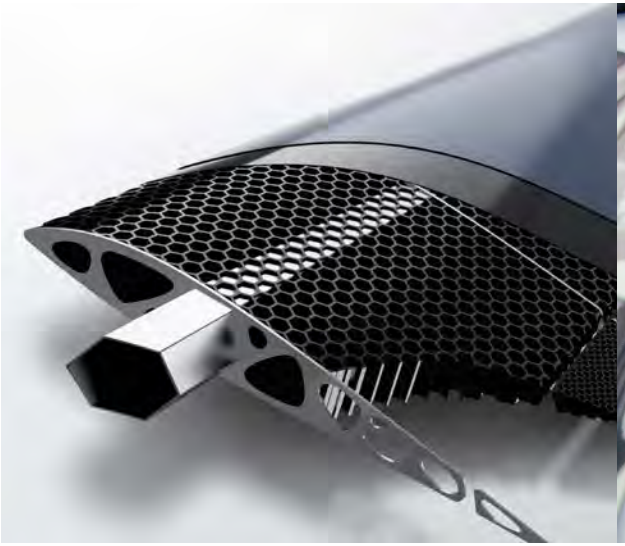
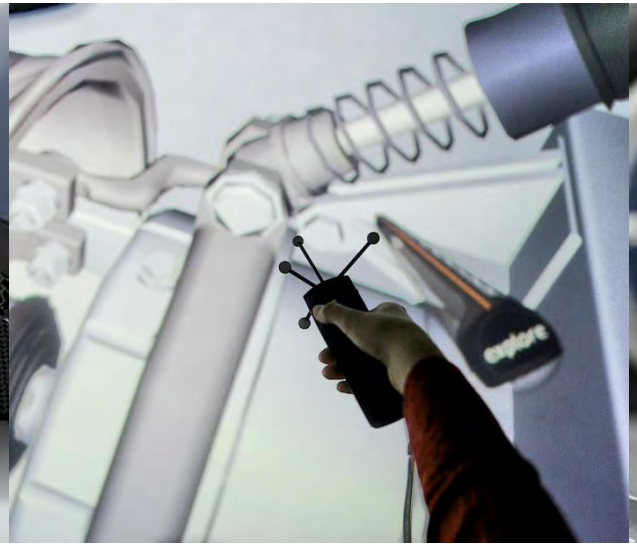
FRIEDRICH-ALEXANDER
UNIVERSITÄT
ERLANGEN-NÜRNBERG
TECHNISCHE FAKULTÄT

Lehrstuhl für
Konstruktionstechnik
Prof. Dr.-Ing. Sandro Wartzack

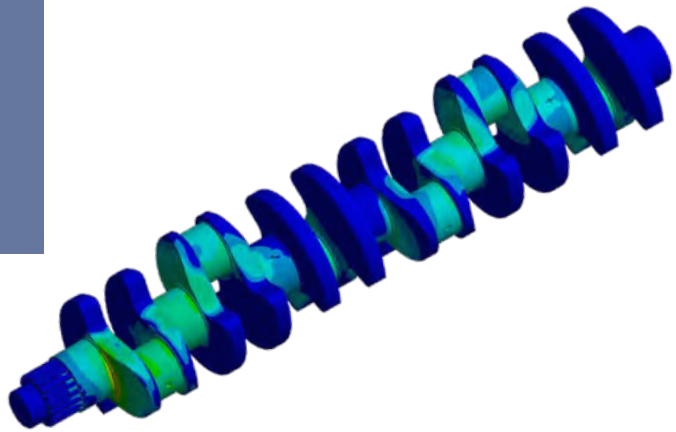
Machine Learning im CAD und CAE Umfeld der virtuellen Produktentwicklung

T. Sprügel, H. Völkl, S. Wartzack





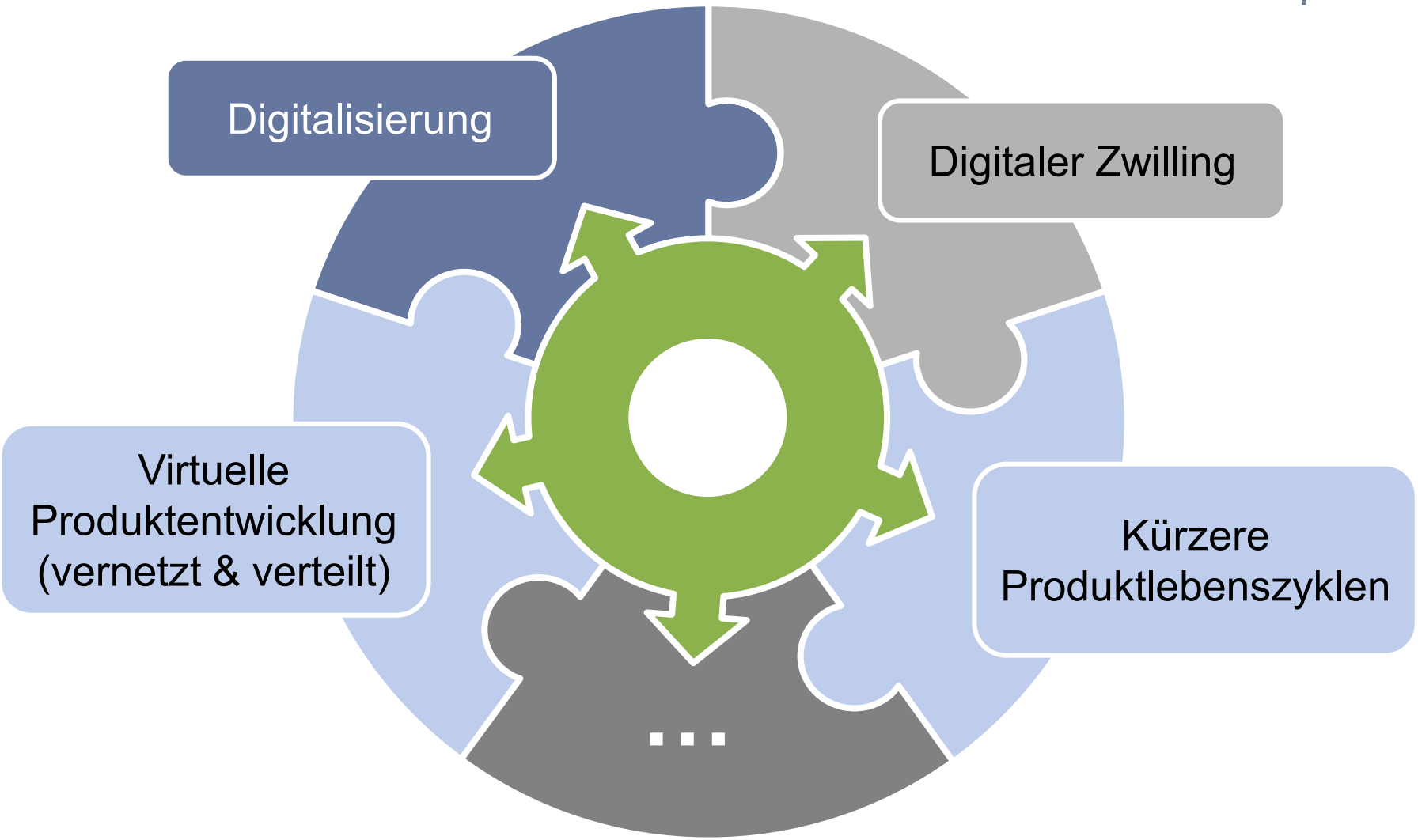
Gliederung



- Trends der Produktentwicklung
- Machine Learning
  Definition
- Anwendungsfälle:
  1. Endlosfaserverstärkte Thermoplaste
     Bewertung der Fertigbarkeit von Patches
  2. „DNA“ einer FE-Simulation
     Plausibilitätsprüfung für FE-Simulationen
- Danksagung & Kontakt

Aktuelle Trends in der Produktentwicklung

Motivation

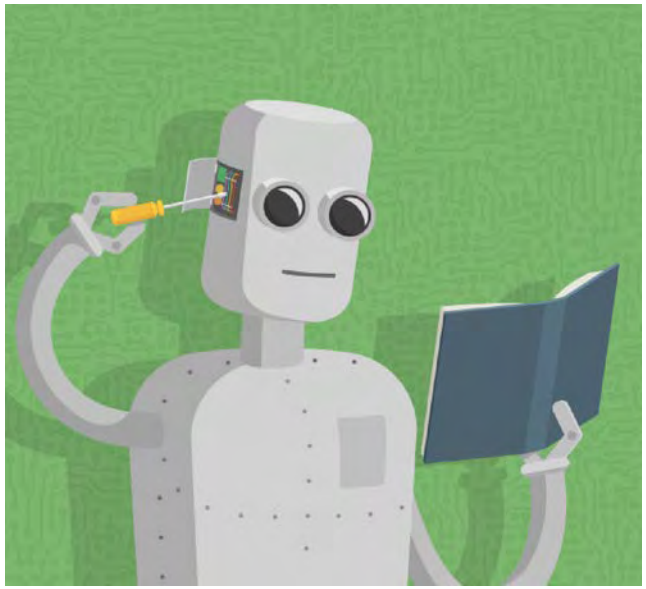


Quellen:
Digital Engineering Magazin: Die fünf Trends in der Produktentwicklung 2018
KPMG: Whitepaper 2018, Innovation wie am Fließband

© LEHRSTUHL FÜR KONSTRUKTIONSTECHNIK

Machine Learning

Definition



Bildquelle: towardsdatascience.com

Machine Learning

- Künstliche Intelligenz
- Datenbestände
- Erkennung von Mustern

Generierung von künstlichem Wissen aus Erfahrungen

- Verallgemeinerung
- Problemlösung
- Analysen

© LEHRSTUHL FÜR KONSTRUKTIONSTECHNIK
Friedrich-Alexander-Universität Erlangen-Nürnberg
Prof. Dr.-Ing. Sandro Wartzack

Machine Learning ⟷ Virtuelle Produktenwicklung

Anwendungsfall #1:

Endlosfaserverstärkte Thermoplaste

→ Bewertung der Fertigbarkeit von Patches

Anwendungsfall #2:

„DNA“ einer FE-Simulation

→ Plausibilitätsprüfung für FE-Simulationen

© LEHRSTUHL FÜR KONSTRUKTIONSTECHNIK
Friedrich-Alexander-Universität Erlangen-Nürnberg
Prof. Dr.-Ing. Sandro Wartzack

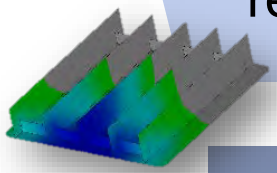
Motivation

Requirements for efficient composite lightweight design

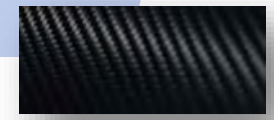
> “Ist das Kostenziel nicht erreichbar, ist ein sauberer Bruch zu machen, das Konzept zu ändern (....) oder gar das Projekt zu stoppen.”
>
> SCHÜRMANN 2009

➡ Early phase evaluation – as early as possible…

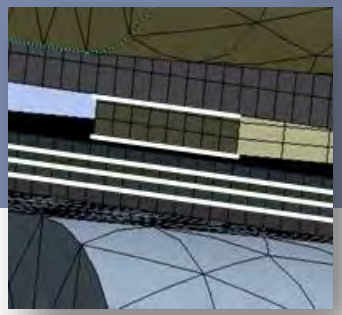
Short fibre reinforced plastics



Endless fibre reinforced plastics



Hybrid adhesive joints



© LEHRSTUHL FÜR KONSTRUKTIONSTECHNIK
Friedrich-Alexander-Universität Erlangen-Nürnberg
Prof. Dr.-Ing. Sandro Wartzack

Composites – curse and blessing

Previous methods for the design of endless FRP

Classical methods	Computer aided methods
Classical laminate theory	FE-models
Carpet Plots	Optimisation algorithms
Net Theory	Altair OptiStruct (commercial)
Composite Discs	Etc.
Laminate strength diagramms	

+ Short calculation times	+ Detailed problem definition
+ Low effort	+ Random load cases and geometries
− Severe simplification	− High effort
− Simple geometries and load cases	− High computation time

− Predefinition of parameters
− Unstructured procedure
− Necessity of experience

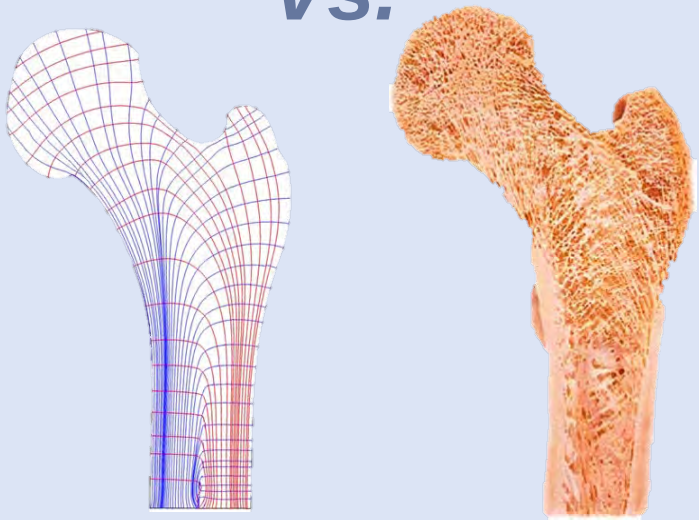
© LEHRSTUHL FÜR KONSTRUKTIONSTECHNIK
Friedrich-Alexander-Universität Erlangen-Nürnberg
Prof. Dr.-Ing. Sandro Wartzack

Predesign
Principle of Load Path

Load Path

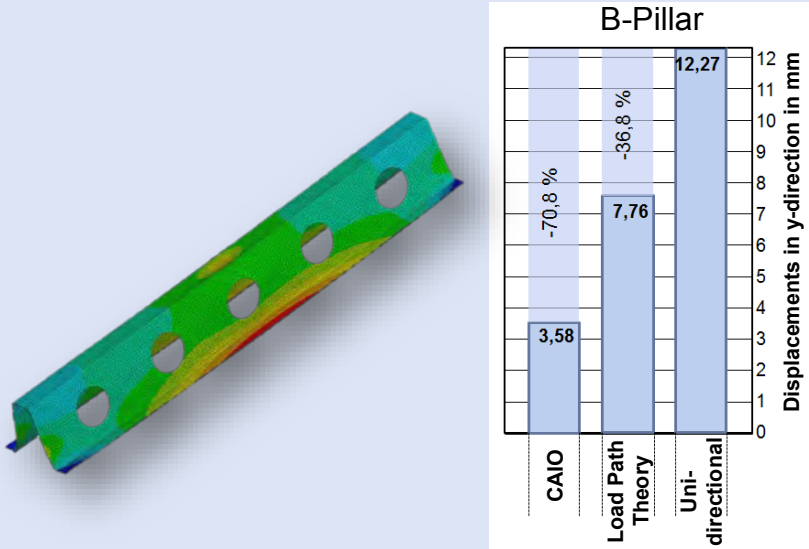
… in nature

Simulation *Vs.* Nature



The human femur as an example

… with composites



Enormous increase in stiffness and strength

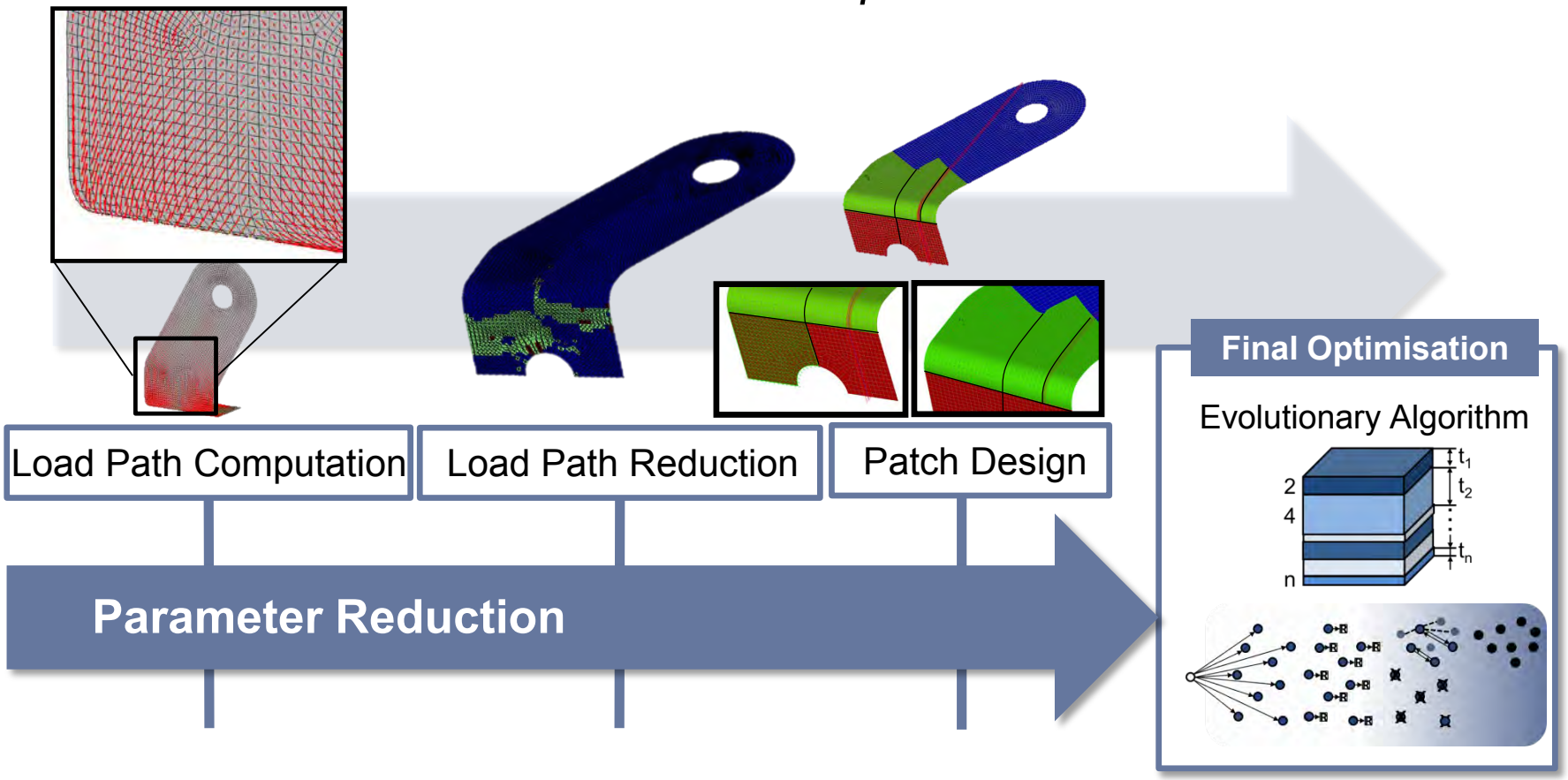
© LEHRSTUHL FÜR KONSTRUKTIONSTECHNIK
Friedrich-Alexander-Universität Erlangen-Nürnberg
Prof. Dr.-Ing. Sandro Wartzack

Simulation-driven Design | mfkCODE

Design of composites structures

mfkCODE

A computational design approach for endless fibre reinforced composite structures

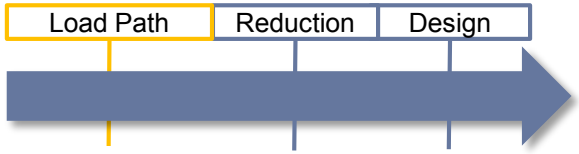


© LEHRSTUHL FÜR KONSTRUKTIONSTECHNIK
Friedrich-Alexander-Universität Erlangen-Nürnberg
Prof. Dr.-Ing. Sandro Wartzack

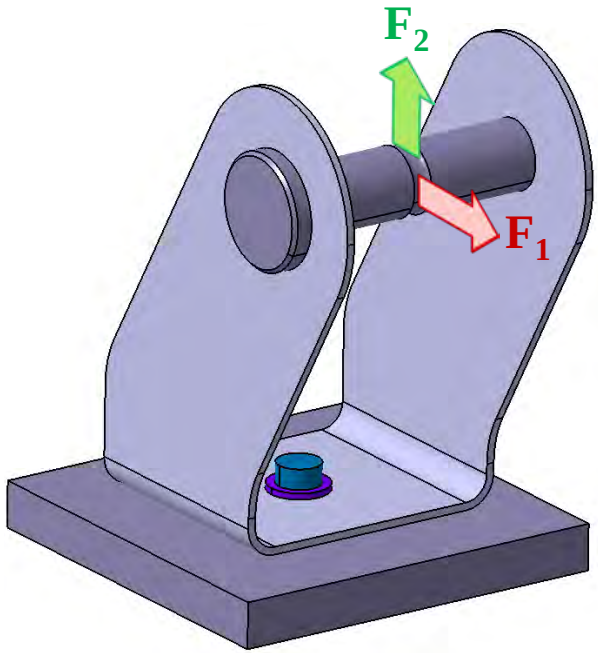
Klein

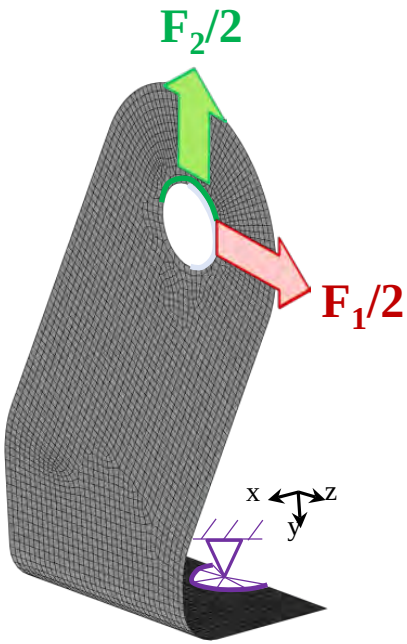
Simulation-driven Design | mfkCODE

Load Path Computation



Demonstrator: Simplified bolt tab





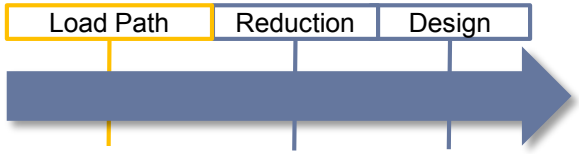
CAD-Model

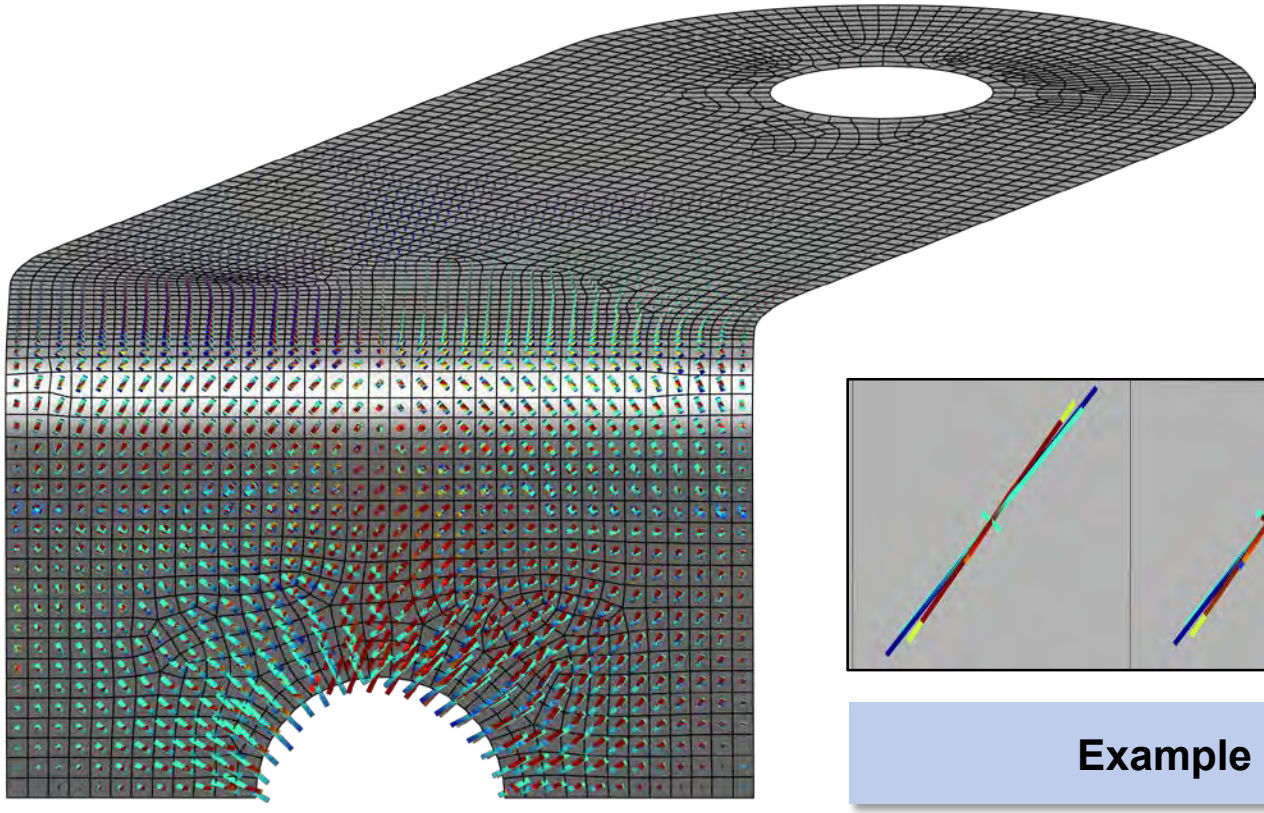
Simlified FE-Model

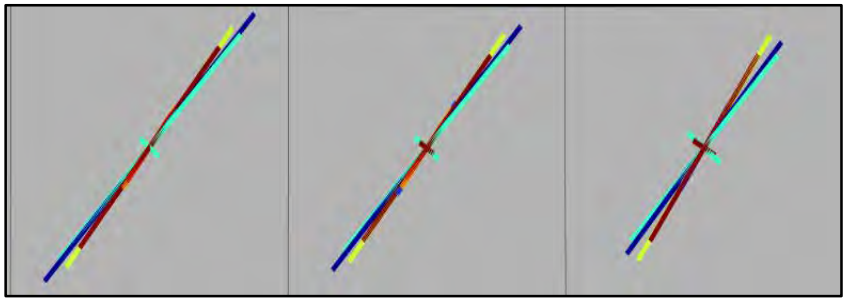
© LEHRSTUHL FÜR KONSTRUKTIONSTECHNIK
Friedrich-Alexander-Universität Erlangen-Nürnberg
Prof. Dr.-Ing. Sandro Wartzack

Simulation-driven Design | mfkCODE

Load Path Computation







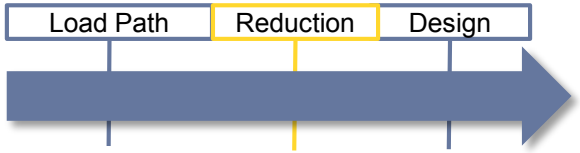
Example Elements

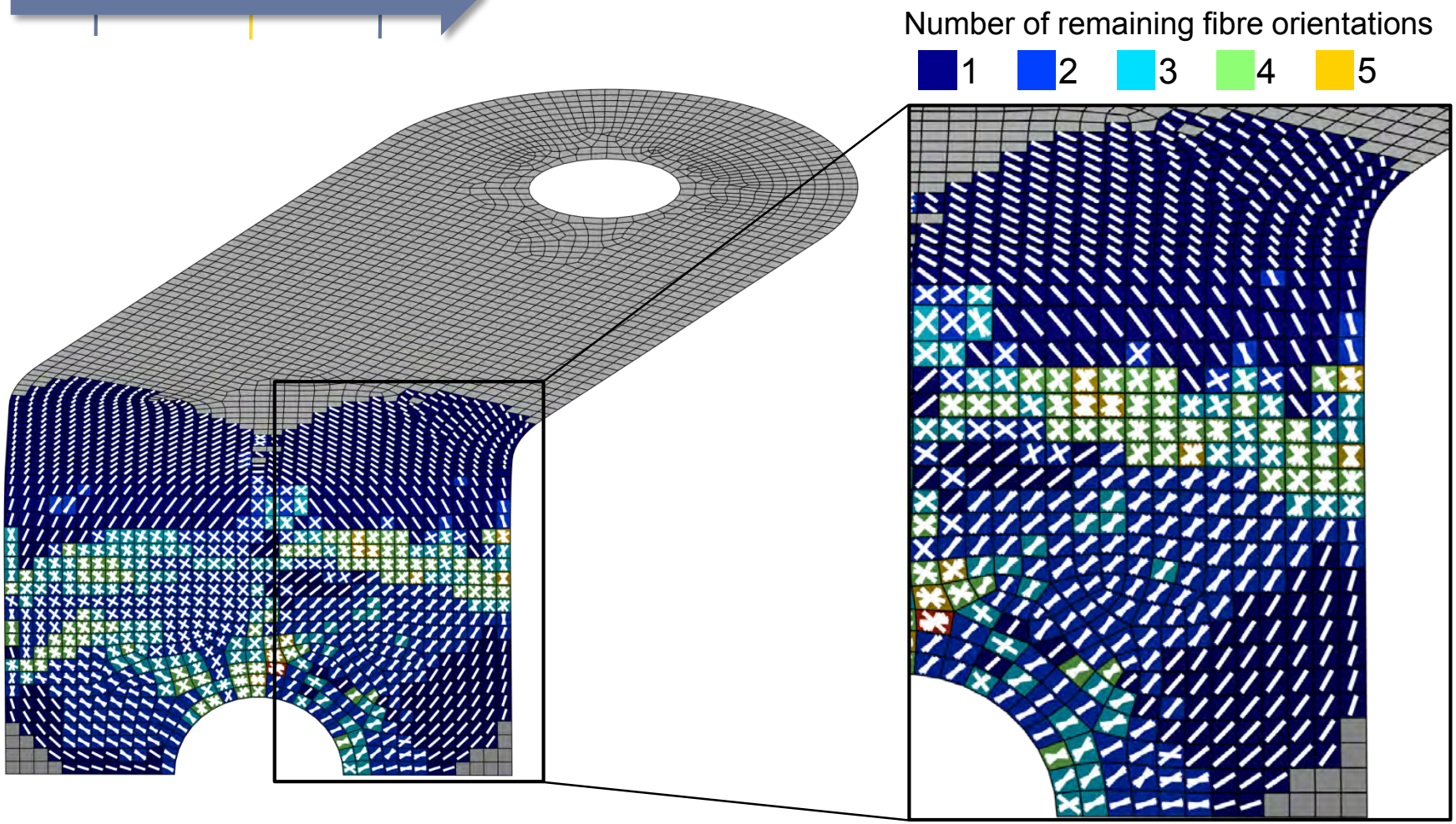
© LEHRSTUHL FÜR KONSTRUKTIONSTECHNIK
Friedrich-Alexander-Universität Erlangen-Nürnberg
Prof. Dr.-Ing. Sandro Wartzack

Klein

Simulation-driven Design | mfkCODE

Load Path Reduction



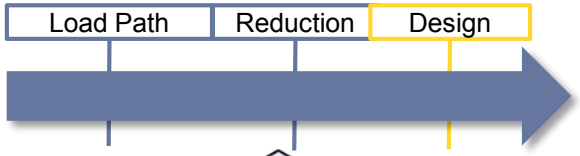


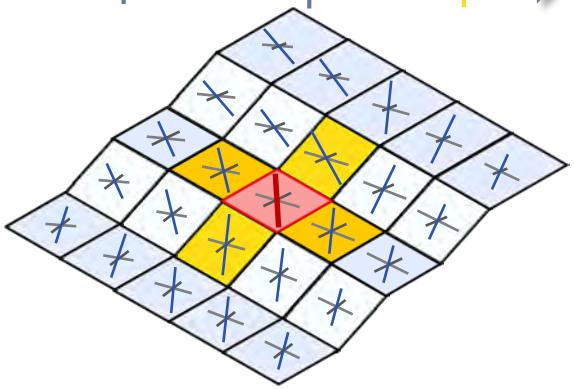
© LEHRSTUHL FÜR KONSTRUKTIONSTECHNIK
Friedrich-Alexander-Universität Erlangen-Nürnberg
Prof. Dr.-Ing. Sandro Wartzack

Klein

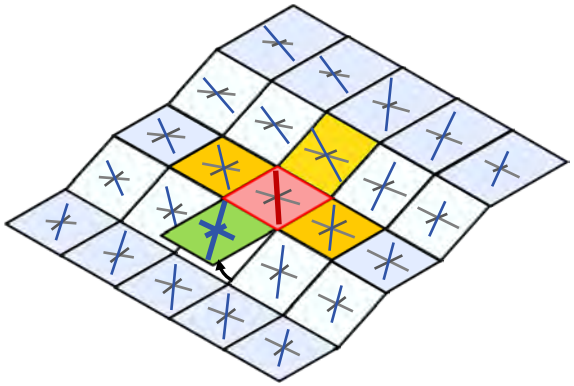
Simulation-driven Design | mfkCODE

Load Path Reduction

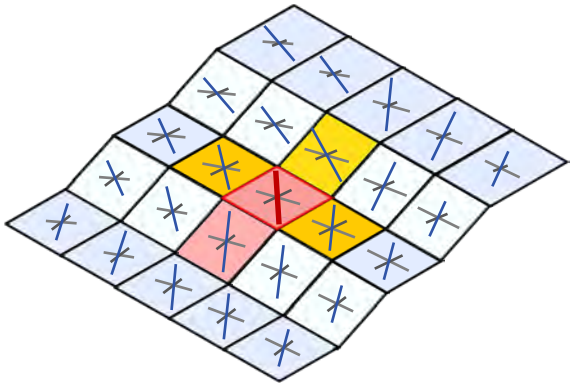




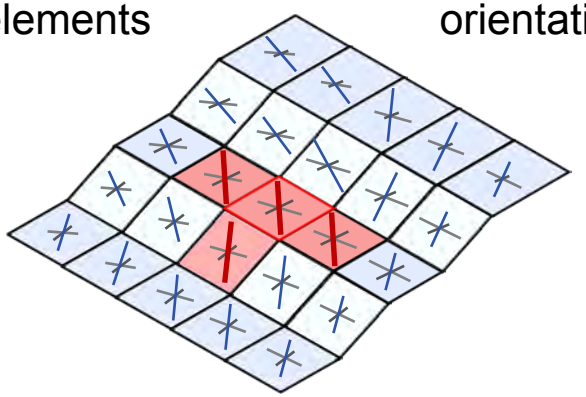
a) Selection of start and neighbour elements



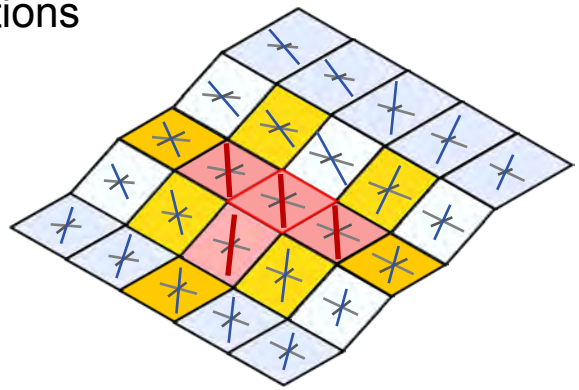
b) Checking fibre orientations



c) Adding to cluster



d) End of iteration

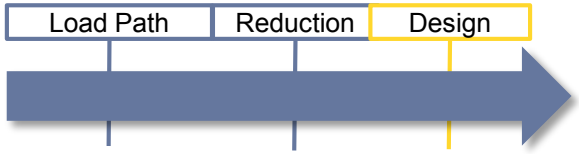


e) Start of next iteration

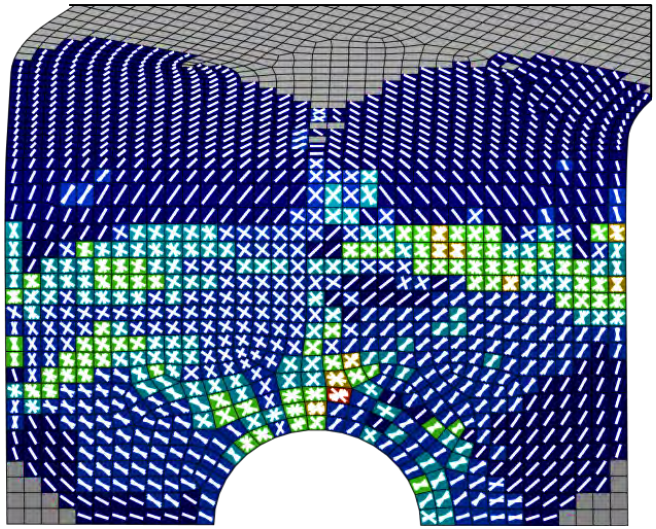
© LEHRSTUHL FÜR KONSTRUKTIONSTECHNIK

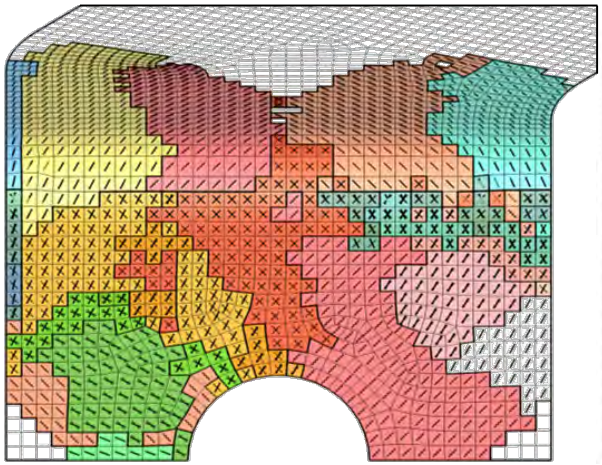
Simulation-driven Design | mfkCODE

Clustering of areas with constant fibre orientation

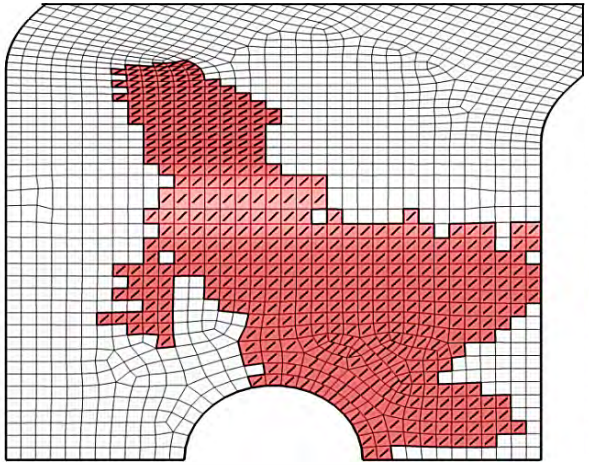


Remaining fibre orientations

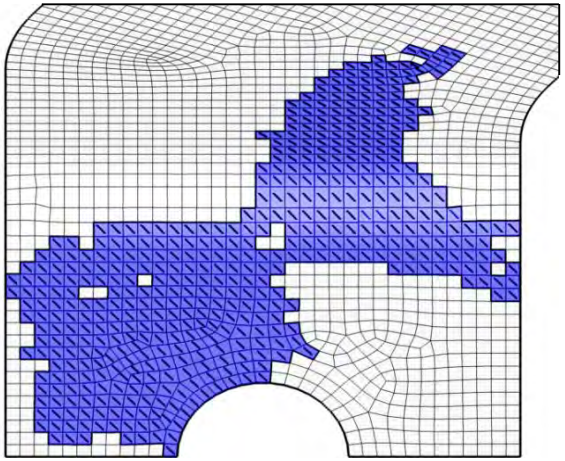




Overlaid clusters



Example cluster 1



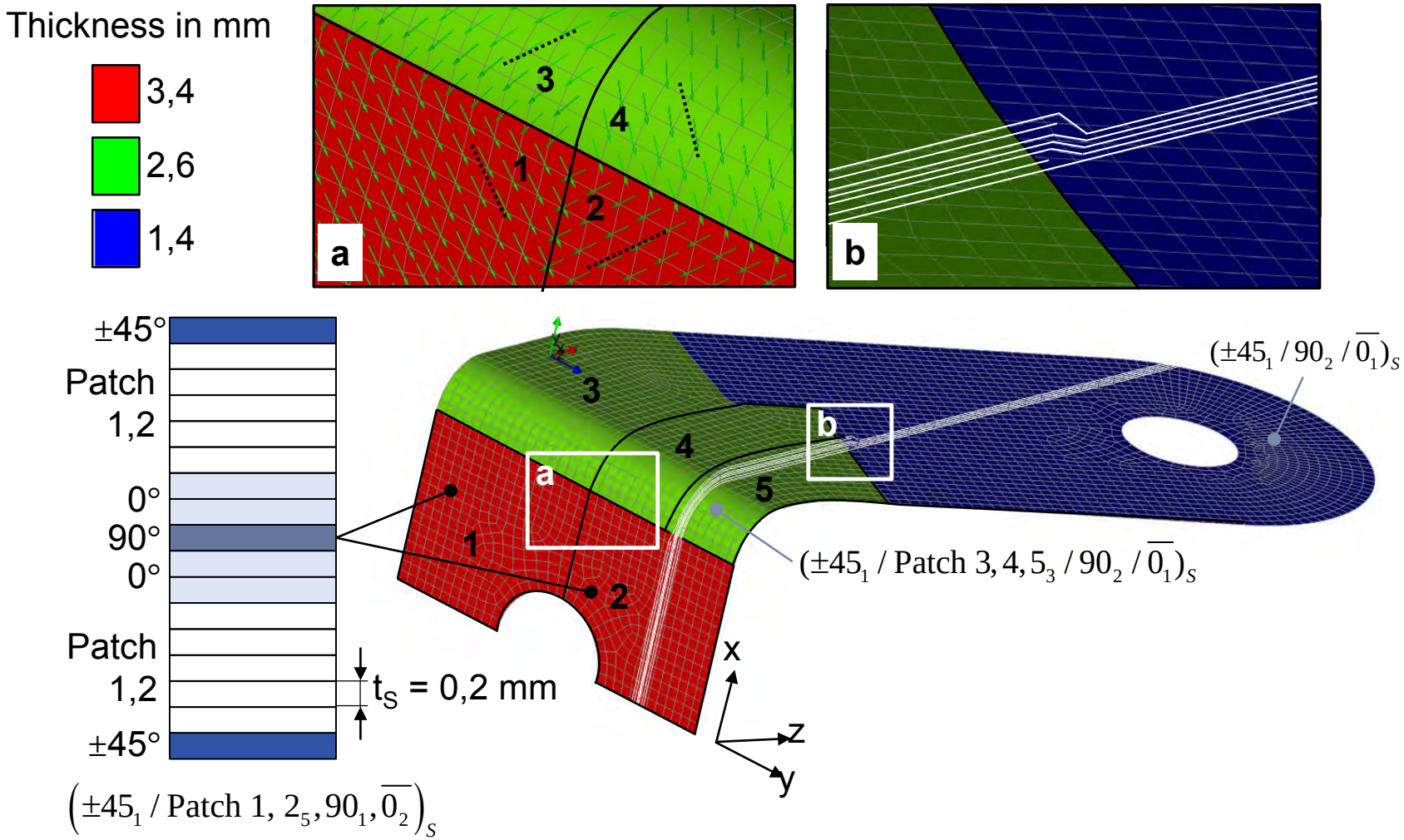
Example cluster 2

© LEHRSTUHL FÜR KONSTRUKTIONSTECHNIK
Friedrich-Alexander-Universität Erlangen-Nürnberg
Prof. Dr.-Ing. Sandro Wartzack

Klein

Simulation-driven Design | mfkCODE

Results after optimisation



© LEHRSTUHL FÜR KONSTRUKTIONSTECHNIK
Friedrich-Alexander-Universität Erlangen-Nürnberg
Prof. Dr.-Ing. Sandro Wartzack

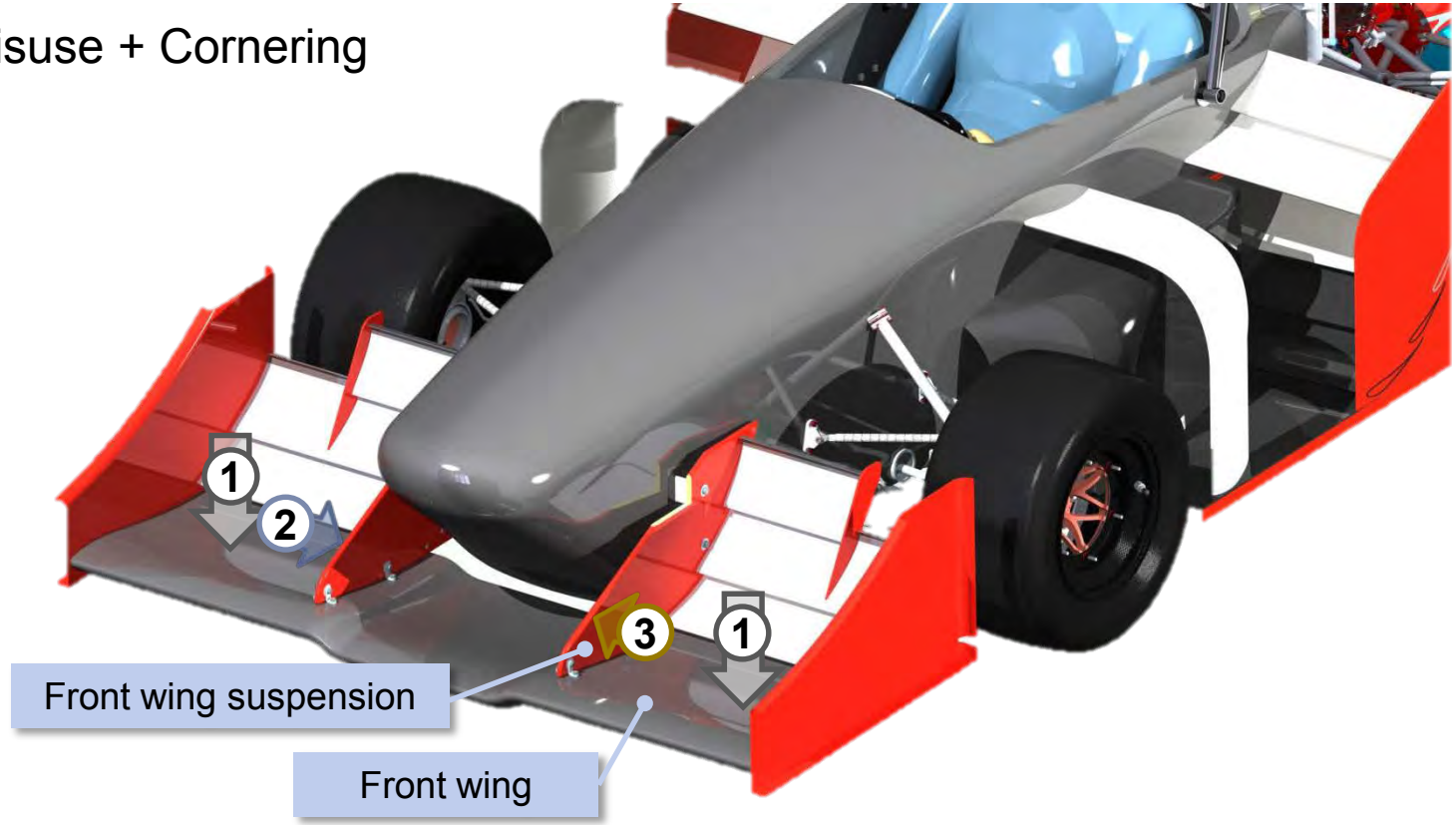
Klein

Simulation-driven Design | mfkCODE

Example: Front wing suspension

① = „Downforce“

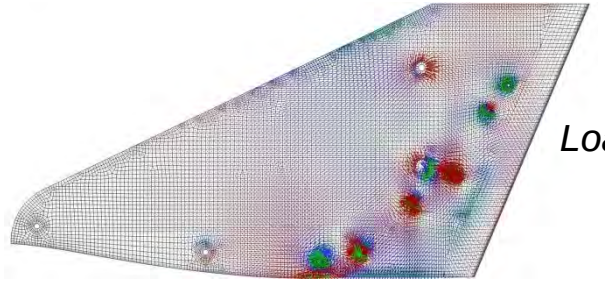
② ③ = Misuse + Cornering



© LEHRSTUHL FÜR KONSTRUKTIONSTECHNIK

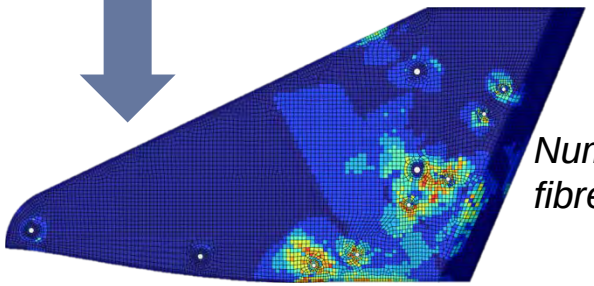
Simulation-driven Design | mfkCODE

Design of endless fibre reinforced FRP structures



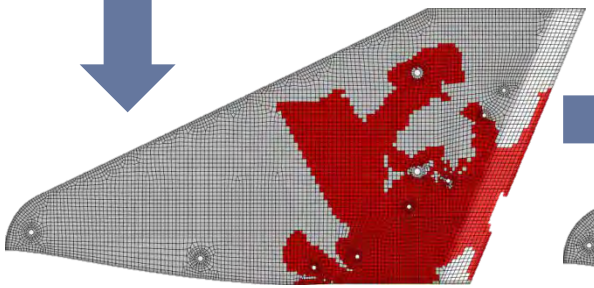
Load Paths

Load Path Computation

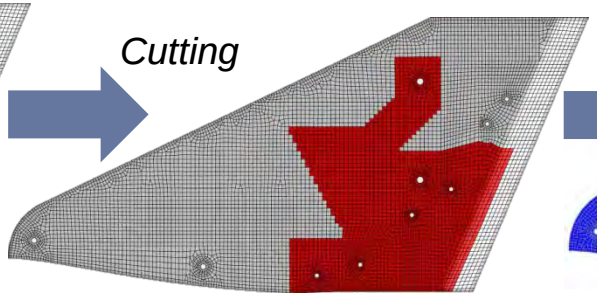


Number of fibre orientations

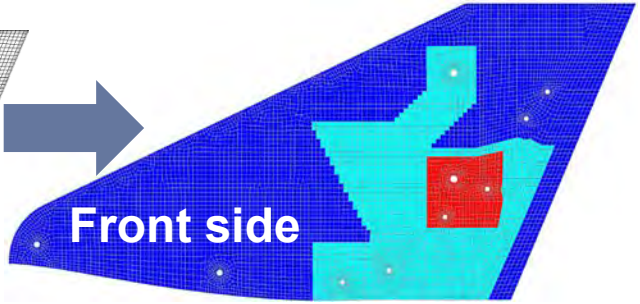
Load Path Reduction



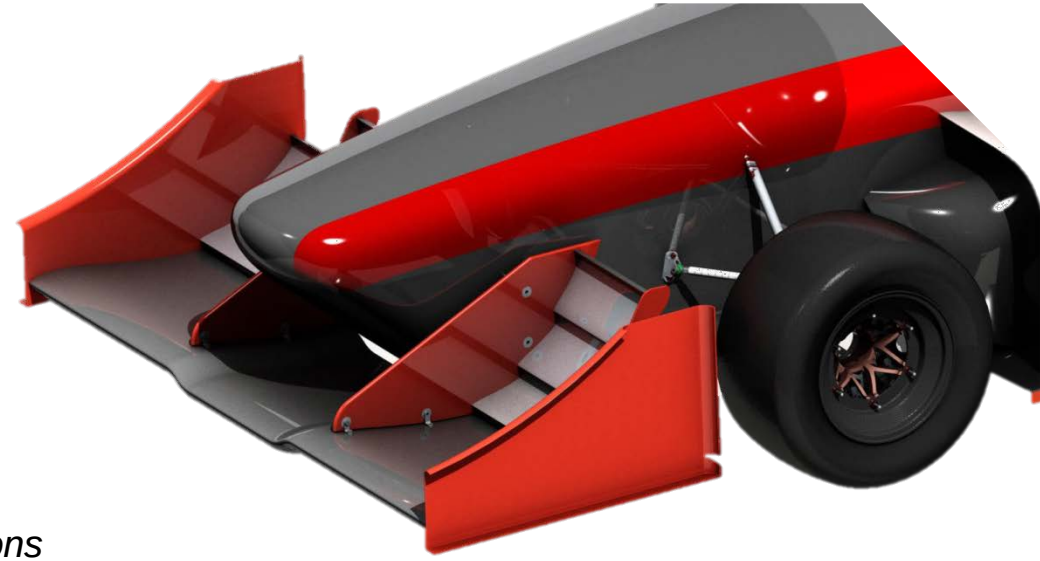
Cutting



Laminate Design



Final Laminate Design

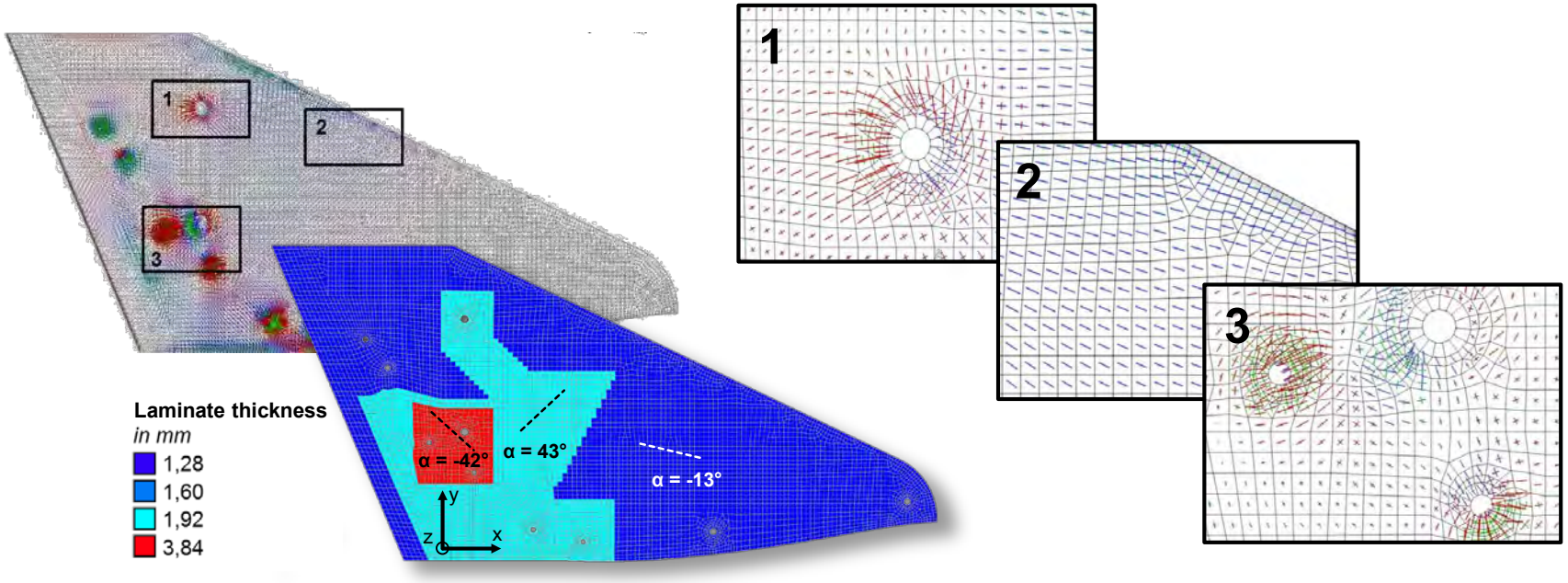


© LEHRSTUHL FÜR KONSTRUKTIONSTECHNIK
Friedrich-Alexander-Universität Erlangen-Nürnberg
Prof. Dr.-Ing. Sandro Wartzack

Klein

Simulation-driven Design | mfkCODE

mfkCODE exploiting high lightweight potential



Parameter	Constraint / Objective	„Flugzeugbau-laminat“		„Kreuzverbund“ (locally reinforced)		*mfk*CODE optimised
Max. displacement (load case 1)	≤ 6 mm	5.55 mm		5.49 mm		5.97 mm
Max. displacement (load case 2 and 3)	≤ 15 mm	11.20 mm		12.38 mm		12.50 mm
Weight	minimum	807 g		500 g		408 g
Weight (without core and inserts)		**703.5 g**	-43 % →	**396.5 g**	-23 % →	**304.5**

© LEHRSTUHL FÜR KONSTRUKTIONSTECHNIK
Friedrich-Alexander-Universität Erlangen-Nürnberg
Prof. Dr.-Ing. Sandro Wartzack

Quelle: Klein, D.; Kieser, C.; Wartzack, S.:.Auslegung von CFK-Strukturen – ein neuer Ansatz. Lightweight Design (5/2016), S. 46-51. Die Originalpublikation ist erhältlich auf springerprofessional.de

Machine Learning ⟷ Virtuelle Produktenwicklung

Anwendungsfall #1:

Endlosfaserverstärkte Thermoplaste

→ Bewertung der Fertigbarkeit von Patches

Anwendungsfall #2:

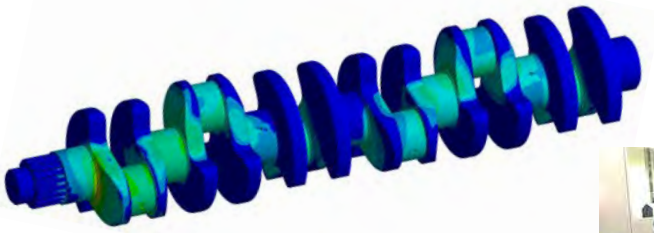
„DNA“ einer FE-Simulation

→ Plausibilitätsprüfung für FE-Simulationen

© LEHRSTUHL FÜR KONSTRUKTIONSTECHNIK
Friedrich-Alexander-Universität Erlangen-Nürnberg
Prof. Dr.-Ing. Sandro Wartzack

Typischer Produktentwicklungsprozess

Motivation



Konzept → CAD-Modell → FE-Absicherung → Versuch →

Konstrukteur

Berechnungs-ingenieur

Versuchs-Ingenieur

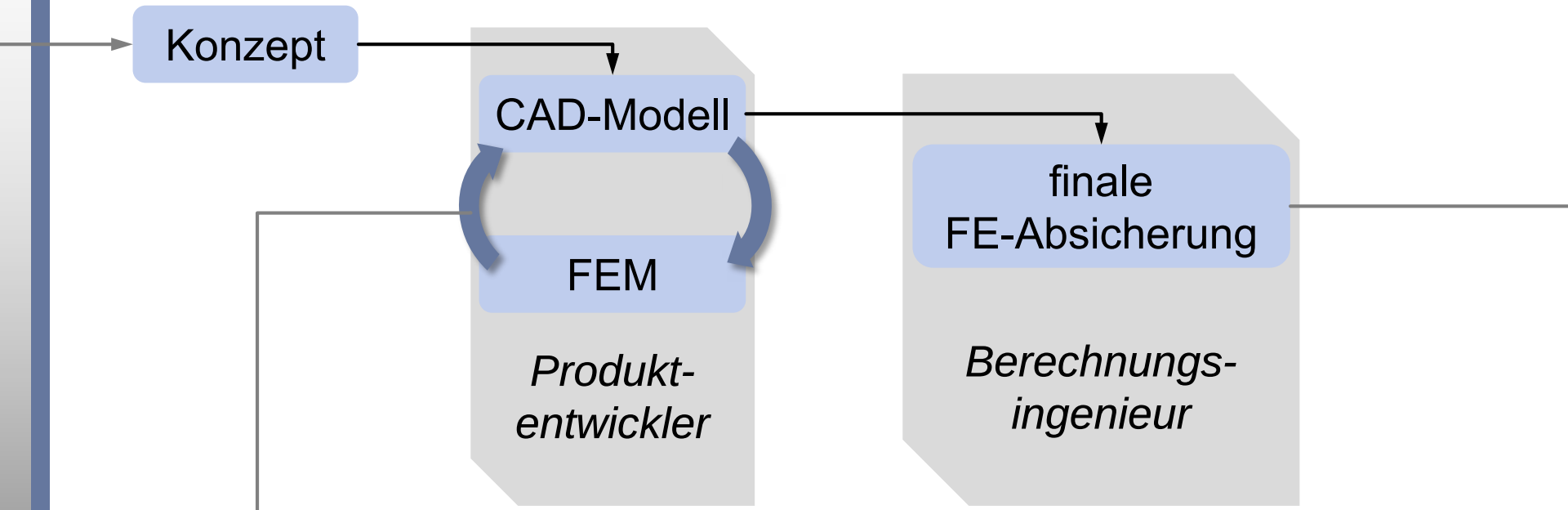
CADFEM:
„Produktsimulation für jeden Ingenieur“

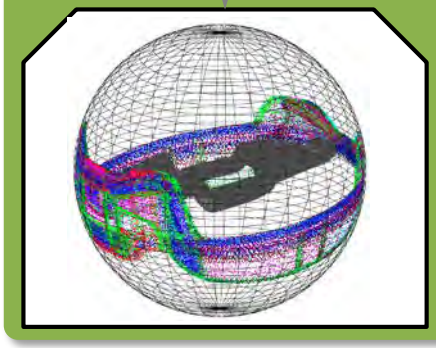
Experis.com:
„Berechnungsingenieure sind gesuchte und wichtige Mitarbeiter“

© LEHRSTUHL FÜR KONSTRUKTIONSTECHNIK
Friedrich-Alexander-Universität Erlangen-Nürnberg
Prof. Dr.-Ing. Sandro Wartzack

Zukünftiger Produktentwicklungsprozess

Motivation



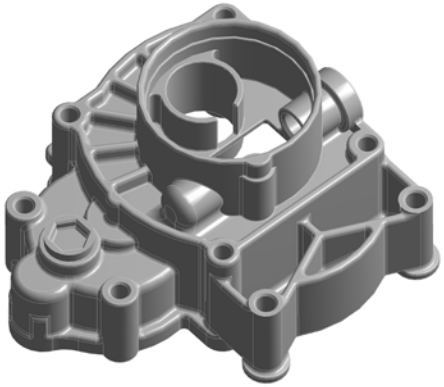


Plausibilitätsprüfung für beliebige FE-Simulationen mittels Deep-Learning
(Nutzung von bereits existierenden Simulationsdatenbeständen)

© LEHRSTUHL FÜR KONSTRUKTIONSTECHNIK
Friedrich-Alexander-Universität Erlangen-Nürnberg
Prof. Dr.-Ing. Sandro Wartzack

Forschungsfrage und Herausforderung

Wie können beliebige Geometrie-Daten[1] einheitlich an Machine-Learning Algorithmen[2] übergeben werden?



1) CAD-Geometrie, Scan-Daten, etc.

2) Künstliche Neuronale Netze, Support Vector Machines, Response Surfaces, etc.

Herausforderung:

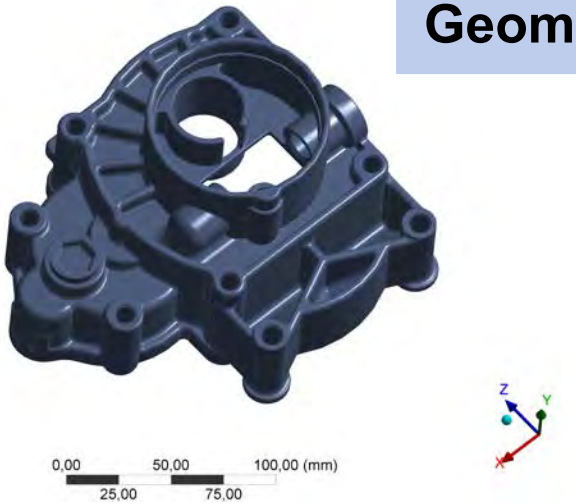
Beliebige Geometrien auf eine fixe Anzahl an Werten reduzieren

(Dimensionsreduktion auf einheitliche Anzahl an Werten)

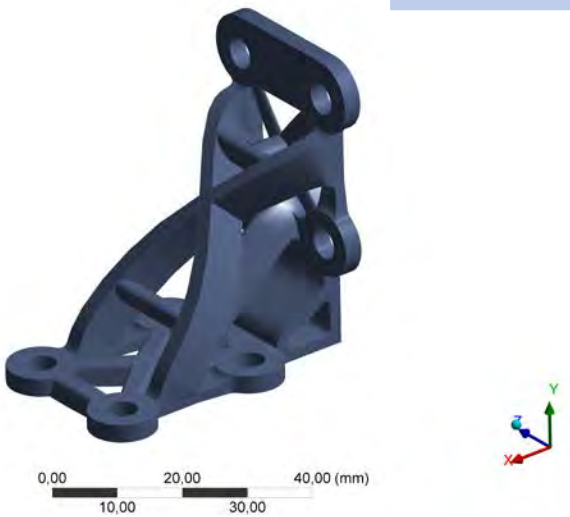
© LEHRSTUHL FÜR KONSTRUKTIONSTECHNIK
Friedrich-Alexander-Universität Erlangen-Nürnberg
Prof. Dr.-Ing. Sandro Wartzack

Forschungsfrage und Herausforderung

Geometrie #1



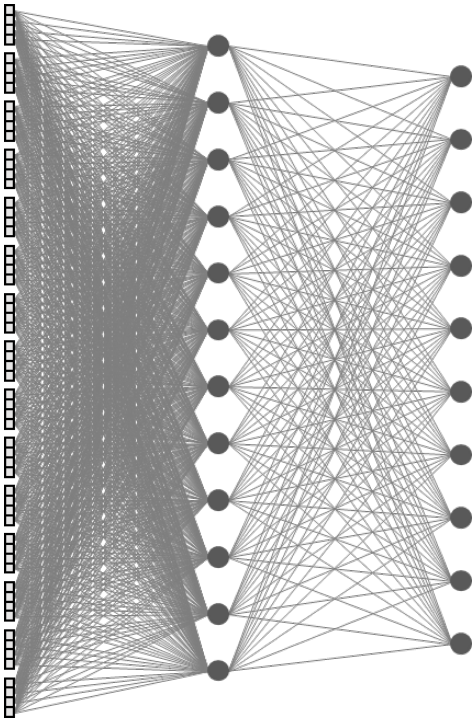
Geometrie #2



?

?

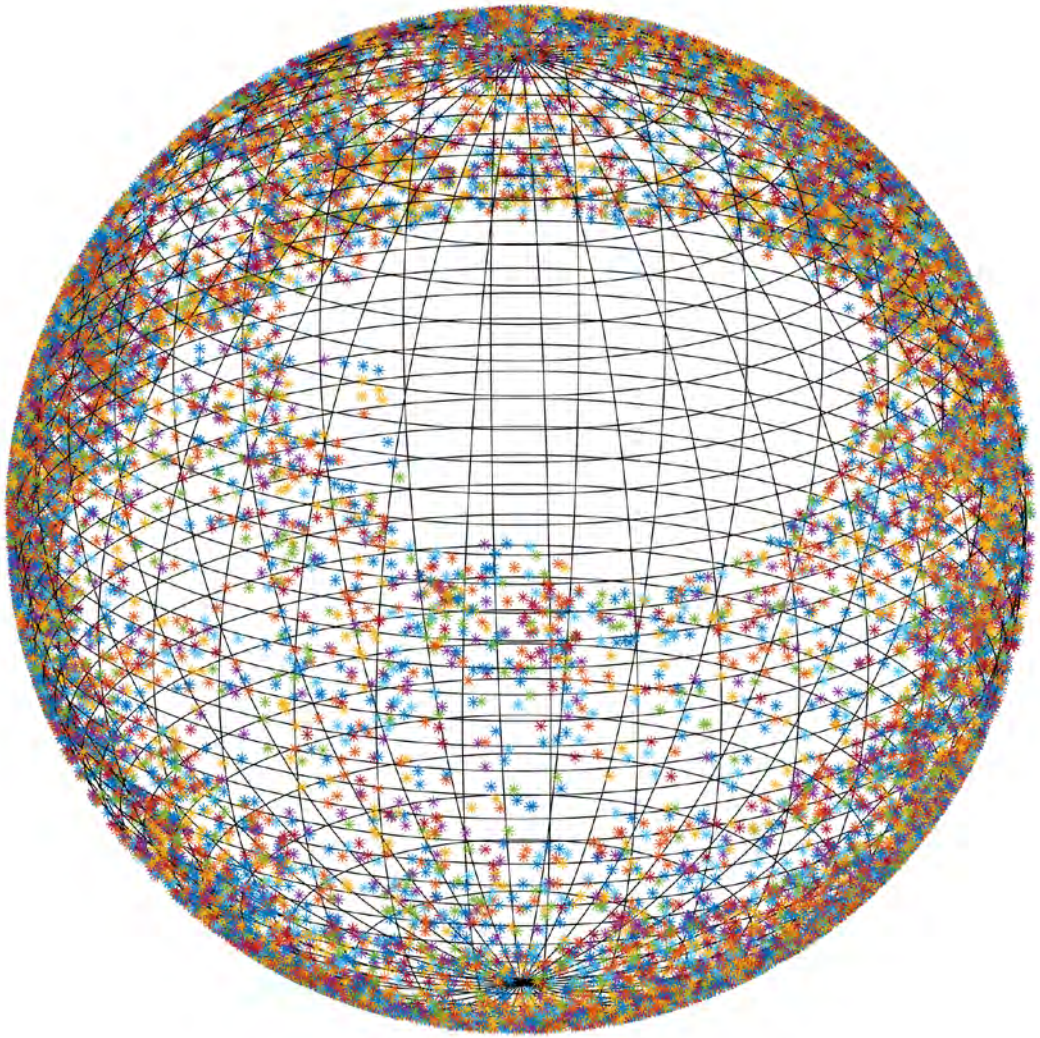
Machine Learning Algorithmus z. B. KNN



© LEHRSTUHL FÜR KONSTRUKTIONSTECHNIK
Friedrich-Alexander-Universität Erlangen-Nürnberg
Prof. Dr.-Ing. Sandro Wartzack

Scientific approach

FE Netz & Sphärische Detektorfläche



FE-Netz

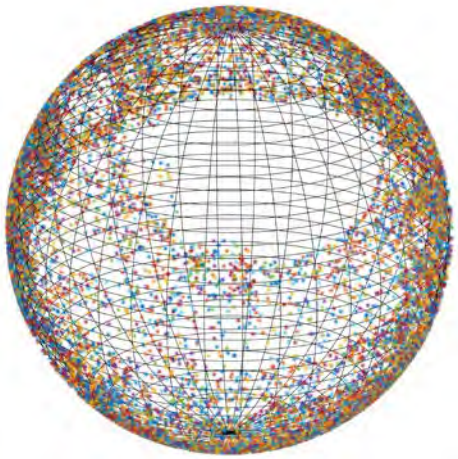
z. B. aus:

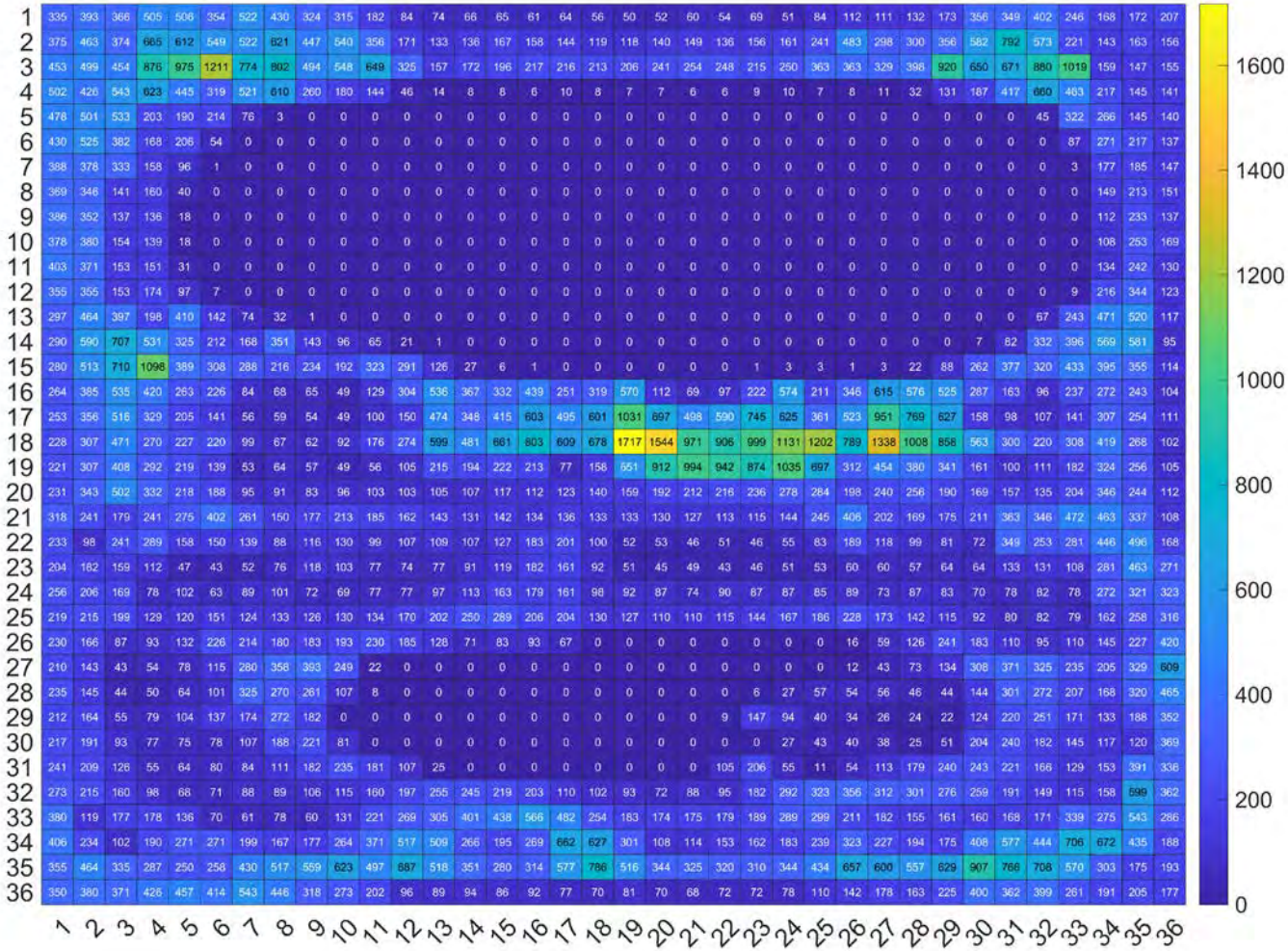
- ANSYS
- Abaqus
- Z88 Aurora
- ...

© LEHRSTUHL FÜR KONSTRUKTIONSTECHNIK
Friedrich-Alexander-Universität Erlangen-Nürnberg
Prof. Dr.-Ing. Sandro Wartzack

Methodik

Detektor Matrix



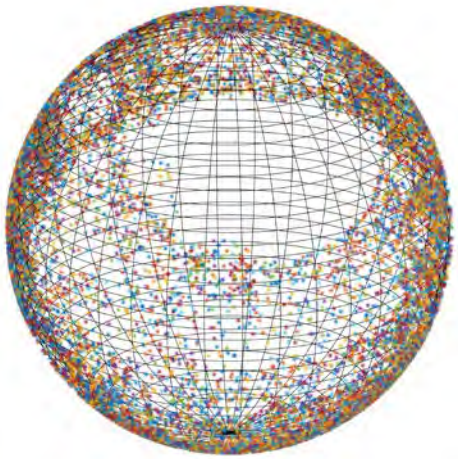


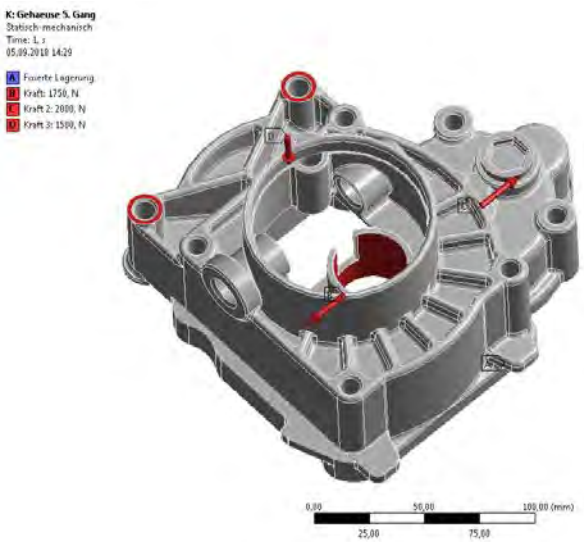
Aus Visualisierungsgründen: Detektormatrix eines anderen Bauteils

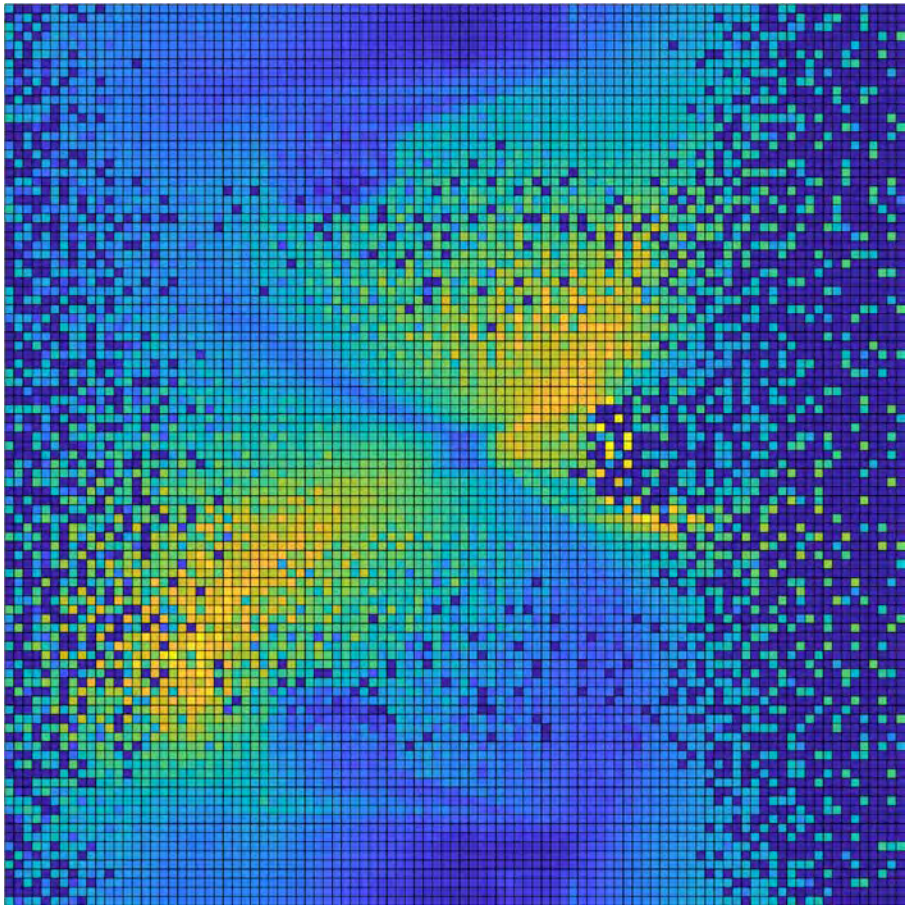
© LEHRSTUHL FÜR KONSTRUKTIONSTECHNIK

Methodik

Erstellung weiterer Matrix für Vergleichsspannung







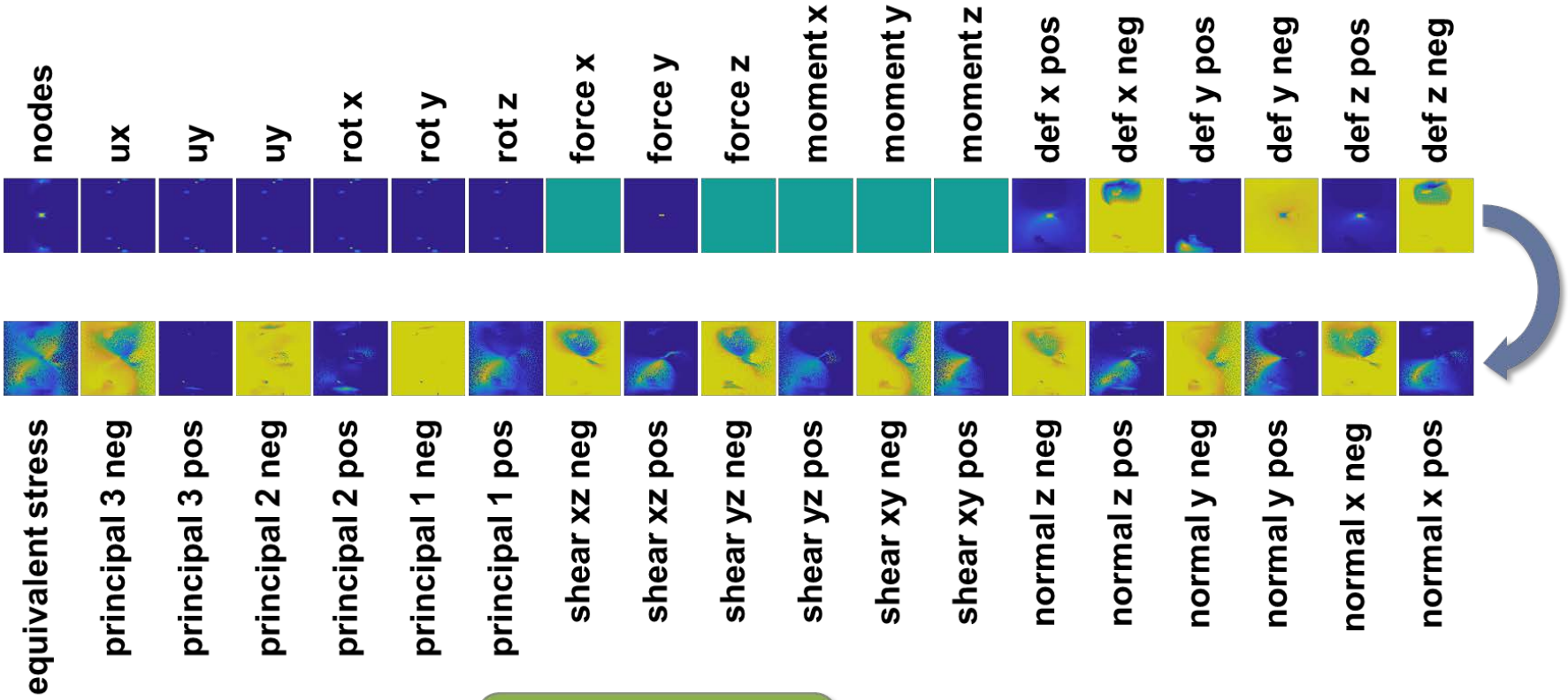
Detektormatrix 100x100 Pixel

für von Mises Vergleichsspannung
Normierung [0 1]

© LEHRSTUHL FÜR KONSTRUKTIONSTECHNIK
Friedrich-Alexander-Universität Erlangen-Nürnberg
Prof. Dr.-Ing. Sandro Wartzack

Methodik

„DNA“ einer FE-Simulation



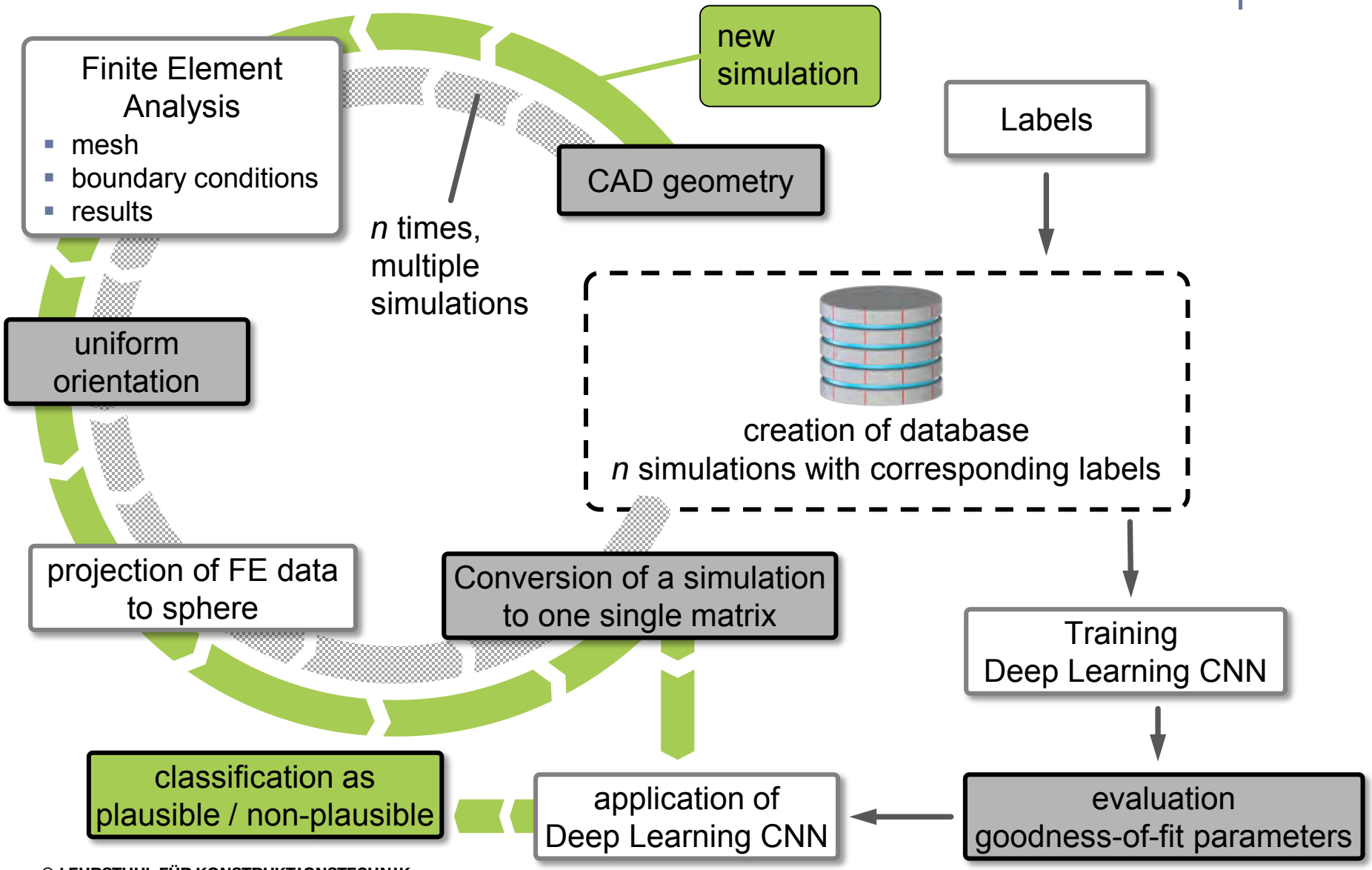
„DNA of FE simulation“

100 x 100 matrices → 100 x 3.800

© LEHRSTUHL FÜR KONSTRUKTIONSTECHNIK
Friedrich-Alexander-Universität Erlangen-Nürnberg
Prof. Dr.-Ing. Sandro Wartzack

Vorgehen

Plausibilitätsprüfung von FE-Berechnungen

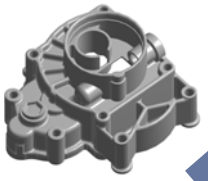


© LEHRSTUHL FÜR KONSTRUKTIONSTECHNIK
Friedrich-Alexander-Universität Erlangen-Nürnberg
Prof. Dr.-Ing. Sandro Wartzack

Plausibilitätsprüfung mit Deep Learning CNN

Zusammenfassung

Methodik

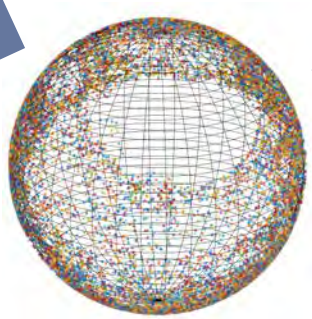


CAD

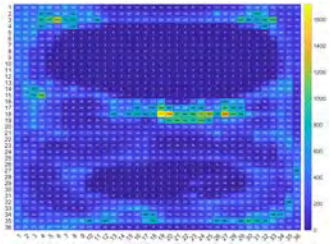
FE Netz

Sphärische Detektorfläche

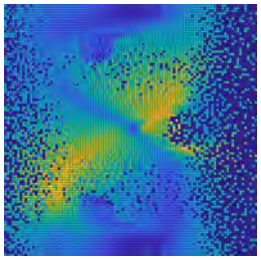
Projizierte Knoten

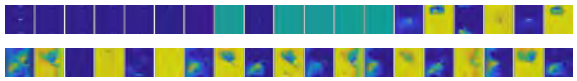


Knoten Matrix

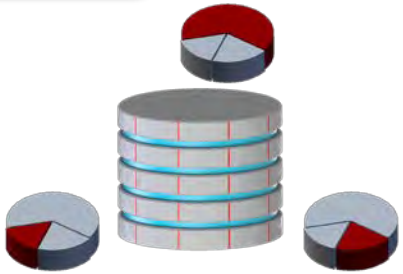


Matrix für versch. Ziel & Eingangs-größen



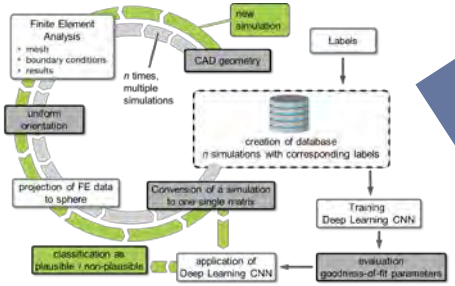


DNA einer FE Simulation



Schaffung Datenbasis

Automatische Plausibilitätsprüfung mit Deep Learning



© LEHRSTUHL FÜR KONSTRUKTIONSTECHNIK
Friedrich-Alexander-Universität Erlangen-Nürnberg
Prof. Dr.-Ing. Sandro Wartzack

Danksagung & Kontakt

The authors would like to thank the NVIDIA Corporation and the academic GPU Grant Program for the donation of a Tesla GPU.

This research work is part of the FAU “Advanced Analytics for Production Optimization” project (E|ASY-Opt) and funded by the Bavarian program for the “Investment for growth and jobs” objective finance by the European Regional Development Fund (ERDF), 2014-2020. It is managed by the Bavarian Ministry of Economic Affairs and Media, Energy and Technology. The authors are responsible for the content of this publication.

European Union
European Regional Development Fund

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
TECHNISCHE FAKULTÄT

© LEHRSTUHL FÜR KONSTRUKTIONSTECHNIK
Friedrich-Alexander-Universität Erlangen-Nürnberg
Prof. Dr.-Ing. Sandro Wartzack

Lehrstuhl für
Konstruktionstechnik
Prof. Dr.-Ing. Sandro Wartzack

TOBIAS SPRUEGEL, M.Sc.
Büroanschrift: Raum 00.028, Paul-Gordan-Straße 5, 91052 Erlangen
Postanschrift: Martensstraße 9, 91058 Erlangen
Tel: +49 (0)9131/85-23658
Fax: +49 (0)9131/85-23223
E-Mail: spruegel@mfk.fau.de
Web: www.mfk.fau.de