BIT's 5th Annual World Congress of
Smart Materials-2019
Time: March 6-8, 2019
Venue: Sheraton Parco de' Medici Rome Hotel, Rome, Italy

Interreg SLOVENIJA – AVSTRIJA
Evropska unija | Evropski sklad za regionalni razvoj

From 4D-Printing (4DP) to Selforganisational Manufacturing (SM)

FH-Prof. Mag. DI Dr. Bernhard Heiden, MBA b.heiden@fh-kaernten.at

Silvia Walder BSc., Hannes Oberlercher MSc., Jona Bushati BSc., Clarissa Becker BSc., Monika Decleva Bsc., Dr. Günter Wuzella

16h20-16h45, Friday 8th March 2019, Room Monaldeschi, Lower Floor, Sheraton Parco 1, Section 1.05 3D/4D-Printing and Additive Manufacturing, 6.-8. March 2019, Bit's 5th Annual World Congress of Smart Materials-2019, Sheraton Parco de' Medici Hotel, Rome, Italy

REPUBLIKA SLOVENIJA
SLUŽBA VLADE REPUBLIKE SLOVENIJE ZA RAZVOJ IN EVROPSKO KOHEZIJSKO POLITIKO

KWF Kärntner Wirtschaftsförderungs Fonds

University of Ljubljana
Faculty of Electrical Engineering

„Menschen, die miteinander arbeiten, addieren ihre Potenziale. Menschen, die füreinander arbeiten, multiplizieren ihre Potenziale“

Steffen Kirchner

FH-Prof. Mag. DI Dr. Bernhard Heiden, MBA

Professor for Production Engineering

FH-Prof. DI Dr. Roland Willmann

Professor for Industrial Management

FH-Prof. DI Dr. Erich Hartlieb

Degree programm leader Industrial Engineering Professor für Innovation- und Technologymanagement

Mag. Dr. Petra Hössl

Senior Researcher Start Up Initiative

FH-Kärnten Wirtschaftsingenieurwesen Studiengang WING & IEM

FH-Prof. Dr. Joachim Werner

Professor for Business Adrministration

DI Dr. Josef Tuppinger

Senior Researcher

DI (FH), Mag. (FH) Michael Roth

Scientific Employee

Mag. (FH) Thomas Saier

Scientific Employee

Alexandra Reithofer

Administration

DI Reinhard Tober

Laboratory Engineer Smartlab

Monika Decleva, BSc

Scientific Employee

Tamara Penker

Administration

The CUAS-Interdisciplinary Team for Additive Manufacturing (AM) & iMaterials

FH-Prof. DI Dr. Robert Hauser

Professor for Physics
Head of Mechanical Engineering & Light Weight Construction Studiengang
Focus: Sensors

FH-Prof. Mag. DI Dr. Bernhard Heiden, MBA

Professor for Production Engineering
Focus: Manufacturing

FH-Prof. DI Dr. Franz Riemelmoser, MBA

Professor for Mechanical Engineering
Focus: Light Weight Materials

AM Team:
- Hannes Oberlercher, BSc MSc (FH)
- Bushati Jona

Actual Project
- MMO3D – Development of a Robot Cell for AM, Interreg

Recent Project
– GENFEROS 4.0 – Qualifizierungsnetz FFG – Spreading of AM-technology knowledge for the industry

Von der Idee zur erfolgreichen Marktumsetzung

FACHHOCHSCHULE KÄRNTEN

InnovationsWerkstatt
KÄRNTEN

Impuls

Analyse und Zieldefinition

Ideenentwicklung und -verdichtung

Konzept-entwicklung und Geschäftsmodell

Leistungs-entwicklung und Markttest

Umsetzung und Markteinführung

smart lab
CARINTHIA
Prototyping & Industrie 4.0

- CNC
- LASER CUTTER
- SCHNEIDPLOTTER
- 3D-DRUCK / SCANNING
- ELEKTRONIK
- DESIGN / KONSTRUKTION

Konstruktion und Entwicklung

Prototypen-fertigung

Prototypen-validierung

Overview

(1) Introduction – related Project – MMO3D

(2) From 4D-Printing (4DP) to Selforganisational Manufacturing (SM)

- 5th Main Sentence of Thermodynamics → Application to 4DP and SM
- → Hypotheses, Conclusion and plausibility proof for SM
- 4DP→ SM
- SM-→AM→4DP→SM

(3) Additive Manufacturing of High Performance Composites (AMHPC)

(1) Introduction – Projects related

- Preceding Project
- MMO3D-Project
- Testbench MMO3D
- Application concept MMO3D

(1) PW- Experimental Setup (1)

*, **

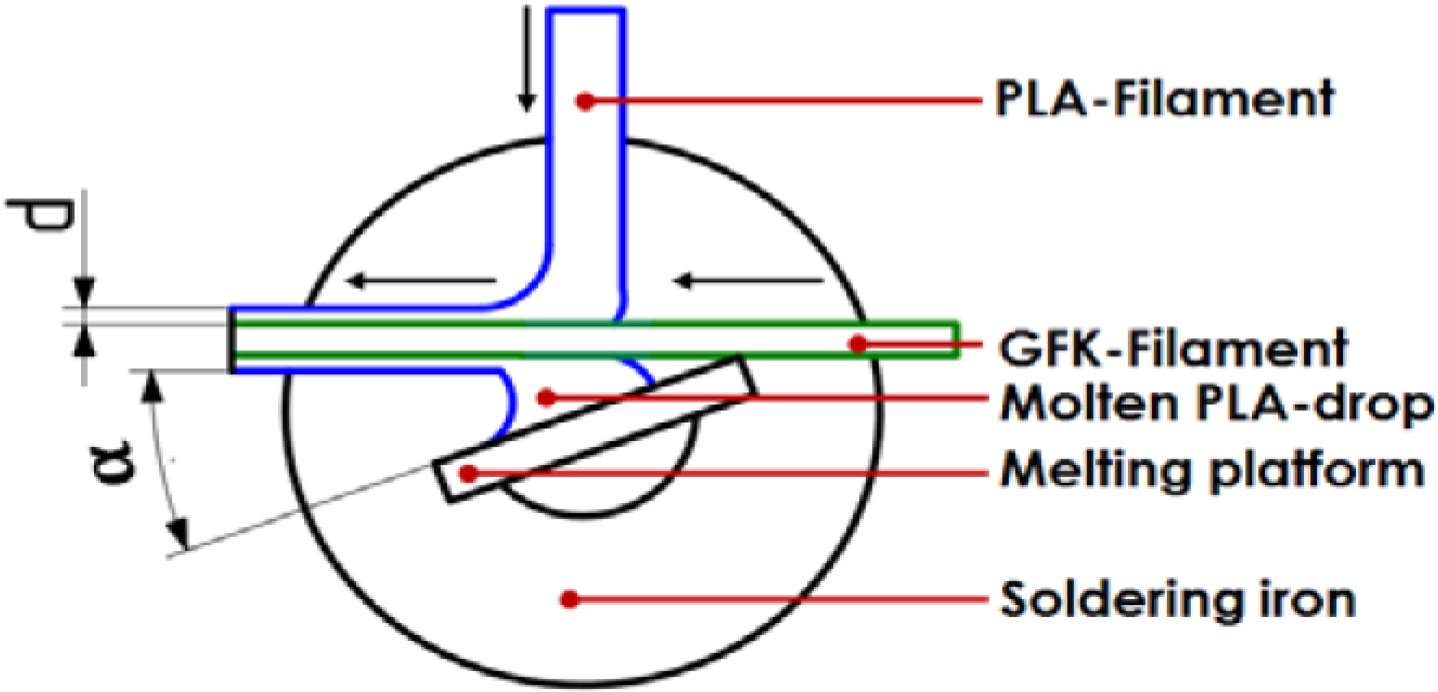
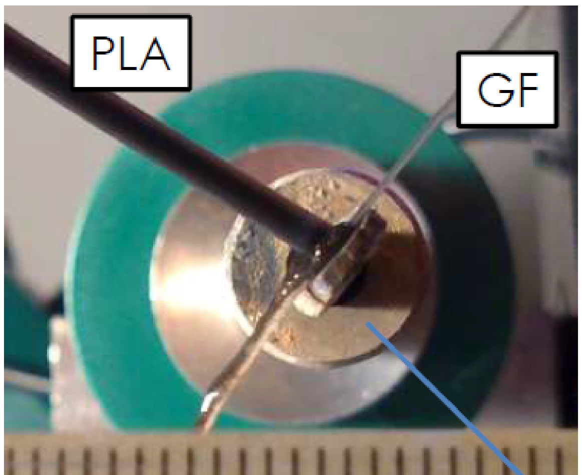


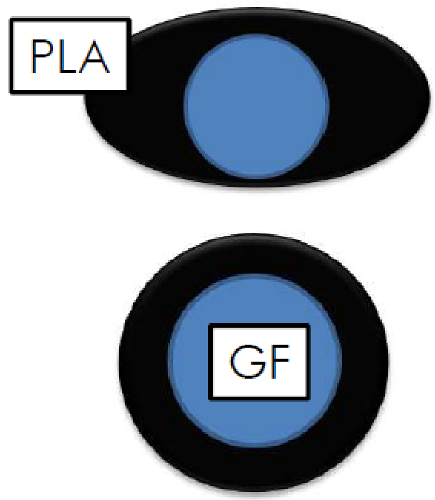
Fig. 1: Coating concept – principal process layout; The filament reinforced fiber (e.g. GFK) is coated with the PLA-filament with coating thickness d*,**

*[LeU16] ,** [HeB17]

(1) Experimental Setup (2)

- Schmelzplattform mittels Lötkolben
- GF-Filament mit PLA-Beschichtung
- Geometrisch verschiedene Versuchsaufbauten (Anstellung der Lötkolbenspitze unter 0°, 45° und 90° zur Horizontalen
- Unterschiedliche Beschichtungsgeometrien





0; 45°
Elliptisch

90°
Rund

Lötkolben; Schmelzplattform

Fig. 2: Melting platform with soldering iron*

*[LeU16]

(1) Coating Thickness - velocity

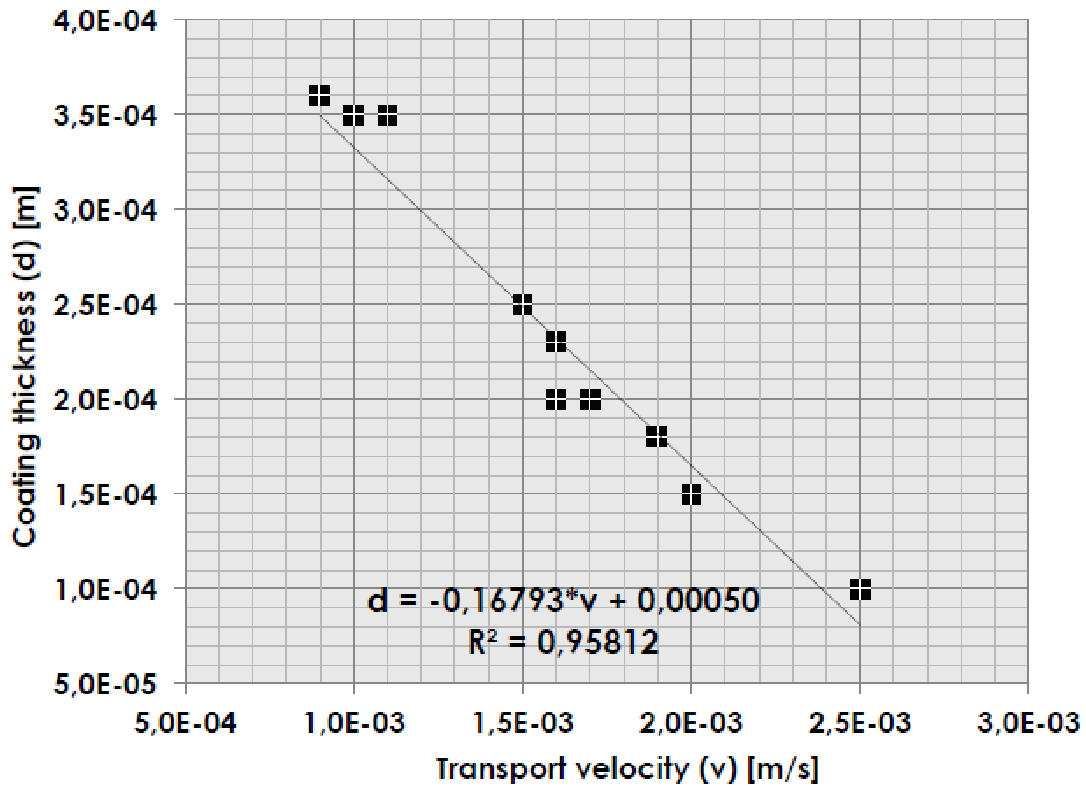


Fig. 3: Coating thickness d over fiber transport velocity v according to [LeU16]*

*[LeU16]

(1) PW-Best working concept

*

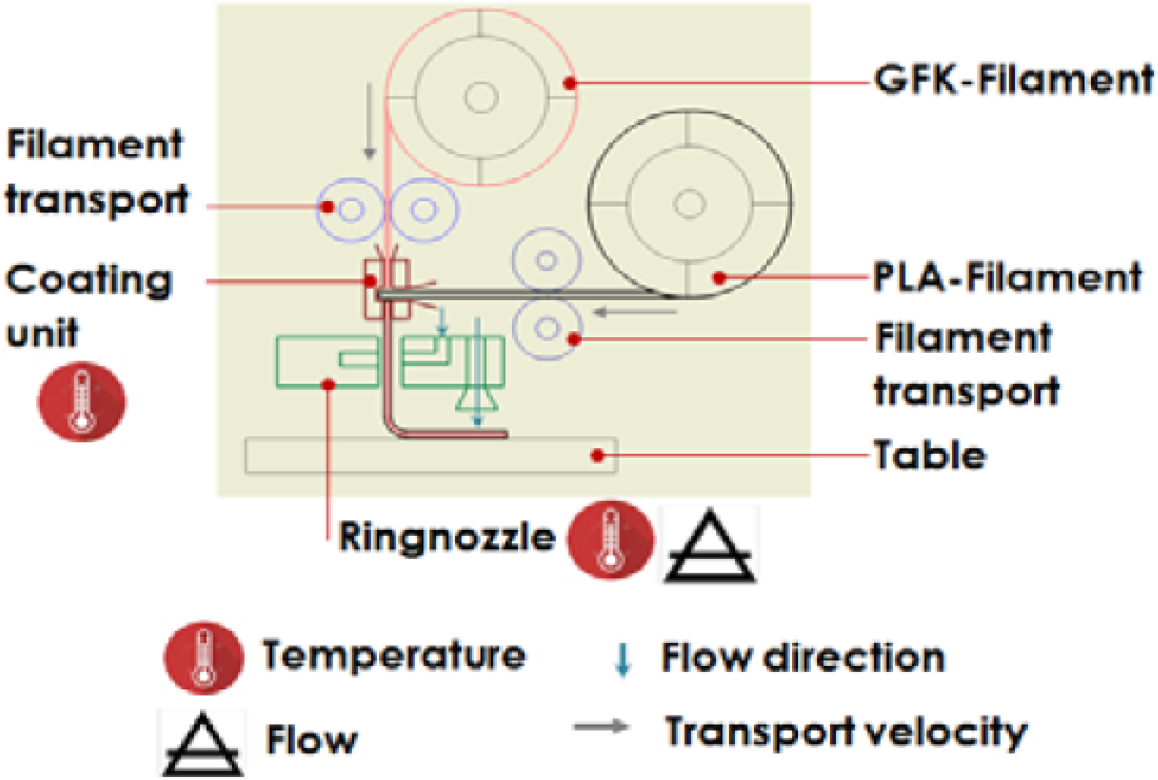


Fig. 4: AM concept for coated fibers *,**

*[LeU16] ,** [HeB17]

(1) Project MMO3D

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Project Partner:

- Carinthia University of Science – study paths Mechanical Engineering, Systems Engineering and Industrial Engineering and Management (Austria)
- Oprema Ravne (Slowenja, Leadpartner)
- Holzkompetenzzentrum W3C, (Austria)
- University Ljubljana (Slowenja, Institut of Robotiks)
- Roboteh (Slowenja)

Schematic fig. of the faser manipulation process*

Goal of Innovation:

- adaptation of a 6-axis robot with a molding technology and a faser manipulator.
- production of geometrically complex products with high strength lightweight materials
  → applications in E-mobility and medical technology.

* http://www.fh-kaernten.at/unser-studienangebot/engineering-it/aktuelles/news-archiv/news-archiv-list/news-archiv-details/entwicklung-von-roboterzellen-fuer-den-3d-druck/ 30.11.2016

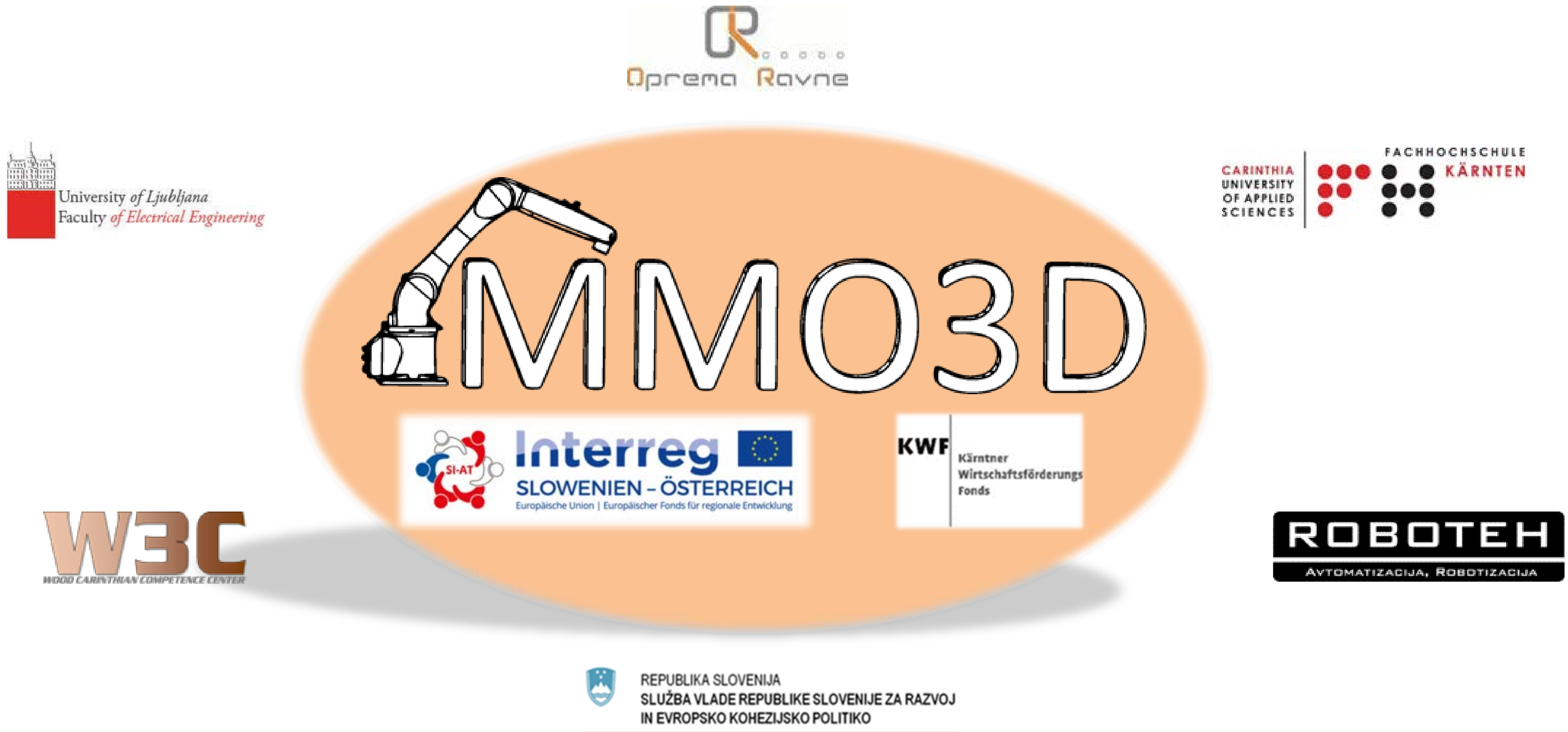

Fig. 4: Consortium for MMO3D

(1) MMO3D (1)

Status 2017 – Printing Head Concept:

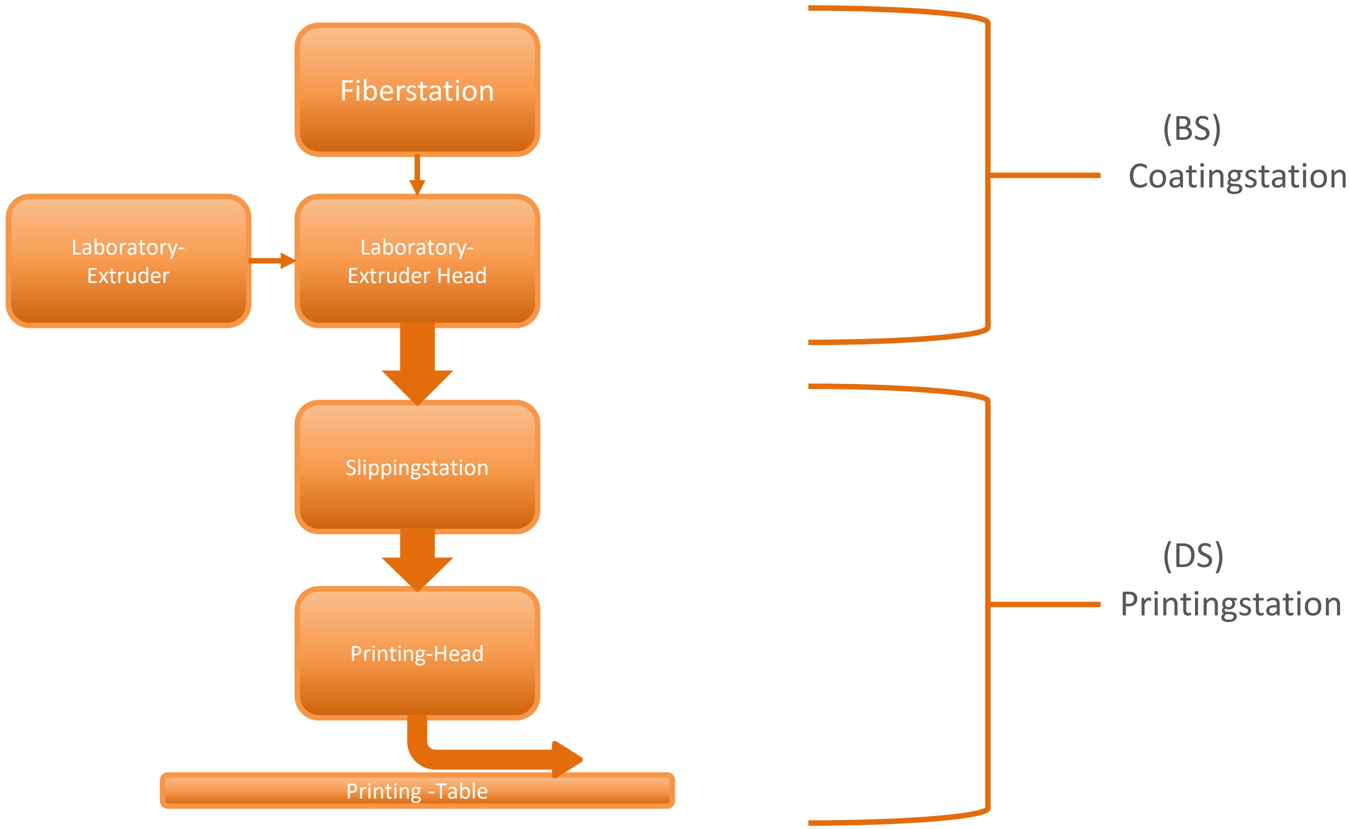

Fig. 5: MMO3D - printing head concept, state September 2017

(1) Project goals MMO3D

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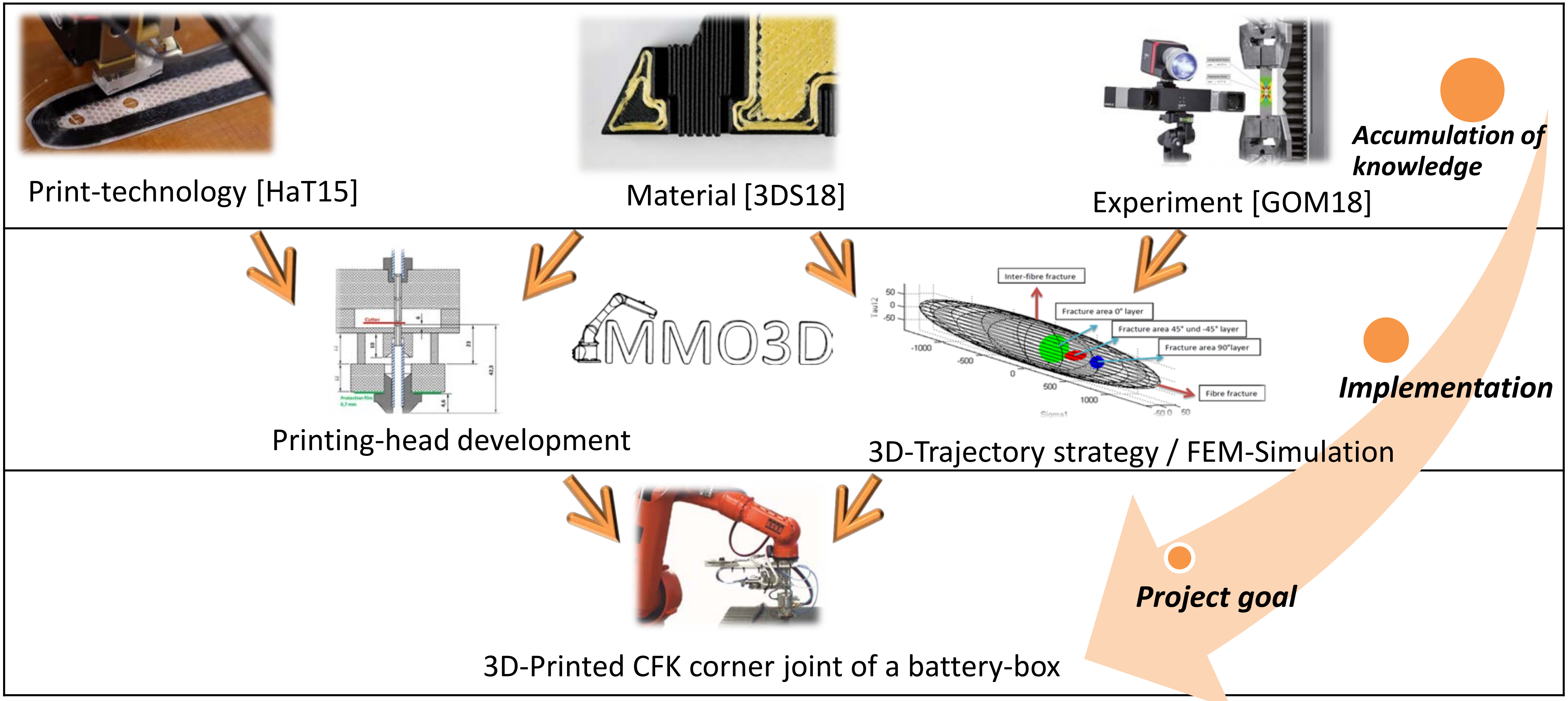

Fig. 6: Project goals for MMO3D

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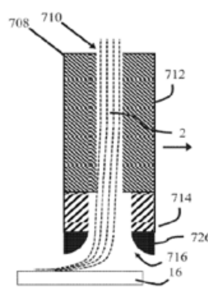
REPUBLIKA SLOVENIJA
SLUŽBA VLADE REPUBLIKE SLOVENIJE ZA RAZVOJ
IN EVROPSKO KOHEZIJSKO POLITIKO
KWF Kärntner Wirtschaftsförderungs Fonds
Oprema Ravne
University of Ljubljana Faculty of Electrical Engineering
CARINTHIA UNIVERSITY OF APPLIED SCIENCES
FACHHOCHSCHULE KÄRNTEN
ROBOTEH AVTOMATIZACIJA, ROBOTIZACIJA
W3C

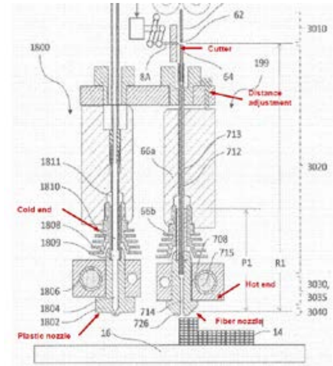
(1) Basics of continuous Fiber Printing

Printing-Head Construction

- A cutting mechanism must be considered
- The filament must be guided through a heated channel, then it exits the nozzle
- The flange of the nozzle flattens the filament and adds the compaction pressure
- A flat section (“flange”) at the nozzle tip to achieve sufficient compaction time (~ 15 mm/s) when the filament is welded to the part surface
- Due to circular symmetry, the nozzle can move and print in any direction, without turning the print head

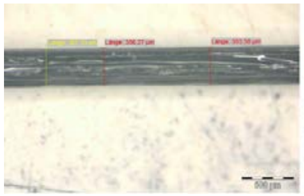
Nozzle [MaG16a] PH MarkOne [MaG16]

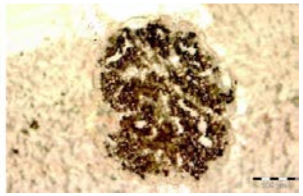




Continuous-Fiber-Filament

- Carbon fiber / polyamide
- Diameter of about 0,35 mm
- Fiber volume fraction of about 34 [%]
- 1 K roving (1000 single carbon fibers)





Printing process

- The print speed must be higher than the filament drive speed
- Compaction pressure must be defined by calibration of the distance nozzle to surface

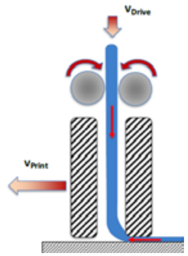


Fig. 7: Basics of continuous fiber printing

(1) Testbench MMO3D

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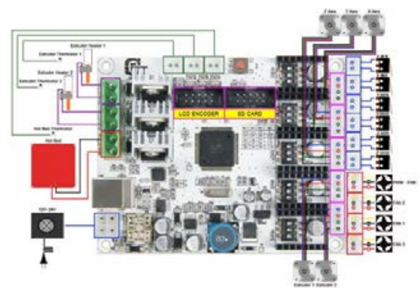
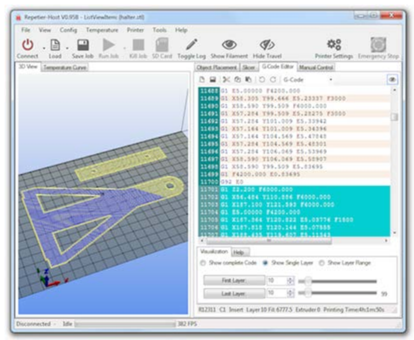
Controller Board

- Designation GT2560
- Controll 2 printing heads (Feeding, Heater, Thermistor,…)
- Controll 3 steppdrives, touch-sensitive switch (X-,Y-,Z-axis)
- Controll 2-3 fans
- Controll 1 servo drive with PWM(Cutter for CFK-fiber)
- Controll 1 Hot-Bed (optional)



Slicer Software

- Generate G-Code
- Manipulation of G-Code for Trajectory path
- Implementing the cutting sequence in the G-Code
- Edit the parameters



Testbench at Carinthia University of Applied Sciences (CUAS)

MMO3D

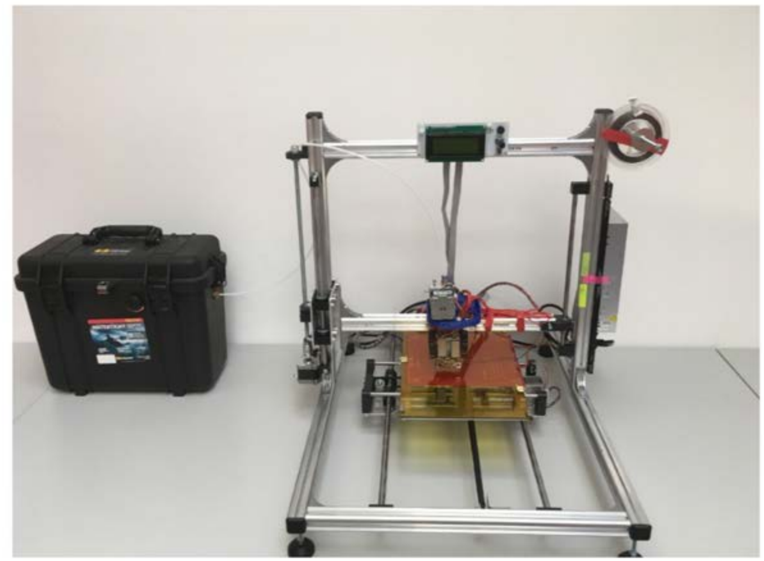
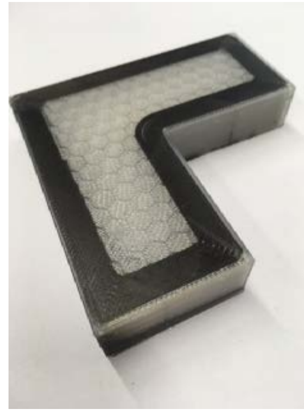


Fig. 8: Testbench for MMO3D printing head at CUAS – October 2018

(1) Application concept of 3D-printed fibers (CFK) in the MMO3D project

- Concentric orientation of the reinforced fibers allow a derivative of the forces.
- Honeycomb structure for good energy absorption.



- L-profile in housing. Housing protects laminate from impacts.
- Is stuck to the housing.

Concept corner joint

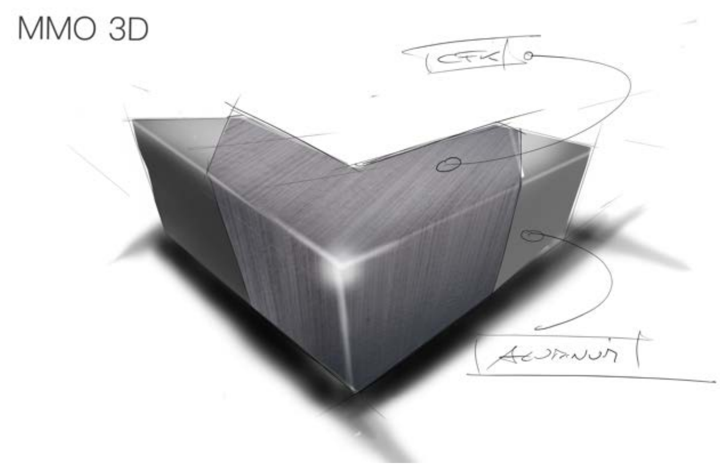


Fig. 9: Application concept of 3D-printed fibers for the reinforcement of edges in the MMO3D project

(1) MMO3D - recent result of printing head and assembly

Fig. 10: Printing Head MMO3D V1

Fig. 11: Printing Head & Robot Assembly - MMO3D -3D Printing

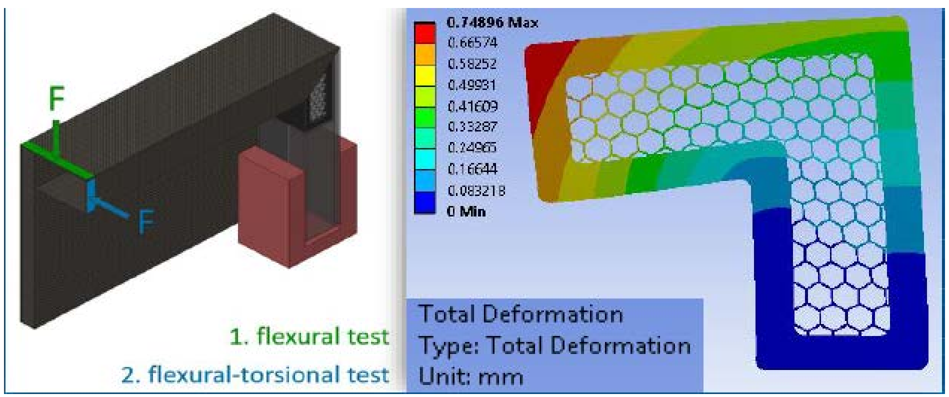


Fig. 12: 3D-Printing Part Ansys Simulation

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5th Main Sentence of Thermodynamics:

Increased Structured Application of Energy Ordering Process itself (can) increase Order
→ more ordered Energy Forms are built from less ordered Forms successively

$$S(dE_i+1)\lrcorner_i < S(dEi)\lrcorner_i \quad i: 1\ldots n$$

Fig. 13: 5th Main Sentence of Thermodynamics

[HeB18]

(2) H1

Hypothesis 1:

Self Organized Manufacturing (SM) Systems are the most energy effective systems*

* In the following, a plausability proof will be given in [HeB19] a cybernetic more detailled proof is given

Hypothesis 2:

4D-Printing (4DP) is more energy efficient as Additive Manufacturing (AM) and less energy efficient then Selforganizational Manufacturing (SM)-Systems

(2) Conclusion

Together with the 5th MS of Thd. follows that:

AM(O)<4DP(O)<SM(O)

...(O)=Order of
...MS of Thd. = Main Sentence of Thermodynamics

(2) Plausibility Proof H1,H2

A dimension can be regarded as a „measure“ with one variable. If there changes a degree in freedom by a new independent controllable parameter, this increases the dimension. The dimension is back coupled with itself e.g. m*m for the area, and also independent i.e. decoupled/weakly coupled. Each new dimension denotes then an <u>emergent parameter</u>, denoting a in general potency. This new dimension then forms a manifold together with the basing dimension parameter.

→ A new control parameter/degree of freedom is identical with emergence/a new dimensionality

→ The new parameter has a new limit → efficiency

Or shorter: Growth has a selfreferential** growth factor and a limiting factor → this leads to a S-Curve* *s.a.[SoA05]

** this refers to e.g. SM

(2) “Macroscopic” - Implications

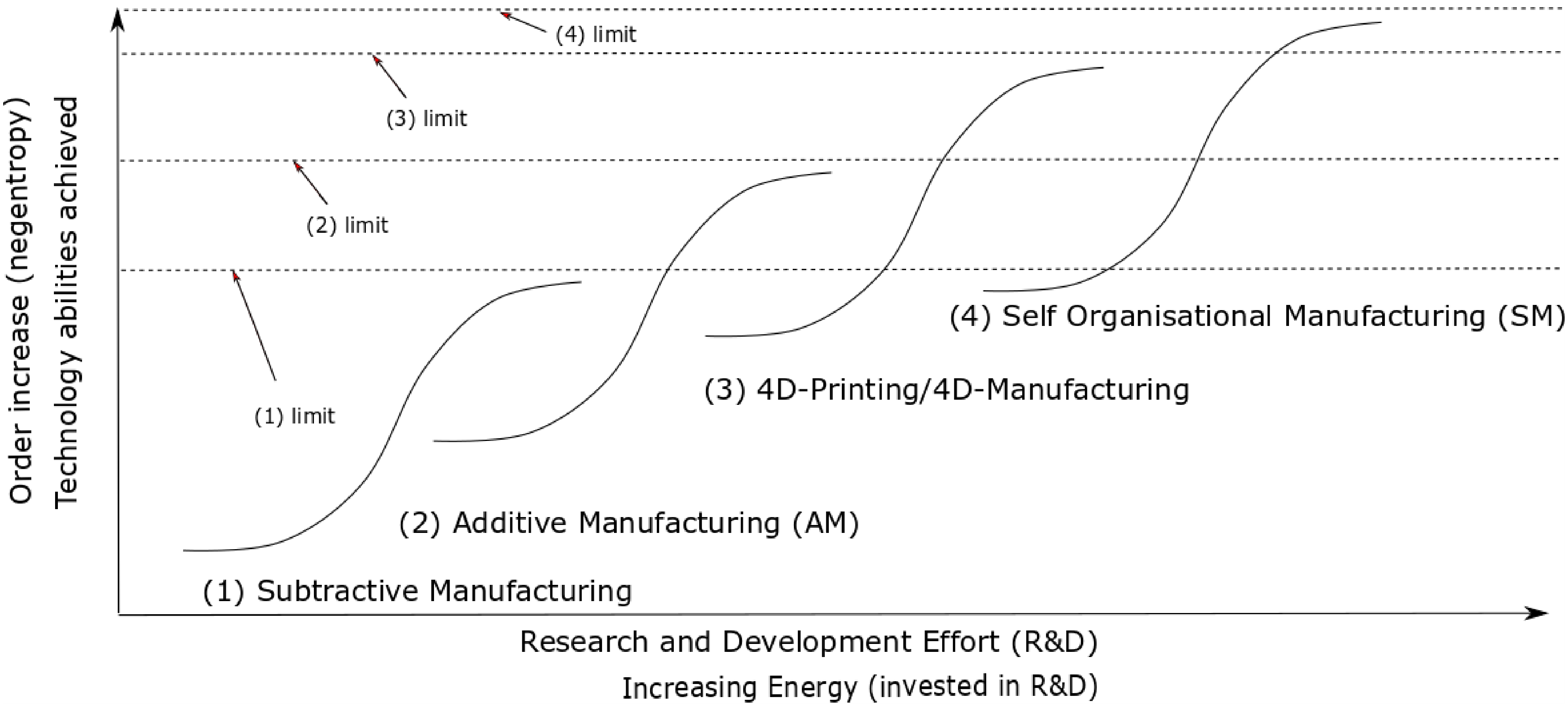


Fig. 14: Subtractive to Selforganisational Manufacturing (SM) with regard to order increase - Technology life cycle curve for Subtractive to SM (Four “S-Curves”)

(2) Conclusion – reasoning with 5th MS Thd.*

→ The second/third/fourth… „ordering“ step does not remove all the order:
  → Order builds upon order
  → Order is stored and reused → Evolution is built upon long time/room/mass trajectories

* [HeB18]

(2) Shape Memory Effect* for 4DP

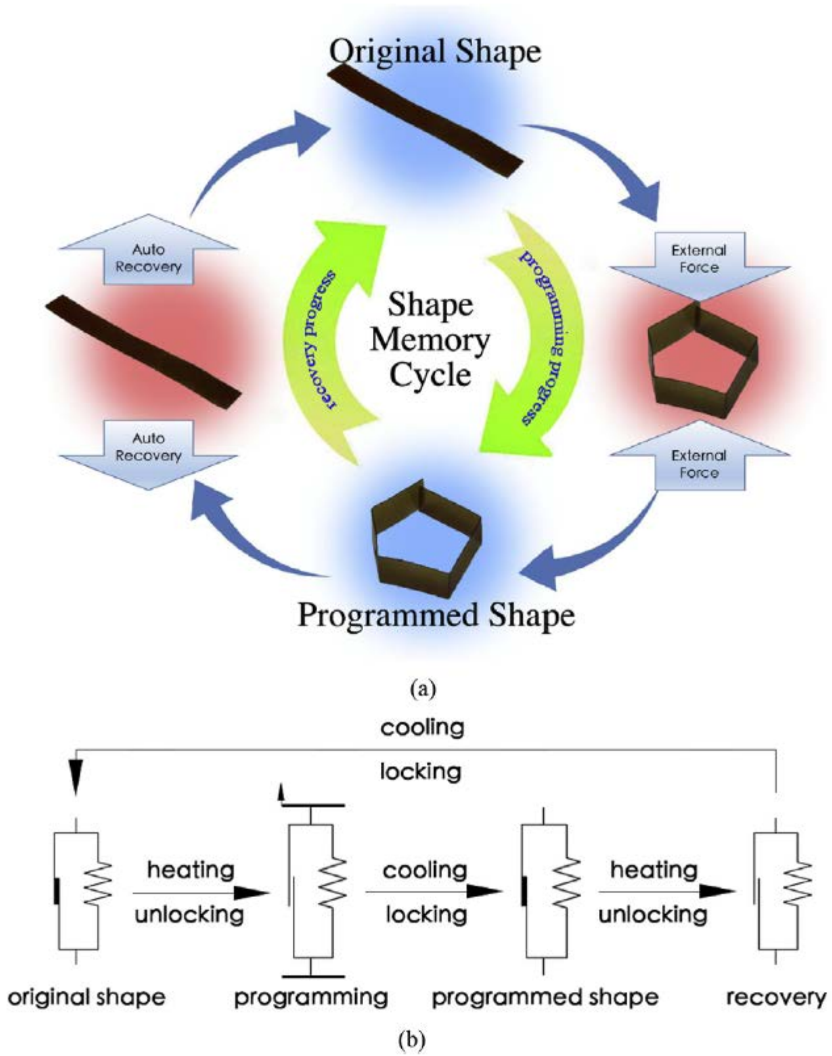


Fig. 15: 4DP – Programmable Shaping of Materials*

Stimulation:*

- Electricity
- Magnetism
- Light
- Microwave/UV
- Solution/Water

*[MuT18]

(2) Material - unchangeable

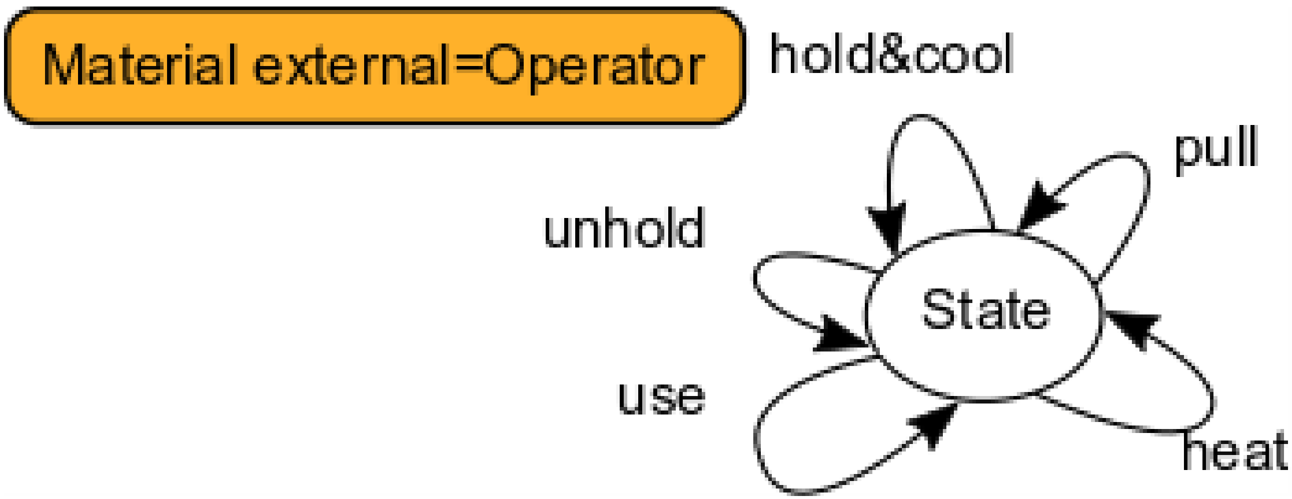


Fig. 16: Material – Decision Process – state diagram, one state is possible

(2) iMaterial – changing with decisions

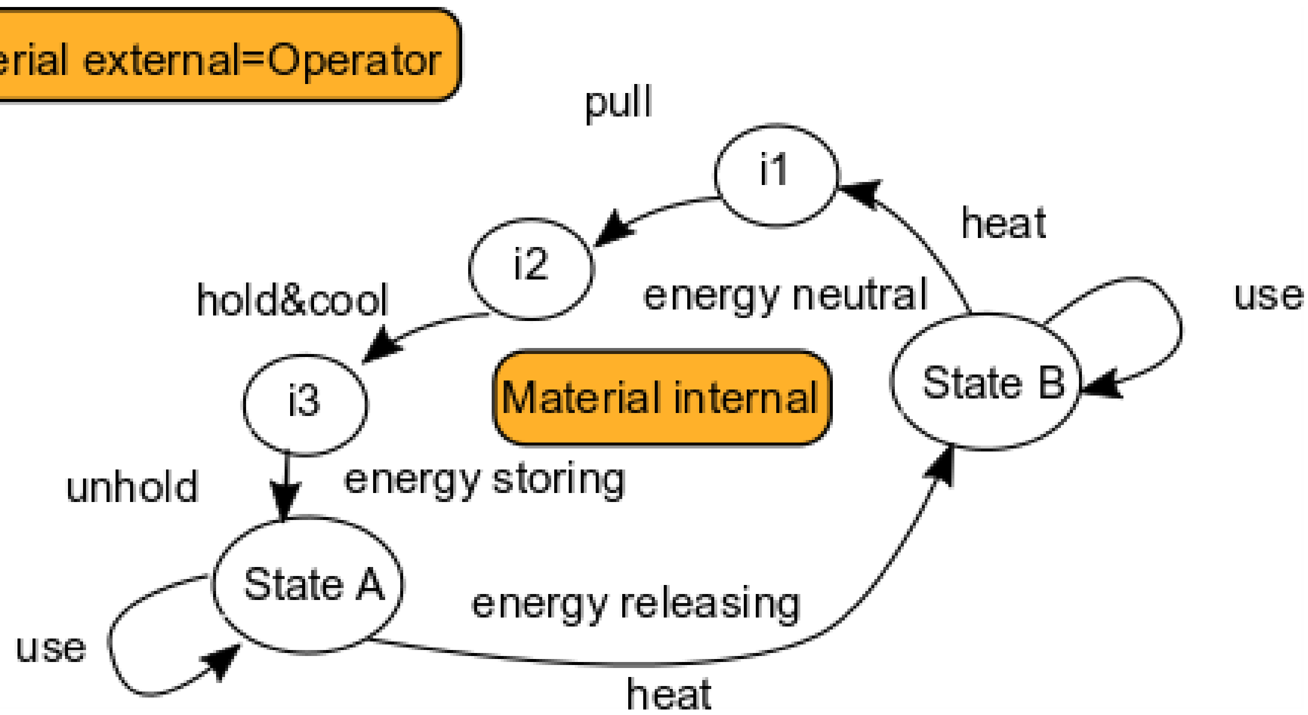
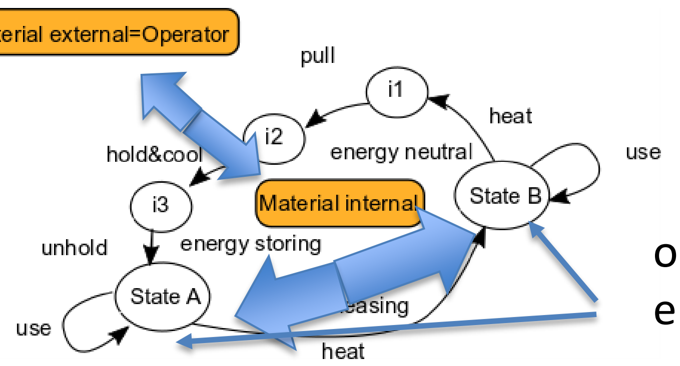


Fig. 17: iMaterial – Decision Process – state diagram, i1..3 internal states, State A,B = different material external „shapes“

(2) H3 & H4

Hypothesis 3:

Material internal and Material external interaction lead to Selforganisational Manufacturing (SM)



one new dimensionality
e.g. parameter length

Fig. 18: iMaterial H3,H4

Hypothesis 4:

Increased dimensionality increases order in 4DP-SM → energy efficiency

(2) SMP vs SMPC for 4DP

- Shape Memory Polymers (SMP)
- Shape Memory Polymer Composites (SMPC)

→ SMP vs. SMPC

→ For SMPCs stimulation

- More precise
- Highly selective*

→ SMPS increases **controllability** compared with SMP

Explained with 5th MS Thd.: The order of the two materials of the SMPC is reused to get a higher order

*[MuT18]

(2) Emergent Parameters SM-, AM, 4DP

SM-: → Phase constant & outer → inner side & use = const.

AM: → Phase change & inside → outside & use = const.

4DP: → Phase change (PC) & inside → outside & use=f(PC)

4DP = 4D-Printing

AM = Additive Manufacturing

SM- = Subtractive Manufacturing

* [HeB18]

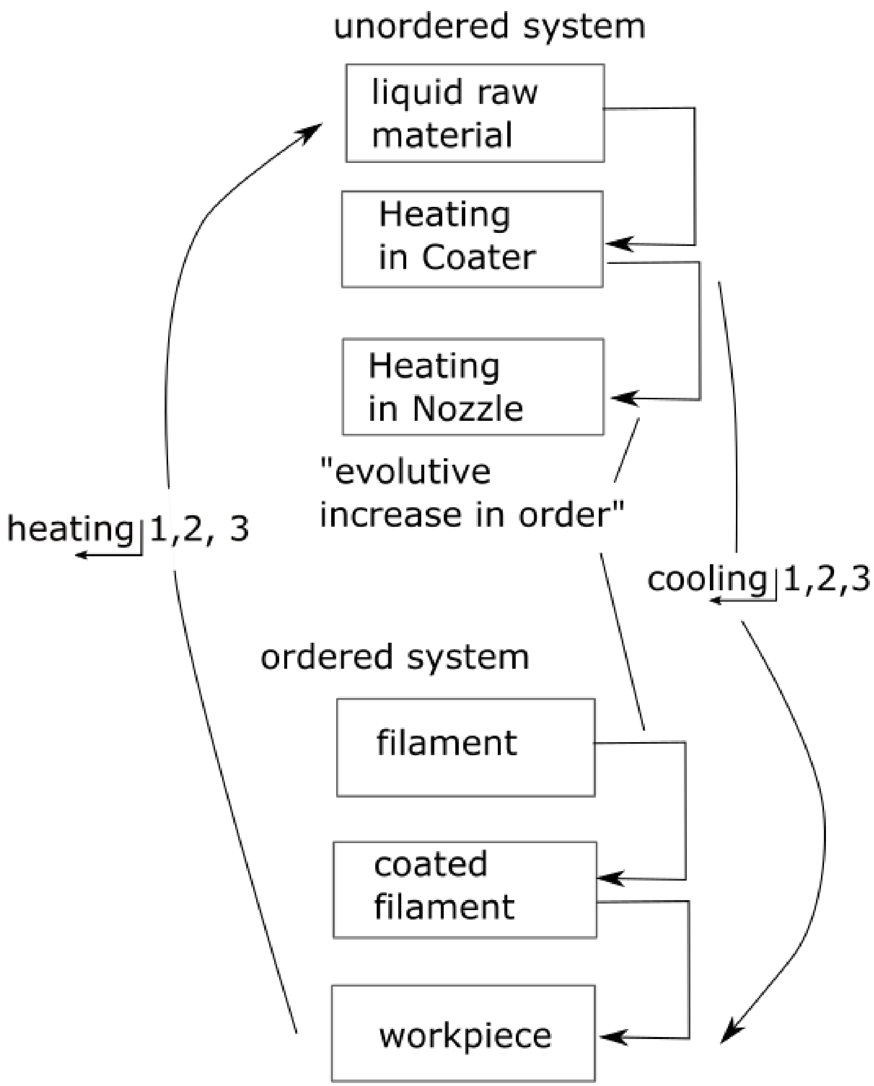
(2) EVOLUTIVE STEPS (Bifurkations)

i3.0	i4.0	i5.0
SM-:	AM:	SM(1):
*PhasenConstancy →	* PhaseChange →	* PhaseChange
*outer → inner →	* inner → outer →	* inner → outer
*outer control CNC →	* outer control CNC →	* inner control SOC *
	→	SM(2):
	→	* PhaseConstancy
	→	* inner → outer
	→	* inner control SOC
		SM(3):
	→	* PhaseChange
	→	* outer → inner
	→	* inner control SOC

Legend:

SM = Additive Manufacturing Self Organized
AM = Additive Manufacturing
SM- = Subtractive Manufacturing
CNC = Computer Numerical Control
SOC= Self Organized Control
i3...5=Industry 3..5

* [HeB18]



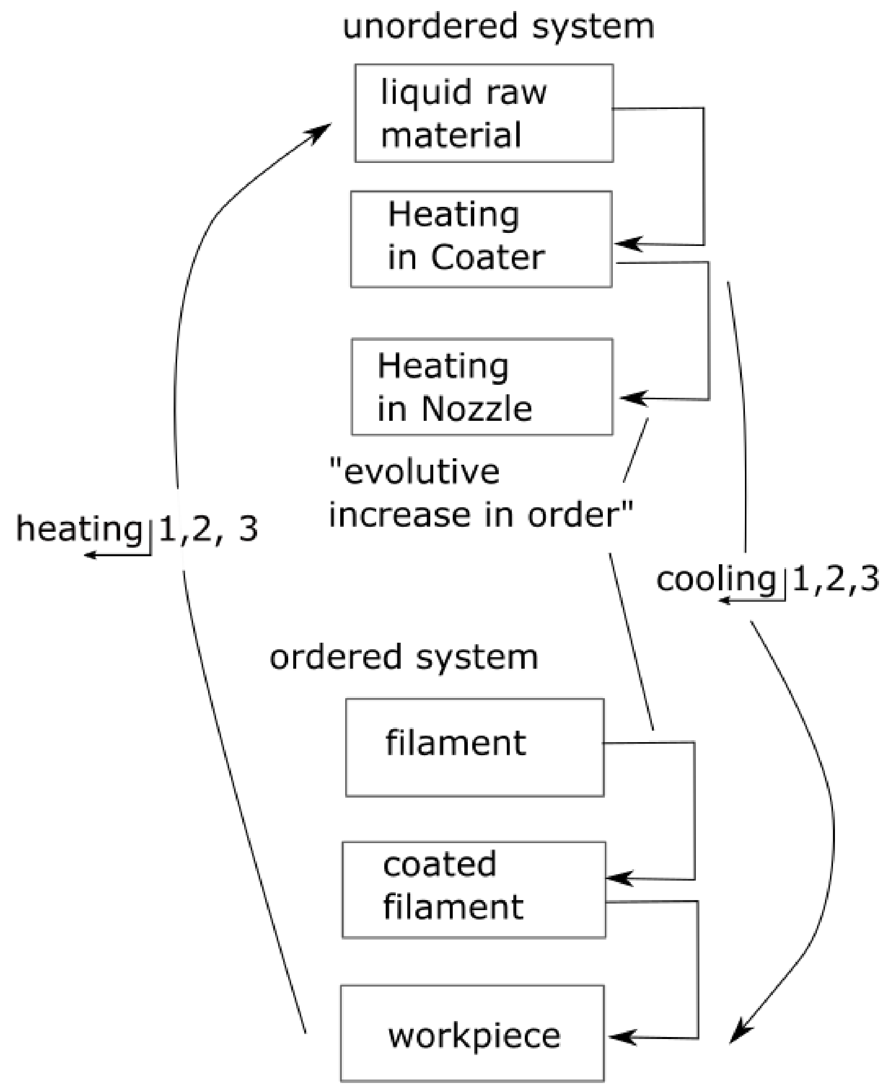
[HeB18]

Fig. 19: FR3DP Process in the context of the 5th Main Sentence of Thermodynamics

B. Heiden, S. Walder, H. Oberlercher, J. Bushati, C. Becker, M. Decleva, G. Wuzella (2019) From 4D-Printing (4DP) to Selforganisational Manufacturing (SM), BIT's 5th Annual World Congress of **Smart Materials-2019**, www.bitcongress.com, March 6-8, 2019, Sheraton Parco de' Medici Rome Hotel, Rome, Italy

(2) Fiber Reinforced 4D-Printing (FR4DP) - 4DP-SM Process

4DP-SM Decisionprocess 4,5,6…



4DP-SM Decisionprocess 4,5,6…

[HeB18]

Fig. 20: FR3DP Process in the context of the 5th Main Sentence of Thermodynamics 4DP-SM

(2) Added Value for Smart Materials (iMaterial)

1. Predictions how to improve AM→4DP→SM Process → Higher Energy Efficiency → predict „right“ direction of development
2. Explain structure of iMaterial production processes and predict potentials
3. Interdisciplinary understanding of iMaterial

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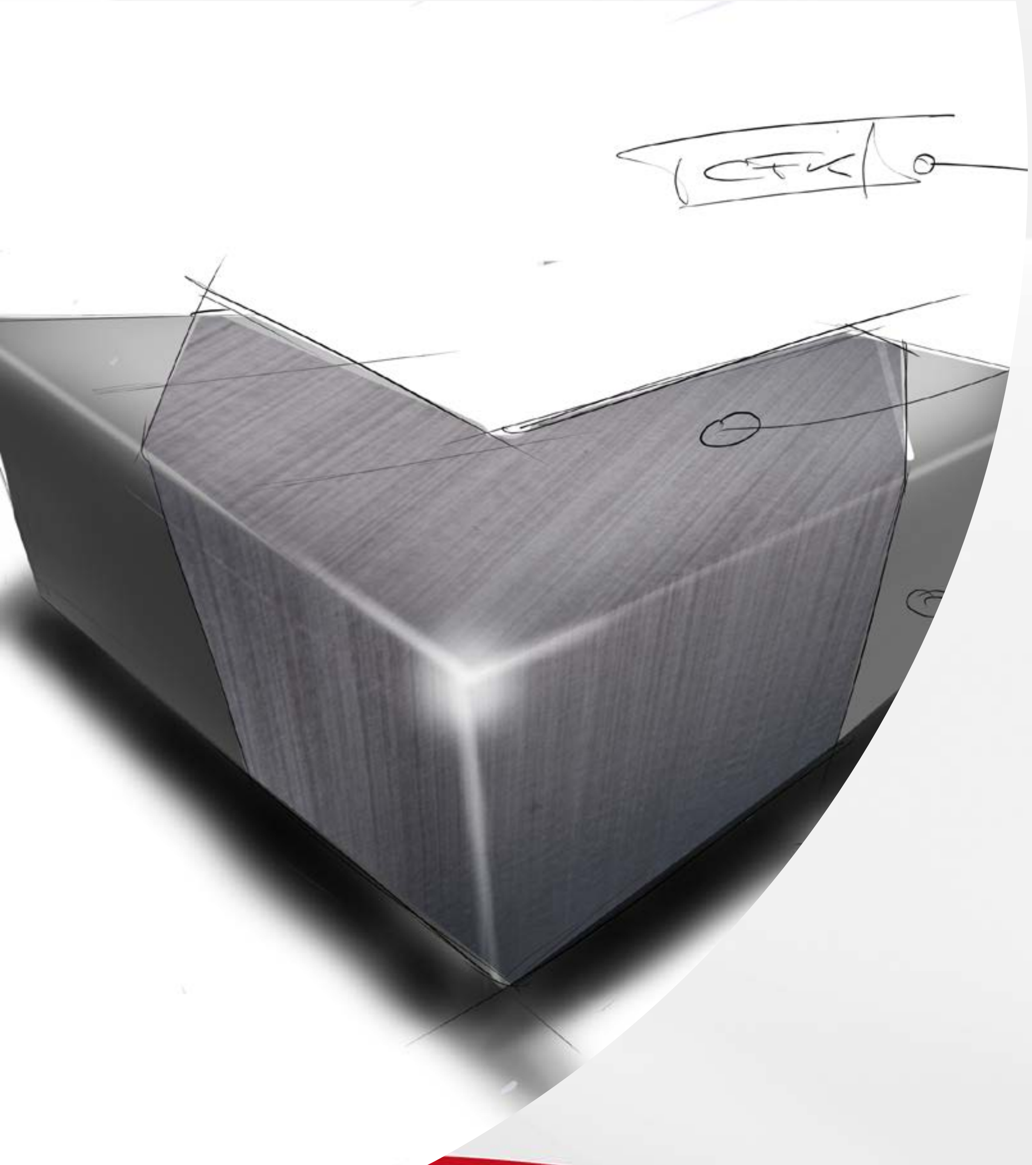

ADDITIVE MANUFACTURING OF HIGH PERFORMANCE COMPOSITES (AMHPC)

VISION for AMHPC

AMHPC - Made in Carinthia@Austria@EU@World

New AM Technology for Fiber Composite Material

USP for AMHPC

Designable iMaterial Properties

- Smart sensor integration
- Simulation based material combinations / hybridmaterials
- Crash resistance optimized construction parts
- Current PhD → High Performance Composites – for crash resistance optimization

Open and further expandable 3D-printing system

- 6-axis technology
- Process parameter control by means of sensors
- Simulation based 3D printed light weight CFK material

Special-Features

- Exchangeable Printing-Head
- Filament production
- Moveable printing object

Next Steps

- Projects AMHPC for further technology development: TRL 4 → TRL 7
- Partners for industrialization

Project topics for cooperation

- Prozess parameter optimization
- continuous test
- Industry-standard (safetey measures etc.) integration
- certification preparation

(2) AMHPC Conference in June:

- Detailed Presentation of MMO3D Project
- Workshop for Follow Up Projects/Startup
- Student Competition Award

If you think that you could be a potential project partner we will invite you to the conference → June/July

→ Write to b.heiden@fh-kaernten.at

Summary

(1) Continuous Fiber Composite 3D-Printing

- Development of a AM method for lightweight applications
- Printing Head Construction
- Testbench at CUAS (Carinthia University of Applied Science)

(2) 5th MS Thd and 4DP-SM

- 4 Hypotheses & Energy Efficiency
- 4DP as decision process → emergent paramters
- SMP & SMPC → FR3DP→FR4DP
- Added Value for iMaterial

(3)Outlook for AMHPC

Thank you cordially for attention!

FH-Prof. Mag. DI Dr. Bernhard Heiden

Professor for
Production Engineering
b.heiden@fh-kaernten.at

PS.: The presentation will be found also at: http://www.dr-heiden.com/Vortraege.htm

Literature AM Recommendation & Presentation 1

[3DS18] 3DSL, 2018, Markforged Mark Two Enterprise 3D Printer, product description, https://www.3dsl.com.au/shop/markforged-mark-two-enterprise-3d-printer/, retrieved 2018/10/02

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ABBREVIATIONS & SYMBOLS

FACHHOCHSCHULE KÄRNTEN

Symbol	Description
A	Work (J)
AM	Additive Manufacturing
c	Speed of Light (m/s)
CNC	Computer Numerical Control
d_eS	Differential Change of Imported Entropy
d_iS	Differential Change of Internal Entropy
dX	Differential of Variable X
E	Energy (J)
E_A	External Energy (J)
i	Index
n	Order of Feedback System
Q	Heat Energy (J)
R&D	Research and Development
S	Entropy ($J*K^{-1}$)
S-Curve	Growth Curve
SM-	Subtractive Manufacturing
SM	Selforganisational Manufacturing
SMPC	Shape Memory Polymer Composites
SMP	Shape Memory Polymer

ABBREVIATIONS & SYMBOLS 2

SO	Self-Organizing (Systems)
T	Temperature (K)
U	Internal Energy (J)