
Elmia Subcontractor 2018

Additive Manufacturing of complex filigree-structured Objects based on Shape-Memory Polymer

Thorsten Pretsch | Dilip Chalissery



Elmia Subcontractor Trade Show, Jönköping, Sweden

15th of November 2018

Content

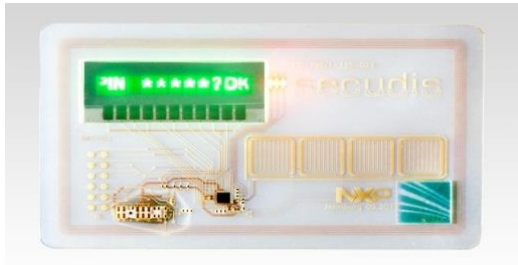
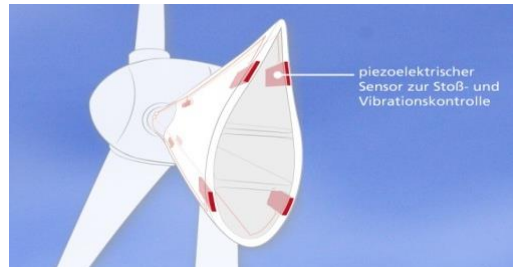
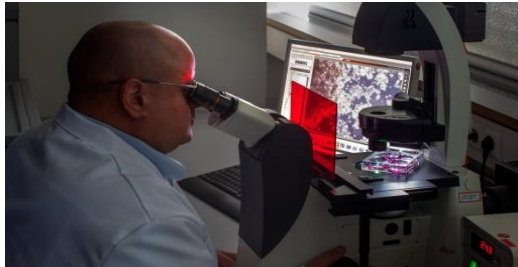
- Introduction
- Motivation
- Conception
- Results
- Summary

The Fraunhofer-Gesellschaft Locations in Germany

- 72 institutes and research units in 2017
- 25,527 staff
- € 2.3 bn research volume



High-Performance Center "Integration of Biological and Physical-Chemical Material Functions"



Objectives

- increasing efficiency of manufacturing processes of complex products
- integration of special functions/functional materials into polymeric structure materials giving shape and stability to a product
- bundling of scientific competences in the Brandenburg-Berlin region (scientific institutions, companies / associations)

Partners

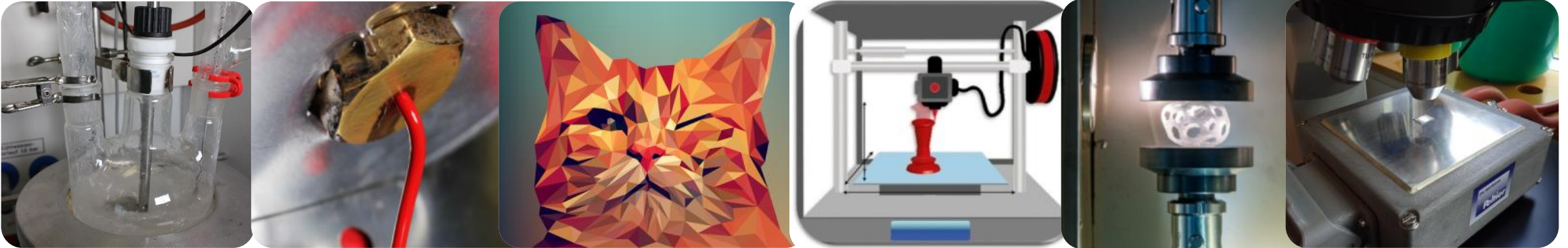
- Fraunhofer Institute for Applied Polymer Research IAP and Fraunhofer Institute for Cell Therapy and Immunology IZI-BB
- University of Potsdam
- BTU Cottbus - Senftenberg
- MPI of Colloids and Interfaces

Project

- Integration of shape-memory properties into polymeric 3D printing materials

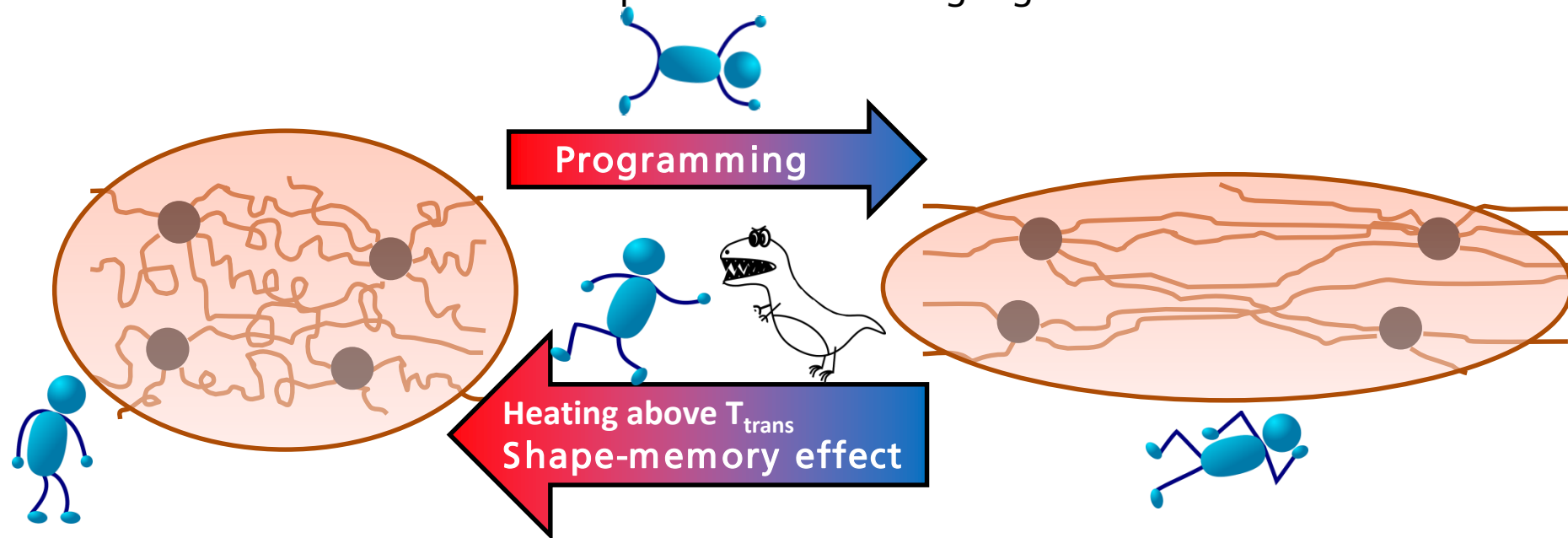
Shape-Memory Polymers

- Technology Enablers
 - Polymer Synthesis
 - Processing Technology
 - Component Design
 - Additive Manufacturing
 - Programming
 - Analytics/Characterization



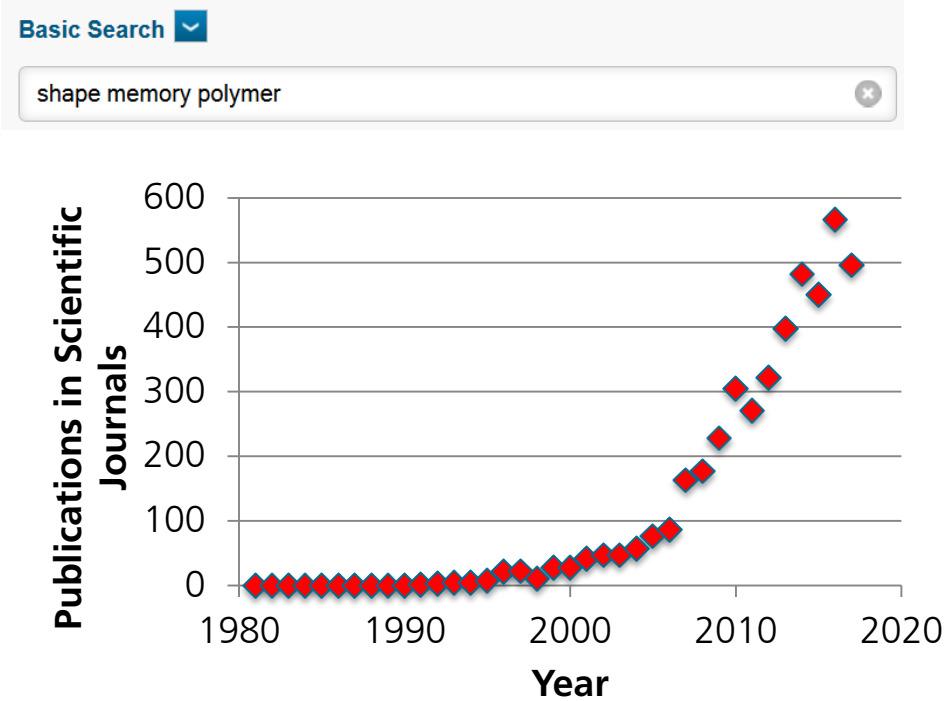
Shape-Memory Polymers

- **Definition:** Shape-memory polymers (SMPs) are stimuli-responsive polymeric materials. SMPs can be deformed from an as-processed permanent shape and stabilized in a temporary shape by thermomechanical treatment, which is also referred to as “programming”. As a result, the polymer maintains its stress-free state until shape recovery is triggered through an external stimulus like heat.
- **Structure:** The shape-memory properties of a polymer are closely linked to its network structure. Suitable polymer network architectures consist of netpoints and switching segments.



Shape-Memory Polymers

Scientific publications




Web of Science, July 2018

 Frost & Sullivan Jan 2015, NE5D-MT.

Market studies



Top 20

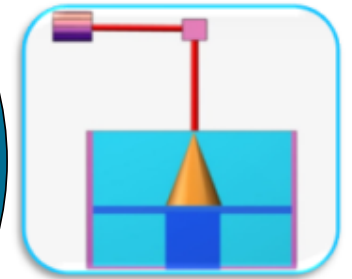
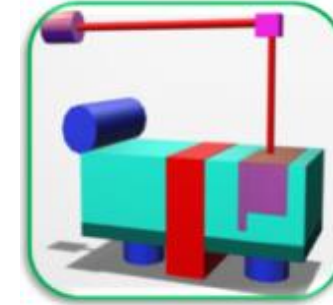
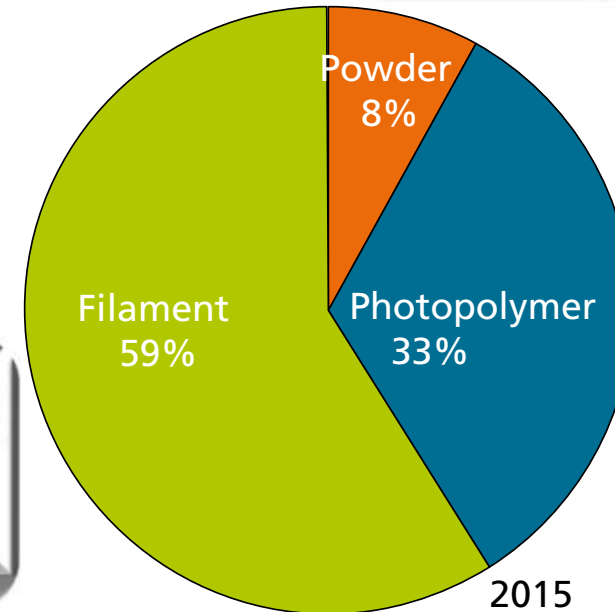
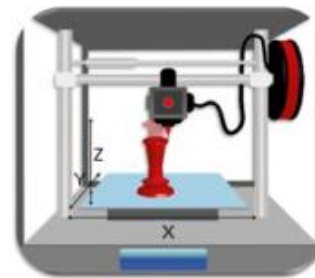


4-D Printing ✖	Context Aware Mobile Computing
Nanobots	Haptic Holography
Cognitive Computing	Bionic Prosthetics
Brain Machine Interfaces	Scentography
Powered Exoskeletons	Private Cloud Orchestration
Smart Pills	Synthetic Biology
Electroceuticals	Web 3.0
Smart Fabrics ✖	Telescopic Pixel
Wearable Devices	Polymer Chameleons ✖
Wireless Electricity	Graphene Technology
Flexible Electronic Devices	



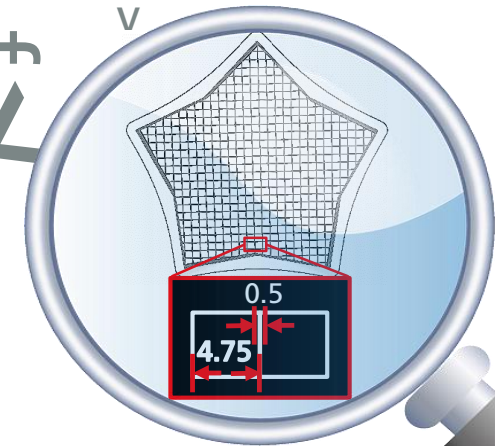
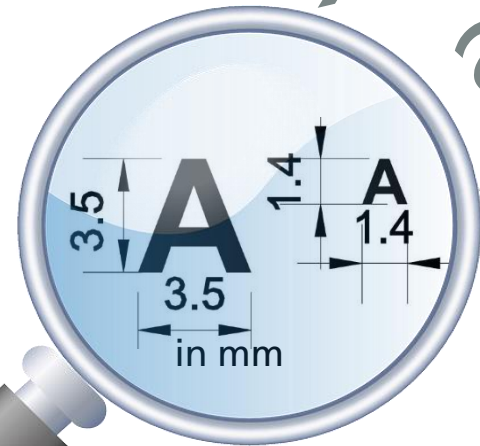
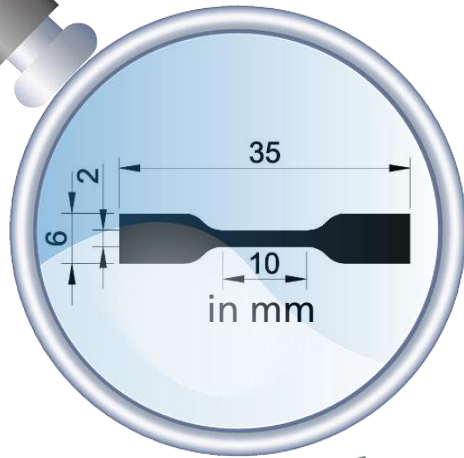
Additive Manufacturing

- Used for modelling and prototyping
- Individualization of products
- Cost-efficient production in small quantities
- Number of 3D-printable materials is still low
- Market shares of 3D-Printing materials:
 - **2015:** 59% filament materials, revenue \$800 million
 - **Forecast for 2025:** 83% filament materials, revenue \$8.500 million



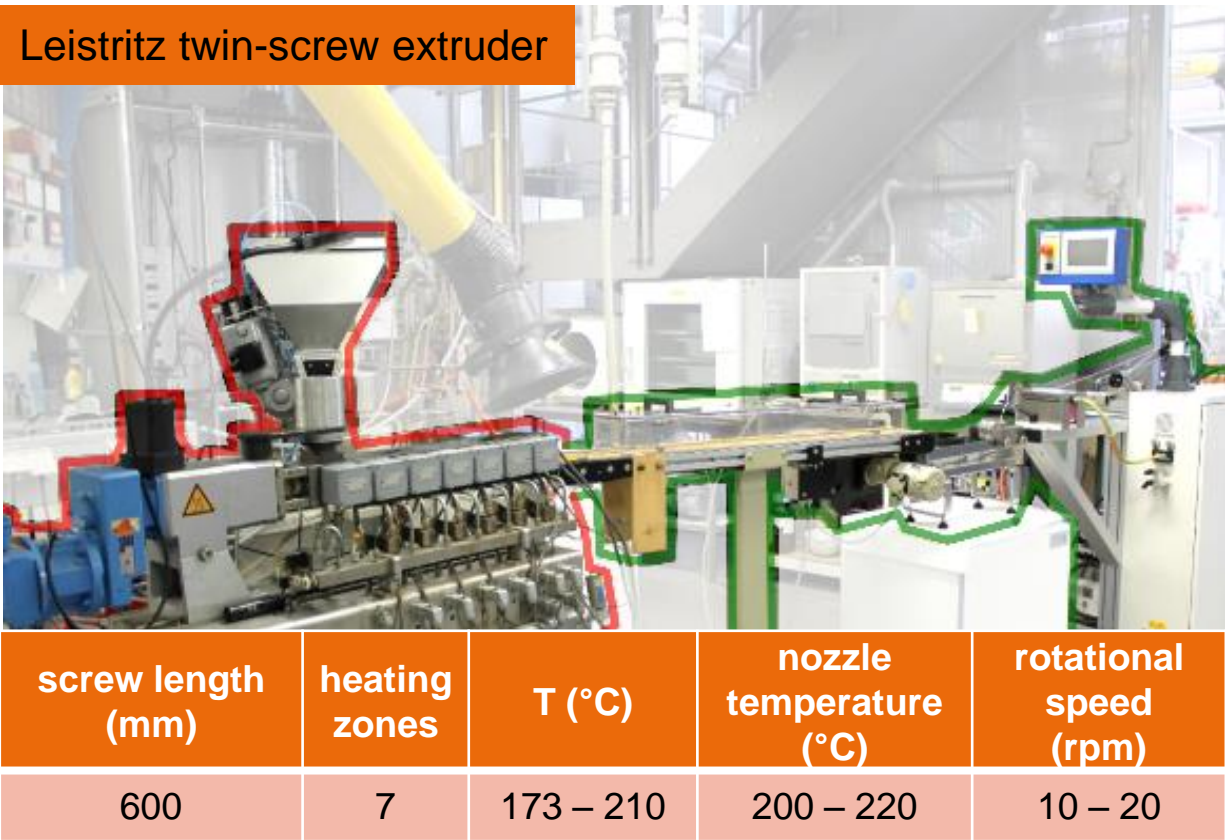
📄 R. Gordon, J. Harrop, 3D Printing Materials 2016-2026: Status, Opportunities, Market Forecasts, IDTechEx Ltd, 10.5.15

Complex filigree-structured Objects

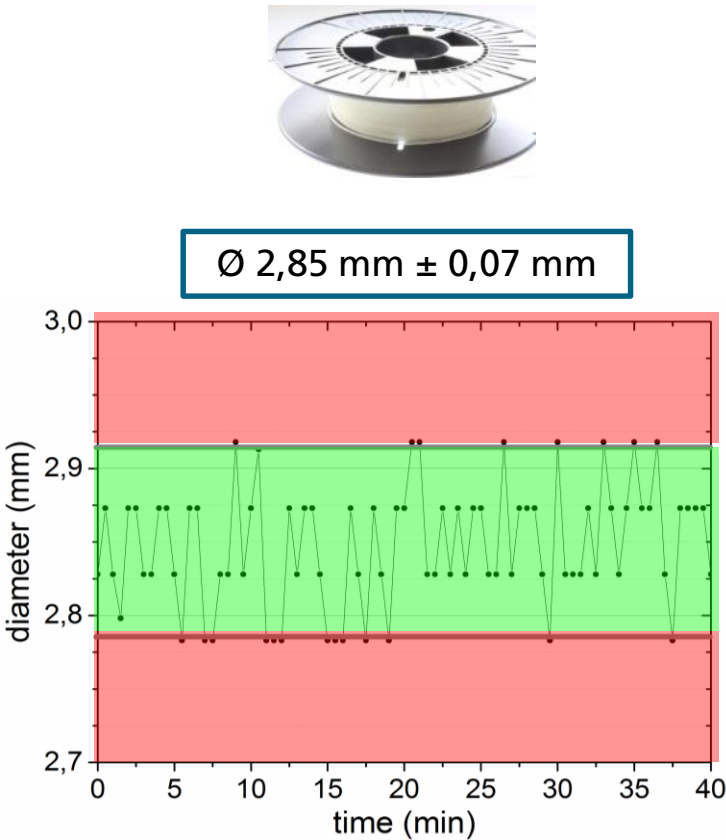


Filament Production

■ Extrusion of TPU (Covestro Deutschland AG)

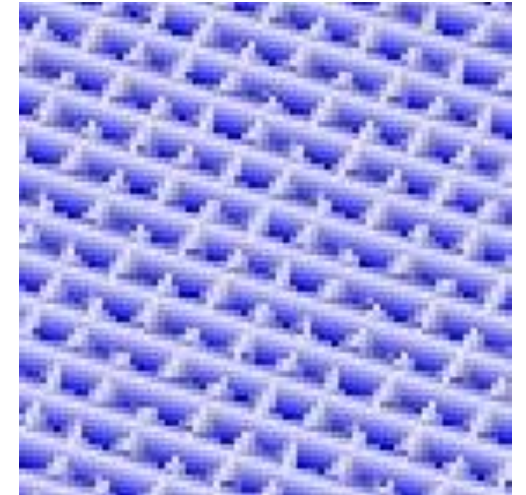
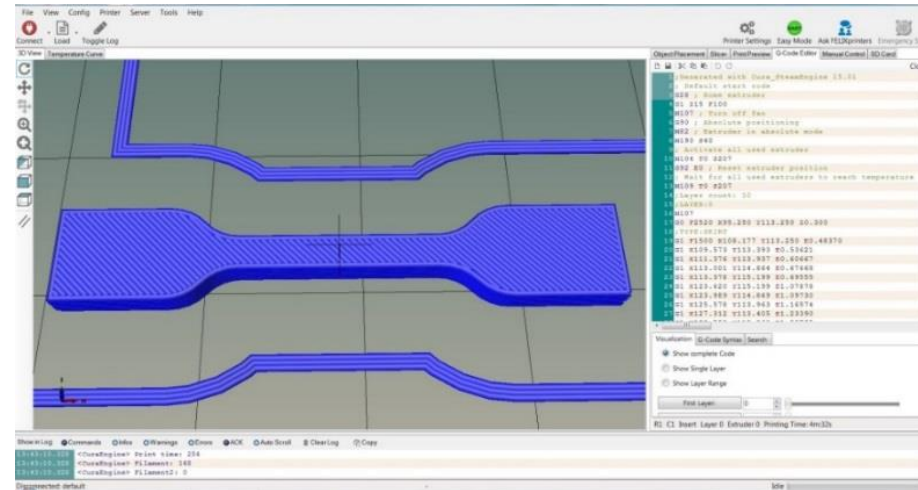
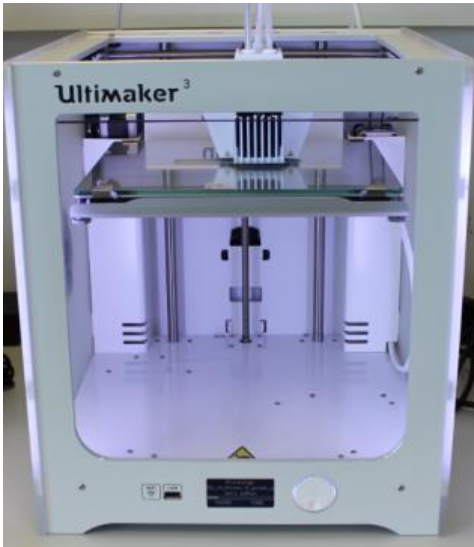


■ Filament diameter control



Motivation: Better Control over 3D-Printing Processes

- Design of a tensile bar (type 5B, ISO 527-2: 1996) using AutoCAD
- Converting the digital model into printing instructions (slicing)
- **General problem:** no control over structure (**printing pattern**)



Print software: Repetier-Host, Hot-World GmbH & Co. KG

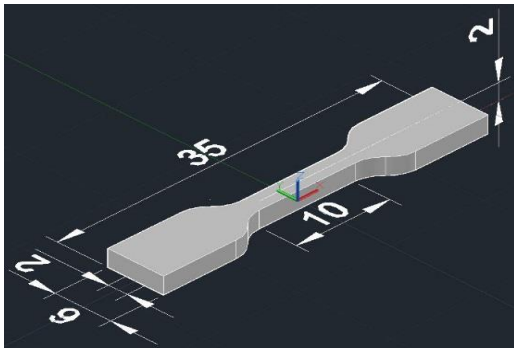
Visualization of 3D-Printing Paths

■ Solution:

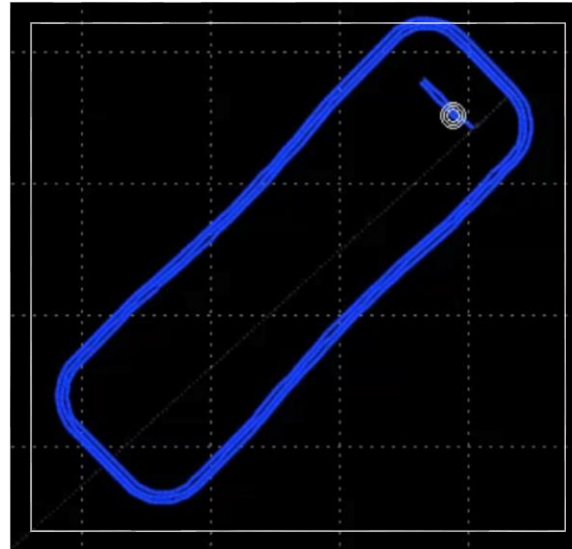
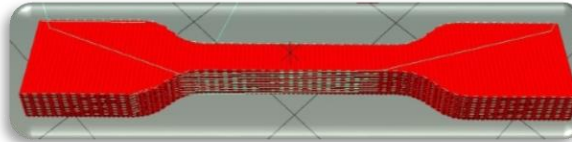
Change of strand deposition direction
→ realization of new structures

■ Tensile bar:

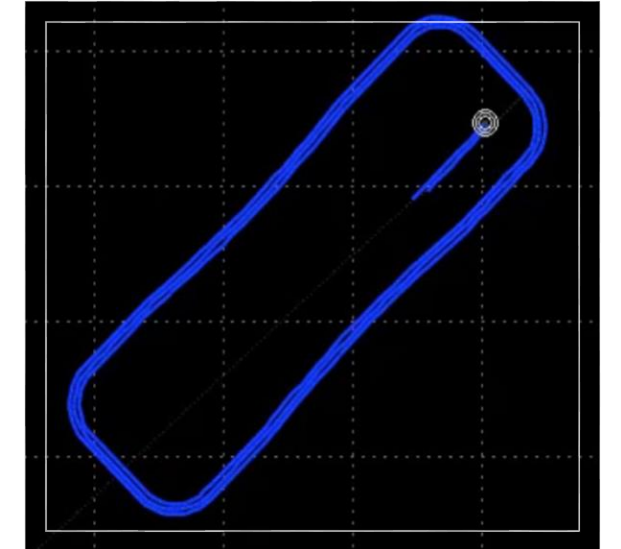
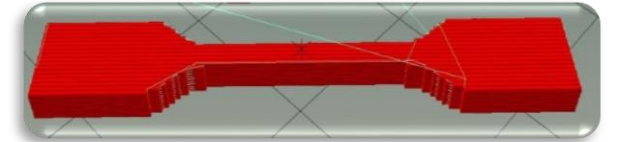
- Height: 2 mm
- 18 layers
- Layer thickness ~ 110 μm



“Vertically-printed” (16 min)

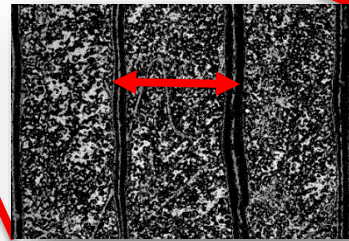
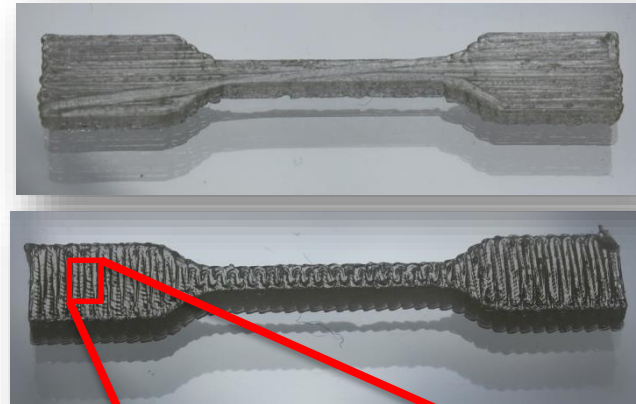
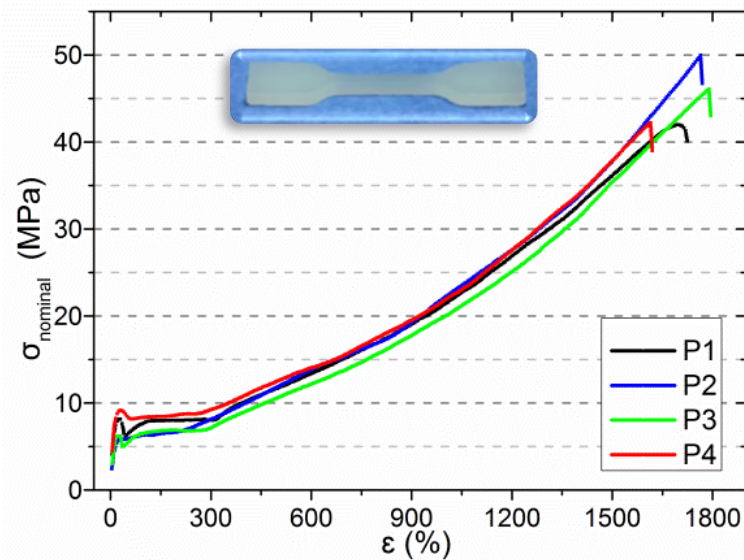
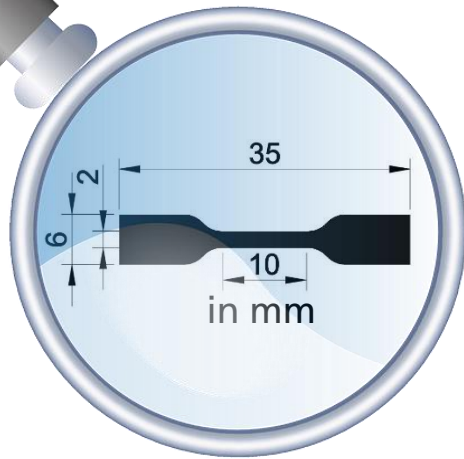


“Horizontally-printed” (8 min)

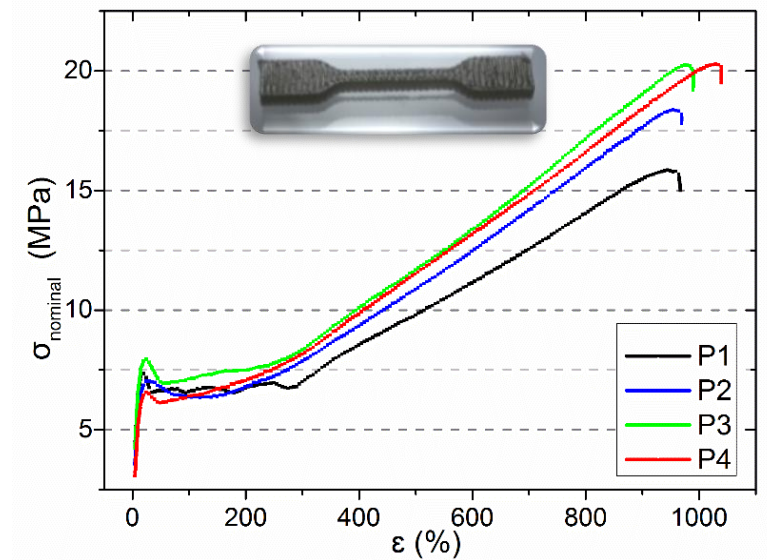
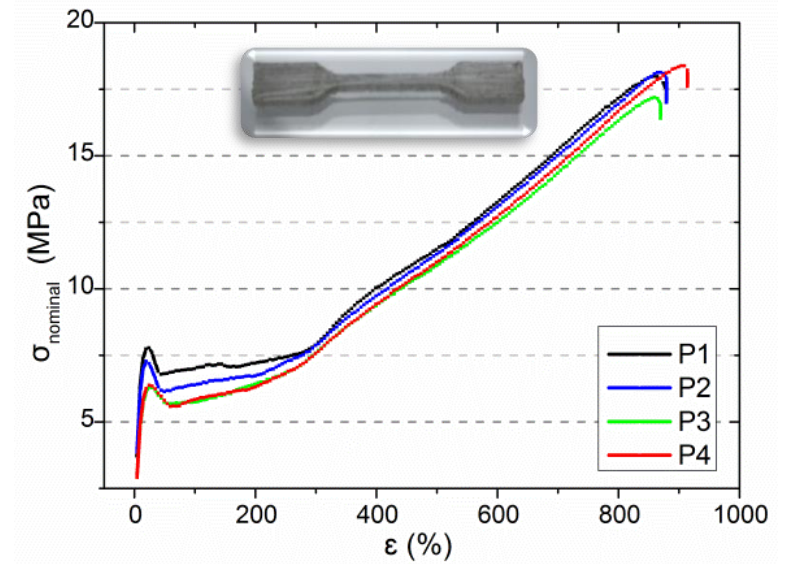


simulation software: GCode Print Simulator v1.30

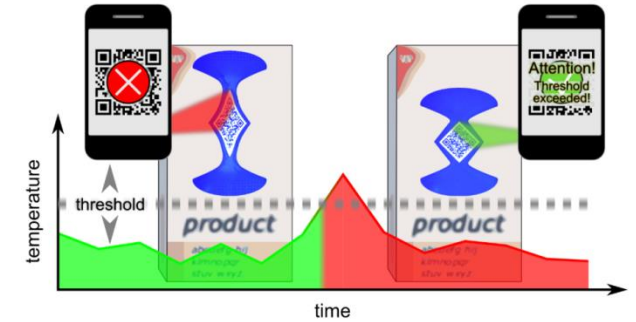
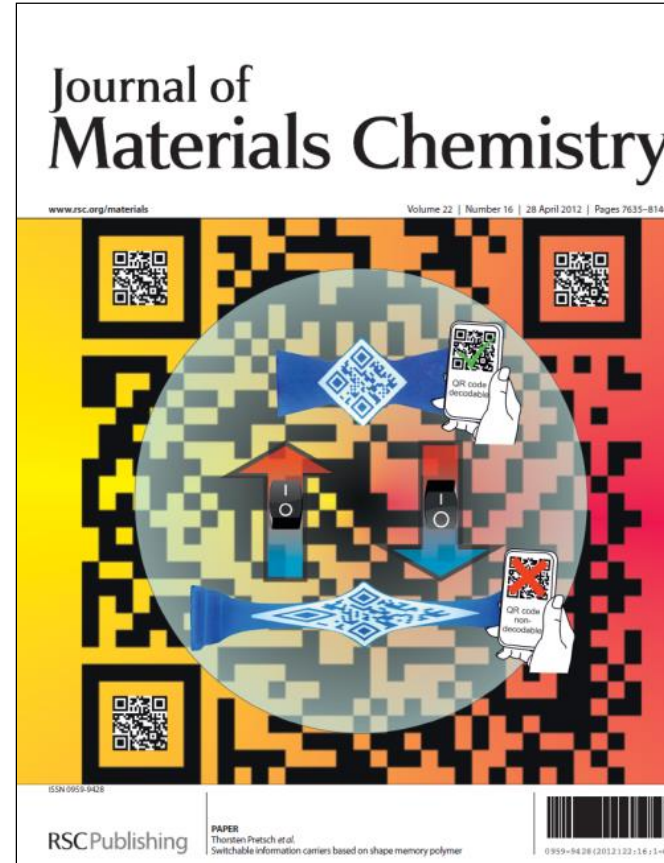
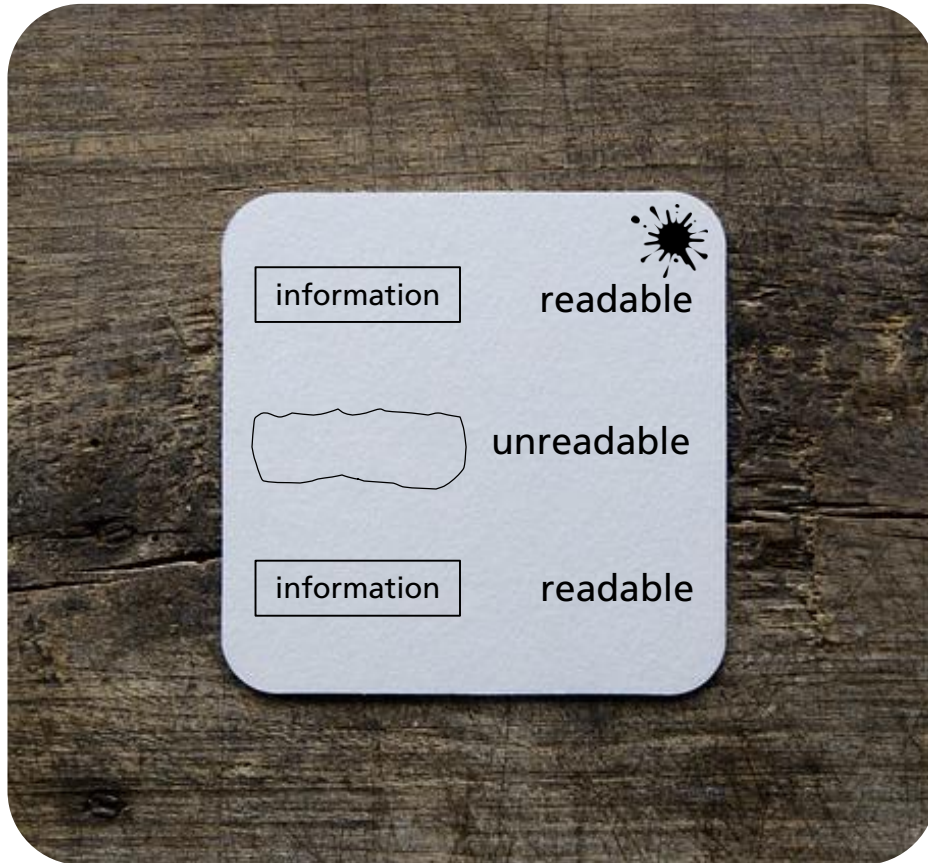
Additive Manufacturing and Characterization



Diameter of polymer strand:
~ 400 μm



Quick Response (QR) Code Carriers

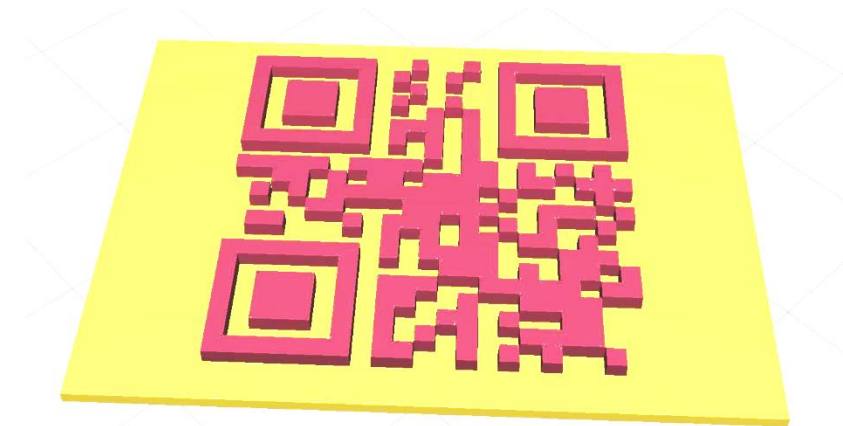


Pretsch, T., Ecker, M., Schildhauer, M., Maskos, M., *J Mater Chem A* **2012**, 22(16), 7757-7766.

Fritzsche N., Pretsch T. *Macromolecules* **2014**, 47 (17), 5952-5959

Quick Response (QR) Code Carriers

- Additive manufacturing of information carriers using fused filament fabrication (FFF)
 - Generation of QR code "Fraunhofer IAP"*
 - Development of virtual design for QR code carrier**



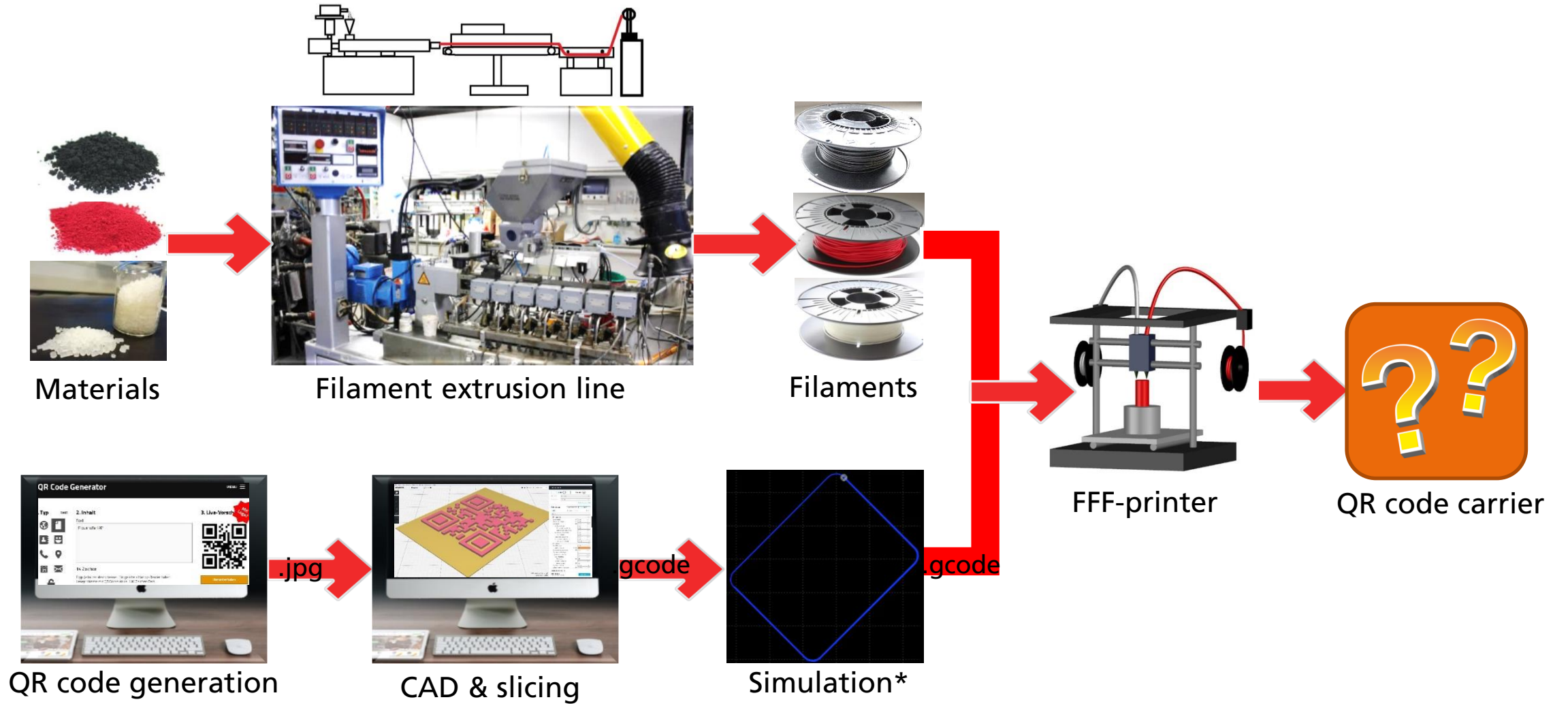
thickness of upper layer: 270 μm

thickness of substrate: 270 μm

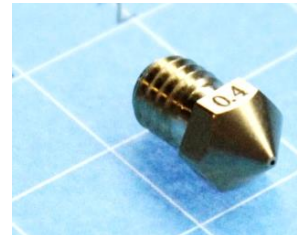
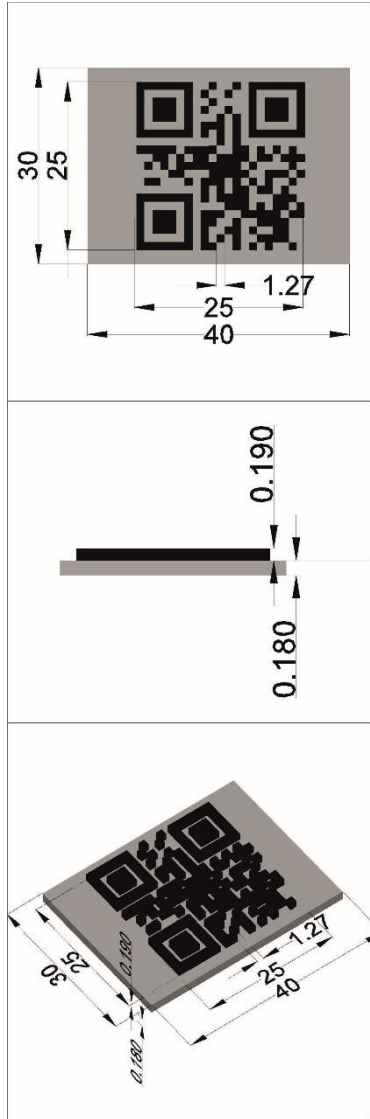
* QR Code generator: <http://goqr.me/de/>

** produced with Cura 3.2.1

Filament Extrusion, virtual Design and Additive Manufacturing



Additive Manufacturing



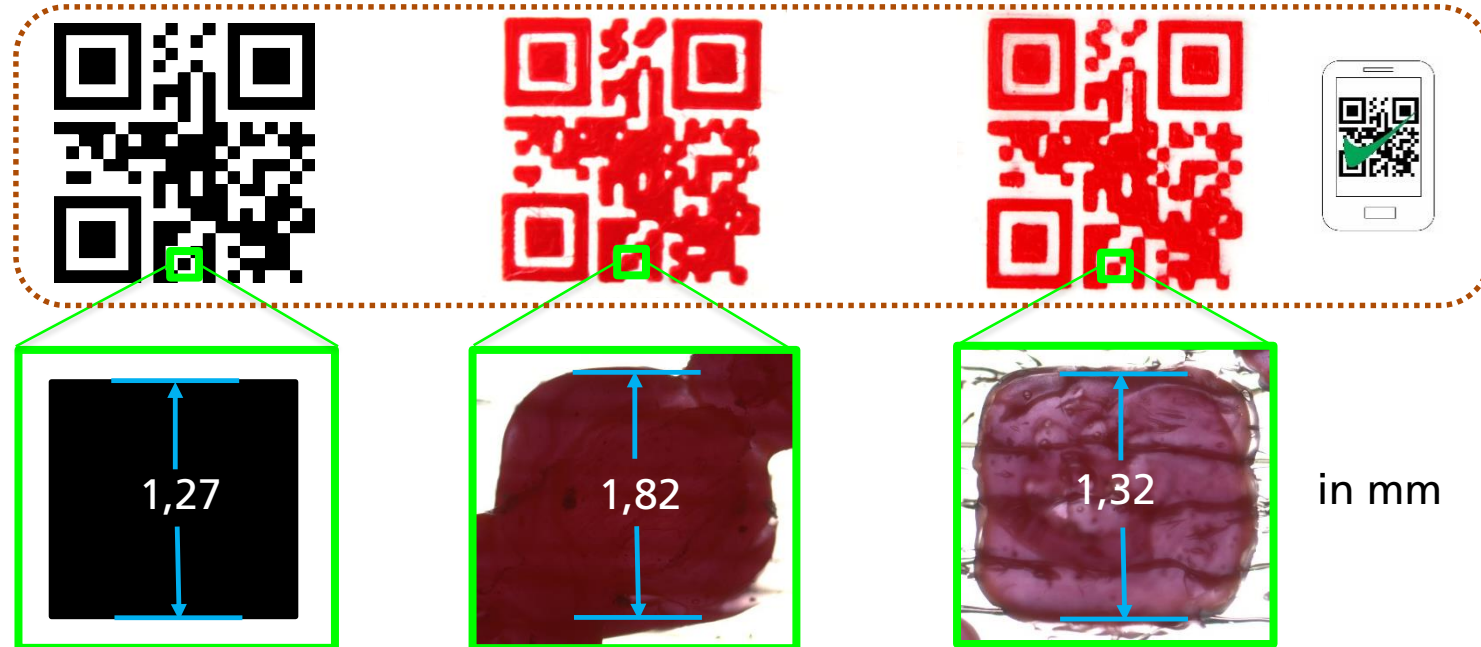
$\text{Ø} = 400 \text{ µm}$

made in 12 min



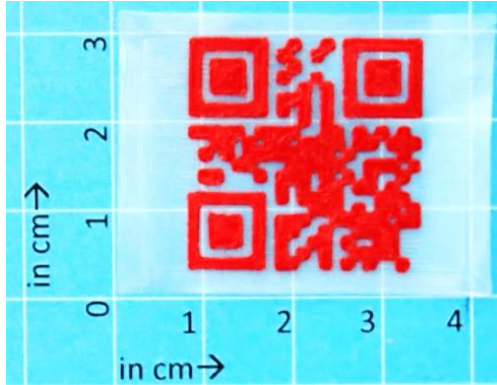
$\text{Ø} = 100 \text{ µm}$

made in 25 min



in mm

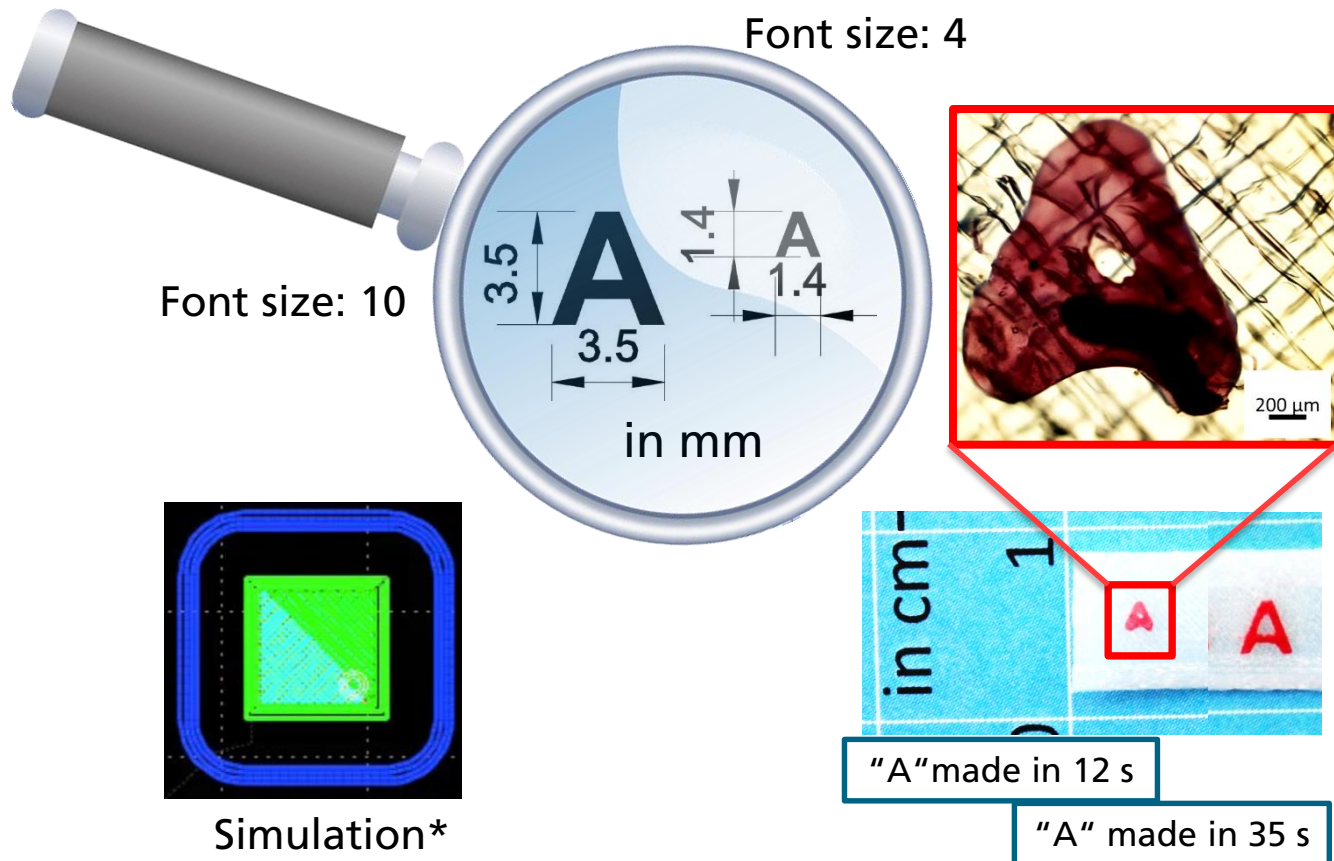
Programming and Thermoresponsiveness



23 °C	23 °C	35 °C	45 °C	55 °C	60 °C
Permanent shape	Temporary shape				Recoverd shape

Additive Manufacturing

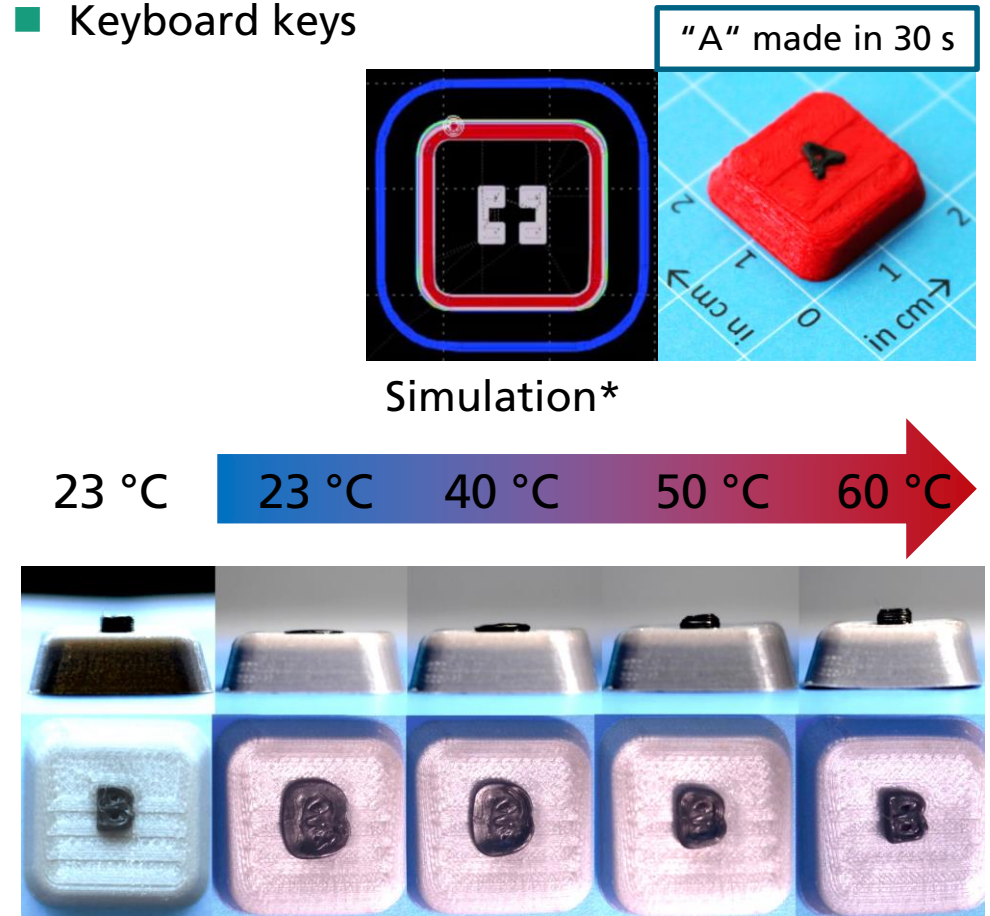
- Block letters (here: font Arial)



* simulation software: GCode Print Simulator v1.30

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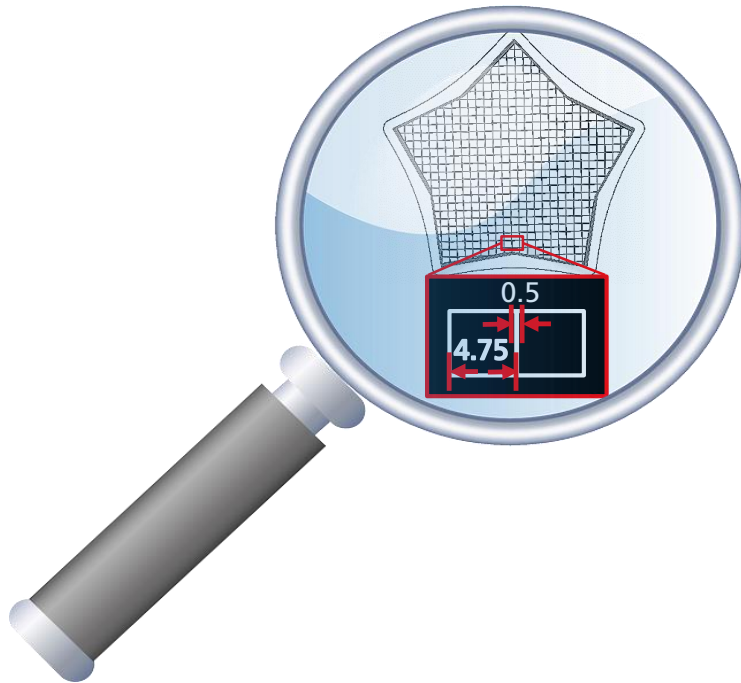
- Keyboard keys



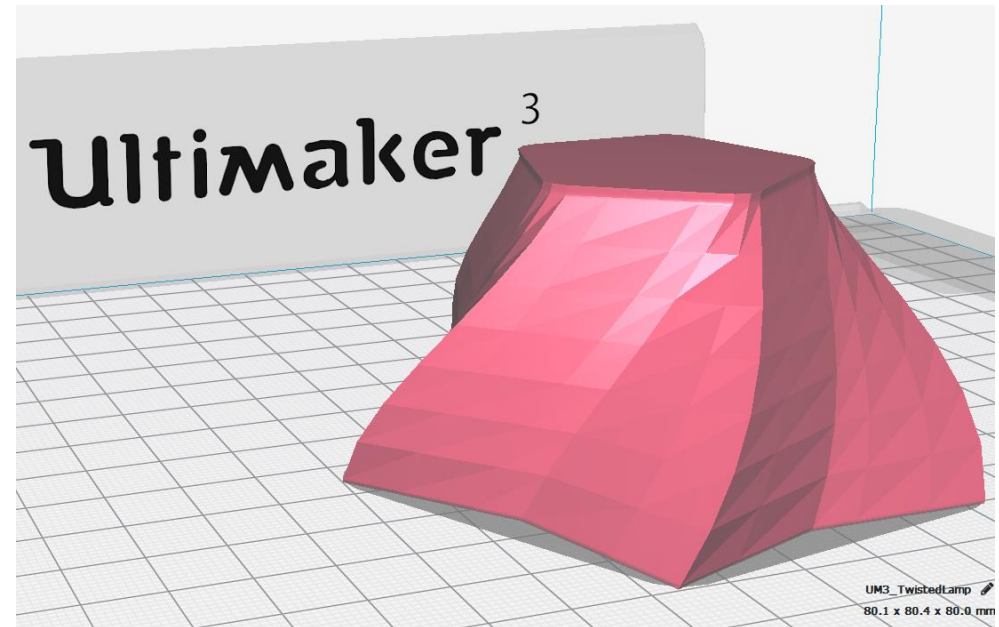
Other complex filigree-structured Objects

■ Additive manufacturing of star-shaped objects using FFF

■ Conceptual development



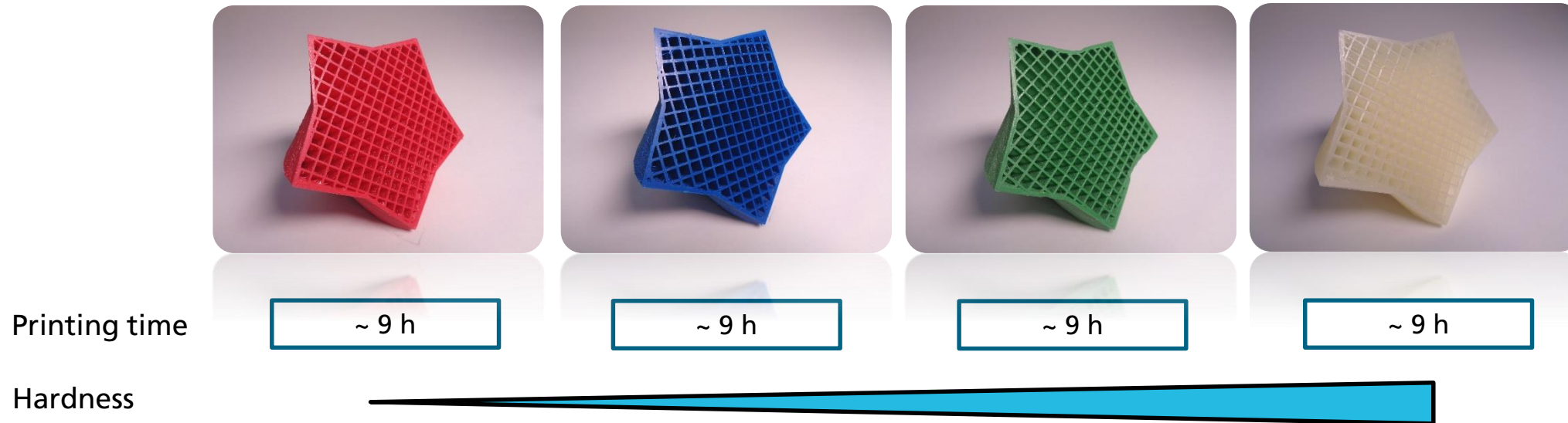
■ Virtual design*



* produced with Cura 3.2.1

Filament Extrusion and Fused Filament Fabrication using other TPUs

- TPUs from Covestro Deutschland AG refined with masterbatches from ROWA Masterbatch GmbH



Portfolio of Services

- Development of printable materials
 - Polymer synthesis (not shown)
 - Filament extrusion
 - Thermoplastic polymers
 - Processing
 - Compounding (not shown)
 - Quality control
- CAD
- Control over 3D-printing pattern
- Rapid prototyping: fused filament fabrication (FFF)
- Complex filigree-structured objects
- 3D-print objects with shape-memory properties (information carriers, etc.)

Acknowledgement

- This work was supported as Fraunhofer High Performance Center for Functional Integration in Materials (project 630039).
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- Ministry for Science, Research, and Culture, State of Brandenburg (MWFK)
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Thank you for your attention!

Please visit us at C05:20



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