iCAT 2018

Additive Manufacturing – a system theoretic approach

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

Ulrich Leiter MSc BSc, ulrichleitner@gmx.net

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

„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

Mag. Dr. Patrick Holzmann

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

Joris Löschnig

Student Staff Member
Smartlab

Monika Decleva, BSc

Scientific Employee

Tamara Penker

Administration

The CUAS-Interdisciplinary Team for Additive Manufacturing (AM)

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 Projects
- MMO3D – Development of a Robot Cell for AM, Interreg
- GENFEROS 4.0 – Qualifizierungsnetz FFG – Spreading of AM-technology knowledge for the industry
- Planned: Metal 3D-Printing 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 – Projects related

(2) A system theoretic approach

(3) Implications

(1) Introduction – Projects related

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

(1) PW- Experimental Setup (1)

*, **

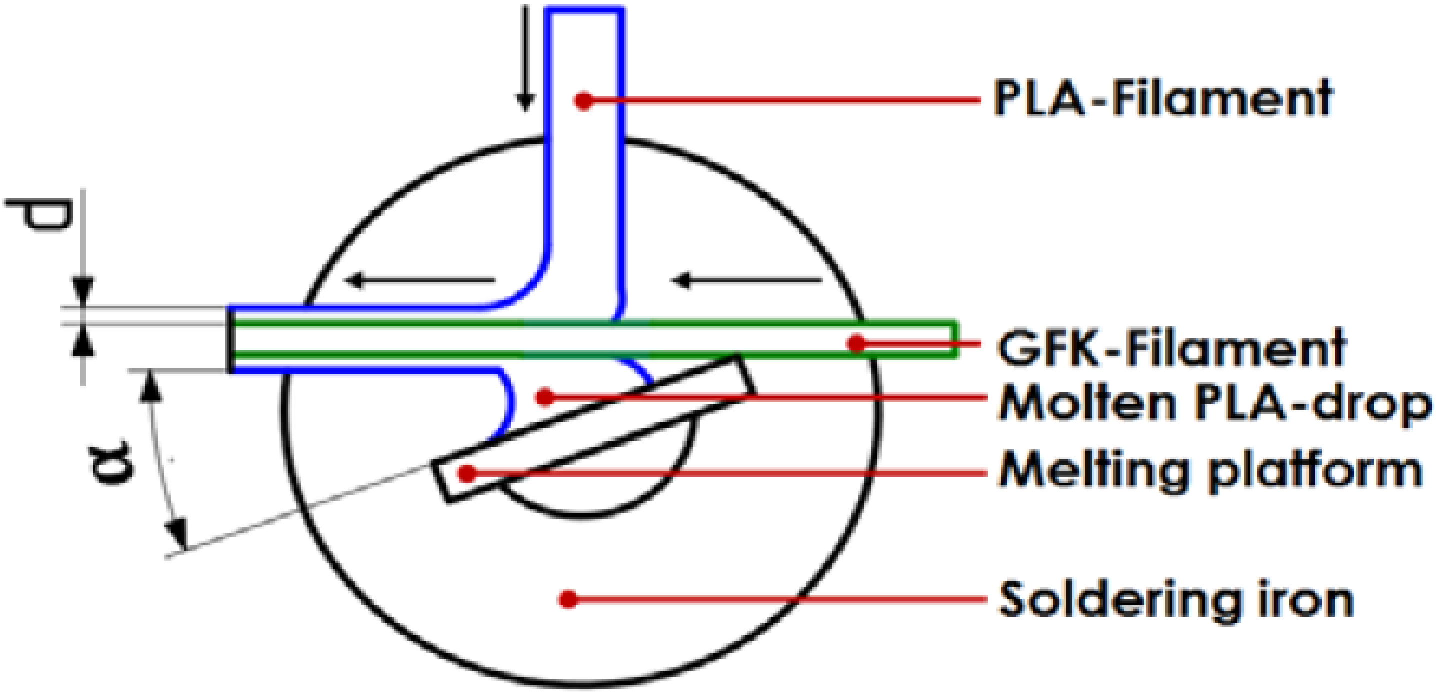


Fig. 1: Coating concept – principal process layout; The filament reinforced fiber (e.g. GFK) is coated with the PLA-filament with coating thickness d*,**

*[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

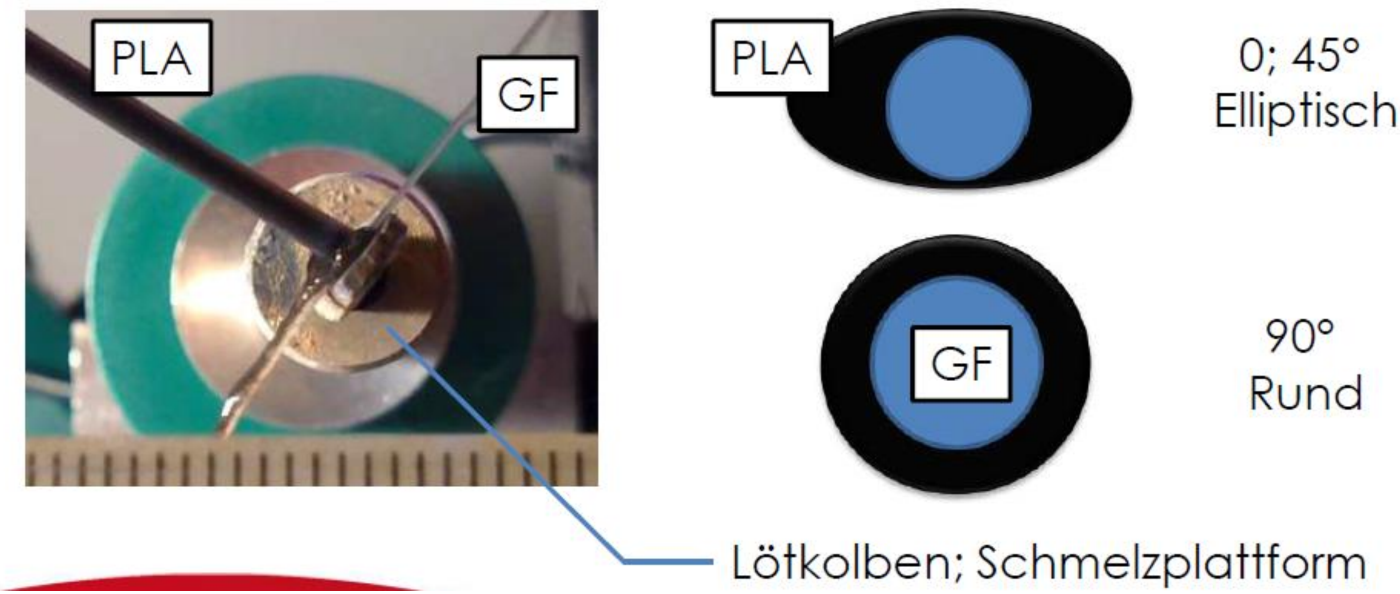


Fig. 2: Melting platform with soldering iron*

*[LeU16]

(1) Coating Thickness - velocity

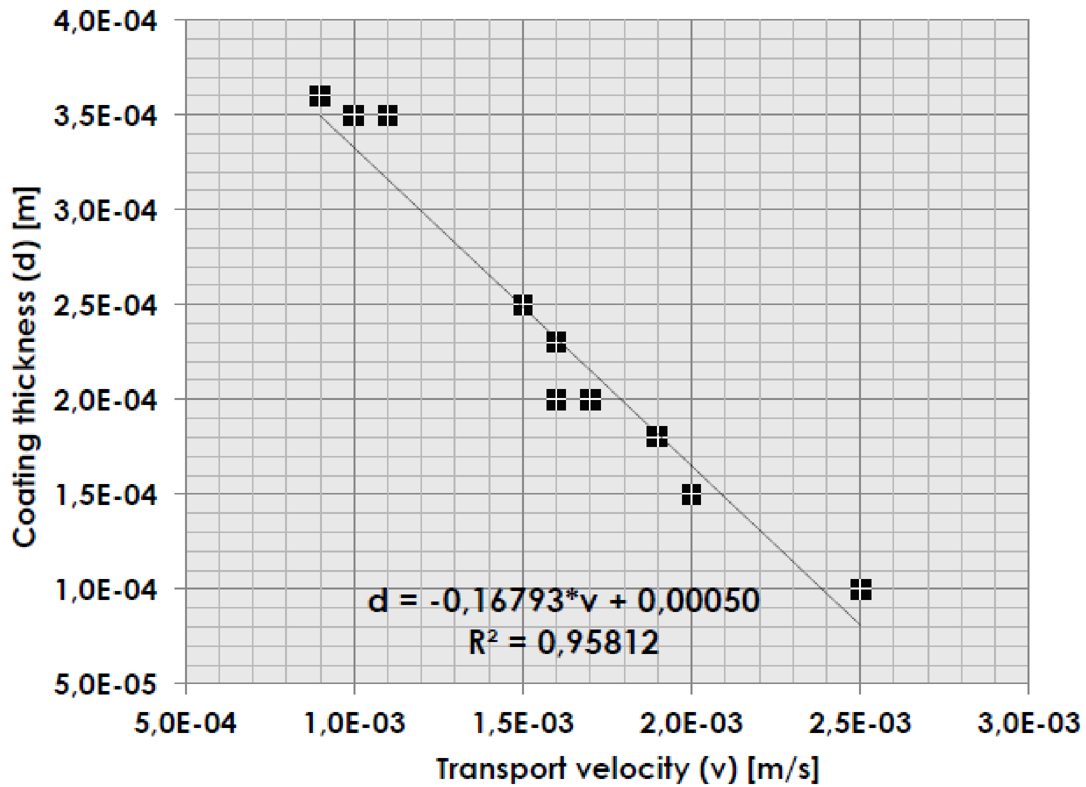


Fig. 3: Coating thickness d over fiber transport velocity v according to [LeU16]*

*[LeU16]

(1) PW-Best working concept

*

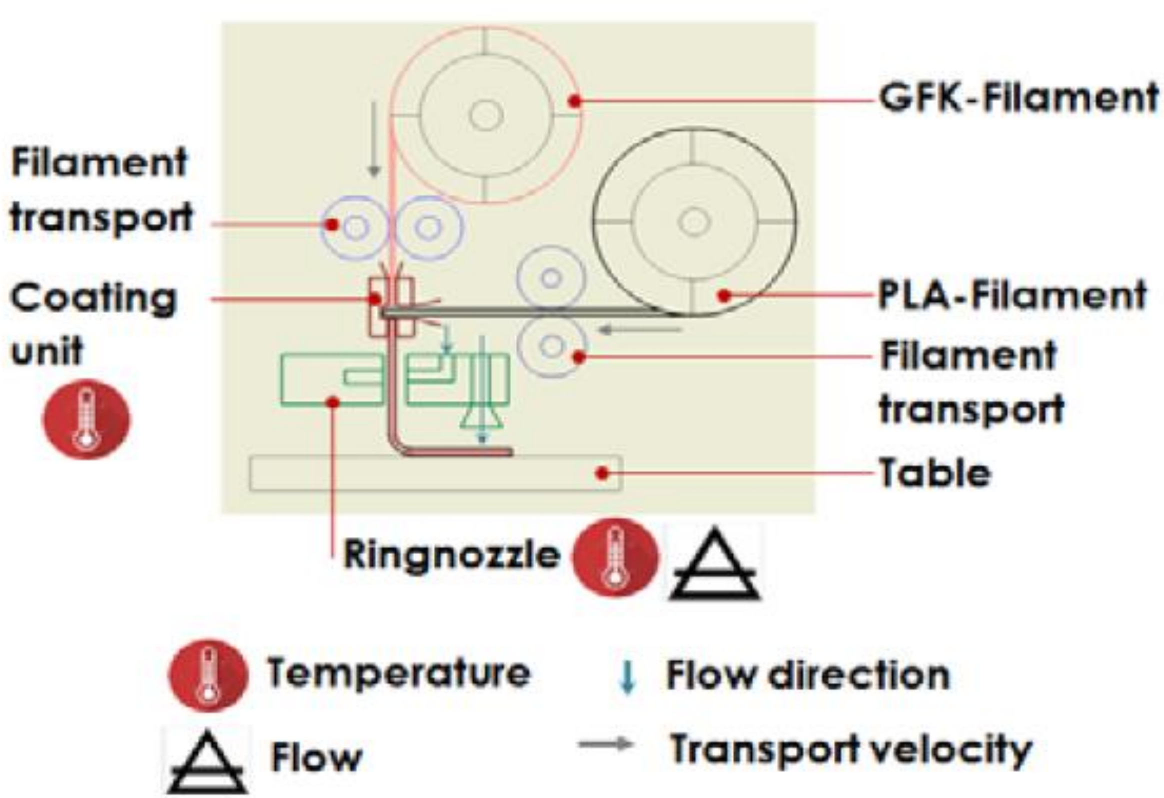


Fig. 4: AM concept for coated fibers *,**

*[LeU16] ,** [HeB17]

(1) Project MMO3D

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

(1) Project description / consortium / activities

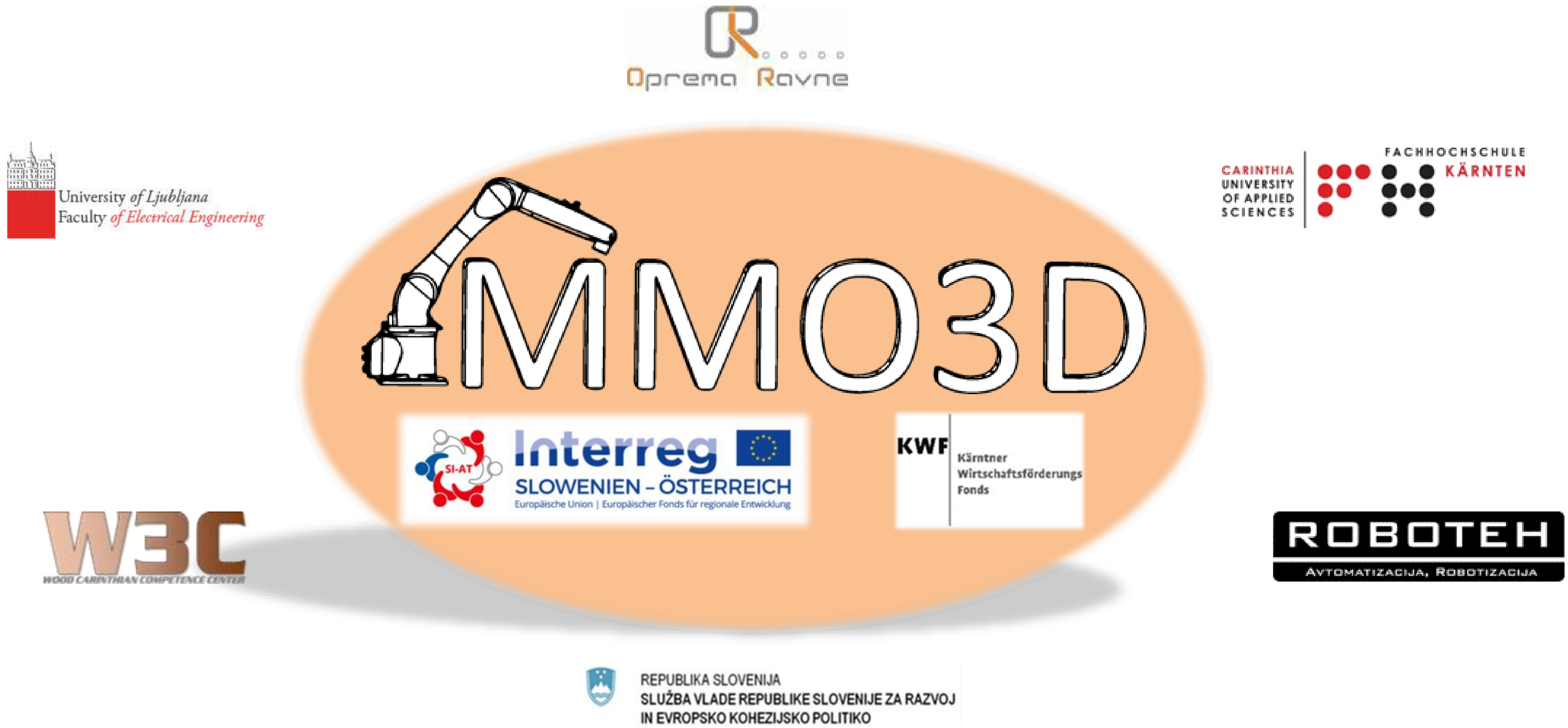


Fig. 4: Consortium for MMO3D

Status 2017 – Printing Head Concept:

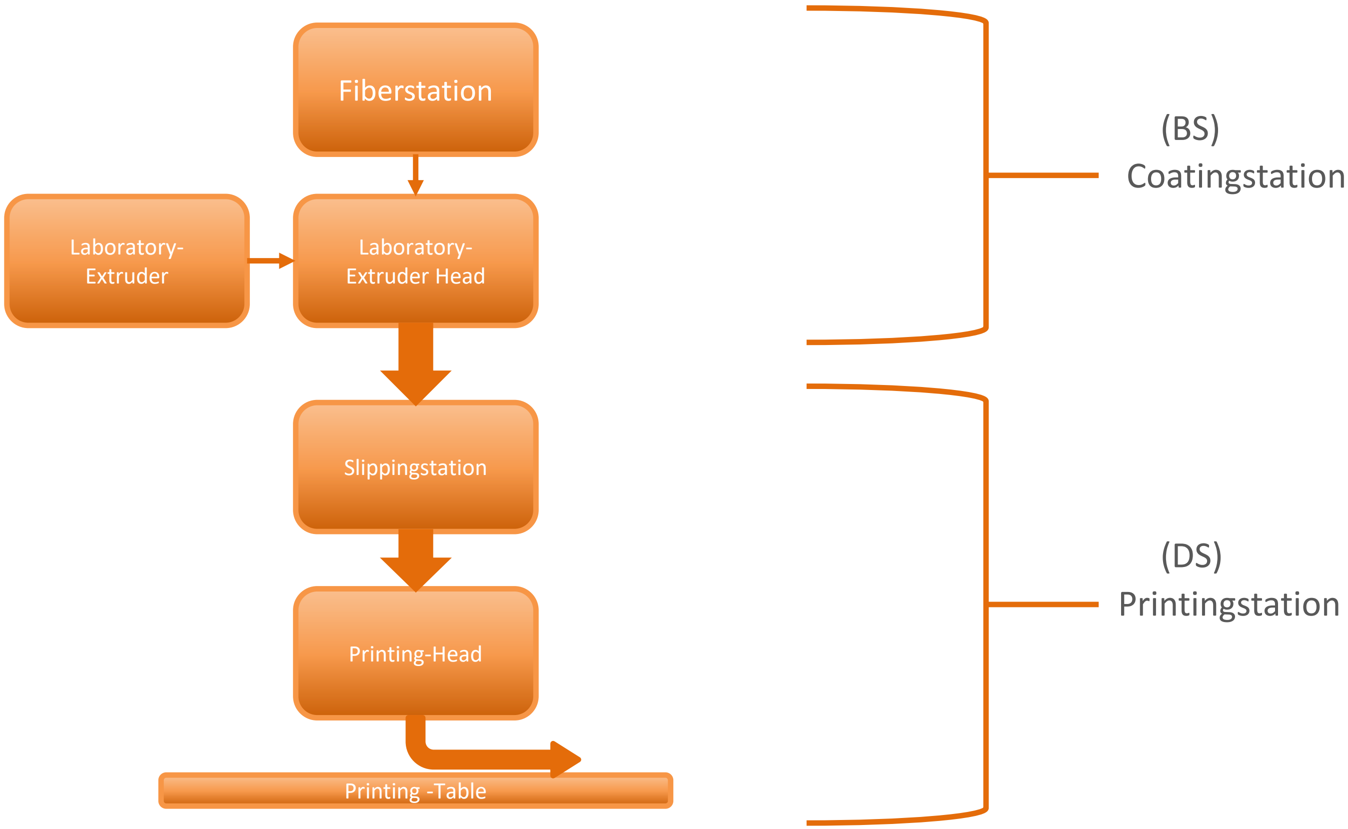


Fig. 5: MMO3D - printing head concept, state September 2017

(1) Project goals

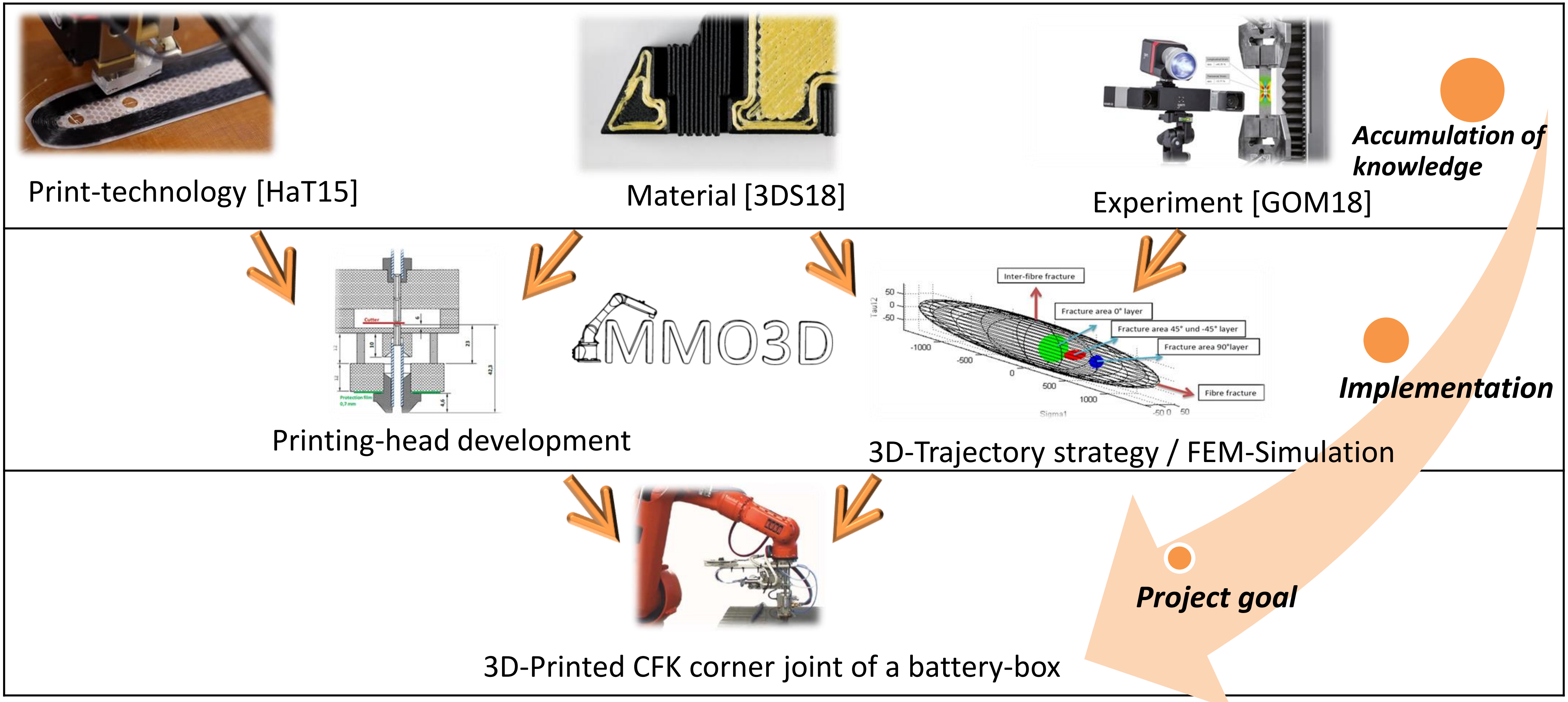


Fig. 6: Project goals for MMO3D

Interreg SLOWENIEN – ÖSTERREICH

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

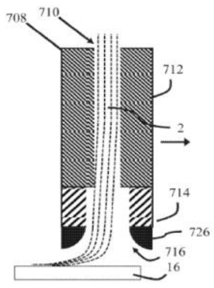
W3C Wood Carinthian Competence Center

(1) Basics of continuous Fiber Printing

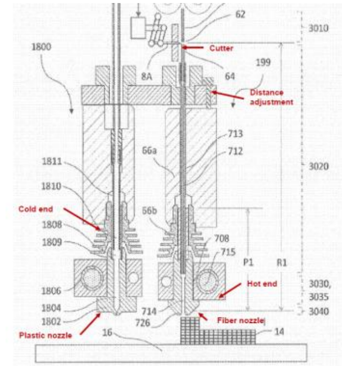
Printing-Head Construction

- 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]

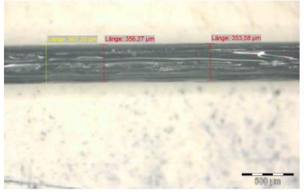


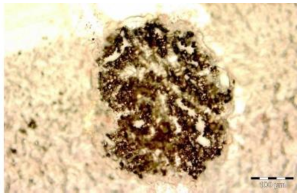
PH MarkOne [MaG16]



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

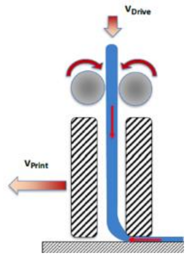
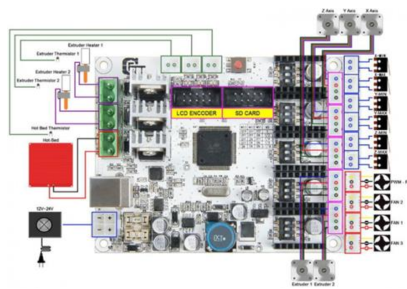


Fig. 7: Basics of continuous fiber printing

(1) Testbench MMO3D

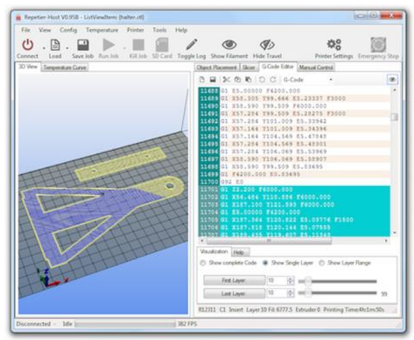
Controller Board

- 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)

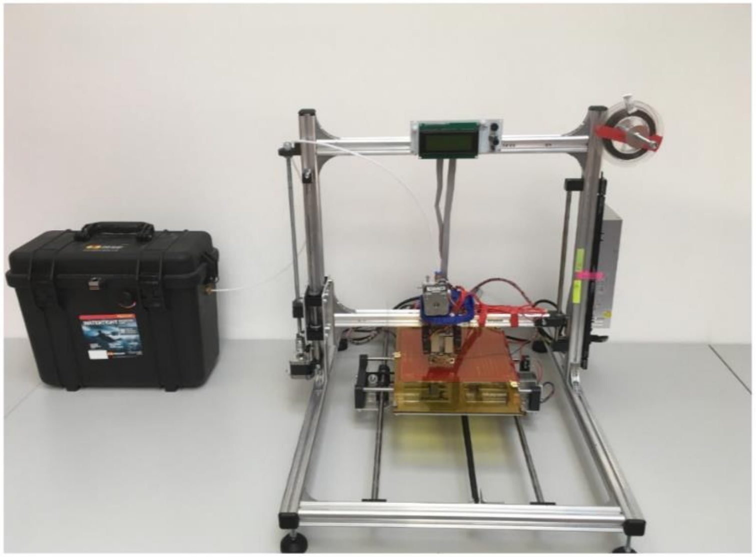
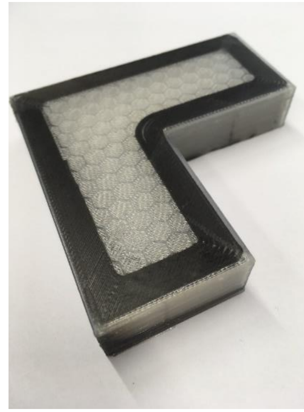


Fig. 8: Testbench for MMO3D printing head at CUAS – October 2018

(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

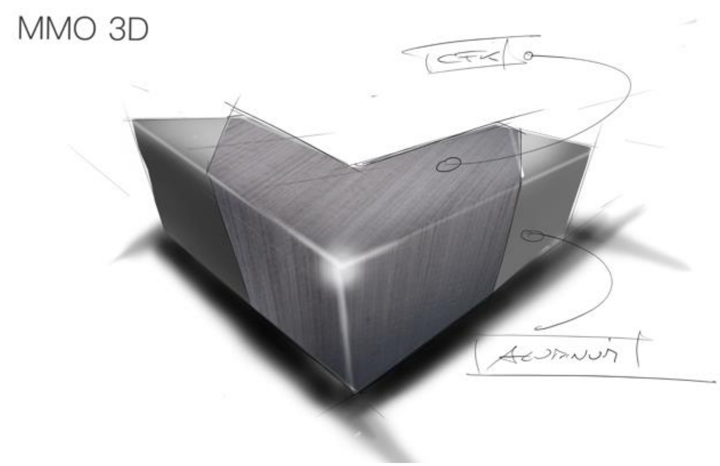


Fig. 9: Application concept of 3D-printed fibers for the reinforcement of edges in the MMO3D project

(2) A system theoretic approach - Overview

FACHHOCHSCHULE KÄRNTEN

- Asymmetry AM/SM & Industry 3-5 (i3-5)
- A system theoretic approach → Deduction of new Natural Law Structures (Main Sentences of Thermodynamics)

(2) Asymmetry AM vs. SM

AM: - Everything that can be digitalised can be produced

- Everything that as material can be
  - „extruded & be molten“
  - „pulverised & be molten“
  - „made single & is to be glued“ is suitable for an AM method

SM: - Only a small part of model materials, that can be digitalised, is producible with a SM Maschine

- The limitation of the machine lies in the outer room from the perspective of the production process (outer surface of the workpiece, outer room of the production machine)
- Everything that can be free cutted, can be manu-factured

SM = Subtractive Manufacturing   AM = Additive Manufacturing

(2) Asymmetry AM vs. SM (I)

Conclusion:

AM: → controllable standardized phase transformation (phase change of starting material)

→ controlled standardized binding (phase change of locking agent)

→ approximation to the form coming from inside (as a production process)

SM: → controlled unstandardized cutting process (partitioning) with constant phase

→ approximation to the workpiece form from the outer side

AM = Additive Manufacturing
SM = Subtractive Manufacturing

(2) Asymmetry AM vs. SM (II)

Conclusion:

AM: → Phase change & inside → outside
SM: → Phase constant & outer → inner side

manufacturing

AM = Additive Manufacturing
SM = Subtractive Manufacturing

(2) EVOLUTIVE STEPS (Bifurkations)

FACHHOCHSCHULE KÄRNTEN

i3.0

SM:
*PhasenConstancy
*outer → inner
*outer control CNC

i4.0

AM:
* PhaseChange
* inner → outer
* outer control CNC

i5.0

AMSO(1):
* PhaseChange
* inner → outer
* inner control SOC *

AMSO(2):
* PhaseConstancy
* inner → outer
* inner control SOC

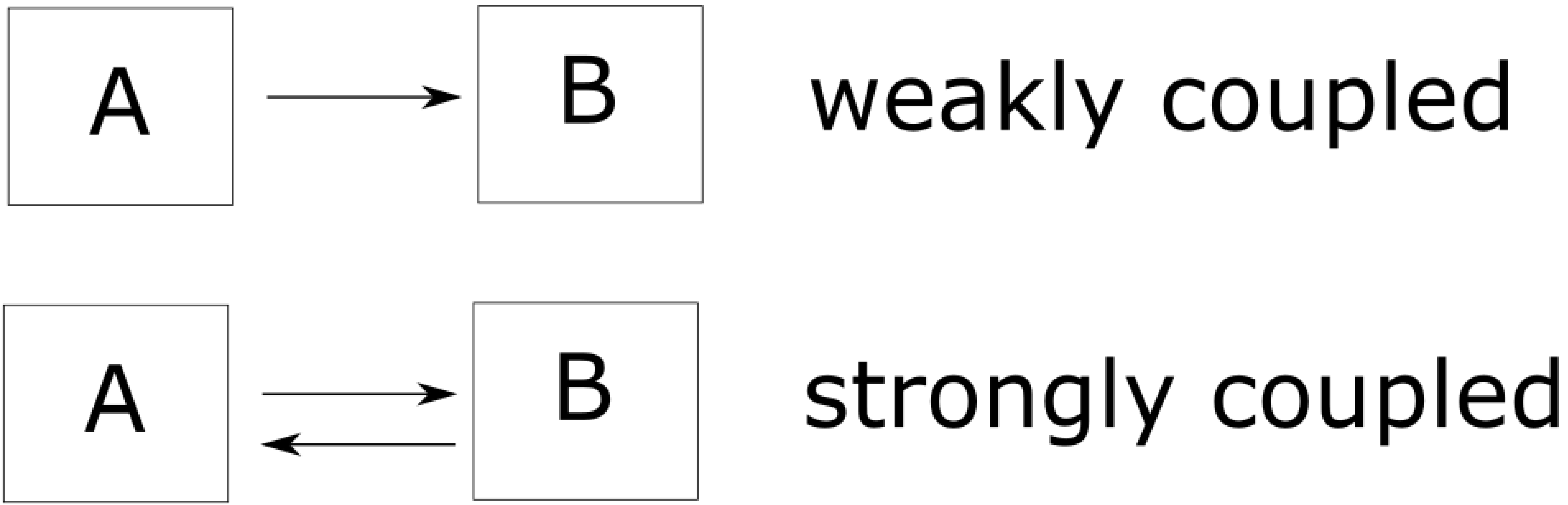
AMSO(3):
* PhaseChange
* outer → inner
* inner control SOC

Legend:

AMSO = Additive Manufacturing Self Organized
AM = Additive Manufacturing
SM = Subtractive Manufacturing
CNC = Computer Numerical Control
SOC= Self Organized Control

(2) A system theoretic approach 1

*

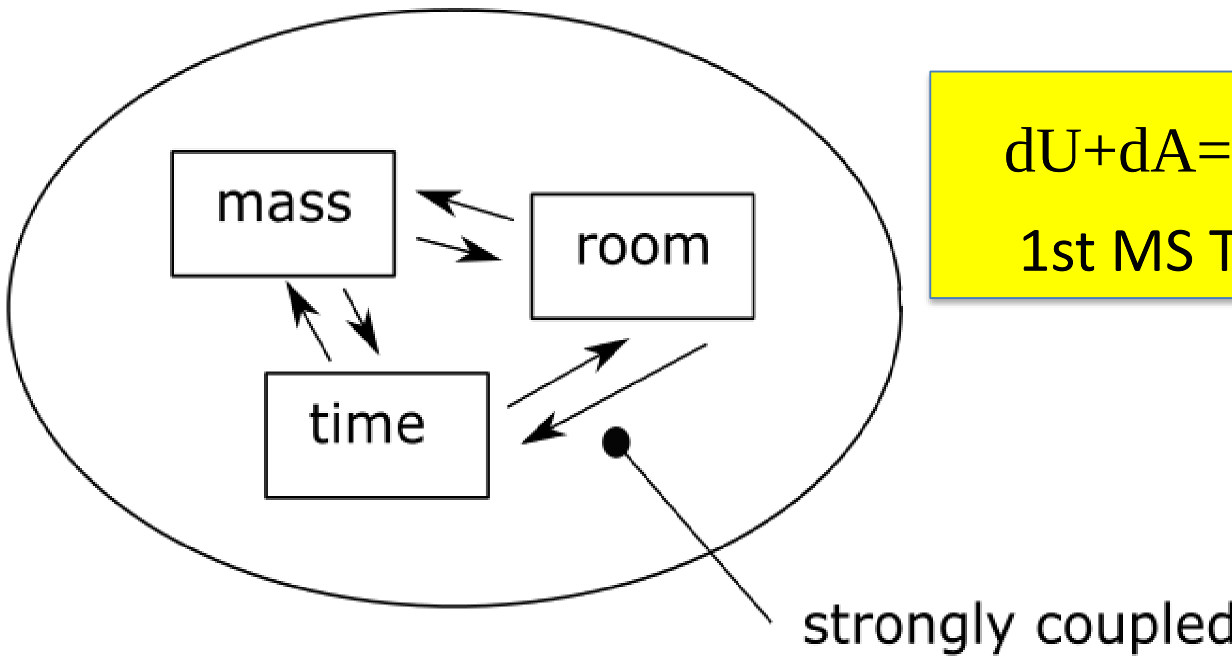


* in principle according to [LuJ08]

(2) A system theoretic approach 2

$E=m*c^2$

$E[J]=[kg*m^2/s^2]\sim E[Mass*Room/Time^2]$



$$dU+dA=dQ+dE_A$$

1st MS Thd.

Fig. 10: 1st Main Sentence of Thermodynamics (MS Thd.) described with regard to physical dimensions

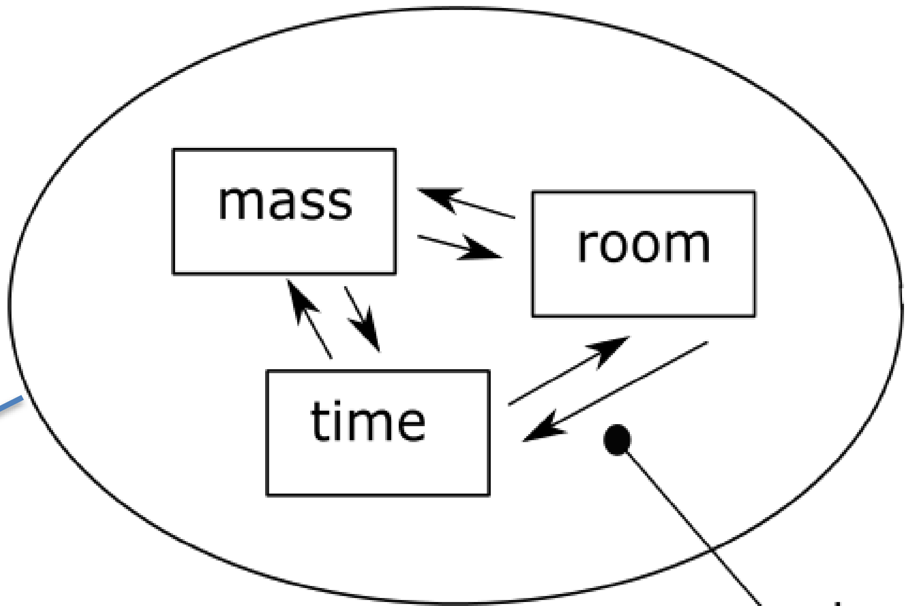
…MS Thd. = Main Sentence of Thermodynamics

(2) A system theoretic approach 3

$E=m*c^2$

$E[J]=[kg*m^2/s^2]\sim E[Mass*Room/Time^2]$

weakly coupled



$dU+dA=dQ+dE_A$

1st MS Thd.

strongly coupled

Temperature

$dS\geq 0$

2nd MS Thd.

Fig. 11: 1st and 2nd Main Sentence of Thermodynamics (MS Thd.) described with regard to physical dimensions

…MS Thd. = Main Sentence of Thermodynamics

(2) Coupling Analysis

Weakly coupled because:

(T→0)→(S→0)
3rd MS Thd.

Asymmetrie:

- Temperature can disappear
- Room/Time/Mass does not disappear

→ Hence there is a dependency of energy on the temperature,

When the temperature is Zero there is no influence on the energy

→ Hence the coupling is in principal weak (in this case)

…MS Thd. = Main Sentence of Thermodynamics

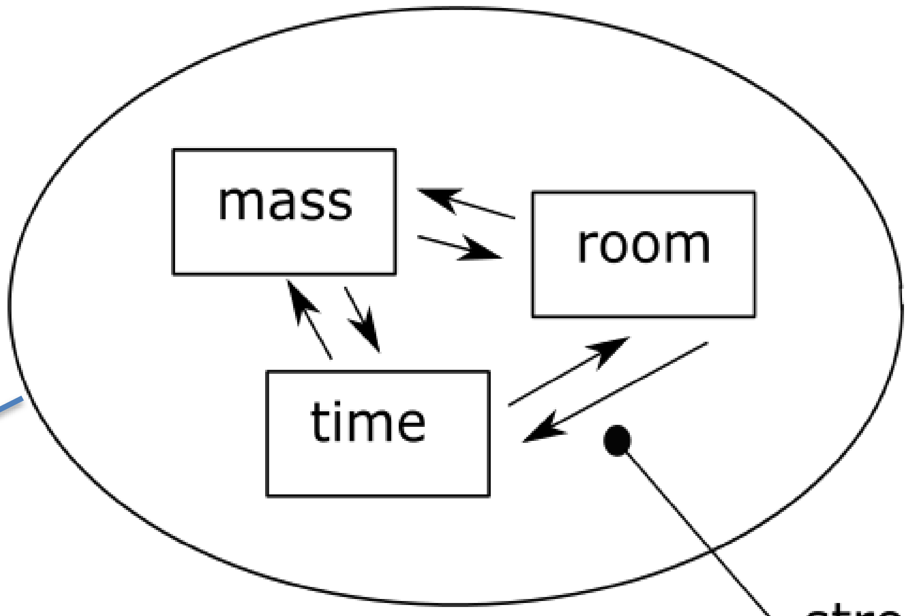
(2) A system theoretic approach 4

$E=m*c^2$

$E[J]=[kg*m^2/s^2]\sim E[Mass*Room/Time^2]$ $S[J/K]$

$S(dE_{i+1})<S(dE_i)$
i: 1…n
4th MS Thd.

strongly coupled



$dU+dA=dQ+dE_A$
1st MS Thd.

Temperature

$dS\geq 0$
2nd MS Thd.

strongly coupled

Fig. 12: 1st, 2nd and 4th Main Sentence of Thermodynamics (MS Thd.) described with regard to physical dimensions

…MS Thd. = Main Sentence of Thermodynamics

FACHHOCHSCHULE KÄRNTEN

4th Main Sentence of Thermodynamics:

Energy Forms have different orders:

→ more ordered Energy Forms can more broadly be used

$$S(dE_{i+1}) < S(dE_i) \quad i: 1 \ldots n$$

Fig. 13: 4th Main Sentence of Thermodynamics

(2) Unifying Main Sentences of Thermodynamics 1

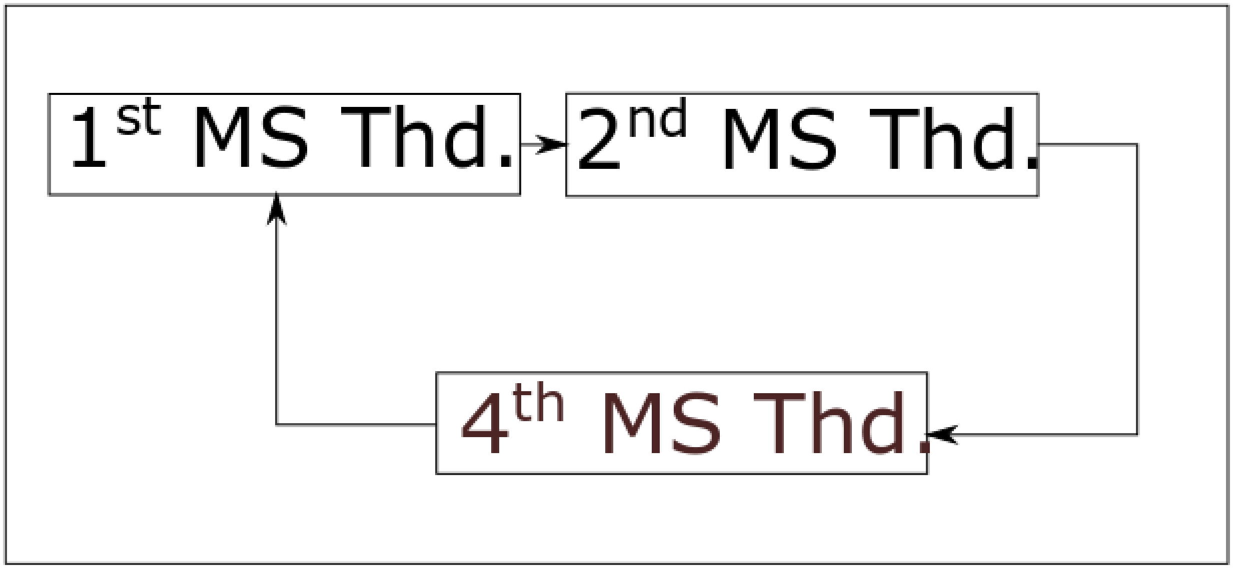


Fig. 14: 4th Main Sentence of Thermodynamics - overall feedback structure

…MS Thd. = Main Sentence of Thermodynamics

(2) Unifying Main Sentences of Thermodynamics 2

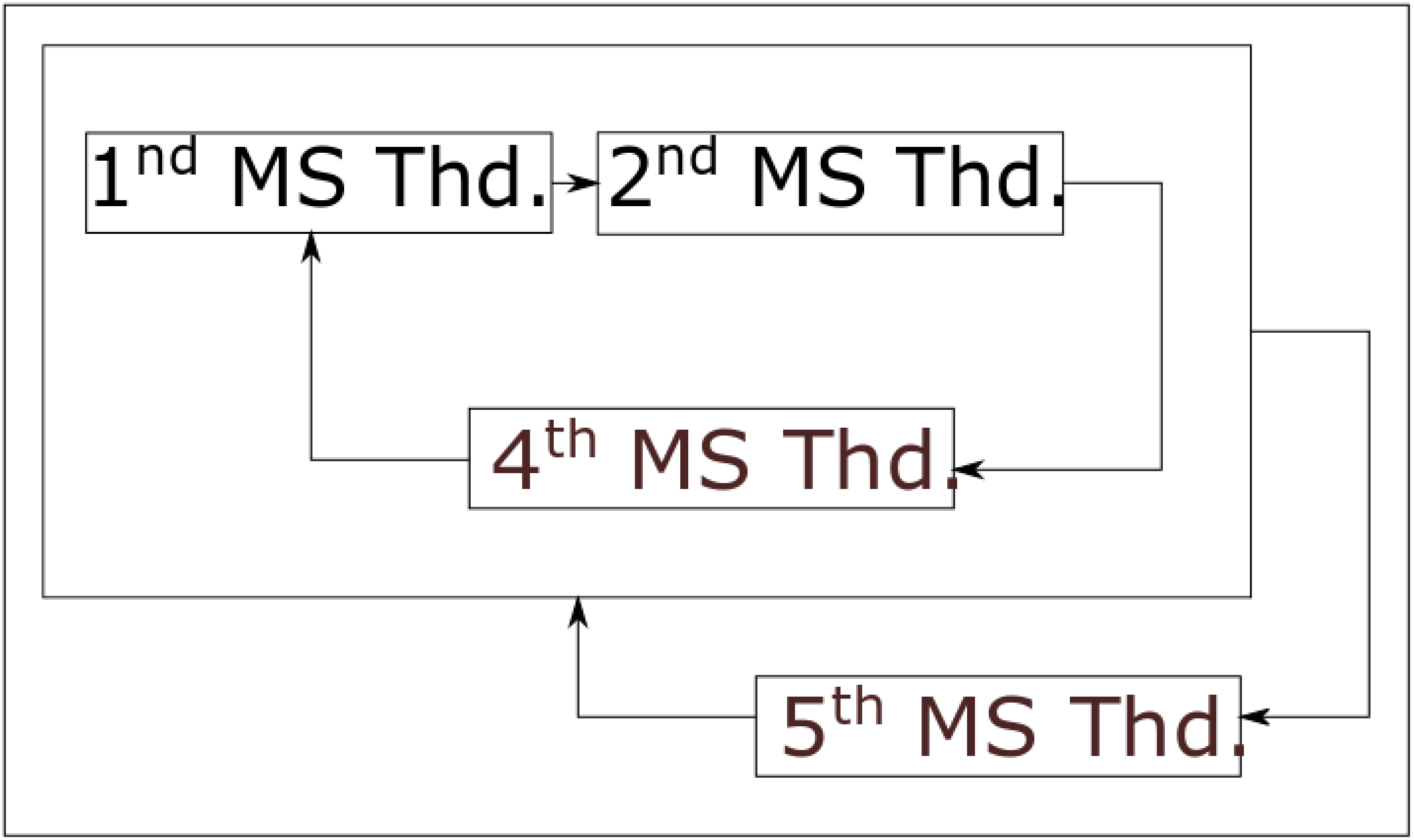


Fig. 15: 5th Main Sentence of Thermodynamics

…MS Thd. = Main Sentence of Thermodynamics

FACHHOCHSCHULE KÄRNTEN

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

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

Fig. 16: 5th Main Sentence of Thermodynamics

(2) A system theoretic approach 7 – with restriction:

$$^{*}\quad dS = d_eS + d_iS$$

→ Order has to be imported increasingly

*Prigogine in [BeL10]

(3) Implications Overview

- AM vs. SM regarding to energy efficiency potential
- Relation of AM Processes to 5th MS Thd.
  → FDM
  → SLM
  → 3DP
  → FR3DP
- Democratization
- Added Value MS Thd. for AM

(3) Implications

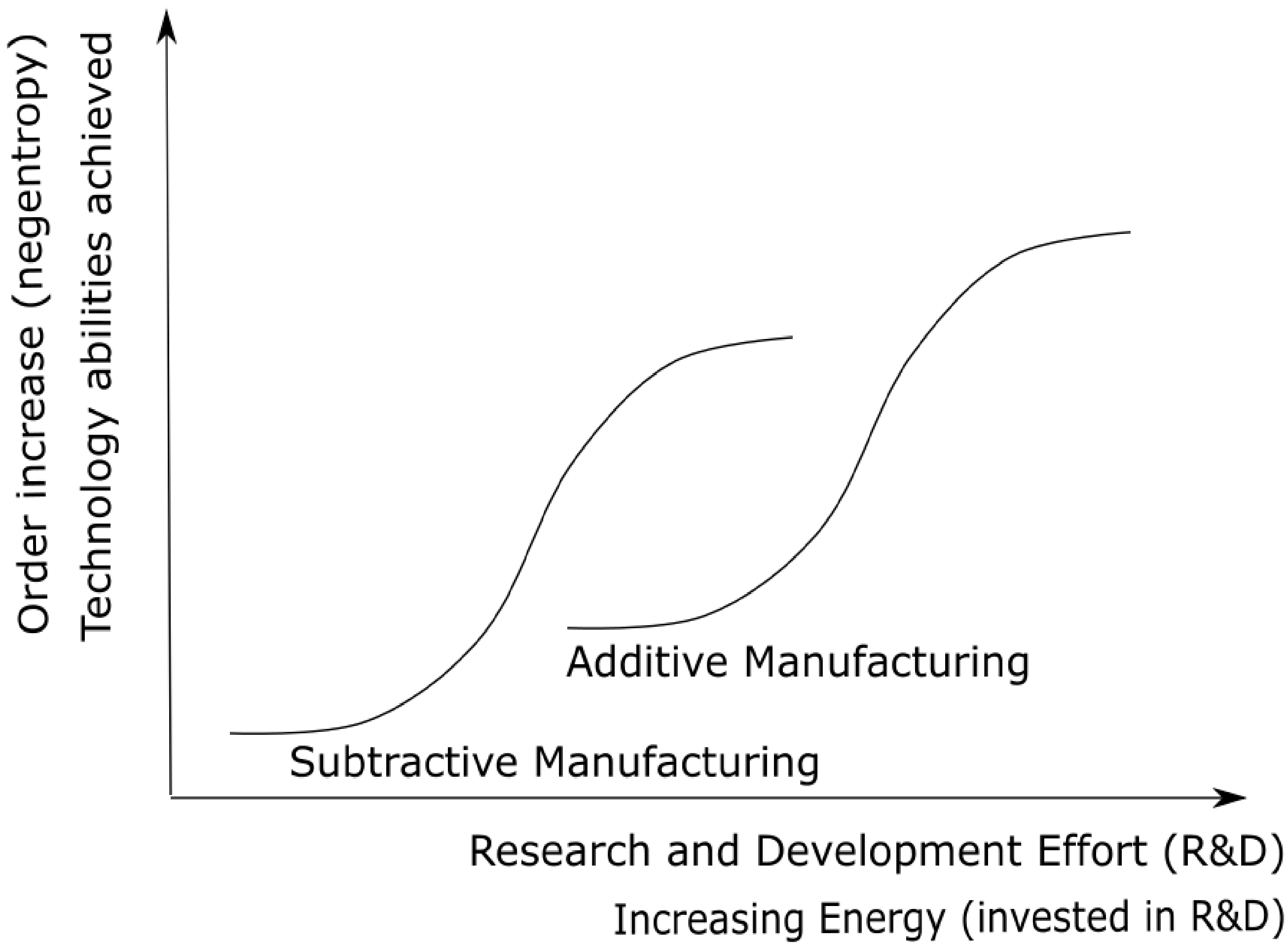


Fig. 17: AM vs. SM with regard to order increase - Technology life cycle curve for Subtractive and Additive Manufacturing (SM&AM) – Two "S-Curves"

(3) Fused Deposition Melting - Process

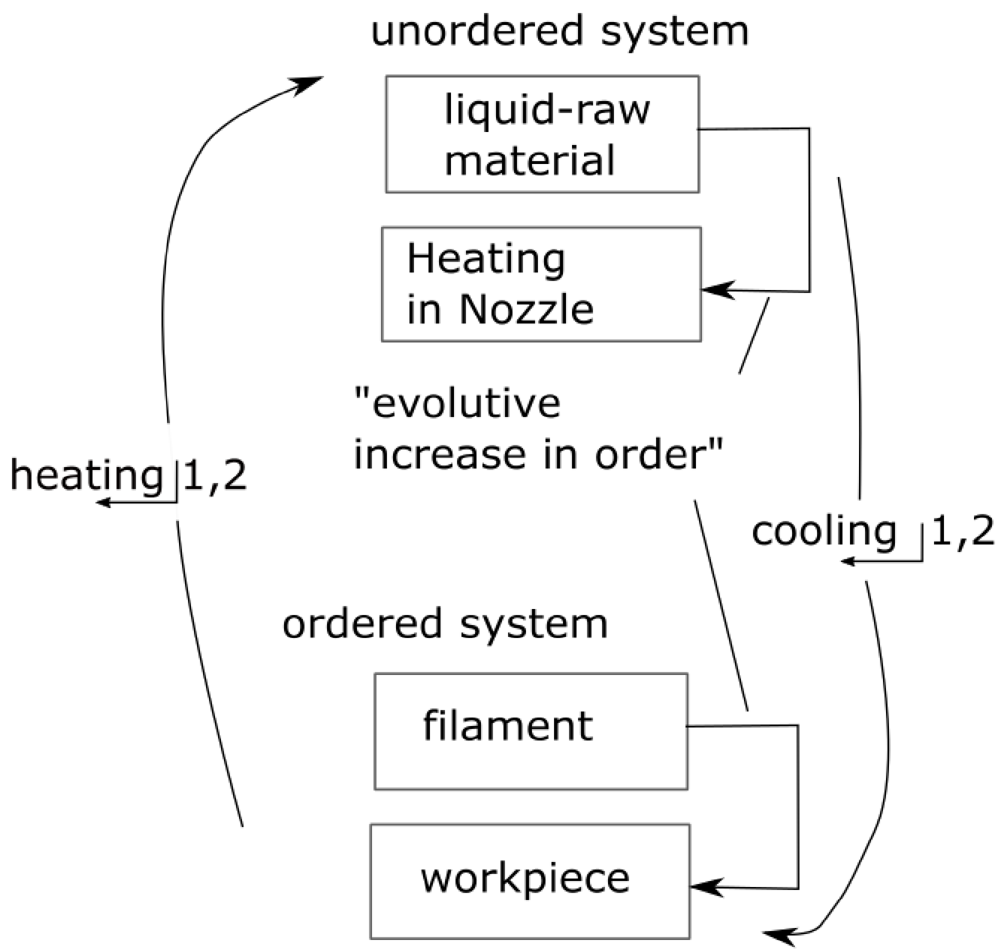


Fig. 18: FDM Process in the context of the 5th Main Sentence of Thermodynamics

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(3) Selective Laser Sintering (SLM) - Process

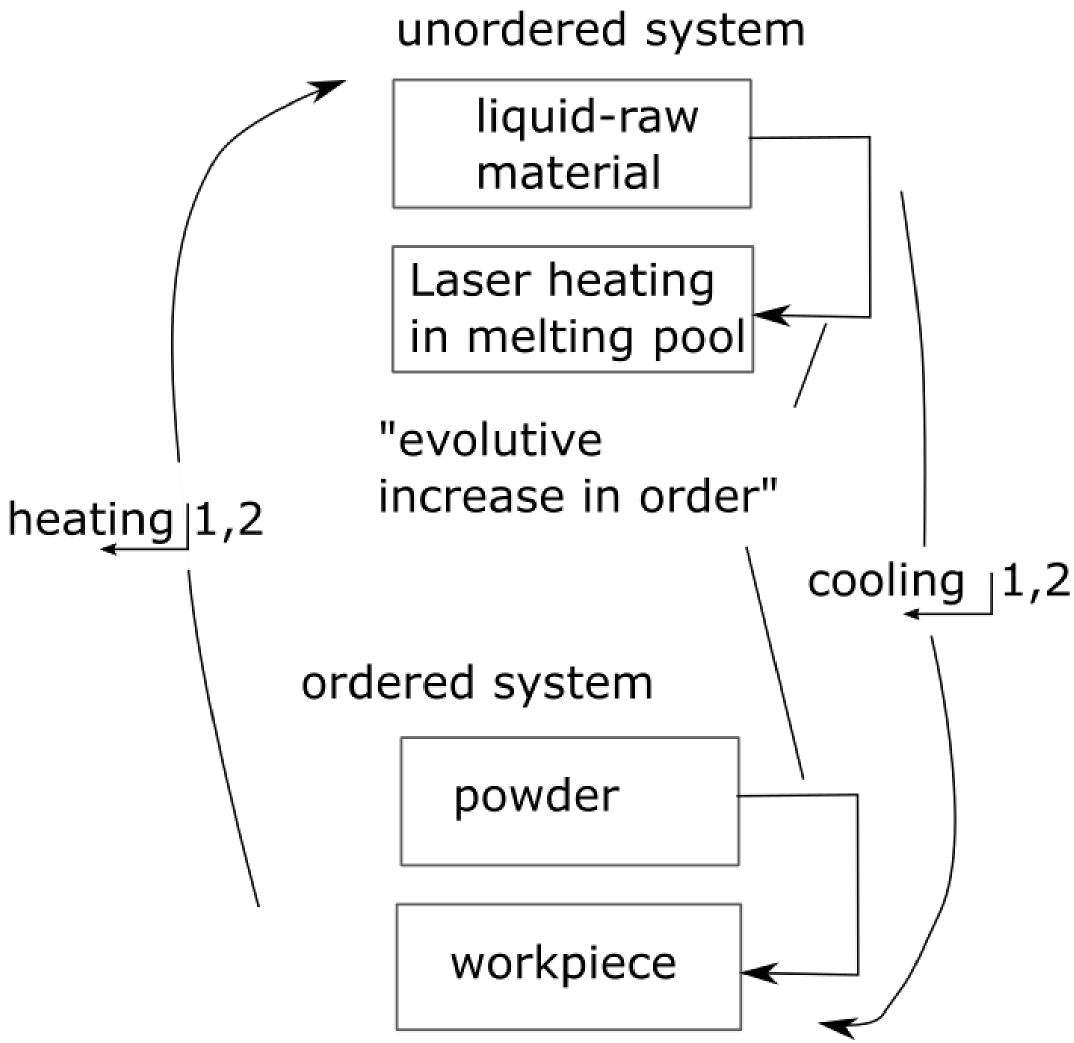

Fig. 19: SLM Process in the context of the 5th Main Sentence of Thermodynamics

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(3) 3D-Printing (3DP) - Process

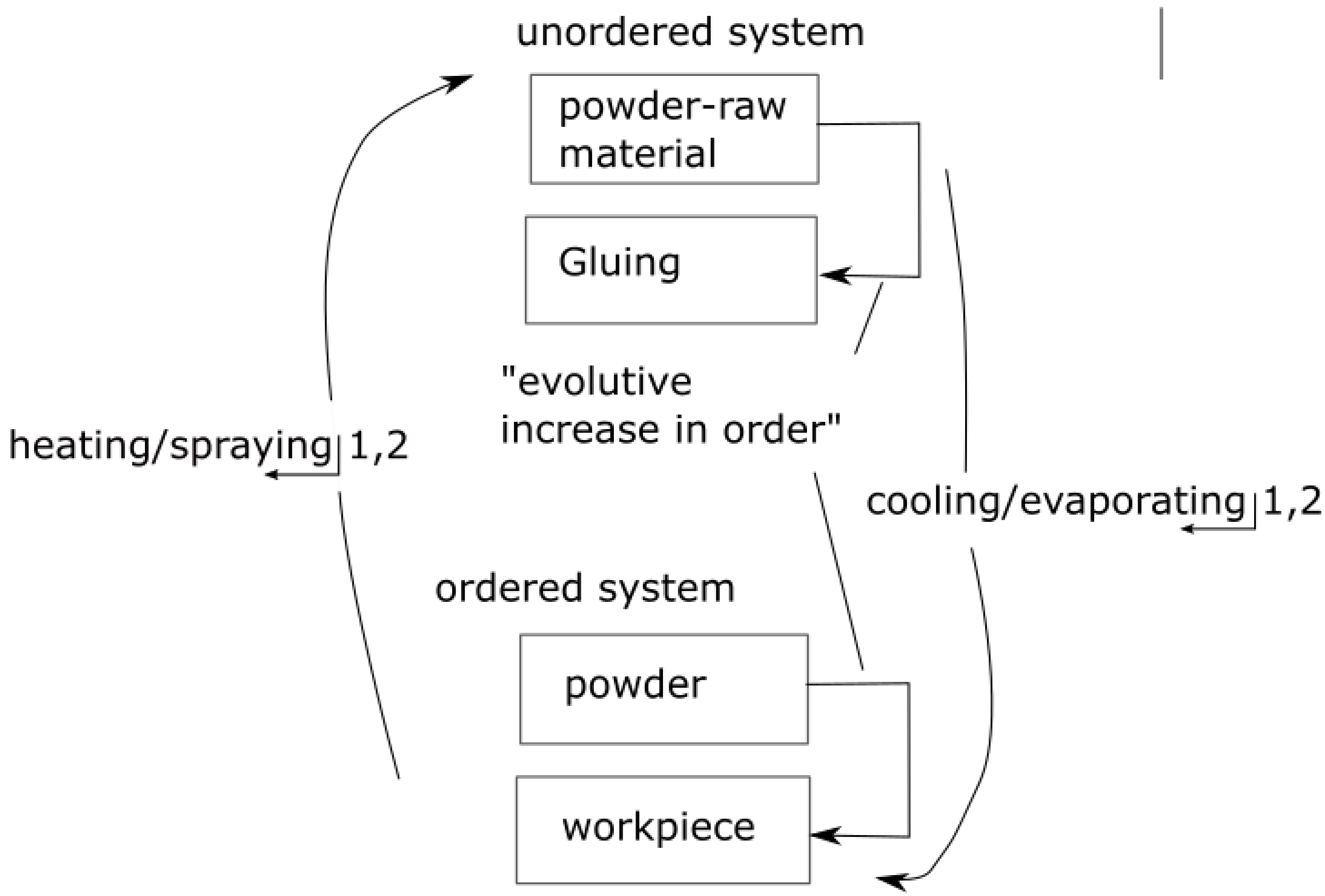

Fig. 20: 3DP Process in the context of the 5th Main Sentence of Thermodynamics

FACHHOCHSCHULE KÄRNTEN

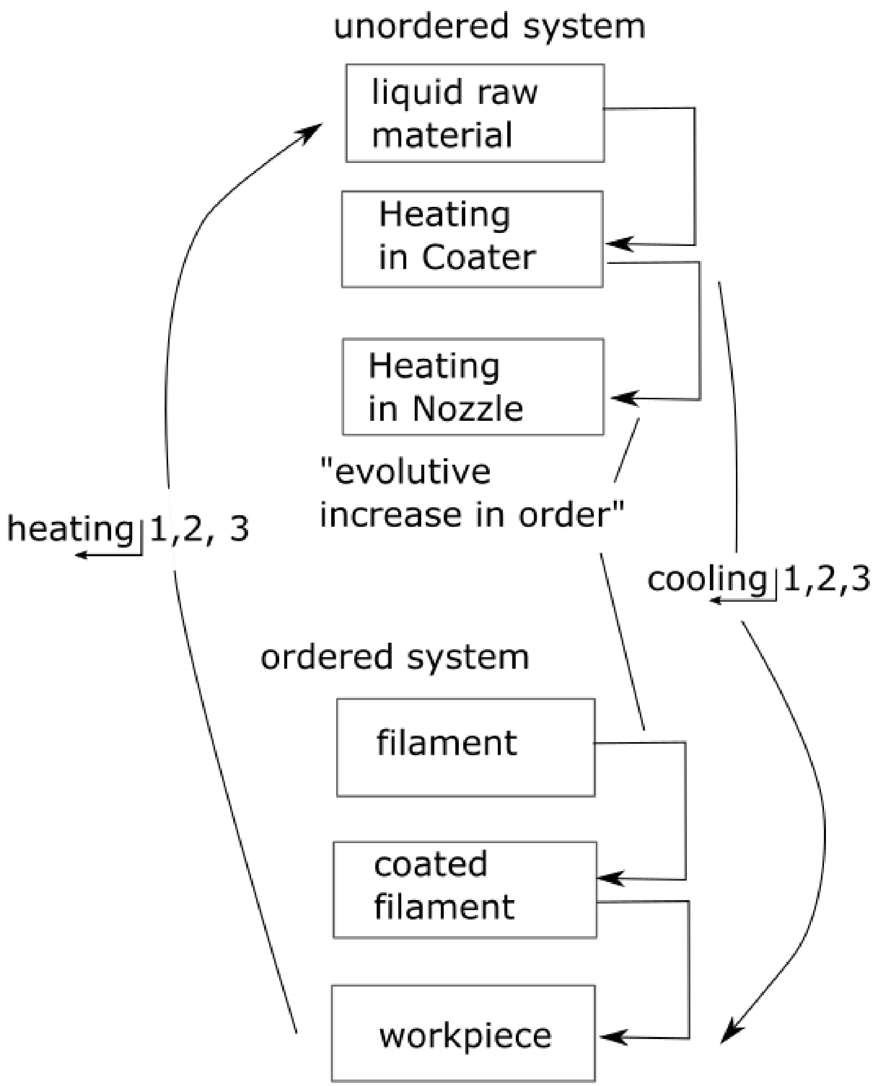

Fig. 21: FR3DP Process in the context of the 5th Main Sentence of Thermodynamics

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(3) Conclusion

→ The second/third „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

(3) Application in the field of AM 5th MS Thd.

- Open Source 3D-Printing Systems increase order because they reuse „ordered systems“ i.e. working concepts
  → Company value can be created by spezialisation in new application field (this increases overall system order)
  → Democratization of companies: Even smaller companies are able to succeed on the market

...MS Thd. = Main Sentence of Thermodynamics

(3) Implications

→ AM → leads to democratisation

→ Democracy can lead to higher order

* Additive Manufacturing

(3) Added Value for AM

1. Predictions how to improve AM Process → Higher Energy Efficiency → predict „right“ direction of development
2. Explain Structure of AM Process and predict Potentials
3. Interdisciplinary understanding of AM

Open Questions

1. How can **order** be measured practically – especially in AM?
2. How can this be shown on all length/time/mass/temperature scales?
3. What other fundamental relations (laws) can be found with respect to other dimensions (SI Units)?

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) Deduction of new thermodynamic nature laws systemtheoretically

(3) Implications

- Energy Efficiency in AM
- Predictions of reasonable development
- Interdisciplinary Work

Thank you cordially for attention!

FH-Prof. Mag. DI Dr. Bernhard Heiden

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

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

Literature AM Recommendation & Presentation 1

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ABBREVIATIONS & SYMBOLS

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

Reservoir - Relations

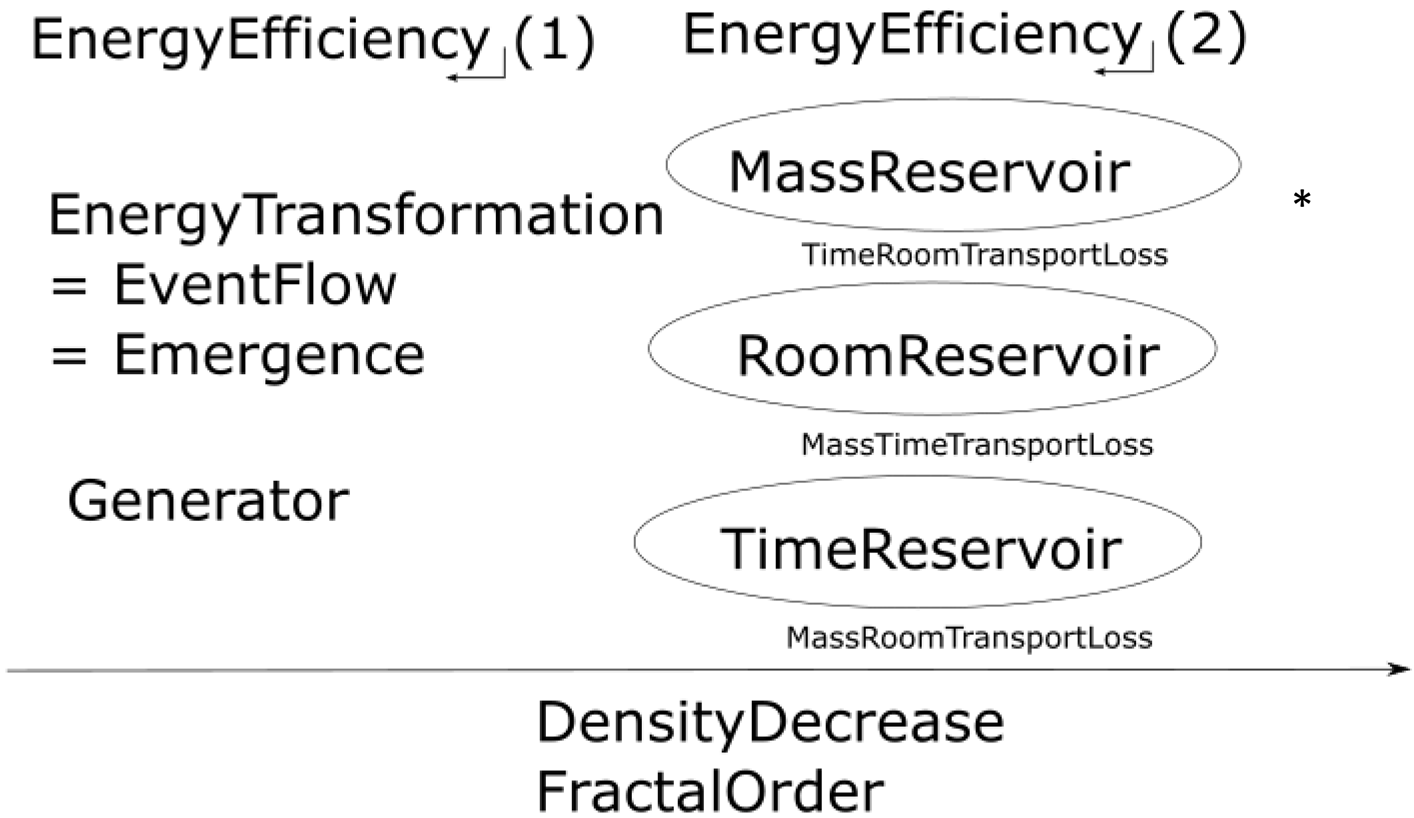

Fig. 22: 5th Main Sentence with regard to Flow and Storage-Quantities

* Follows from the theorem of Liouville [WuG00] p.179 f.