Additive Manufacturing of Flexible Polymers

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This presentation

1. Where is additive manufacturing today?
2. Additive manufacturing of flexible materials

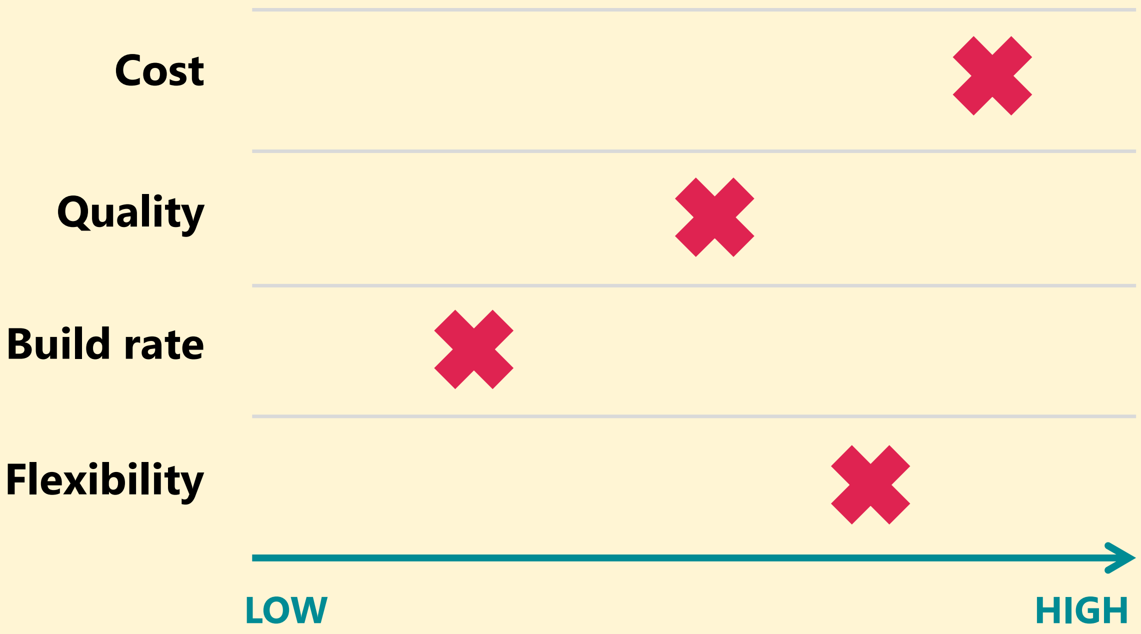
Who am I?

Worked in the AM group at RISE for the last five years.

I work with process development for **novel AM technologies** and particularly using robotics and AM together.

Where is additive manufacturing today?

3D printing has come a long way since its origins in the mid 1980s. However, there are still many challenges to overcome, such as right-first-time capabilities, material availability and process robustness.



Additive manufacturing (AM) is a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies.

Other terms used are 3D-printing, rapid prototyping, free form fabrication and direct manufacturing.

Why additive manufacturing?

Advantages

1. Design freedom
2. Short lead times
3. Reduced material waste
4. Single step manufacturing
5. Low cost for small series
6. Design customization

Application areas

- Rapid prototyping
- Rapid tooling
- Rapid manufacturing
- Part repair
- Part consolidation

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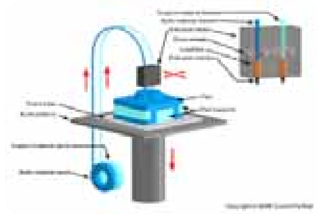
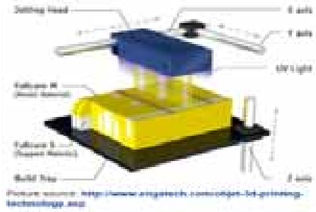
Additive Manufacturing: 7 Categories of Technologies

Material extrusion



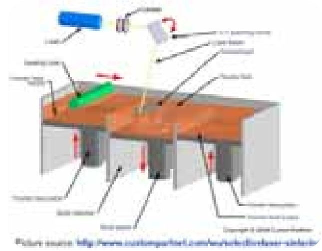
Material is selectively dispensed through a nozzle or orifice.

Material jetting



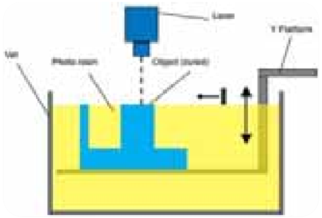
Droplets of build material are selectively deposite.

Powder bed fusion



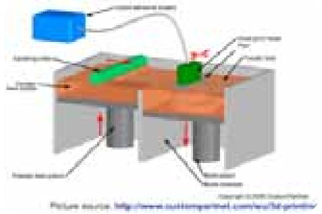
Thermal energy selectively fuses regions of a powder bed.

VAT photo polymerization



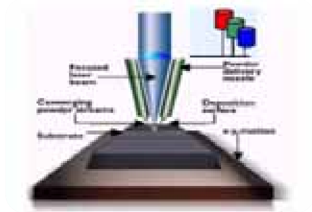
Liquid photopolymer in a vat is selectively cured by light-activated polymerization.

Binder jetting



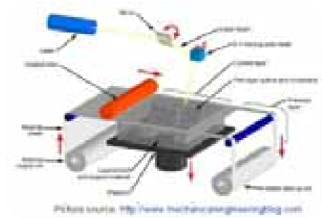
Liquid bonding agent is selectively deposited to join powder material.

Directed energy deposition



Focused thermal energy is used to fuse materials by melting as the material is being deposited.

Sheet lamination

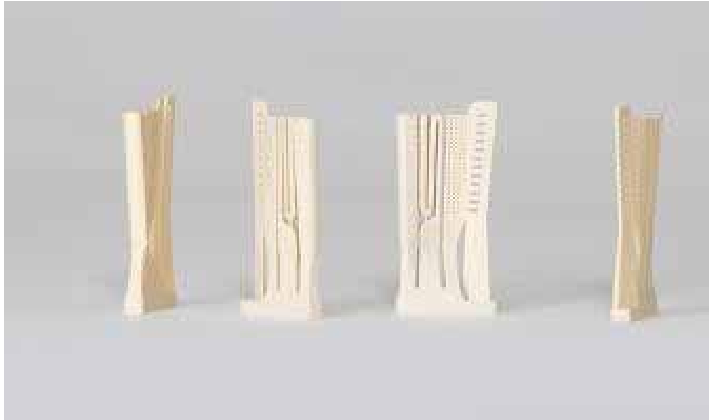


Sheets of material bonded to form an object.

01. 3D-printed Aston Martin for Skyfall

02. Fuel injection for LEAP jet engine (GE)

03. Ceramic cores for investment casting (Lithoz)



04. Impossible faucet by American Standard

05. 3D-printed turbine blades by Siemens

06. 3D-printed hearing aids

A Brief Timeline of Additive Manufacturing

1984
Chuck Hull invents stereolithography.
(U.S. Patent 4,575,330)

1986
Selective laser sintering patented by Carl Deckard.
(U.S. Patent 4,863,538)

1987
3D Systems founded, 1st commercial equipment for plastics.

1989
Fused Deposition Modelling patented by Scott Crump.
(U.S. Patent 5,121,329)

1989
Stratasys founded.

1995
EOS releases first commercial metal printer.

1997
Arcam founded.

2005
RepRap Project started to develop printers which can print its own components.

2009
Makerbot founded.

2012
First 3D printed titanium jaw implanted.

2012
Lithoz releases first commercial ceramic printer.

2016
Siemens in Finnspång builds AM workshop for 200 MSEK.

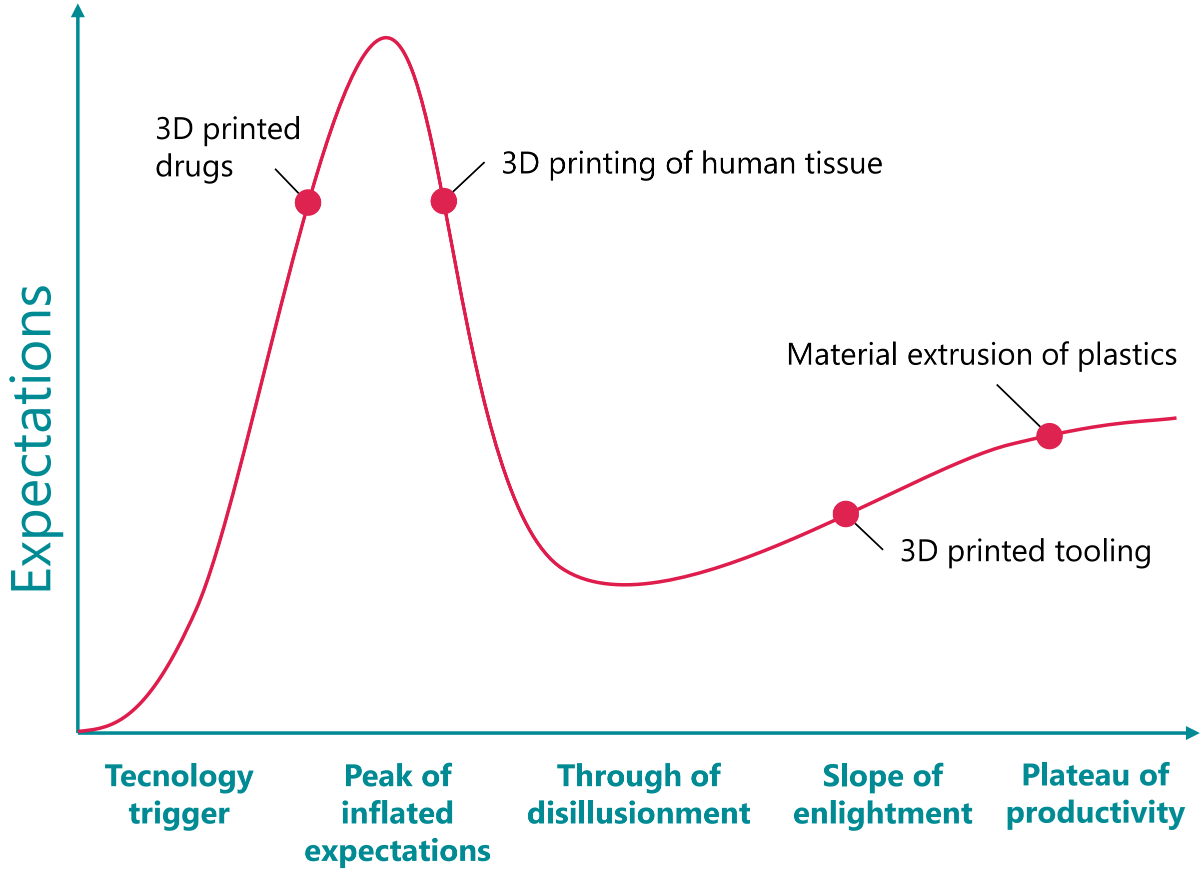
2016
GE Additive starts to manufacture LEAP engine.

2016
Cellink founded and starts selling bioprinters.

1980 1990 2000 2010 2020

Gartner Technology Curve for AM

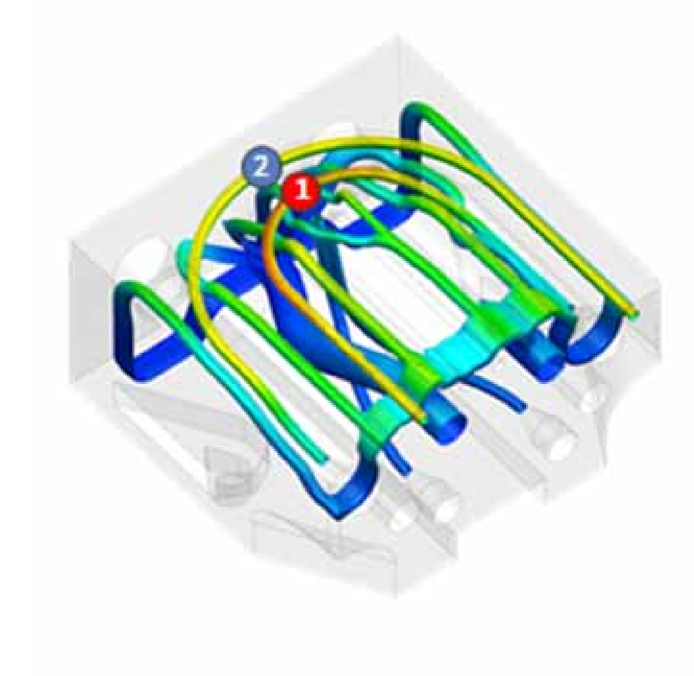
Predicting the adoption of new technologies such as additive manufacturing.



Common applications

Tooling

Lightweight parts



Improved functionality

Flexible Materials

- Historically both limited material availability and limited performance
- Several recent business cases with high volume production

Adidas FUTURECRAFT 4D
https://news.adidas.com/futurecraft/adidas-4d-range-expands-with-new-reflective-alphaedge-4d-running-shoe/s/306db084-c380-41c6-96eb-0675e66a6928

AM Technologies for Flexible Materials

Thermoplastic elastomers

Material extrusion, powder bed fusion

Thermoset/crosslinked elastomers

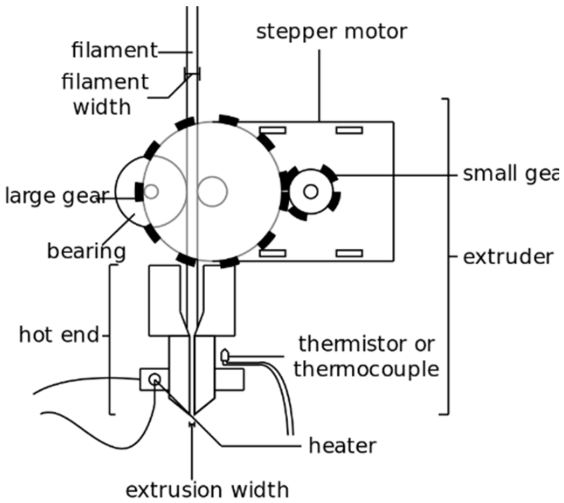
Material jetting, vat photo-polymerization

Material Extrusion

- Extrusion of thermoplastic polyurethanes or thermoplastic copolyesters
- Hardness: Shore 70A – 95A
- Feature resolution of 100-150 µm

Thermoplastic polyurethane Shore 92A
https://www.stratasys.com/materials/search/fdm-tpu-92a

Material Extrusion



+ Low start-up cost

+ Multi-material parts possible

- Extrusion failure (buckling, backflow)

- Interlayer adhesion issues (insufficient time for wetting and chain entanglement)

- Low process robustness

- Complex geometries difficult

Material Behaviour and Properties

- Printability decrease with decreasing hardness
- Hygroscopic
- Retraction difficult

Name	Manufacturer	Type	Tensile Strength [MPa]	Elongation at break [%]	Shore A Hardness
NinjaFlex	NinjaTek	TPU	4	660	85
Cheetah	NinjaTek	TPU	9	580	95
FDM TPU 92A	Stratasys	TPU	16.8 - 17.4	550	92
Filaflex	Recreus	TPU-TPE	45	600	82
Filaflex Ultrasoft	Recreus	TPU-TPE	32	900	70

Material Jetting

- Deposition of droplets of photocurable material by a print head
- UV light cures the material
- Polyjet from Stratasys and Multi-jet from 3DSystems
- Allows multifunctional parts

Agilus30 Polyjet Material
https://www.stratasys.com/materials/search/agilus30

Material Jetting

+ High resolution (20 µm - 70 µm)

+ Multi-material possible

+ Graded material possible

- Low viscosity required for jetting -> dilution

- Allergenic resins

- High start-up and material cost

Material Behaviour and Properties

- Relatively low performance
- High resolution
- Very soft materials available

Name	Manufacturer	Tensile Strength [MPa]	Elongation at break [%]	Shore A Hardness
Visijet CE-NT	3DSystems	0.2-0.4	160-230	-
FLX9840	Stratasys	1.3-1.8	110-130	35-40
FLX9860	Stratasys	2.5-4.0	75-85	57-63
FLX9895	Stratasys	8.5-10.0	35-45	92-95
Agilus30	Stratasys	2.4-3.1	220-270	30-35

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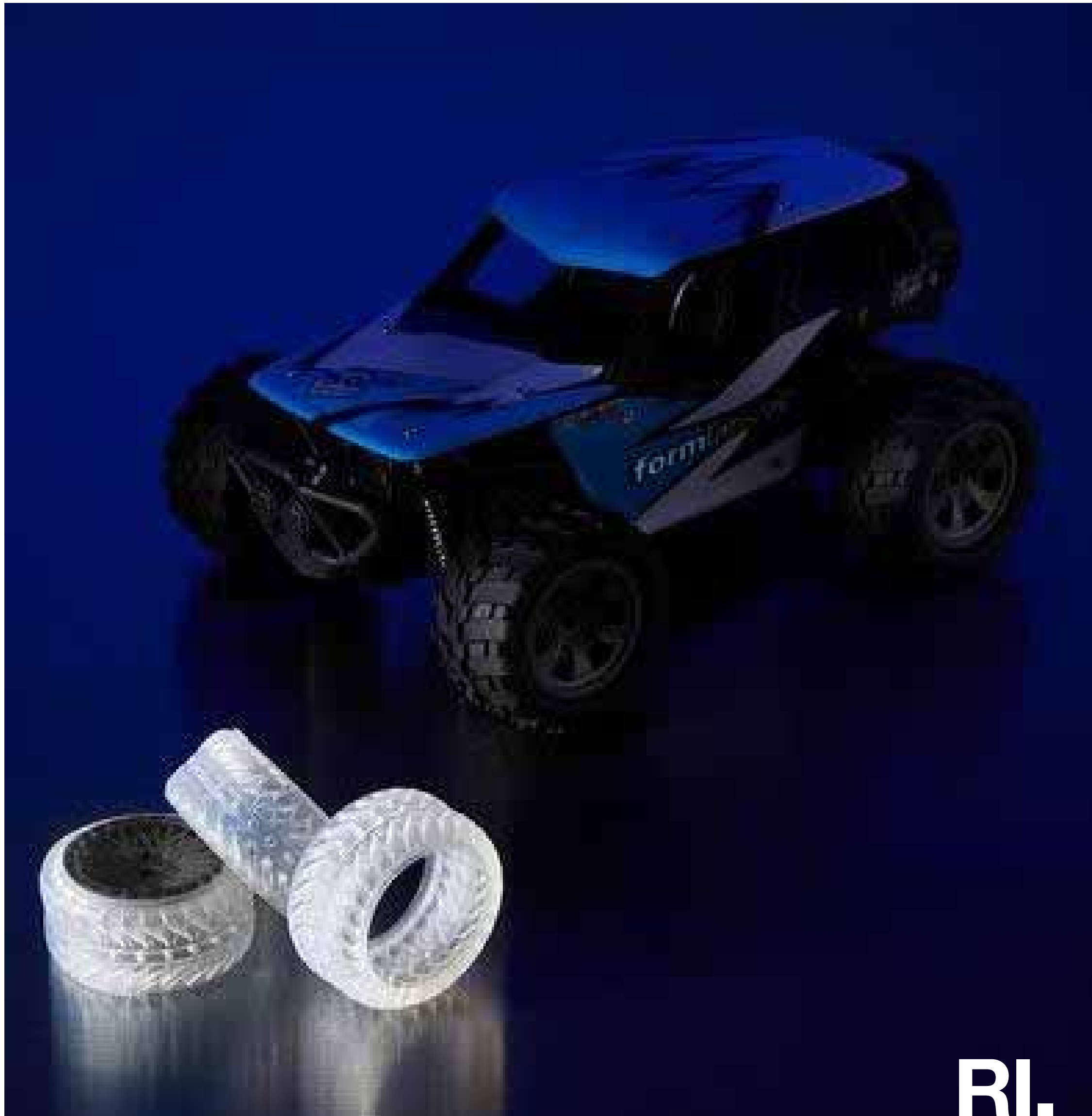
Vat Photo-polymerization

- Photopolymerization of resin
- High resolution possible
- Thermoset elastomers



Components from FormLabs Elastic Resin
https://formlabs.com/blog/elastic-resin-soft-resilient-3d-printing/

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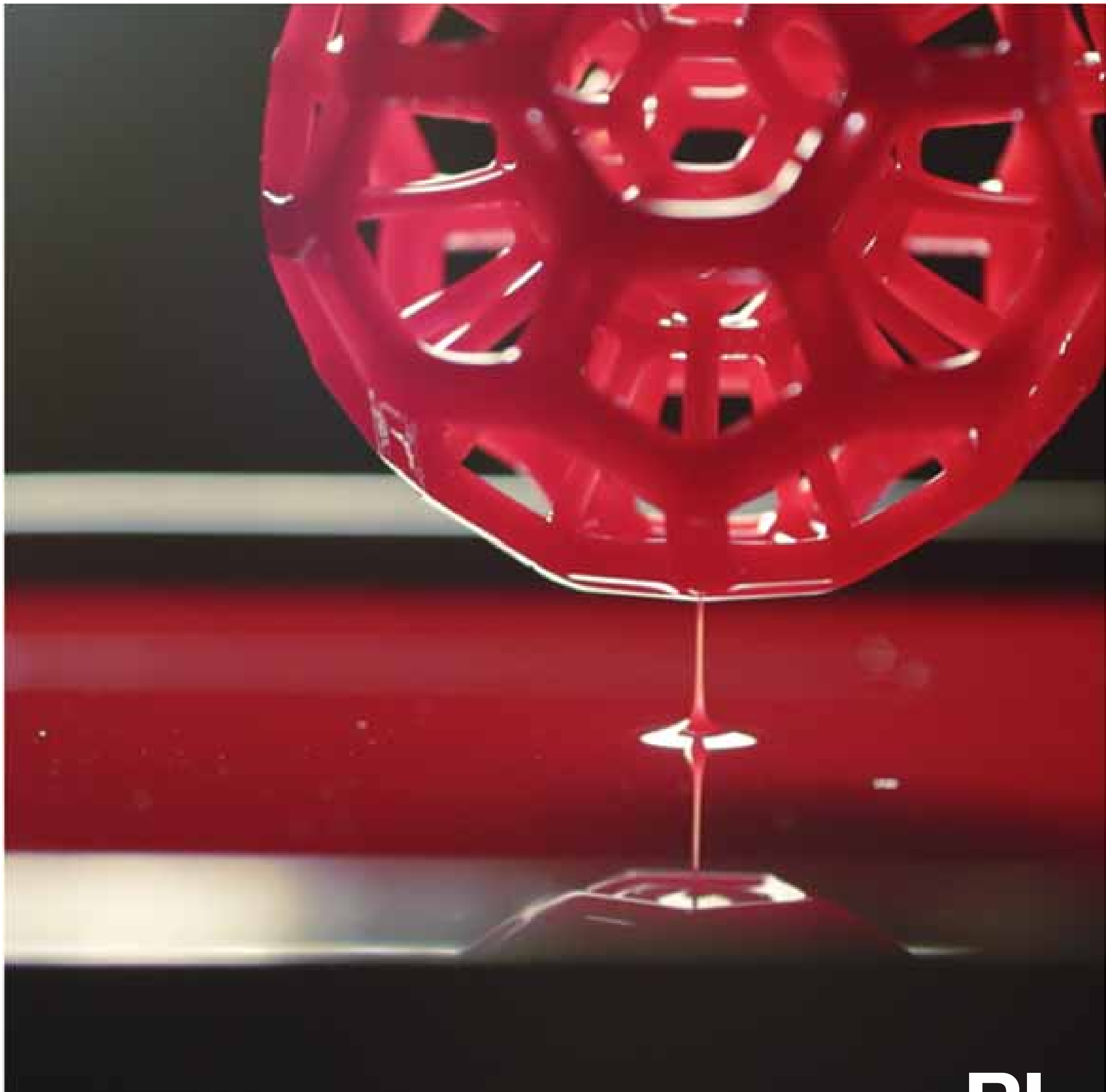
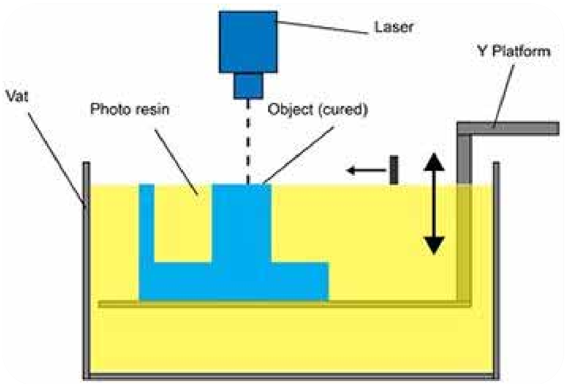
CLIP technology

- Released April 1, 2016
- Digital light projection for photocuring
- Oxygen permeable membrane
- Continous printing without layered structure



CLIP technology
https://3dprintingindustry.com/news/adidas-to-release-a-new-version-of-3d-printed-shoe-alphaedge-4d-155578/

Vat Photo-polymerization



+ High resolution (10 µm - 100 µm lateral)

+ Complex designs possible

- Not possible with multi-material

- Low to moderate viscosity resins possible

- Allergenic materials

- Moderate to high start-up cost

- High material cost

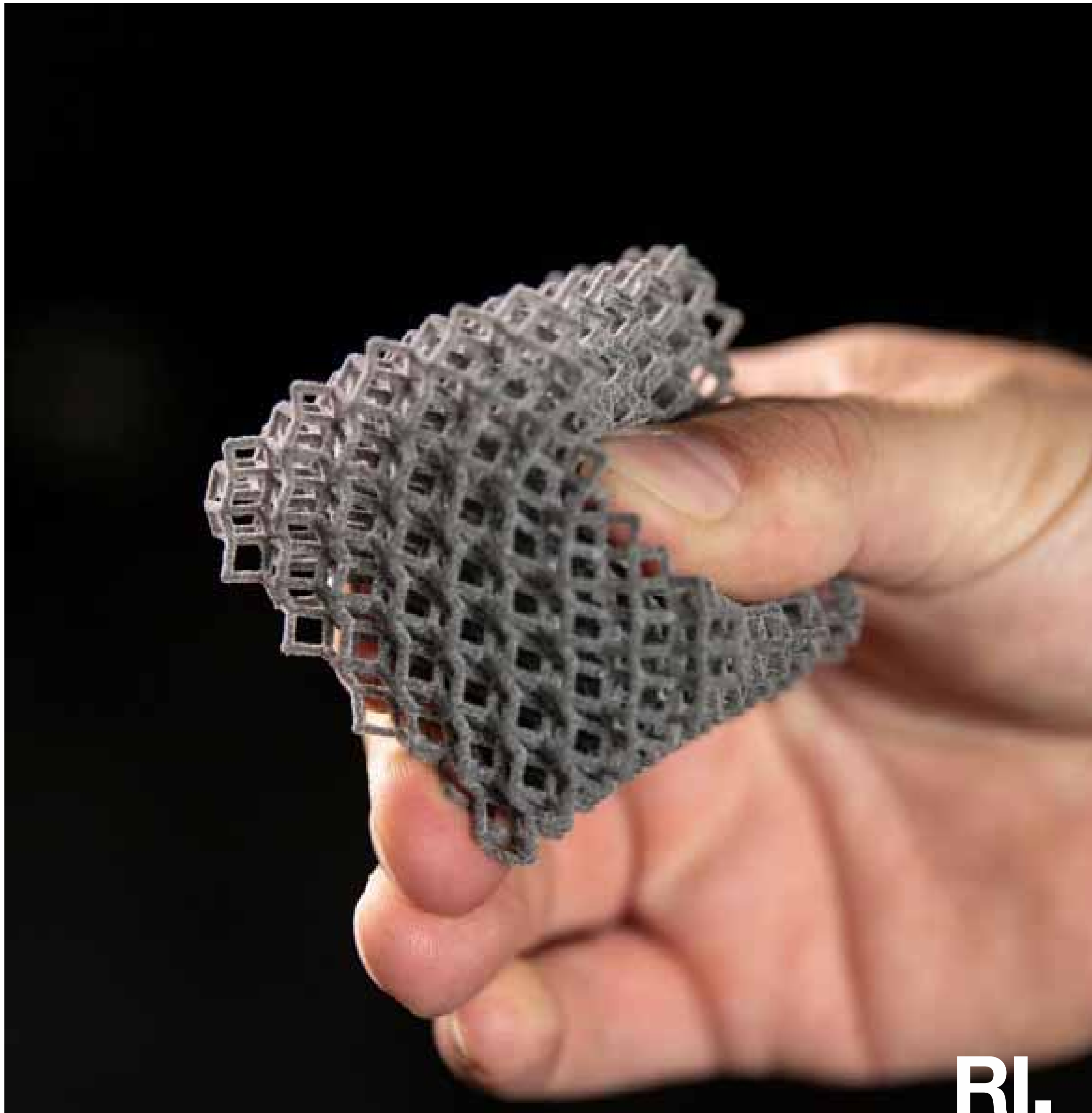
Material Behaviour and Properties

- Relatively low performance
- High resolution
- Very soft materials available

Name	Manufacturer	Tensile Strength [MPa]	Elongation at break [%]	Shore A Hardness
Elastic (green)	Formlabs	1.61	100	40
Elastic (post-cured)	Formlabs	3.23	160	50
Flexible (green)	Formlabs	3.3-3.4	60	70-75
Flexible (post-cured)	Formlabs	7.7-8.5	75-85	80-85
EPU 40	Carbon3D	7.7	>250	68

Powder Bed Fusion

- Powder is selectively joined together by heating with a laser
- Moderate resolution
- 0,1 millimetres layer thickness
- Heated chamber with inert gas required



Ultrasint TPU 90A-01 by Materialise/BASF
https://www.materialise.com/en/manufacturing/materials/ultrasint-tpu-90a-01

Material Behaviour and Properties

- Moderately soft materials
- Rubber-like parts
- Non-slip surfaces

Name	Manufacturer	Tensile Strength [MPa]	Elongation at break [%]	Shore A Hardness
DuraForm TPU	3D Systems	2.1	200	59
Ultrasint TPU 90A-01	Materialise/BASF	8-8.5 (xy) 5-6.5 (z)	260-330 (xy) 50-100(z)	88-90
LUVOSINT X92A-1	Lehmann & Voss & CO	20 (xy) 15 (z)	520 (xy) 500 (z)	88
Windform RL	Windform	5.0	383	83

Energica motorbike 3D printed soft seat in Windform RL using SLS.
(http://www.windform.com/windform-rl.html)

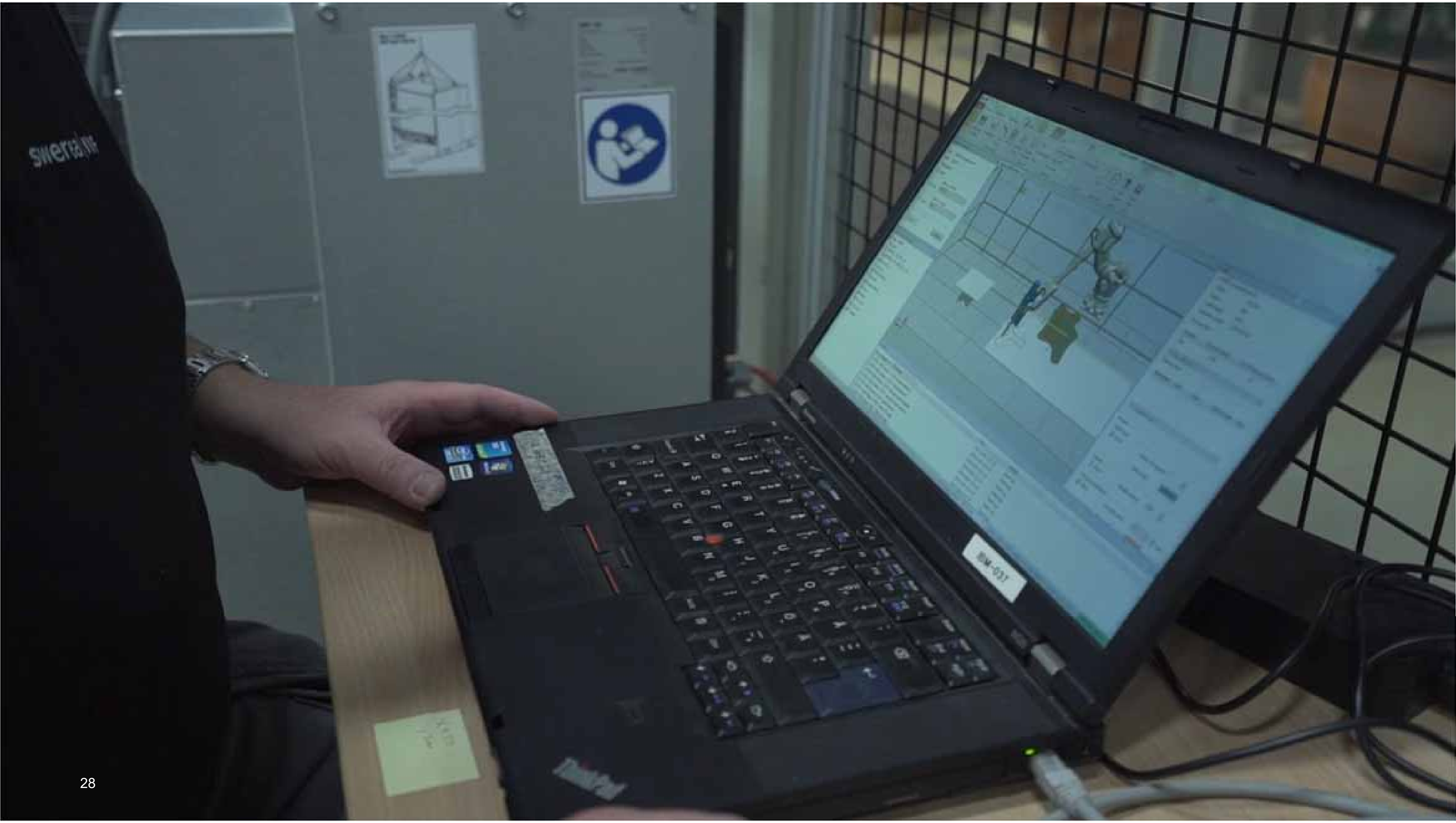
3D printed collection by Dutch designer Iris van Herpen. Printed using SLS by Materialise.
(https://www.materialise.com/en/cases/iris-van-herpen-debuts-wearable-3d-printed-pieces-at-paris-fashion-week)

Adidas FUTURECRAFT 4D shoe. Printed using CLIP.
(https://3dprintingindustry.com/news/adidas-to-release-a-new-version-of-3d-printed-shoe-alphaedge-4d-155578/)

Flexible manufacturing based on robotics

Use of industrial robotics to enable flexible manufacturing through:

- Scalability
- Tool changers
- Hybrid manufacturing
- Inline quality assurance
- Collaborative robot cell


ThinkPad

INDUSTRIAL USE CASE

Personalized furniture on demand at RISE




Companies

- Svenska Woody AB and startup Sculptur AB

Results

- Pre-industrialization tests successful in recycled materials
- Company is ready to go into full production.

Conclusion

- Growing interest with new applications
- Challenging to process due to inherent material properties
- AM technology has to selected on a case by case basis
- Materials which are tailored specifically for AM required
- Complex designs can provide elasticity with variations in density
- Granulate feedstock materials unlocks new possibilities

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