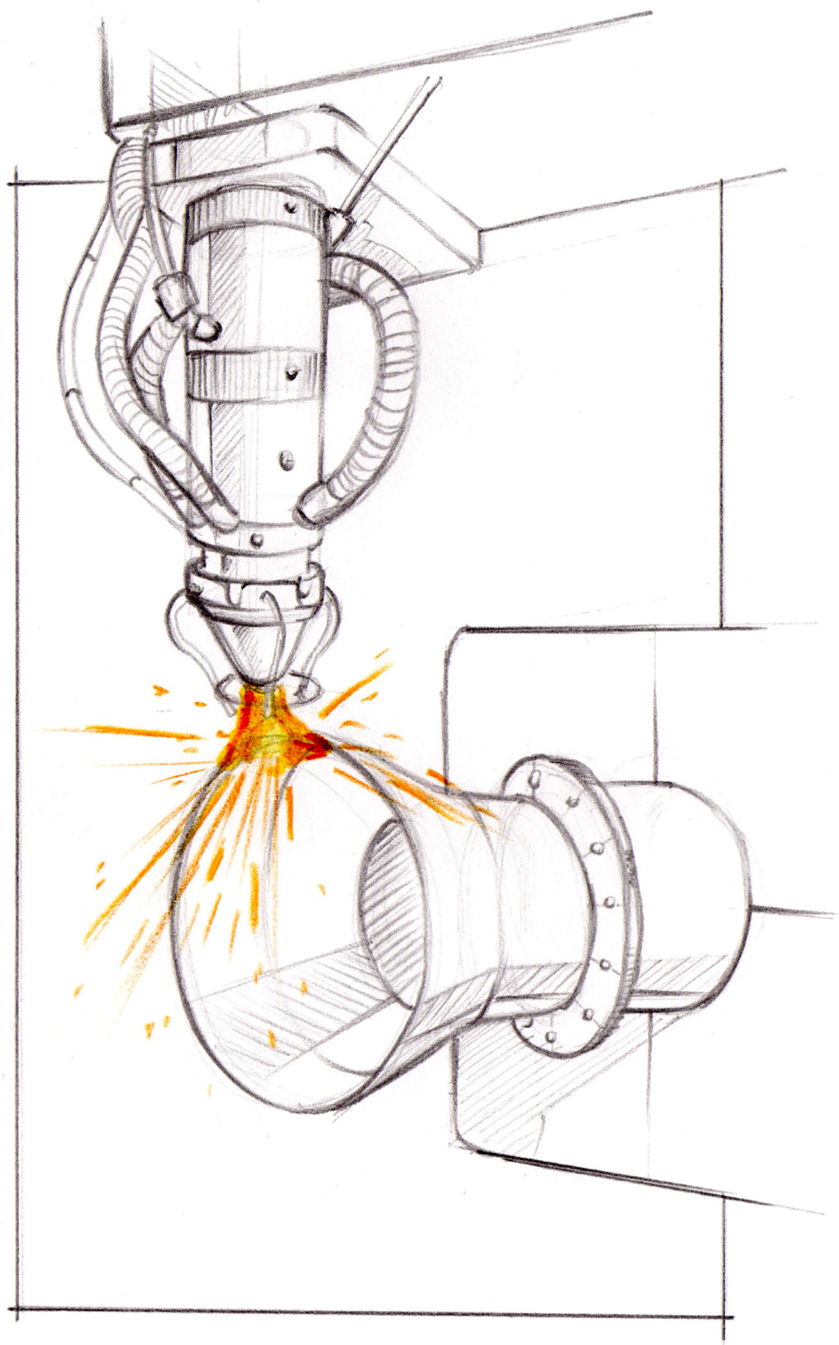
STATE OF THE ART TRADE-OFFS

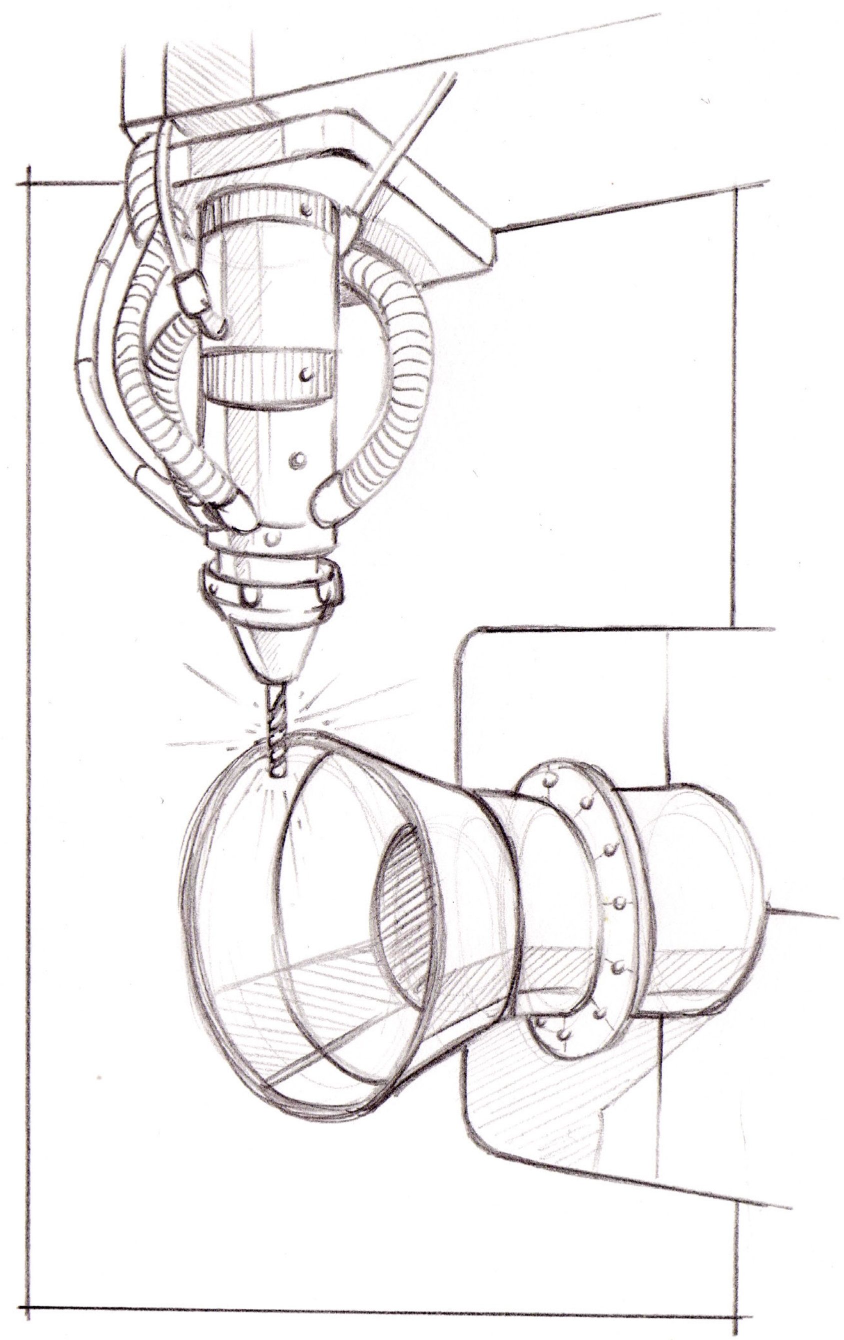
	Build Rate	Surface Quality	Build Volume	Mechanical Properties	Production Lead Time	Material Usage	Process Reliability	Process Yield	Cost	Functionally Graded Parts
Build Rate										
Surface Quality	−									
Build Volume										
Mechanical Properties	−	+								
Production Lead Time	+	−		−						
Material Usage			−							
Process Reliability		+		+	+	−				
Process Yield		+			+	−	+			
Cost	+	−	−	−	−	−	+	+		
Functionally Graded Parts	−			+					−	

SOLUTION FROM TRADE-OFFS ANALYSIS

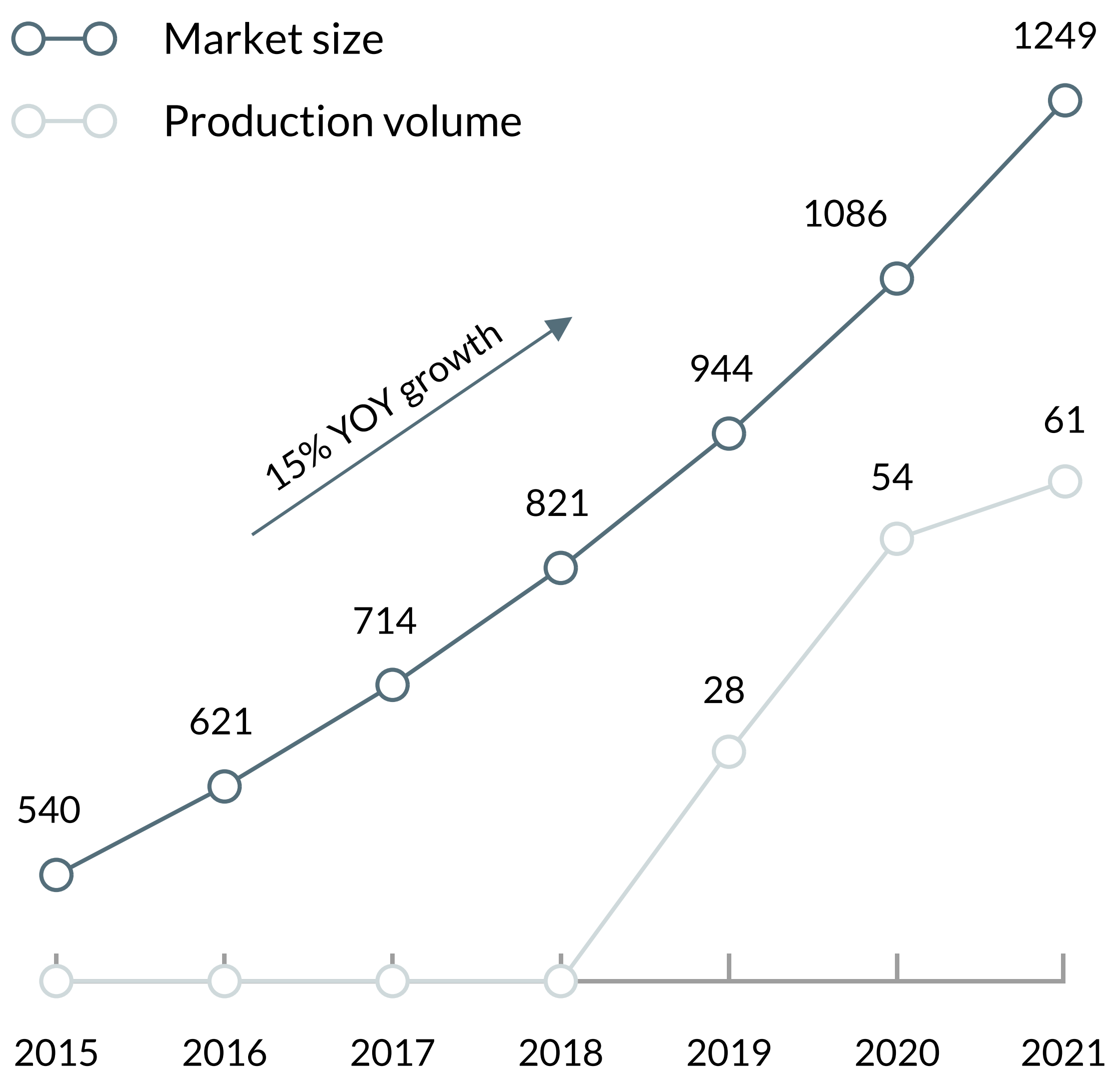
PROBLEM/ REQUIREMENT	INCREASE BUILD RATE	PRODUCTION OF FUNCTIONALLY GRADED PARTS	INCREASE SURFACE QUALITY	INCREASE BUILDING VOLUME	ADEQUATE TOLLERANCES	INCREASE PROCESS RELIABILITY/ PRODUCT QUALITY
SOLUTION	(+) Layer thickness (+) Laser power	Multi-powder management system	(−) Layer thickness Post processing (machining)	(+) Printing area	Change of paradigm needed	Trial and error approach
STATE OF ART TRADE - OFF	(−) Surface quality (−) Mechanical properties	Not feasible	(−) Throughput (+) Cost (+) Production lead time	(−) Material usage	Not feasible	(−) Process yield
FUTURE SOLUTION	DD laser Multiple nozzles	DMD with multi-nozzle system	Laser ablation	Direct metal deposition	Subtractive head	In-line monitoring

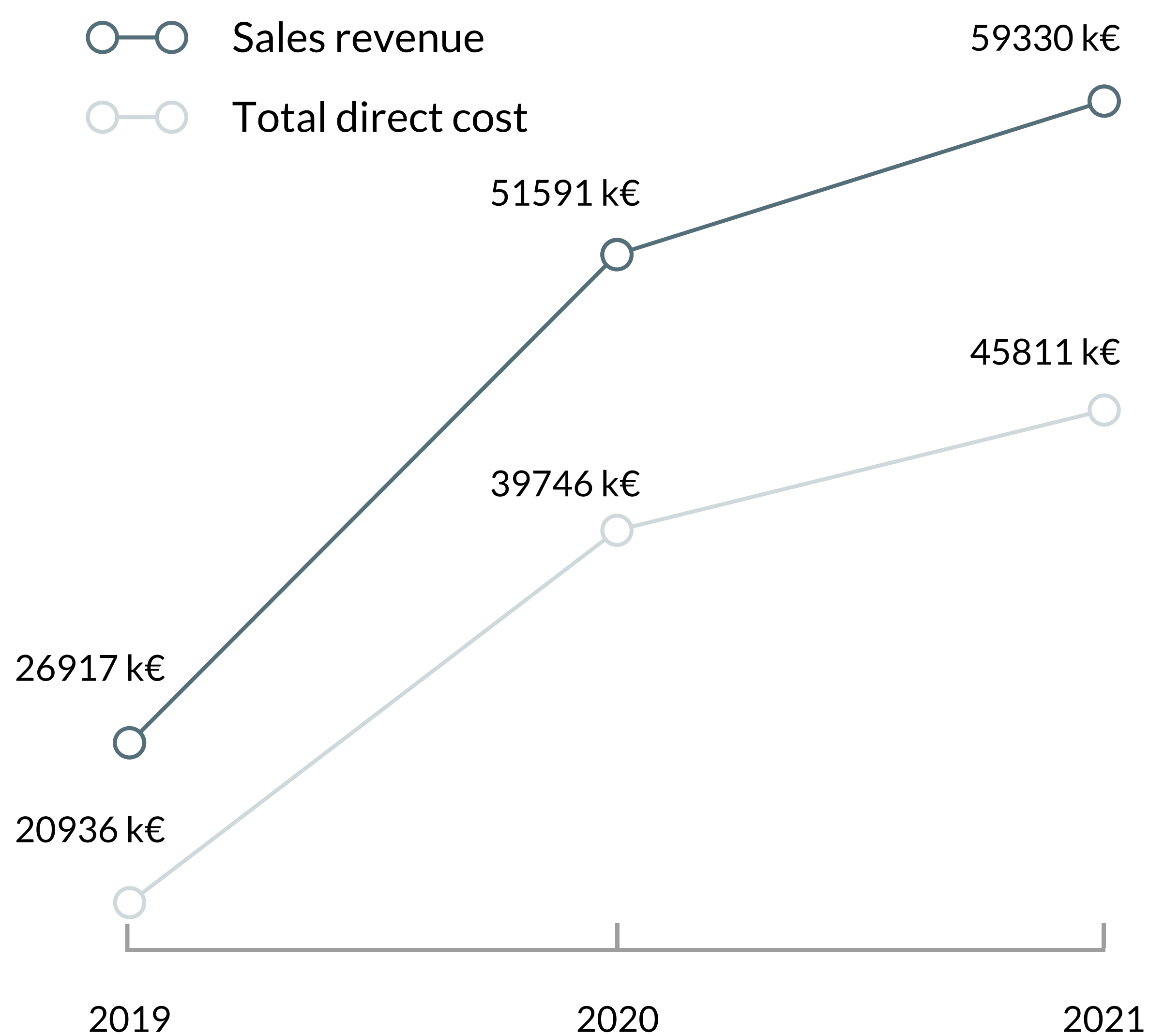
AM MACHINE CONCEPT





FEASIBILITY ANALYSIS

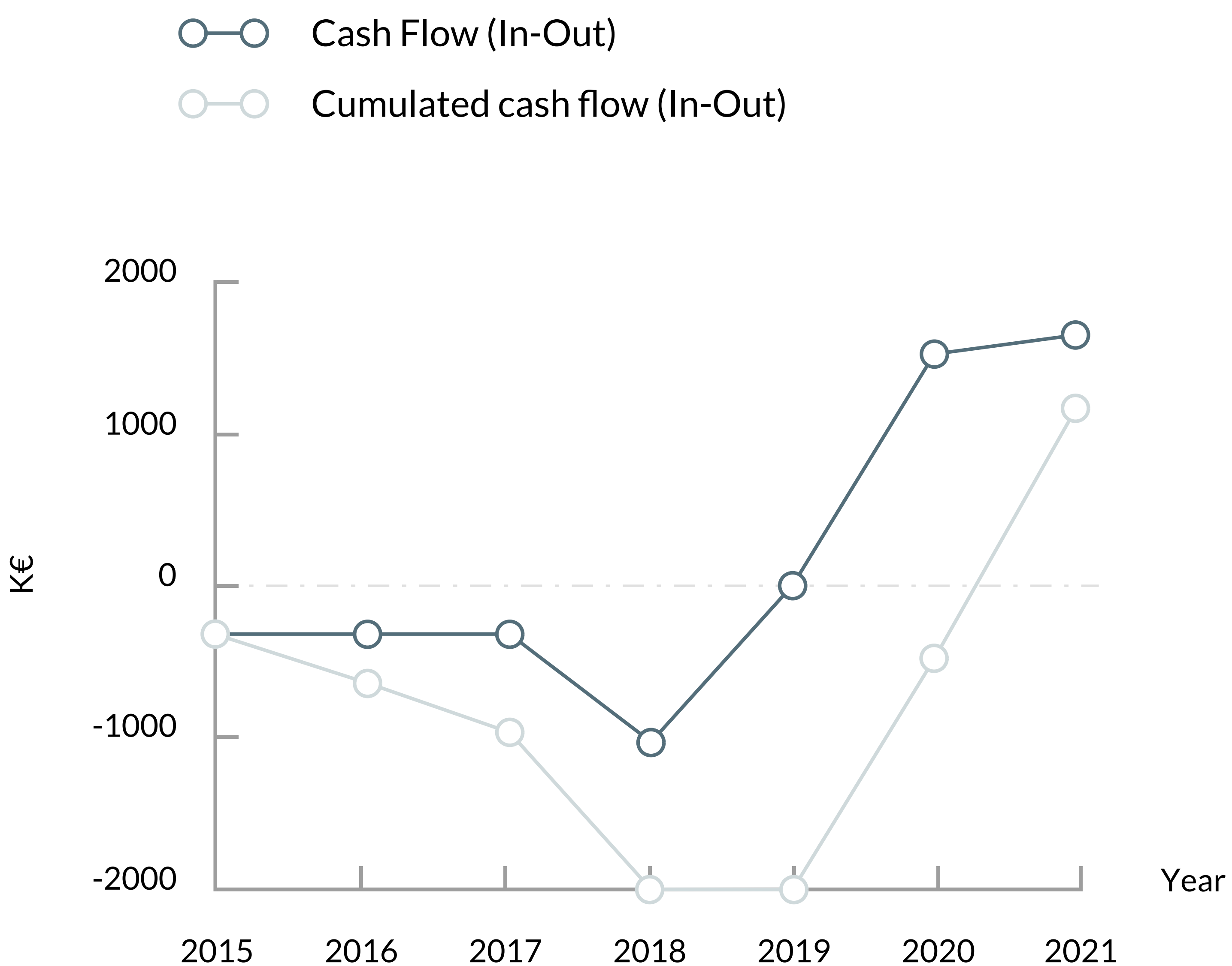




- Conservative assumption of 15% market growth on annual basis
- Market share of 5% reached in 2021

- Product commercialization starting in 2019
- Increasing operating profit (revenues - costs)

FEASIBILITY ANALYSIS



Cash flow forecast shows that the break-even is reached after 2 years from market launch

CONCLUSIONS

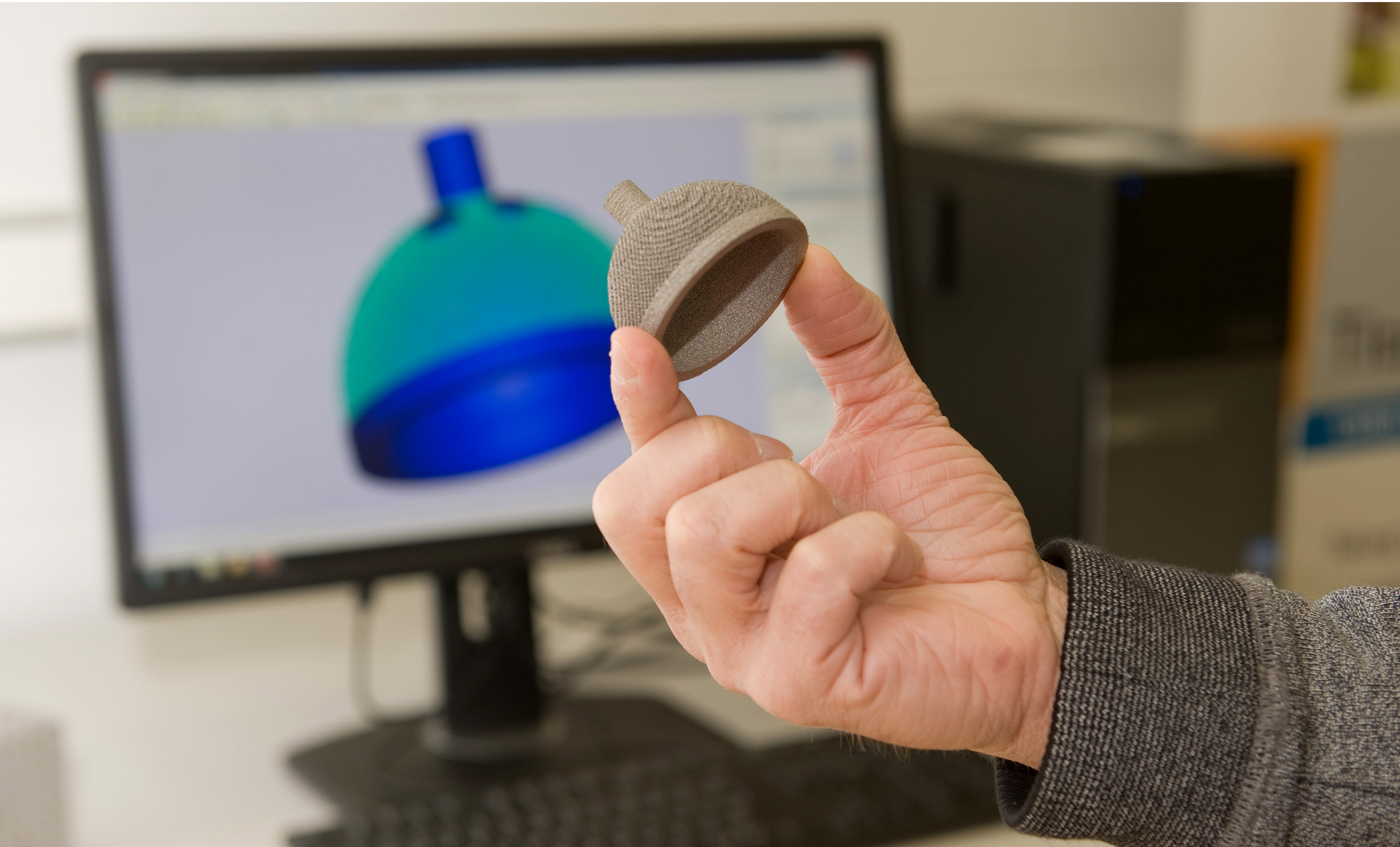
- New possibilities for the aerospace, automotive, biomedical and other sectors
- Minimal use of material
- No design restrictions
- Parts optimized for their function

- State of the art technologies: technological trade-offs and issues in satisfying stakeholders' needs

CONCLUSIONS

- “Machine of the future” concept breaks examined trade-offs by integrating:
  - Multi-nozzle Direct Energy Deposition system with a direct diode lasersource, capable of processing multiple materials at the same time
  - Laser ablation system for surface quality improvement
  - A closed-loop control system to constantly monitor process parameters
  - A machining head for achieving strict toleraces

THANKS



Back-up

METHODOLOGY

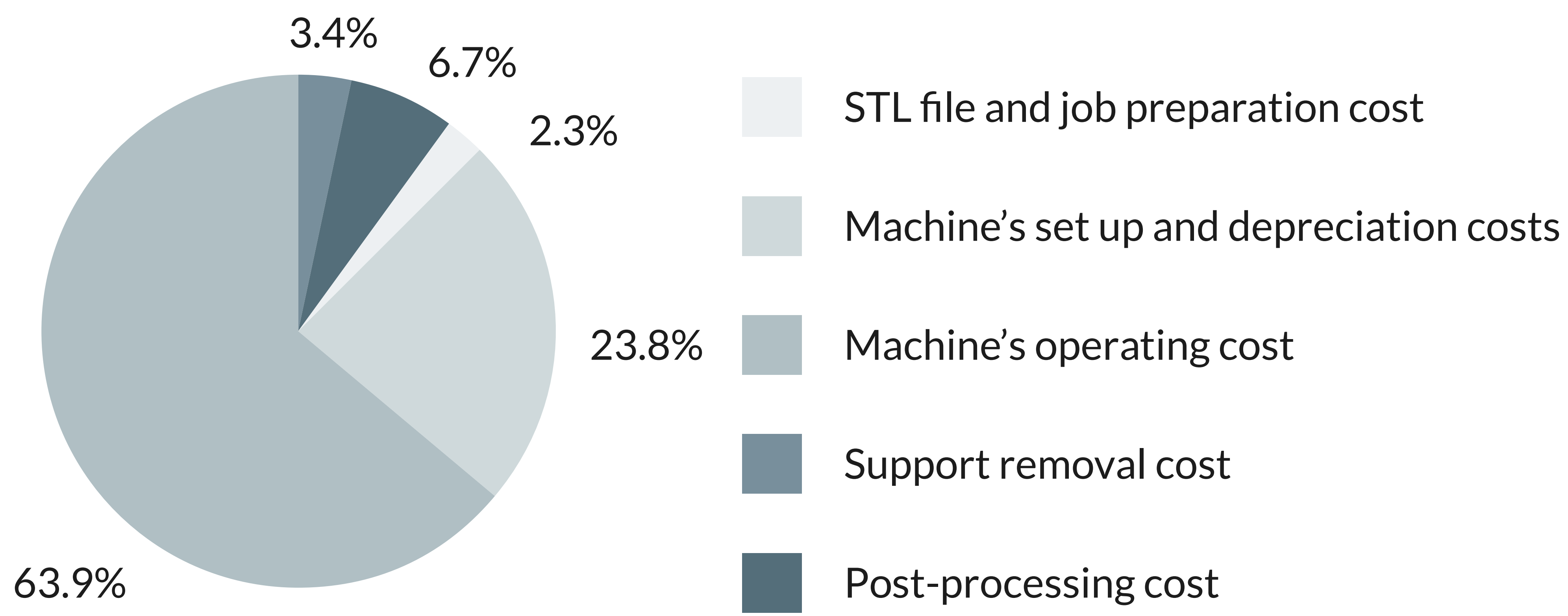
		Q2-2014 (APR-MAY-JUN)	Q3-2014 (JUL-AUG-SEP)	Q4-2014 (OCT-NOV-DEC)	Q1-2015 (JAN-FEB-MAR)	Q2-2015 (APR-MAY-JUN)	Q3-2015 (JUL-AUG-SEP)	Q4-2015 (OCT-NOV-DEC)
REQUIREMENTS ELICITATION &STATE OF THE ART ANALYSIS & SCENARIO	Visits, interviews	Visit to PPP Lab and IIT Lab in Torino		Visit to Prima Industrie in Torino	Visit to Avio Prop in Cameri (NO)	Visit to Sinteaplustek in Assago (MI) & Interview to Medacta		
	Research activities	Understanding of the technology	Technical report redaction	Report review	Future trends and scenario analysis	Updating of the report with integrations and revised parts		
	Conferences	MakeForum attendance at POLIMI		Rapid Manufacturing Forum attendance at Malpensa Airport				Conference on AM attendance at EMO Milano 2015
TOPOLOGICAL OPTIMIZATION & DEMONSTRATOR PRINTING				Selection of the case study	CAD development, topological optimization of the part and validation analyses (iterative process)		Cost analysis of the optimized part	3D printing of the final metal demonstrator and machining of the traditional component
FINAL ASP REPORT & POSTER					Mid-term review presentation	Organization of the previously produced material according to the ASP index		Handing in of the report and poster

FEASIBILITY ANALYSIS

Base Case Scenario

		2015	2016 (E)	2017 (E)	2018 (E)	2019 (E)	2020 (E)	2021 (E)
Market size	Machine number	540	621	714	821	944	1086	1249
Market share	%					3%	5%	5%
Production volume	Machine number					28	54	62
Unit Price	k €	950	950	950	950	950	950	950
Sales Revenues	k €					26,917	51,591	59,330
R&D	Number of employees				2	2	2	2
Management	Number of employees				1	1	1	1
Blue collar	Number of employees					20	30	40
Labor cost	k €				122	602	842	1,082
Overhead	k €	55	55	55	75	75	75	75
Structure and axis	k €					7,083	13,577	15,613
Metal multi-nozzle deposition head	k €					2,833	5,431	6,245
Laser source	k €					5,667	10,861	12,491
NC	k €					2,833	5,431	6,245
Milling head	k €					1,417	2,715	3,123
Material cost	k €					19,834	38,015	43,717
Other direct costs (energy,...)	k €				6	425	815	937
Total direct cost	k €	55	55	55	203	20,936	39,746	45,811
Marketing and distribution cost	k €					5,383	10,318	11,866
Start-up expenses R&D	k €	270	270	270	135			
Start-up expenses manufacturing	k €				700	600		
Cash Flow IN	k €					26,917	51,591	59,330
Cash Flow OUT	k €	325	325	325	1,038	26,919	50,065	57,677
Cash Flow Delta	k €	-325	-325	-325	-1,038	-2	1,527	1,653
Cumulated Cash Flow	k €	-325	-650	-975	-2,013	-2,015	488	1,165
Present value of cash flow delta	k €	-325	-295	-269	-780	1	948	1,027
NPV	304							

Engine Bracket Manufacturing Costs



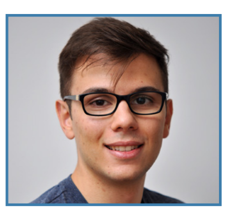
TEAM MEMBERS

Veronica Bianchi, Biomedical Engineering, Politecnico di Torino
investigated the different sectors where AM has a large influence detailing the more relevant applications and took part to the topological optimization of the 3D-printed demonstrator.

Arianna Decaneto, Management Engineering, Politecnico di Milano
provided an in-depth analysis of AM costs and future economic trends; moreover, she was involved in the stakeholders and requirements analysis.

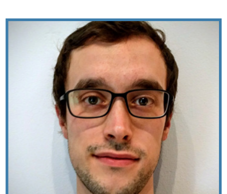
Felipe Hernández Villa-Roel, Design&Engineering, Politecnico di Milano
contributed with design competencies to the conception of the case-study; in addition, he made it possible to manufacture polymeric prototypes.

Francesco Maja, Mechanical Engineering, Politecnico di Torino [communication coordinator]
exploited his CAD-modeling competencies working at the topological optimization of the demonstrator. Furthermore, he examined in depth the properties of metal 3D-printed parts and went into a comparison of AM machines.



Gianluca Nicosia, Electronic Engineering, Politecnico di Milano [team controller]
as team controller coordinated the work of all the team components and verified the consistency of the final report; he was also involved in the state of the art study of AM processes and in the stakeholders and requirements analysis.

Andrea Pavanello, Design&Engineering, Politecnico di Milano
investigated the latest software used in the AM design phase, was in charge of the graphic aspects and carried out the CAD modeling activity of the mechanical case-study.



Diego Pintossi, Material Engineering, Politecnico di Milano
examined in depth the metallic materials available for different laser AM processes, analyzed the properties of the 3D-printed parts and was involved in the stakeholders and requirements analysis.