Fraunhofer IWU

Technische Universität München

PROJECT GROUP
RESOURCE-EFFICIENT MECHATRONIC PROCESSING MACHINES

# TRIZ-BASED BIOMIMETIC PART-DESIGN FOR LASER ADDITIVE MANUFACTURING

T. Kamps[a*], C. Münzberg[c], L. Stacheder[b], C. Seidel[a, b], G. Reinhart[a, b], U. Lindemann[c]


[a]Fraunhofer-Institute for Machine Tools and Forming Technology
[b]Institute for Machine Tools and Industrial Management, Technichal University of Munich
[c]Institute of Product Development, Technical University of Munich
* Corresponding author: Tel.: +49 821 56883 57; fax: +49 821 56883 50

*E-mail address:* tobias.kamps@iwu.fraunhofer.de.

# AGENDA

- Motivation and research focus
- Introduction of a new design approach
- Case study
- Summary and outlook

# MOTIVATION AND RESEARCH FOCUS

## HOW TO OPTIMIZE THE DESIGN PROCESS SPECIFICALLY FOR LASER ADDITIVE MANUFACTURING?

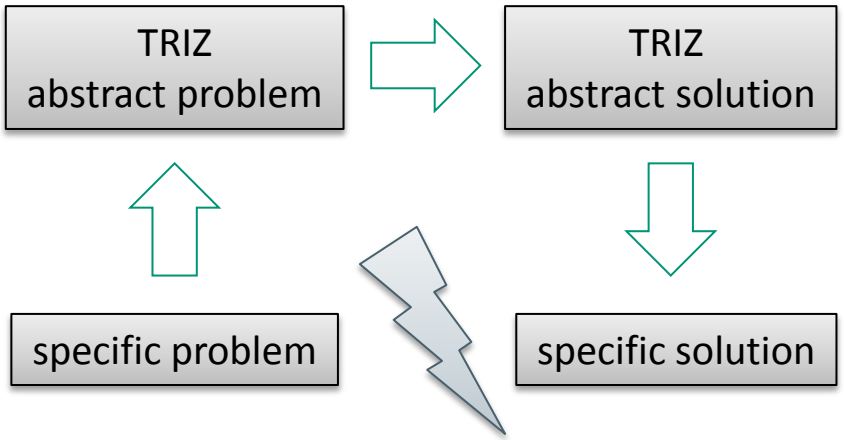
### DESIGN FOR AM

**VDI 3405:** part orientation, application of support structures, material properties, post-processing etc.

"designer's mind-sets have to adapt to a different way of production and design"

**VDI status report of 2014**

**application-oriented methodology**




„theory of inventive problem solving"
LINDEMANN 2009, 2014; SCHAAL 2011


„learning from nature"
NACHTIGALL 2002



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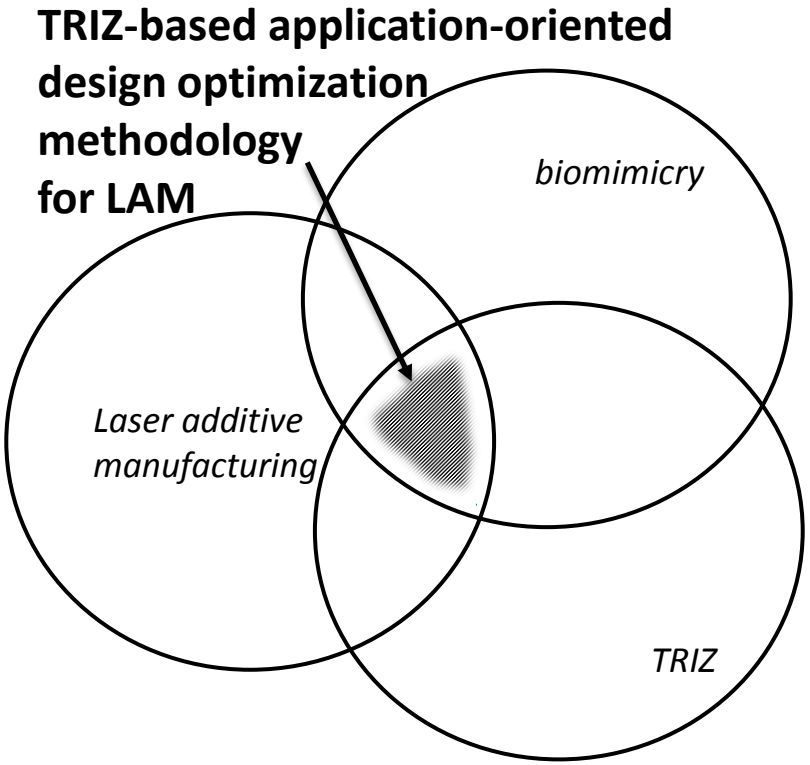
# MOTIVATION AND RESEARCH FOCUS
## TRIZ-BASED INTEGRATION OF BIOMIMETICS AND DESIGN FOR AM

**OBJECTIVES**

- PICKING SUITABLE METHODS FROM THE TRIZ-METHODOLOGY
- EFFICIENT OPTIMIZATION OF A GIVEN PART
- SYSTEMATIC CREATION OF LARGE SOLUTION SPACE OF BIOMIMETIC ANALOGIES FOR GIVEN APPLICATION
- EVALUATION OF SUITABLE ANALOGIES
- EVALUATION OF CREATED SOLUTIONS IN TERMS OF DESIGN RESTRICTIONS DICTATED BY LASER ADDITIVE MANUFACTURING
- ENSURING APPLICATION-ORIENTATION WITHOUT REDUCING SOLUTION QUALITY



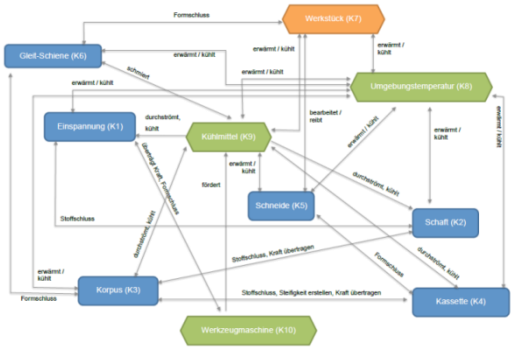
# INTRODUCTION OF A NEW DESIGN APPROACH

## TRIZ-BASED BIOMIMETIC PART DESIGN FOR LAM

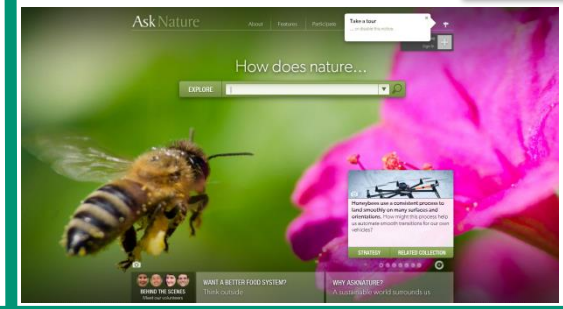
**2** TRIZ abstract problem

impact analysis and problem formulation

LAM feasibility check




**3** TRIZ abstract solution




solution space generation via biomimicry

LAM performance check

$$FI = \frac{1}{e^{\frac{1}{n}\sum_{i=1}^{n}\left(\left|\frac{x_{BT,i}-x_{p,i}}{x_{p,i}}\right|\right)}}$$

analytical evaluation

augmented functional modelling

**1** specific problem

**4** specific solution

application-oriented methodology for functional part optimization

www.asknature.com, Zugriff am 14.06.2015, The Biomimicry Institute





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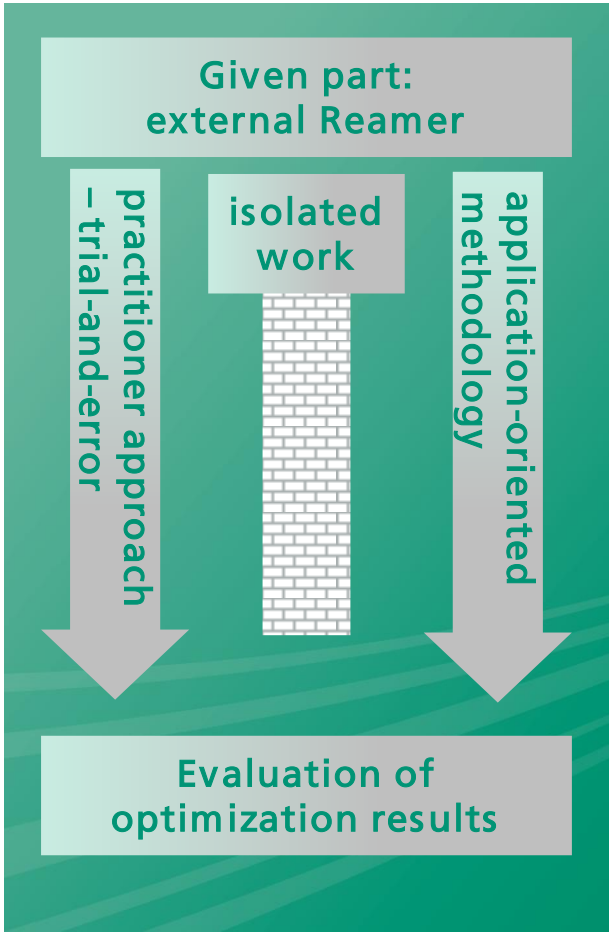
# INTRODUCTION OF A NEW DESIGN APPROACH
## PART DESIGN EVALUATION FOR LAM

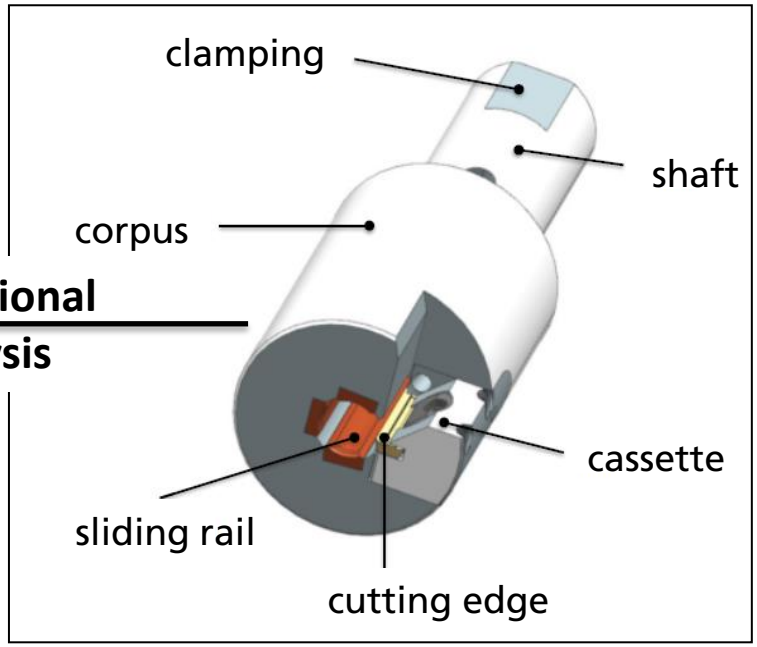
| Name | Equation | Parameters | Purpose | Source |
|---|---|---|---|---|
| feature index | $\mathrm{FI} = \frac{1}{e^{\frac{1}{n}\sum_{i=1}^{n}\left(\left\lvert\frac{x_{BT,i}-x_{p,i}}{x_{p,i}}\right\rvert\right)}}$ | $x_{BT}$ value for a feature (Ra, min. wall thickness etc.)<br>$x_P$ maximum feature value | degree of exploitation of LAM-potential | Zhang et al. 2014 |
| complexity index | $\mathrm{KI} = \frac{\sqrt{O_{BT}}}{\sqrt[3]{V_{BT}}}$ | part volume $V_{BT}$<br>and part surface $O_{BT}$ | degree of part complexity | Zhang et al. 2014 |
| massivity index | $\mathrm{MI} = 1 - \frac{\log\left(\frac{V_{BB}}{V_{BT}}\right)}{2}$ | part volume $V_{BT}$ and bounding box volume $V_{BB}$ | degree of part complexity | Macht 1999 |
| orientation index | $OI = \frac{1}{N_a + N_n} + \frac{N_a}{N_a + N_n}$ | $N_a$ functional surface<br>$N_n$ non-functional surface | degree of effort for part orientation | Zhang et al. 2014 |
| safety index | $SI = \frac{R_m}{\sigma_{vM\_max}}$ | $R_m$ tensile strenght<br>$\sigma_{vM\_max}$ von Mises stress | efficiency of part mass usage | Klein 2013 |
| lightweight construction indicator | $LBK = \frac{F_{all}}{F_{part}}$ | $F_{all}$ overall stress<br>$F_{part}$ part permanent weight | indicator for actual load capacity use | Klein 2013 |
| mass reduction index | $MA = \frac{m}{m_{old}}$ | $m_{old}$ original part mass<br>$m$ reached part mass | degree of mass reduction | |

multiple analytical measures for part design evaluation

# CASE STUDY
## EXTERNAL REAMER PROVIDED BY MAPAL DR. KRESS KG - METHODOLOGY




functional analysis



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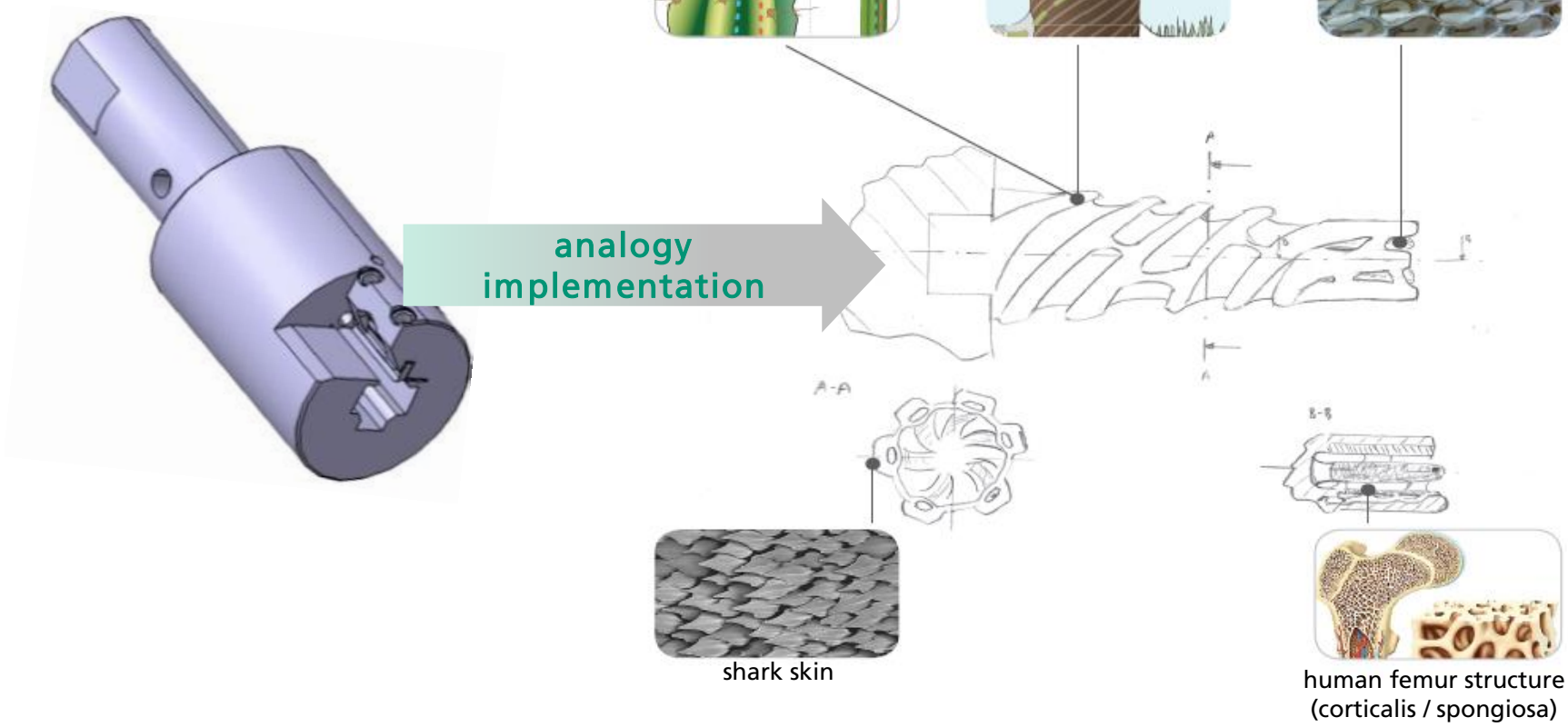
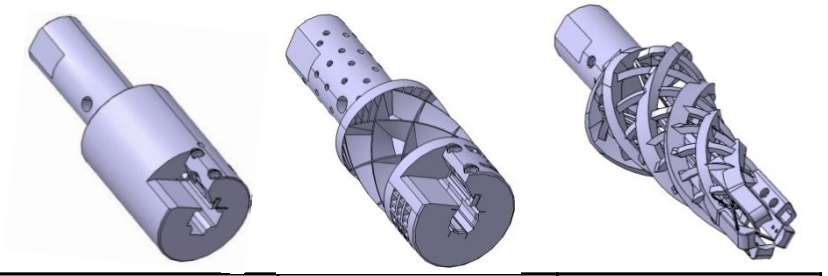
# CASE STUDY

## EXTERNAL REAMER PROVIDED BY MAPAL DR. KRESS KG – ANALOGY SEARCH



# CASE STUDY
## EXTERNAL REAMER PROVIDED BY MAPAL DR. KRESS KG – RESULTS AND EVALUATION



| | | Reamer conventional | Reamer LAM-non-TRIZ-optimized | Reamer TRIZ-optimized |
|---|---|---|---|---|
| **PART-DATA** | | | | |
| mass (TiAl6V4) | **m** [g] | 232 | 107 | 86 |
| volume | $V_{BT}V_{BT}$ [mm³] | 52080 | 23980 | 19280 |
| surface | $O_{BT}O_{BT}$ [mm²] | 15000 | 33000 | 36000 |
| **PROCESS-PERFORMANCE** | | | | |
| complexity-index | **KI** | 3,28 | 6,30 | 7,11 |
| massivity-index | **MI** | 0,82 | 0,66 | 0,56 |
| orientation-index | **OI** | 0,63 | 0,83 | 1,25 |
| **PART-PERFORMANCE** | | | | |
| lightweight construction indicator | **LCI** (normalized) | 0,03 | 0,09 | 0,49 |
| mass ratio | **MA** [%] | 100 | 46 | 37 |
| safety-index | **SI** | 159 | 131 | 29 |

**the systematic approach offers better design results regarding process and part performance**

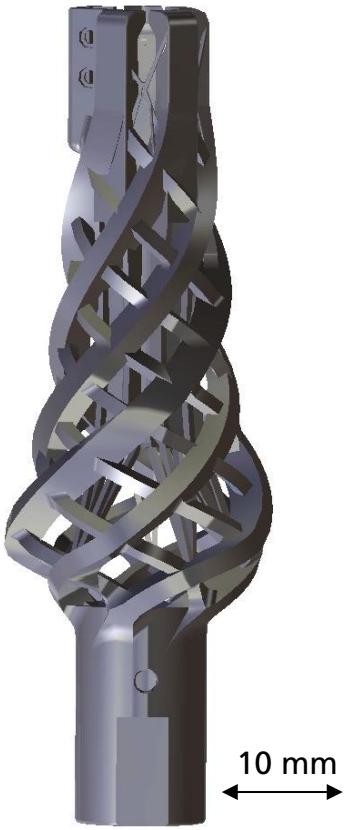
# SUMMARY AND OUTLOOK
## …NATURE KNOWS BEST…

- LAM possesses a great potential regarding part complexity and adaption for an innovative part design
- Thus, design optimization is a complex challenge for the designer that requires systematic design Approaches for optimal use of "complexity for free"
- Nature offers a vast solution space for technical problems
- The case study of an external reamer shows a superior solution to a trial-and-error approach

LAM leverages an economical transfer of analogies due to low part complexity costs.

In spite of 250 years of taxonomic classification and over 1.2 million species already cataloged in a central database, 86% of existing species on Earth and 91% of species in the ocean still await description (Mora et al. 2011).

Biological solutions have been field-tested for over 3.8 billion years.




Constantly growing analogy database to be used specifically for LAM!