Tooling applications of additive manufacturing
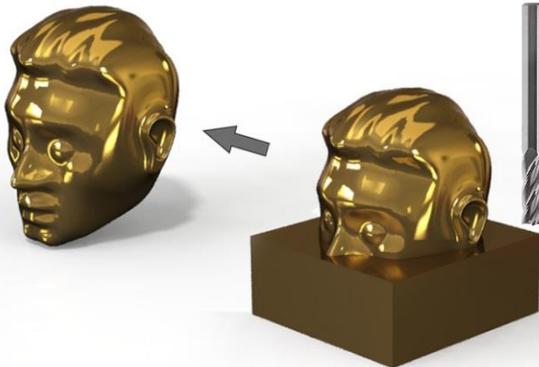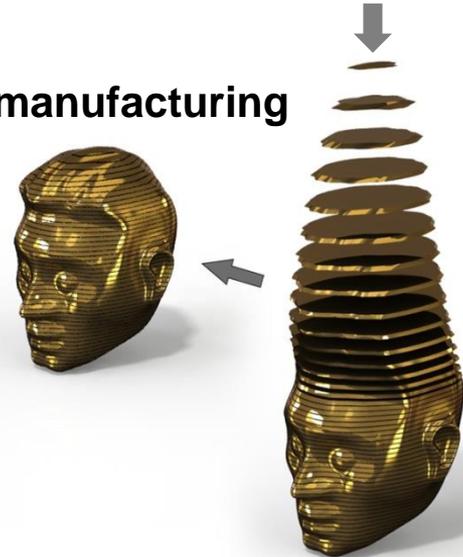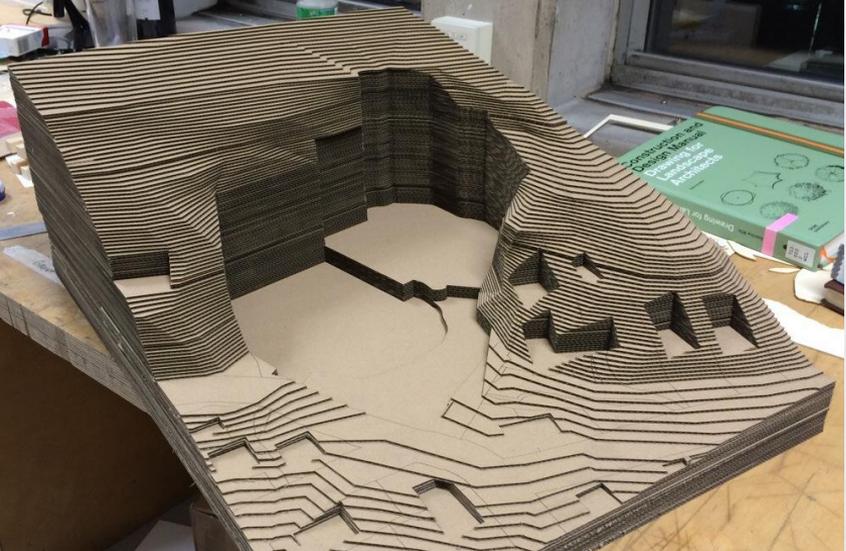
Olaf Diegel

Additive manufacturing (3D Printing)

- Generate a **3D CAD model**
- Software slices the 3D model into thin slices
- Machine builds it **layer upon layer**
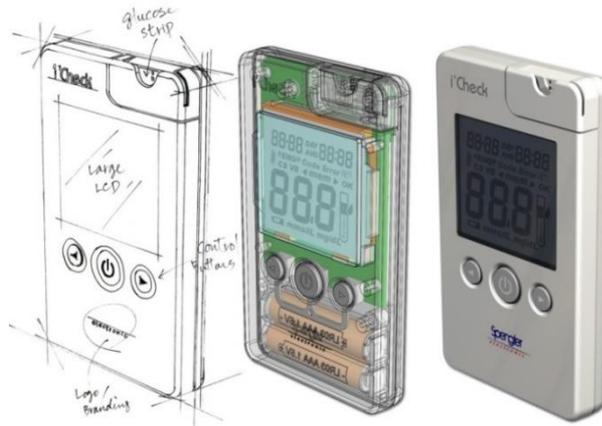
Subtractive manufacturing
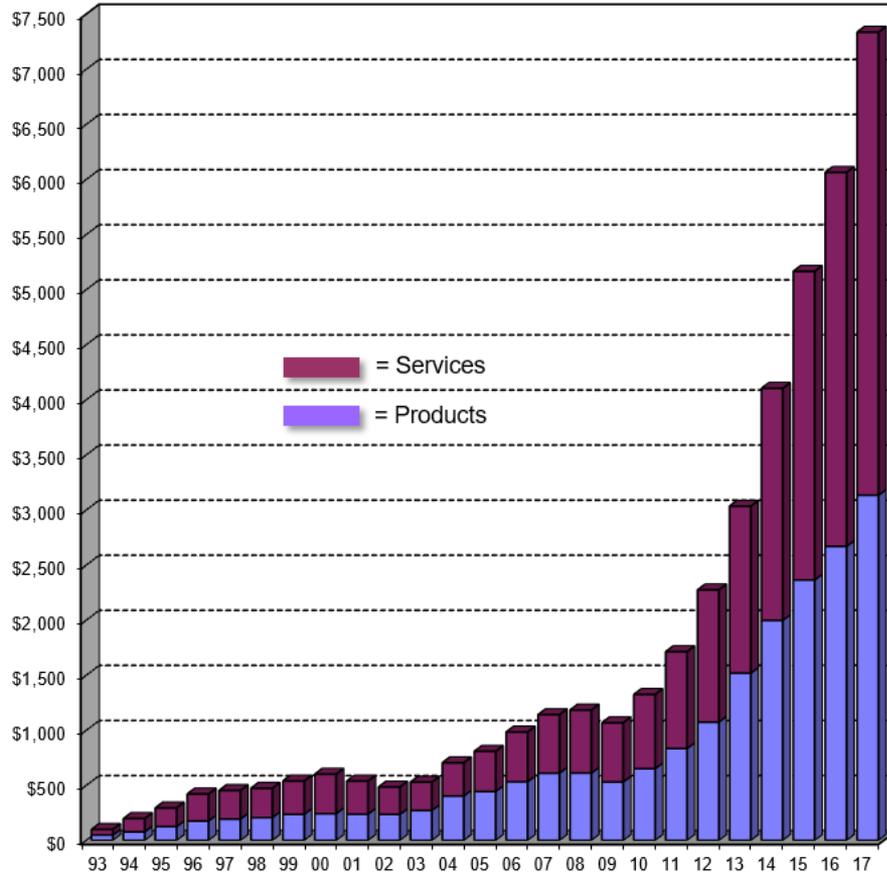
Additive manufacturing

The past

- For most of its first 3 decades, additive manufacturing (AM) was known as **rapid prototyping**, and used for prototyping.
- In the last decade AM has begun to make appearances in real products, ie. moved to **rapid manufacturing**.
- This has generated a lot of **hype and a few myths**

Industry Growth

Unprecedented worldwide growth! 21% in 2017.

Growth in Sweden in 2015 was greater than in the last decade.

2016 saw the installation of, at least, 7 metal systems and 25 high-end polymer systems in Sweden.

2017 saw, at least, 10 metal systems and 15 high-end polymer systems .

Reality check

- **Additive Manufacturing (AM, or 3D Printing) will NOT replace conventional manufacturing.**

- **It is a complementary technology that, for certain products, and if used the right way, gives huge advantages over conventional manufacturing.**

- **But, for it to offer advantage everything needs to be designed for additive manufacturing (DfAM).**

- **Not everything should be 3D printed! Only use 3D printing when it truly offers you that advantage!**

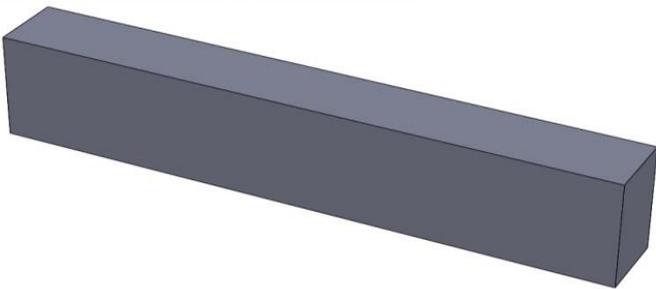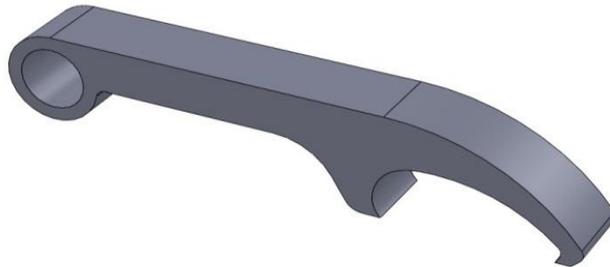# DfAM: aesthetic complexity

Courtesy of American Standard

DfAM: topology optimisation
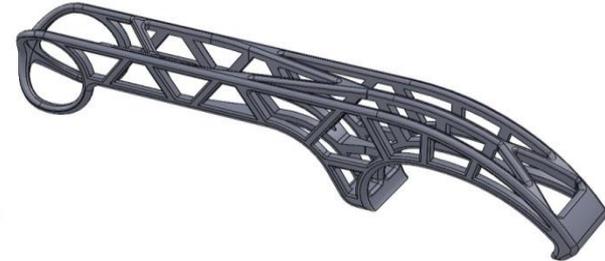
Topology optimisation: using maths to remove whatever material is not contributing to improve the mechanical characteristics of a part

Solid Billet: 10.39gms

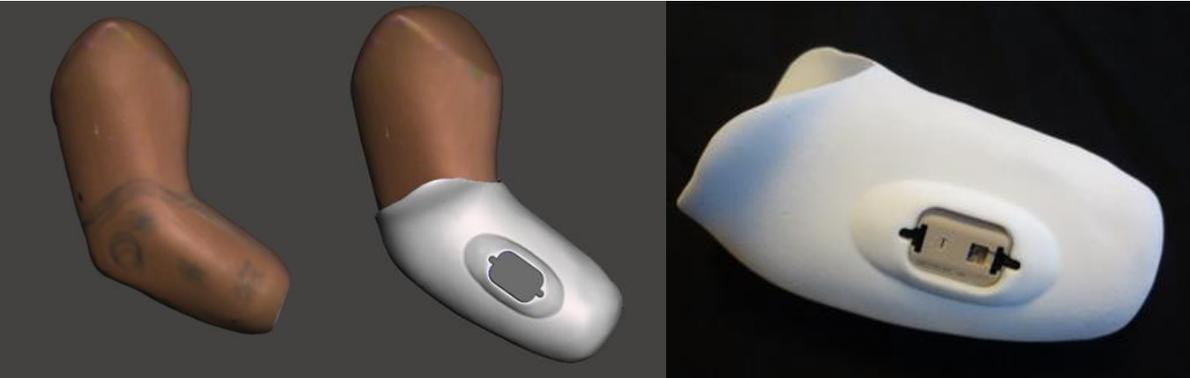Solid Machined/Cast: 4.22gms

Topology Optimised AM: 0.95gms

DfAM: mass-customisation: medical

The old fashioned way

Custom prosthetic 3D printed for 2 ½ year old Neya
by Emelie Strömshed at Lund University

The new way

Part consolidation: Siemens burner
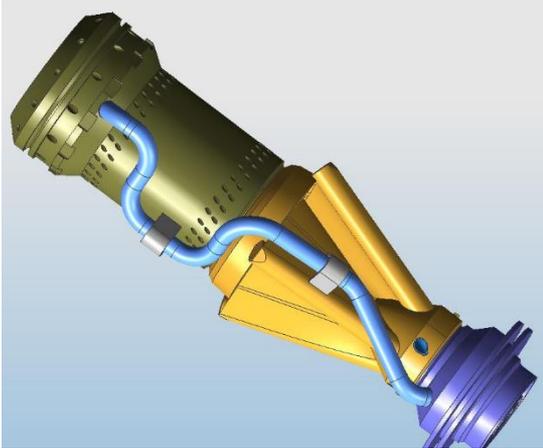
Conventionally manufactured burner front

- 13 machined parts, joined by 18 welds.
- Thermal Barrier Coating on front surface.
- External pilot gas feed
- Standard lead time 26 weeks (excl. TBC)
- Weight: 4,5 kg
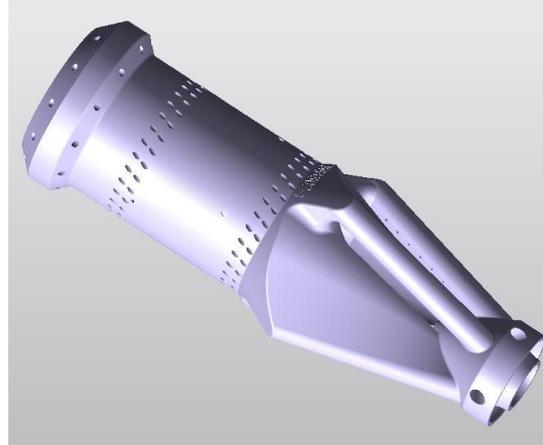
AM adapted burner front

- 1 single part
- Optimized cooling, possible to remove TBC
- Pilot gas feed integrated in structure
- Standard lead time 3 weeks (excl. TBC)
- Weight: 3,5 kg

Courtesy of Siemens

Think beyond direct part production

- Most of us think of AM for final part production
- It also has the potential for making tools for conventional production to:
  - shorten time-to-market
  - improve efficiency of tools

Only print what is useful. The rest can be made the traditional way

The goal of AM tooling

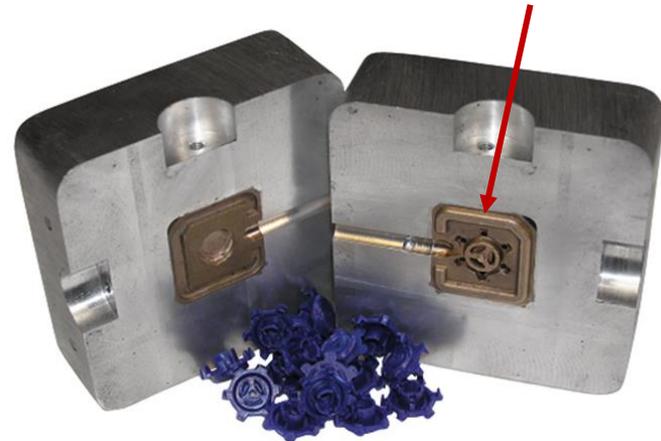- The objective of using additive manufacturing to produce tools is both to **reduce the lead-time** required to make the tools, **reduce the cycle time** of the parts being made by the tools, and to **improve the quality** of the parts being made by the tools.

- In the 90s, there was a lot of excitement about this possibility but, unfortunately, the AM technologies were not quite good enough.

- But with recent advances in technologies, many companies are now beginning to use AM-produced tooling.

Polymer tools for short-run products

- Both injection molding and sheet-metal forming tools can be made with polymer AM technologies
- But they will, typically, only last for a few (10 to 100) shots, depending on the material and geometry

Bi-Link business case

High temperature resin and long flow paths with narrow sections

- Dimensions: 150 mm x 6.35 mm
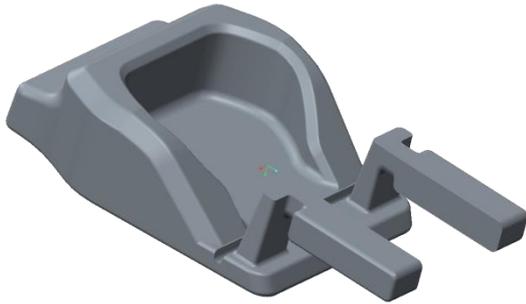- Thinnest wall section: 0.6 mm
- Flatness: <0.15 mm
- 8 shots @ 343°C

Bi-Link business case

Thermoplastic elastomer (TPE) with rapidly evolving design

- Min thickness: 0.5 mm
- Max thickness: 2.0 mm
- 4 iterations across 6 days
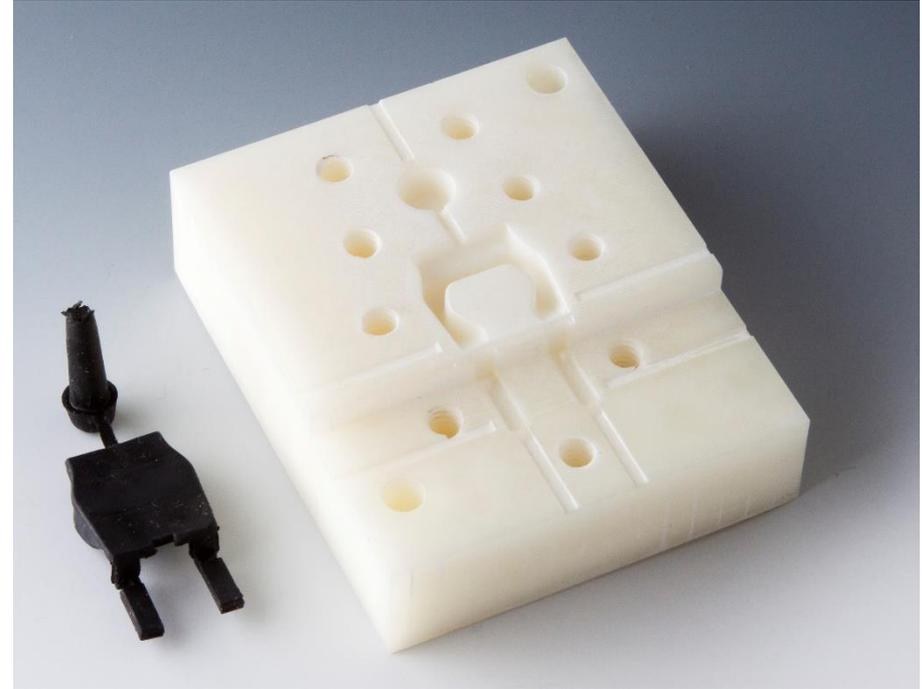
Bi-Link business case

Injection molded parts with metal inserts
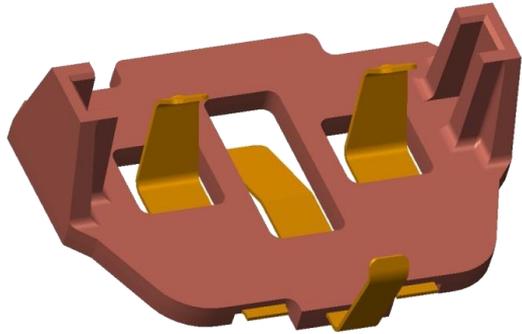
- Metal: 0.15 mm
- Resin: Polyethylene (PE)
- First shot with inserts <1 day
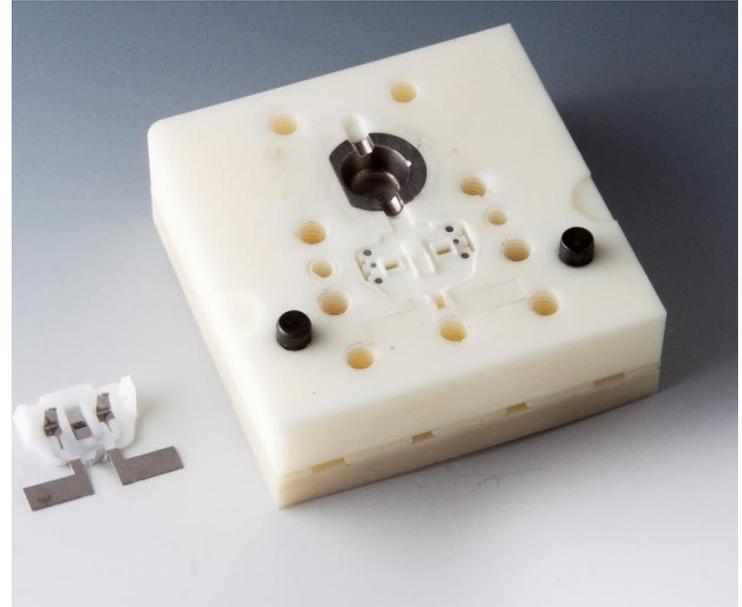
Polymer sheetmetal forming tools

- Sheet-metal forming tool for Pryer Technology Group using Ultem 9085

Method	Cost	Time
CNC Machining	$1,500	5 days
FDM Tooling	$450	1 day
SAVINGS	$1,050 (70%)	4 days (80%)

Metal hard-tools

- A variety of AM tool steels are available for the production of injection molding and sheet-metal forming tools
  - Tool Steel: Maraging 300, Tool Steel H13, Stainless Steel 316L, 15-5PH, 17-4 PH

- If well designed, such tools will last as long (and potentially longer) as conventionally made tools.

- When we talk about metal AM for tooling, we are only talking about using AM for the **tool insert**. Not for the entire mold-block

Make your tool more efficient

- Part cooling is an important part of the process to produce quality parts but can **consume up to 50% to 80% of the cycle time** per build.

- By adding **conformal cooling channels** to your tool, you can greatly increase its **running efficiency**, improve part **quality**, and extend the **tool life.**

DfAM for tooling: Conformal cooling
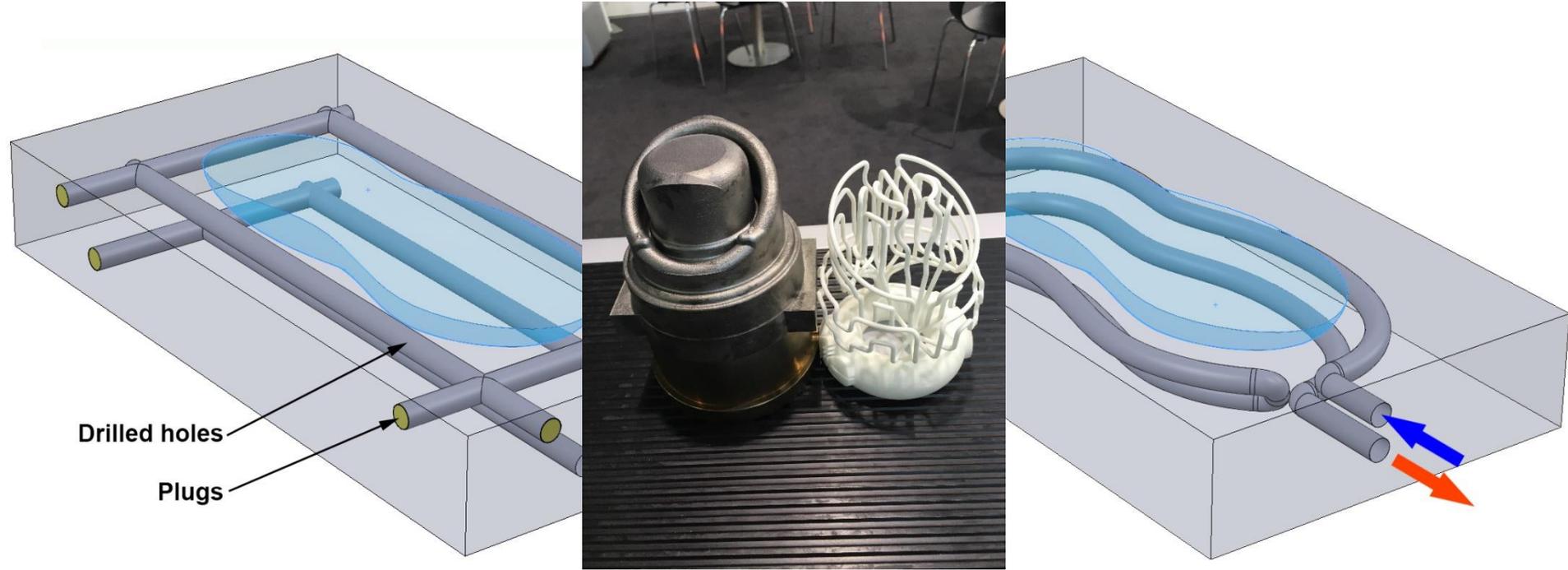
With conventional tooling, cooling channels are made by drilling straight holes. With AM complex curved holes can be made to get cooling where it is needed.

Why use conformal cooling?

- Conformal cooling channels, applied with no engineering simulation or analysis will, generally, result in about a 10% cycle time improvement.

- Conformal cooling channels, applied with engineering simulation and analysis will, generally, result in cycle time improvements from 20% to 40%.

Why use conformal cooling?

- Increase cycle time

- Case study for Phillips Plastics

- Cycle time with 1 cavity conventional tooling: 16.78 seconds

- Cycle time with 4 cavity DMLS conformal cooling: 13.02 seconds

- CAVITY TO CAVITY **CYCLE TIME IMPROVEMENT: 22.4%**
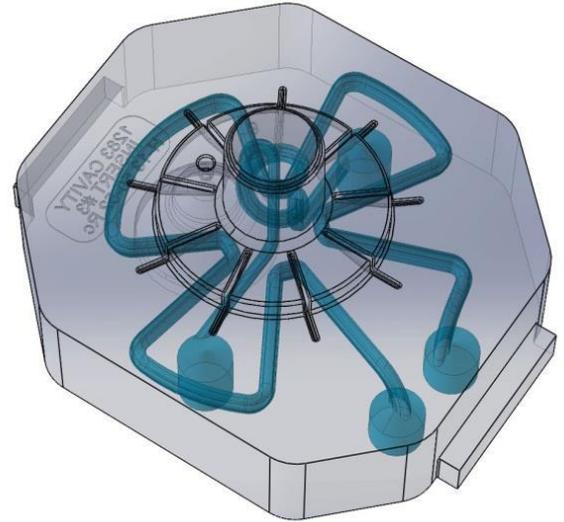
Why use conformal cooling?

When plastic cools evenly, internal stress is minimized. This results in a higher quality part with less warping or sink marks. Better controlled cooling allows you to control how the plastic solidifies in the mold and, therefore, to minimize part distortion and shrinkage.
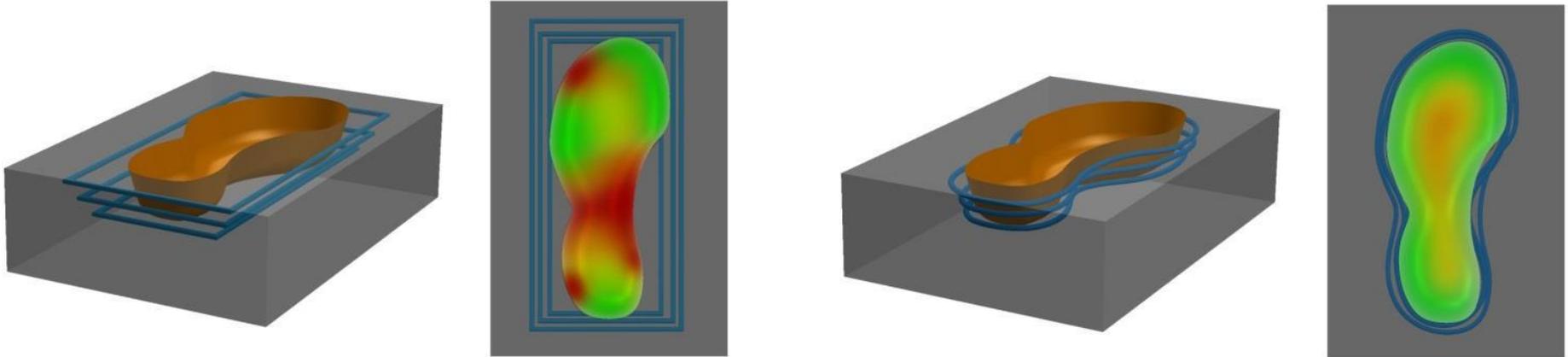
Why use conformal cooling?

- Improve part quality

- Case study for Phillips Plastics

- Flatness spec with conventional tooling: .25 mm: .15 min .223 max

- Flatness spec with DMLS conformal cooling: .2 mm: .080 min .161 max

- QUANTIFIABLE PART **FEATURE IMPROVEMENT: 20%**
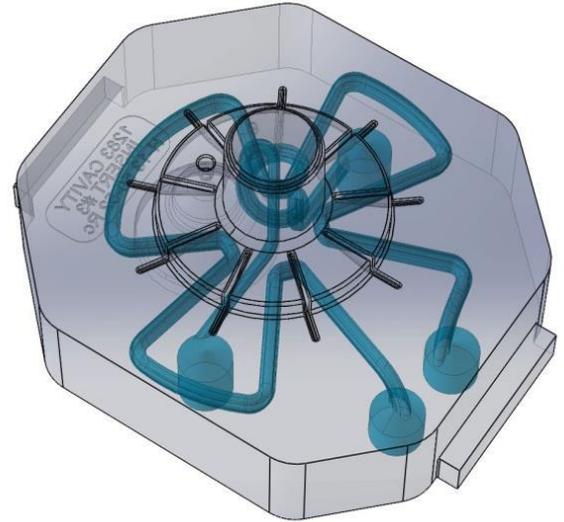
Think about which part of your tool is worth printing

- Like with most conventional tooling, it is best to use AM only for a **tool insert** that drops into a conventional mold base.

- You may often find that a large part of your tool is a relatively simple geometry that can be more efficiently manufactured with a traditional technology. In that case use a **hybrid strategy**.

Tool Insert

Mold Base
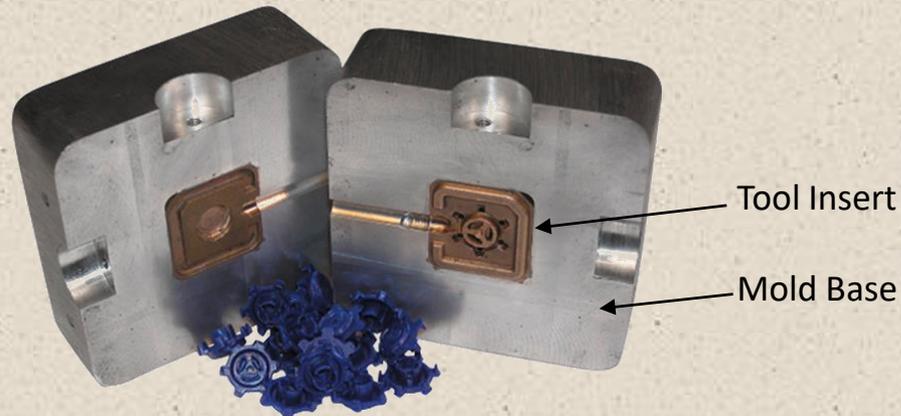
DfAM: Hybrid conventional/metal AM molds
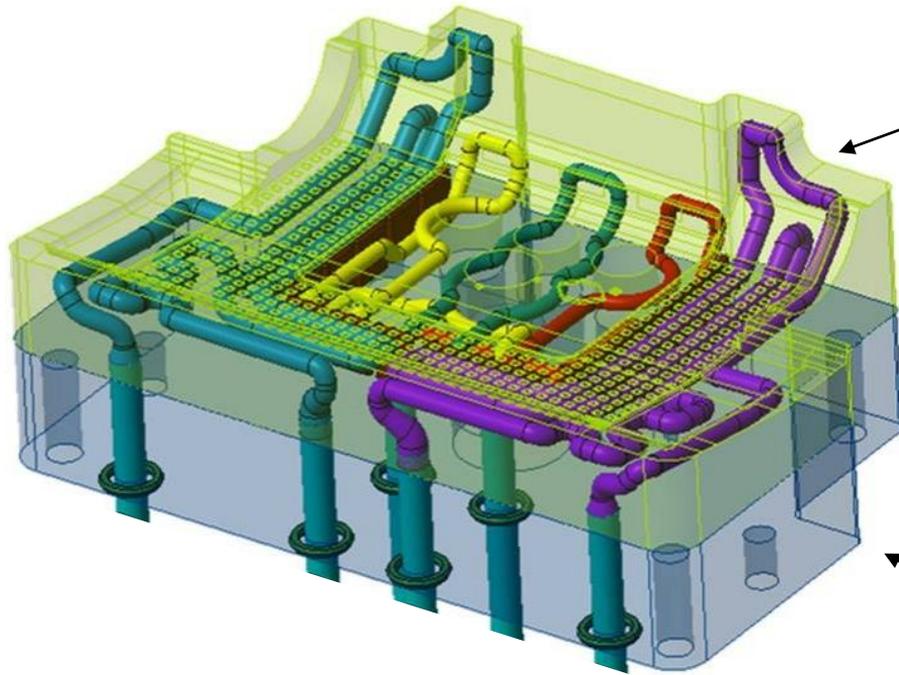
This part of tool is complex, so ideal for Metal AM

This part is simple, so make on CNC machine and build AM part on it

Huge growth in AM, but low industrial adoption

- The principal reason for this is **high cost.**
- So, **what determines the cost** of AM parts?
- **Can this be influenced** by design for AM.
- If so, what are the main parameters that affect cost that can be affected by design?
- Is it economical to print parts that have not been designed for AM?

Machine cost for 2 year payback

Machine purchase cost	Hourly machine running cost
$500,000	$37.45/hour
$650,000	$48.69/hour
$1,000,000	$74.91/hour
$1,200,000	$89.89/hour

AM post-processing costs

Service providers were asked, in 2017, what percentage of their part costs were attributed to printing vs pre and post-processing.

	Metal	Polymer	Both
Pre-processing	13.2%	10.9%	10.2%
Post-processing	31.4%	20.2%	27.0%
Total pre/post	**44.6%**	**31.1%**	**37.0%**
Printing	55.4%	68.9%	63.0%

Designing to minimize post-processing can have a serious consequence on price.

AM Cost per hour

For example

- Using an average machine hourly cost of $65/hour
- If a part takes 10 hours to print, that's $650 of machine time
- If a part takes 100 hours to print, that's $6500.
- If post-processing is 45% of the cost, that 100 hour part now jumps up to almost $12,000!!!
- Suddenly DfAM to reduce print times and therefore costs is of great interest!

What design factors affect print time?

AM process step	Affected by design
Pre-processing and printing	
Clean the AM system	No
Purge the system of oxygen	No
Preheat the AM system	No
Print the parts	
Spread layer of powder (recoater time)	No
Laser scans the contour lines	**Yes**
Laser scans the interior hatch patterns	**Yes**
Remove build platform from machine	No
Recycle powder	No
Post-processing	
Thermal stress relief	**Yes**
Remove parts from build plate	No
Hot isostatic pressing	No
Remove support structures	**Yes**
Heat treatment	**Yes**
Shot-peening, surface machining, etc.	No
Inspection	No

The printing process
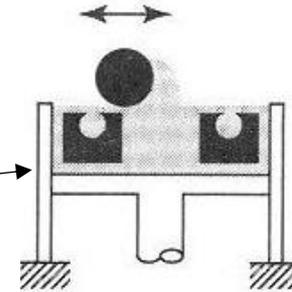
If 100mm high
@ 50μ layers
= 2000 layers
@ 10 sec/layer
= 5.5 hours
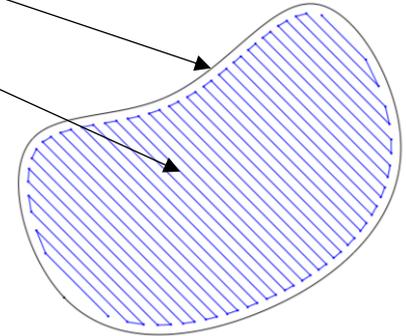
What determines machine costs?

- Machine costs are determined by the amount of material that has to be melted.

- For a 100mm cube, there is a lot of material to be melted

- For a slice of the model, the laser has to scan about 100 metres of material (at 0.1mm hatch spacing)

- if the beam is travelling at 330 mm/s, it will take 300 seconds, or 5 minutes, to hatch that slice of the model, or $5.41 of machine time.

- That equates to 2000 x $5.41= $10,820 of machine time!
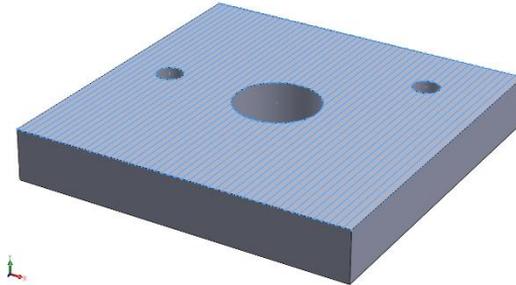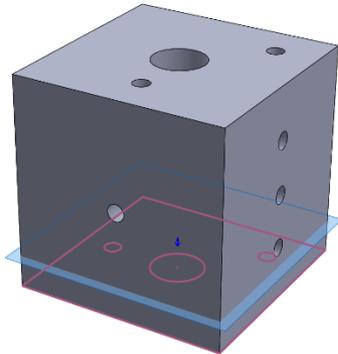
What determines machine costs?

- In contrast, simply shelling the part removes a huge amount of time.

- the total scan distance is only about 4.5 m.

- This represents a scan distance reduction of over 95%.

- If the beam is travelling at 330mm/s, it will take 13.6 seconds to hatch that slice of the model, or $0.24 of machine time.

- That equates to 2000 x $0.24 = $480,00 of machine time
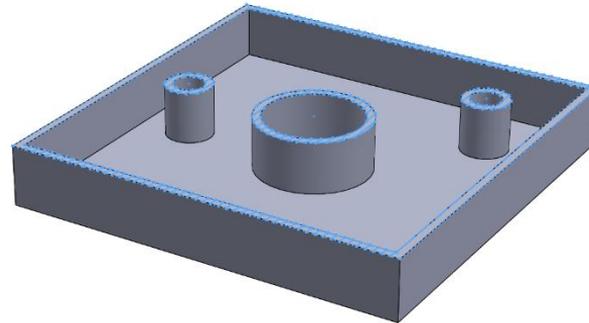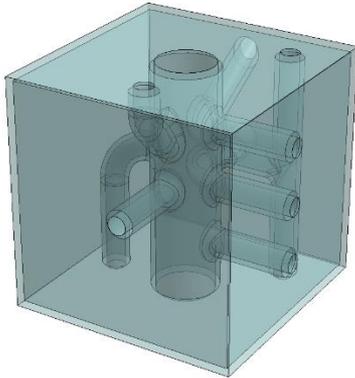
What determines machine costs?

If you design the part for AM, the scan times and costs get even further reduced.

	Solid	Shelled	DfAM
Print times	191 hours	36 hours	19 hours
Bureau quotes for part in 316L Stainless	$15,293.82	$ 3735.12	$ 1986.25
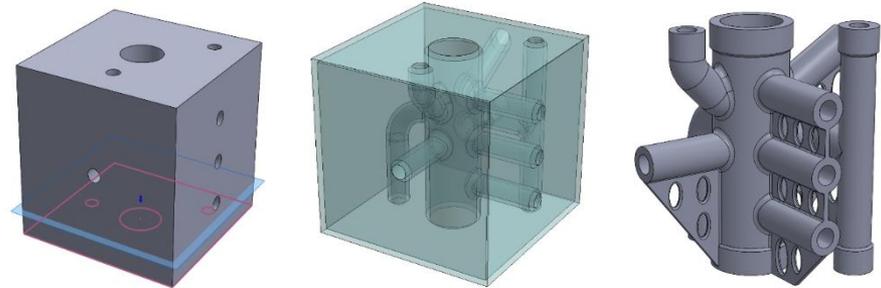
The economics of AM Tooling

- Typically, AM hard-tools will cost a little bit more (between 10% to 30%) than conventional tooling. This can be drastically reduced through good DfAM practices.

- But they will normally be manufactured approximately 3 to 10 times faster than conventional tools.
  - Note of caution: Most figures on this compare AM tools made in-house to conventional tools made through sub-contractors.

- AM tools with conformal cooling can shorten the cycle time by 10% to 40%.

- What is the economic value of such time savings?

Vilecon business case
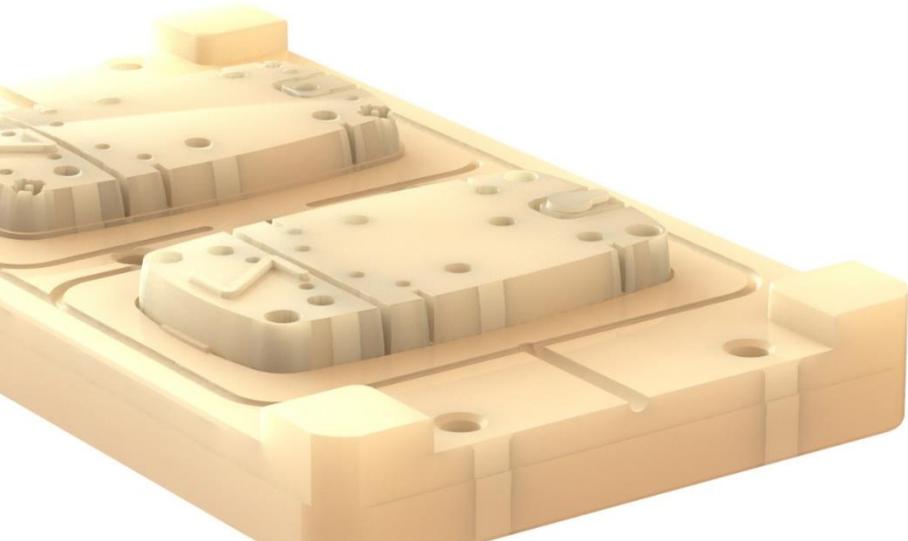
- Main Issue: Only 200 units required

- Printed on ProJet 3500HDMax
- 3DSYSTEMS VisiJet M3-X material
- Verified using SOLIDWORKS
- Molded by Vilecon

Tooling setup

Injection molding of the parts

Manufacturing methods

	#parts	Mold cost	Part cost	Lead time	Material properties
Direct 3D printing	1-10	-	$100	1 day	3D print material
RTV Mold	10-50	$500	$10	3 days	Polyurethane
Soft Tooling (CNC alu) / Printed tooling	100-200 / 10-200	>$2000 / >$500	$2 / $3	2 weeks / 2 days	Production thermoplastics
Hard Tooling (CNC steel)	200 -	>$10000	$0.50	6 weeks	Production thermoplastics

Questions?
Discussion?