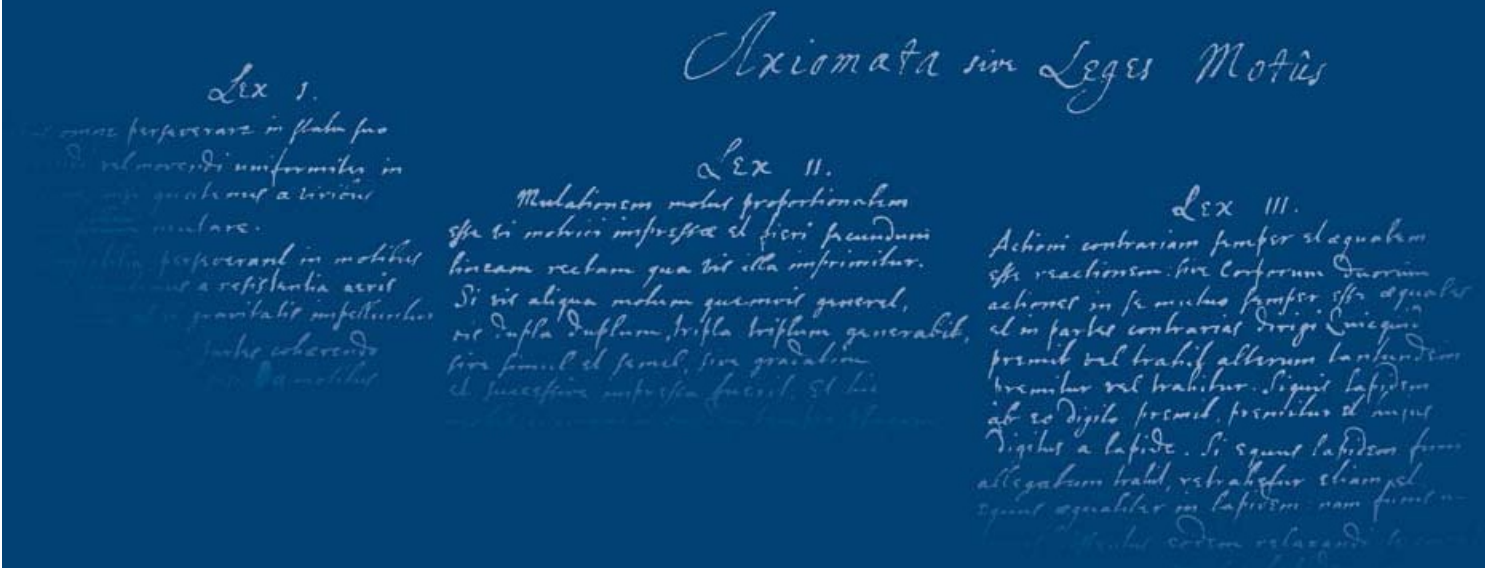
LTM LCM

# Annual Report 2025

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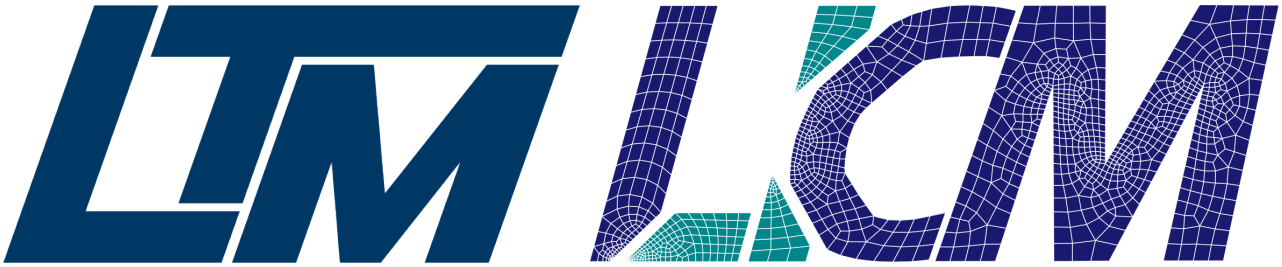

# Annual Report 2025


**Institute of Applied Mechanics**
Prof. Paul Steinmann
Prof. Kai Willner
Prof. Julia Mergheim

—

**Institute of Continuum Mechanics and Biomechanics**
Prof. Silvia Budday

—

FAU Erlangen-Nürnberg

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Paul Steinmann, Kai Willner, Julia Mergheim; Silvia Budday
Institute of Applied Mechanics (https://www.ltm.tf.fau.eu/);
Institute of Continuum Mechanics (https://www.lkm.tf.fau.eu/)
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# Preface

This annual report briefly documents the scientific, teaching, and social activities at the Institute of Applied Mechanics (LTM) and the Institute of Continuum Mechanics and Biomechanics (LKM) at the University of Erlangen-Nürnberg during 2025. At the scientific side the never ending enthusiasm of all members of the institutes did indeed result in exciting research and correspondingly in an internationally recognized output in terms of publications and conference contributions. Likewise the demanding teaching load, e.g. some several thousand written exams that require marking, could only be carried out due to the amazing level of dedication exhibited by all members of the institutes.
Of course all these efforts in turn fully justify team building activities in terms of excursions, barbecues, and various types of parties that characterize the social life at LTM and LKM. In summary we hope that this report convinces the reader of the level of academic achievements at the Institute of Applied Mechanics and the Institute of Continuum Mechanics and Biomechanics during the past year.

Erlangen, December 2025
Paul Steinmann, Kai Willner, Julia Mergheim
Silvia Budday

# Contents


**1 Staff members**

**2 Academic portfolio**

2.1 Graduations and dissertation awards . . . 10
2.2 Teaching and student theses . . . 13
Lectures . . . 13
Teaching awards . . . 14
Student projects and theses . . . 14
Student award . . . 16
LTM juniors – a mentoring program for talented students . . . 16
Ultimate load contest (Traglastwettbewerb) . . . 18
2.3 Seminars . . . 19
Advanced seminar on mechanics . . . 19
LTM/LKM meeting . . . 19
2.4 Science communication and gender equality . . . 20
Girls' Day . . . 20
Mädchen und Technik Praktikum . . . 20
Long Night of Science . . . 21

**3 Scientific contributions**

3.1 Awards and distinctions . . . 23
3.2 Research stays and summer schools . . . 23
3.3 Conferences . . . 25
3.4 Workshops, symposia, seminars, and lectures . . . 33
3.5 Journal articles . . . 35
3.6 Conference proceedings articles . . . 41
3.7 Monographs, books and book chapters . . . 42
3.8 Doctoral theses . . . 43

**4 Ongoing research projects**

**Biomechanics** . . . 45
*Finite element modeling (FEM) to advance extrusion-based 3D bioprinting*
Anahita Ahmadi Soufivand, Sang Jin Lee, Tomasz Jüngst, Silvia Budday . . . 46
*Biomechanical properties and hyperelastic modeling of 3D bioprinted cell-laden hyaluronic acid-based hydrogels during chondrogenesis for cartilage repair*
Jessica Faber, Paula Büttner, Torsten Blunk, Silvia Budday . . . 47
*A micromorphic-based artificial diffusion method for stable finite element approximation of reaction-convection-diffusion problems*
Soheil Firooz, B. Daya Reddy, Vasily Zaburdaev, Paul Steinmann . . . 48
*Modelling Mechanics-Induced Damage of Brain Tissue*
Jaimé Goedhals, Silvia Budday . . . 49
*A constitutive model for multimodal characterization of spinal cord tissue by indentation and large-strain cyclic loading*
Rahul G. Ramachandran, Oskar Neumann, Silvia Budday, Paul Steinmann . . . 50
*Poro-viscoelasticity of human brain tissue: towards robust material parameter identification.*
Alexander Greiner, Ester Comellas, Paul Steinmann, Silvia Budday . . . 51
*In silico modeling of brain malformations*
Jan Hinrichsen, Mohammad Saeed Zarzor, Ingmar Blümcke, Silvia Budday . . . 52
*Multi-scale simulation of bone adaptation*
Annika Karweger, Areti Papastavrou, Peter Pivonka, Paul Steinmann . . . 53
*Real-time visualization of the cellular responses to mechanical loading*
Julia Kolb, Silvia Budday . . . 54
*Material model discovery for human myocardium*
Denisa Martonová, Sigrid Leyendecker, Gerhard A. Holzapfel, Ellen Kuhl . . . 55

*Mechanical characterization of spinal cord tissue*
Oskar Neumann, Rahul Gopalan Ramachandran, Silvia Budday, Paul Steinmann 56
*Regional mechanics of human brain white matter and lower brain stem*
Nina Reiter, Sophia Auer, Lucas Hoffmann, Lars Bräuer, Friedrich Paulsen, Silvia Budday . . . . . 57
*Mechanical characterization and model discovery of the maternal–fetal interface in health and disease*
Malte Rolf, Saverio Gardellin, Gerhard Sommer, Gerhard A. Holzapfel, Christian Wadsack, Ellen Kuhl . . . . . 58
*Mechanical characterization of a brain phantom in the time and frequency domain*
Laura Ruhland, Kai Willner . . . . . 59
*Grid-independent peridynamic quadrature scheme for efficient nonlocal bone remodeling*
Emely Schaller, Ali Javili, Paul Steinmann . . . . . 60
*Challenges in Mechanical Characterization of Brain Organoids.*
Philipp Scherm, Nina Reiter, Michael Tranchina, Sven Falk, Marisa Karow, Silvia Budday . . . . . 61
*Modeling Tumor-induced brain herniation*
Nicole Tueni, Silvia Budday . . . . . 62
*Finite Element Based Direct Inversion for Magnetic Resonance Elastography*
Yashasvi Verma, Luca Heltai, Paul Steinmann . . . . . 63
*A Unified Framework for Validating Computational Models of Human Brain Development*
Mohammad Saeed Zarzor, Qiang Ma, Bernhard Kainz, Silvia Budday . . . . . 64
*Generation of a virtual twin for the human brain accounting for region- and age-dependent properties*
Sahar Zolghadr, Nina Reiter, Jan Hinrichsen, Silvia Budday . . . . . 65

**Material mechanics** . . . . . 66
*Modeling strain rate-dependent hyperelastoplastic adhesive joints under temperature influence*
Vincent Dötschel, Gunnar Possart, Julia Mergheim . . . . . 67
*Data-driven material characterization: Neural Networks, Sparse Regression, and Material Fingerprinting*
Moritz Flaschel, Paul Steinmann, Denisa Martonová, Carina Veil, Trevor Hastie, Laura De Lorenzis, Ellen Kuhl . . . . . 68
*Damage modelling for the simulation of mechanical joining processes*
Johannes Friedlein, Julia Mergheim, Paul Steinmann . . . . . 69
*Automated Model Discovery of tensional homeostasis in living tissues*
Hagen Holthusen, Tim Brepols, Kevin Linka, Ellen Kuhl . . . . . 70
*Improving the Cost of 3D Phase-Field Fracture Simulations*
Paras Kumar, Paul Steinmann . . . . . 71
*On the numerical challenges of rate-independent strain gradient plasticity*
Jose Lara, Paul Steinmann . . . . . 72
*Damage in continuum-kinematics-inspired peridynamics*
Marie Laurien, Ali Javili, Paul Steinmann . . . . . 73
*Experimental investigations of photo-sensitive polymers with polarized light*
Markus Mehnert . . . . . 74
*Soft Cutting Mechanics*
Miguel Angel Moreno-Mateos, Paul Steinmann . . . . . 75
*A cycle jump method for accelerating cyclic loading simulations*
Maxim Rodschei, Gunnar Possart, Paul Steinmann, Julia Mergheim . . . . . 76
*Efficient phase-field fracture simulations for fracture analysis in heterogeneous materials*
Maurice Rohracker, Julia Mergheim . . . . . 77

*Configurational forces in soft materials using the mixed formulation*
Erodita Saliji, Paul Steinmann . . . . . 78
*Configurational forces explain echelon cracks in soft materials*
Angel Santarossa, Miguel Angel Moreno-Mateos, Paul Steinmann . . . . . 79
*Volumetric viscosity - an extension for the Three-Network-Model*
Lars Schmelzle, Gunnar Possart, Julia Mergheim . . . . . 80
*Investigating neural network approaches for accelerating continuum-kinematics-inspired peridynamics simulations*
Aditi Sharma, Ali Javili, Paul Steinmann . . . . . 81
*Generalized mechanical interfaces at finite strains*
Lucie Spannraft, Paul Steinmann, Julia Mergheim . . . . . 82
*Modeling strain hardening in glassy polymers based on the microscopic mechanisms revealed by molecular dynamic simulations*
Wuyang Zhao, Rui Xiao, Sebastian Pfaller, Paul Steinmann . . . . . 83

**Fluid mechanics** . . . . . 84
*A novel data-driven surrogate approach for fast evaluation of the dynamics of soft ellipsoidal micro-particles in dilute viscous flow*
Jana Wedel, Paul Steinmann, Matjaž Hriberšek, Jure Ravnik . . . . . 85

**Multi-scale modeling and simulation** . . . . . 86
*Overcoming hurdles in concurrent discrete-to-continuum coupling*
Lukas Laubert, Sebastian Pfaller . . . . . 87
*Investigation of multiscale fracture mechanisms of thermoplastics using large-scale molecular dynamics simulations reaching up to the microscale*
Eva Maria Richter, Felix Weber, Sebastian Pfaller, Maximilian Ries . . . . . 88
*Reactive coarse-grained molecular dynamics models to capture interphase formation in epoxy-based adhesives*
Maximilian Ries . . . . . 89
*Generating quasi-optimal meshes of virtual elements for heterogeneous bodies: A fully adaptive remeshing procedure*
Daniel van Huyssteen, Paul Steinmann, Felipe Lopez Rivarola, Guillermo Etse . 90
*Validation of fracture simulations with the Capriccio method*
Felix Weber, Maxime Vassaux, Lukas Laubert, Sebastian Pfaller . . . . . 91

**Multi-physics simulation** . . . . . 92
*Pyropiezoelectric energy harvesting using a serial bimorph*
Michael S. Schwarz, Julia Mergheim . . . . . 93
*Experimental and computational characterization of the self-healing behavior in soft shape memory polymer*
Georgino K. Tshikwand, Antonella Caggiano, Ester Comellas, Paul Steinmann . 94

**Optimization and inverse problems** . . . . . 95
*Optimizing remanent magnetization in magnetorheological elastomers under under realistic magnetic actuation*
Chaitanya Dev, Gabriel Stankiewicz, Miguel Angel Moreno-Mateos, Paul Steinmann . . . . . 96
*Topology Optimization of Auxetic Structures for Compliant Mechanism Design*
André Krippner, Gabriel Stankiewicz, Chaitanya Dev, Paul Steinmann . . . . . 97
*A novel multi-thickness 2.5D topology optimization balances structural performance and manufacturability*
Gabriel Stankiewicz, Chaitanya Dev, Paul Steinmann . . . . . 98
*Data-adaptive configurational forces for fracture*
Simon Wiesheier, Miguel Angel Moreno-Mateos, Paul Steinmann . . . . . 99

**Structural dynamics** . . . . . 100
*The Impact of Air Conditions on the Eigenfrequencies of a Violin*
Özge Akar . . . . . 101

**Uncertainty quantification** . . . . . 102

*Adaptive Canonical Polyadic Decomposition for a General Class of Uncertainties*
Dmytro Pivovarov . . . . . 103

**5 Highlights and social activities**
5.1 FRASCAL activities . . . . . 104
FRASCAL RTG Retreat . . . . . 105
Start-up workshop @ ZOLLHOF . . . . . 106
FRASCAL Symposium . . . . . 107
5.2 Capriccio activities . . . . . 108
Conference organisation and participation by the Capriccio group . . . . . 108
Research visits to the Capriccio group . . . . . 110
Capriccio Mini Retreat 2025 . . . . . 112
5.3 Brainiacs activities . . . . . 113
Laboratory reception . . . . . 113
Brainiacs retreat . . . . . 114
5.4 EBM activities . . . . . 115
EBM symposium . . . . . 115
EBM retreat . . . . . 116
5.5 Research Stay at the Nagoya Institute of Technology (NITech) . . . . . 117
5.6 IRTG 2495: Yearly School in Osaka . . . . . 119
5.7 Berg . . . . . 120
5.8 Retreat Kloster Speinshart . . . . . 121
5.9 Summer Party . . . . . 122
5.10 Visiting at QUT . . . . . 123
5.11 GAMM Juniors Fall Meeting . . . . . 124
5.12 ICCB 2025 in Rome . . . . . 125
5.13 Christmas party . . . . . 126

# 1 Staff members

**Professorship Continuum Mechanics**
Prof. Dr.-Ing. habil. Paul Steinmann

**Professorship Continuum Mechanics and Biomechanics**
Prof. Dr.-Ing. Silvia Budday

**Professorship Structural Mechanics**
Prof. Dr.-Ing. habil. Kai Willner

**Working group Computational Mechanics**
Prof. Dr.-Ing. Julia Mergheim

**Visiting Professor**
Prof. Dr.-Ing. Ellen Kuhl


P. Steinmann


S. Budday


K. Willner


J. Mergheim


E. Kuhl

**Assistant and visiting lecturers**
Prof. Dr.-Ing. Ralf Meske, Federal-Mogul Nürnberg GmbH

**Emeritus**
Prof. Dr.-Ing. habil. Günther Kuhn

**Technical and administrative staff**

| | | |
|---|---|---|
| Christian Bänsch | Julia Deserno | |
| Doris Bittner | Simone Schaetzlein | |
| Andrea Dakkouri-Baldauf | Ingrid Weigel | (since 01/03) |


C. Bänsch


D. Bittner


A. Dakkouri


J. Deserno


S. Schaetzlein


I. Weigel

**Post-doctoral researchers**

| | |
|---|---|
| Dr. Moritz Flaschel | |
| Rahul Gopalan Ramachandran, Ph.D. | |
| Dr.-Ing. Hagen Holthusen | (since 01/05) |
| Dr.-Ing. Paras Kumar | (until 31/12) |
| Dr. Sonja Kuth | (until 31/01) |
| Dr.-Ing. Denisa Martonová | (since 01/01) |
| Dr.-Ing. Markus Mehnert | |
| Dr. Miguel Ángel Moreno-Mateos | |
| PD Dr.-Ing. habil. Sebastian Pfaller | |
| Dr.-Ing. Dmytro Pivovarov | |
| Dr.-Ing. Dipl.-Math. techn. Gunnar Possart | |
| Dr.-Ing. Maximilian Ries | |
| Dr. Malte Rolf | (since 01/03) |
| Erodita Saliji, Ph.D. | |
| Dr. Ángel Santarossa | (until 31/12) |
| Dr.-Ing. Dominic Soldner | (until 28/02) |
| Dr.-Ing. Gabriel Stankiewicz | |
| Dr. Georgino Kaleng Tshikwand | |
| Daniel van Huyssteen, Ph.D. | |
| Dr.-Ing. Wuyang Zhao | |

**Doctoral researchers**

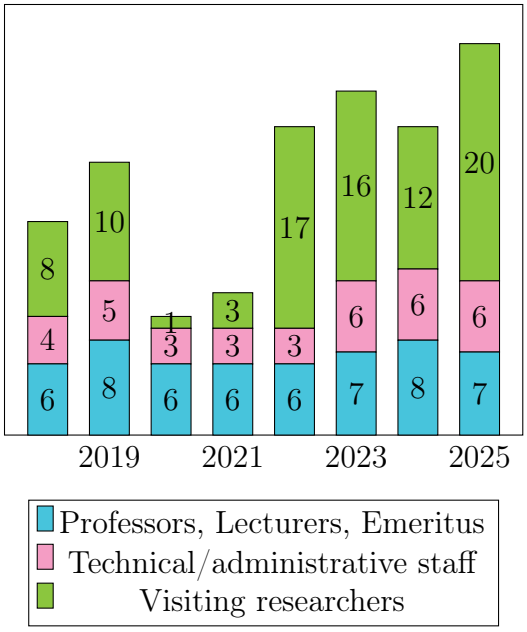
| | |
|---|---|
| Özge Akar, M.Sc. | |
| Chaitanya Dev, M.Sc. | |
| Vincent Doetschel, M.Sc. | (since 01/08) |
| Soheil Firooz, M.Sc. | |
| Johannes Friedlein, M.Sc. | |
| Annika Karweger, M.Sc. | (since 15/05) |
| André Krippner, M.Sc. | (since 01/04) |
| Jose Lara, M.Sc. | |
| Lukas Laubert, M.Sc. | |
| Marie Laurien, M.Sc. | (until 30/09) |
| Michael Lengger, M.Sc. | |
| Eva Maria Richter, M.Sc. | (since 01/01) |
| Maxim Rodschei, M.Sc. | |
| Maurice Rohracker, M.Sc. | |
| Laura Ruhland, M.Sc. | |
| Emely Schaller, M.Sc. | (until 30/09) |
| Lars Schmelzle, M.Sc. | |
| Michael Schwarz, M.Sc. | |
| Jakob Seibert, M.Sc. | (since 01/09) |
| Aditi Sharma, M.Sc. | (since 01/06) |
| Lucie Spannraft, M.Sc. | |
| Yashasvi Verma, M.Sc. | |

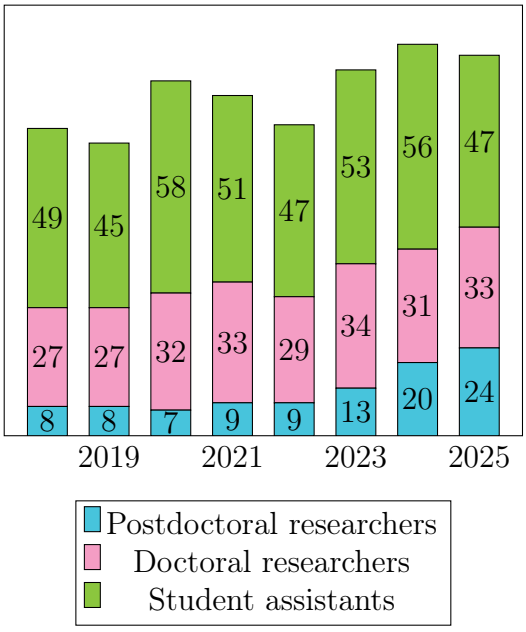
Felix Weber, M.Sc.
Jana Wedel, M.Sc.
Simon Wiesheier, M.Sc.

**Post-doctoral researchers**
Dr. Anahita Ahmadi Soufivand
Dr. rer. nat. Julia Kolb
Nicole Tueni, Ph.D.
Dr.-Ing. Mohammad Saeed Zarzor

**Doctoral researchers**
Jessica Faber, M.Sc., M.Sc.
Jamié Goedhals, M.Sc.
Alexander Greiner, M.Sc.
Jan Hinrichsen, M.Sc.
Oskar Neumann, M.Sc.
Nina Reiter, M.Sc.
Philipp Scherm, M.Sc.
Sahar Zolghadr, M.Sc. (since 01/06)

**Statistics of staff members, student assistants and guests 2018–2025**




The statistics covering the staff over the last years show a general increase in members because of our many research projects. Our institutes hosted a pronounced number of (inter)national guests except during the Covid pandemic.


A. Ahmadi Soufivand


Ö. Akar


C. Dev


V. Dötschel


J. Faber


S. Firooz


M. Flaschel


J. Friedlein


J. Goedhals


R. G. Ramachandran


A. Greiner


J. Hinrichsen


H. Holthusen


A. Karweger


J. Kolb


A. Krippner



P. Kumar



J. Lara



L. Laubert



M. Laurien



M. Lengger



D. Martonová



M. Mehnert



M.A. Moreno-Mateos



O. Neumann



S. Pfaller



D. Pivovarov



G. Possart



N. Reiter



E.M. Richter



M. Ries



M. Rodschei


M. Rohracker


M. Rolf


L. Ruhland


E. Saliji


Á. Santarossa


E. Schaller


P. Scherm


L. Schmelzle


M. Schwarz


J. Seibert


A. Sharma


D. Soldner


L. Spannraft


G. Stankiewicz


G.K. Tshikwand


N. Tueni



D. van Huyssteen



Y. Verma



F. Weber



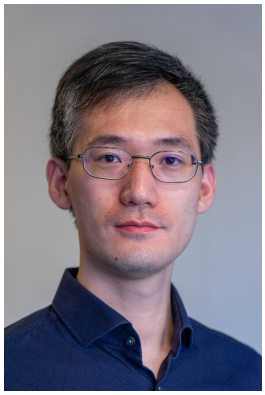
J. Wedel



S. Wiesheier



M.S. Zarzor



W. Zhao



S. Zolghadr

### Commissary

| | |
|---|---|
| Industrial contact | G. Possart |
| Safety commissary | S. Pfaller |
| IT security commissary | C. Bänsch |
| IT administrator assistants | J. Hinrichsen, M. Ries |
| Editor of annual report | L. Spannraft |
| First Aid | Ö. Akar, C. Dev, S. Firooz, M. Laurien, J. Mergheim, D. Pivovarov, E. Schaller, L. Schmelzle, D. Soldner, F. Weber |

### Academics

| | |
|---|---|
| Exam organization | G. Possart |
| Teaching coordination | M. Ries |
| StudOn manager | M. Lengger |
| Teaching experiments contact | M. Ries, L. Spannraft, S. Pfaller |
| Mentors of LTM juniors | Ö. Akar, M. Ries, L. Spannraft |
| TM1 Ultimate Load Contest | M. Mehnert, P. Steinmann, assisted by M. Ries, L. Spannraft |

### Science communication

| | |
|---|---|
| Girls' day/Schülertag | J. Hinrichsen, L. Ruhland |
| Mädchen und Technik Praktikum | L. Laubert, M. Laurien, E.M. Richter, E. Schaller, L. Spannraft |
| Long Night of Science | Capriccio, FRASCAL, EBM members |

### Seminars (organization)

| | |
|---|---|
| Advanced seminar on mechanics | G. Possart |
| LTM/LKM meeting | P. Steinmann |
| LTM/LKM TOPZ | Y. Verma |

### Contributions to social life at LTM and LKM

| | |
|---|---|
| Beverages commissary | J. Faber |
| Chocolate commissary | L. Schmelzle |
| Coffee commissary | Ö. Akar |
| Graduation hatter | M. Schwarz, F. Weber |
| Treasurer for graduation hats | L. Ruhland |
| Organization of trip to Berg | M. Rohracker |
| Organization of mid-year event | M. Rohracker |
| Organization of year-end event | Staff starting at LTM/LKM in 2025 |
| Designer of Christmas card | A. Sharma |
| LTM/LKM band | D. Budday, J. Deserno, S. Firooz, A. Greiner, L. Laubert, E.M. Richter, G. Stankiewicz |

**Visiting researchers and students**

**@ LTM:**

Prof. Wolfgang Bangerth, Colorado State University, USA: 04–05/09/2025
Prof. Tristan Baumberger, Université Paris Cité, France: 19–20/11/2025
Prof. Eran Bouchbinder, Weizmann Institute of Science, Israel: 08–09/12/2025
Prof. Laura de Lorenzis, ETH Zürich, Switzerland: 13–15/07/2025
Mathis Nelson Yann Demeillat, ENSICAEN, France: 23/06–01/08/2025
Prof. Fabrice Detrez, Université Gustave Eiffel, Marne-la-Vallée, France: 14–17/07/2025
Prof. Matjaž Hriberšek, Universität Maribor, Slovenia: 03–07/02, 16–20/06, 08–12/12/2025
Prof. Mahmood Jabareen, Technion, Haifa, Israel: 16/09/2025
Moussa Lamamra, Université Gustave Eiffel, Marne-la-Vallée, France: 01–30/06/2025
Prof. Saulo Martelli, Queensland University of Technology, Australia: 31/03–04/04/2025
Prof. Peter Pivonka, Queensland University of Technology, Australia: 02–04/07/2025
Prof. Jure Ravnik, Universität Maribor, Slovenia: 03–07/02, 16–20/06, 08–12/12/2025
Jolan Paul Thierry, Université de Rennes, France: 12/05–12/07/2025
Dr. Maxime Vassaux, Institut de physique de Rennes, France: 26–30/05/2025
Yuya Watanabe, Nagoya Institute of Technology, Japan: 01/09/2024–26/02/2025

**@ LKM:**

Dr. Ester Comellas, Universitat Politècnica de Catalunya, Spain: 16–20/06/2025
Prof. Barbara Röhrnbauer, ZHAW Zürich, Switzerland: 19–23/05, 21–24/10/2025
PhD Majahonkhe Mcebo Shabangu, University of Cape Town, South Africa: 29/09–28/11/2025
Prof. Xianqiao Wang, University of Georgia: 21–23/05/2025
Prof. Johannes Weickenmeier, Oxford University, UK: 18–20/05/2025

**Student assistants**

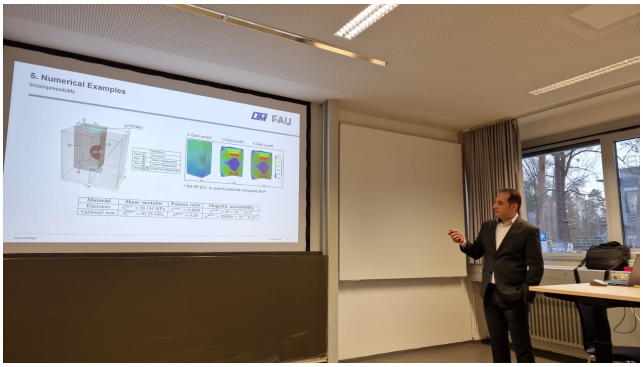
Atharva, Sinnarkar
Azsari, Tahircan
Bicer, Emine Deniz
Boltyschew, Elisabeth
Chaitali, Patil
Chowdhry, Haren
Daub, Lieselotte
Doddbele Aswatha Narayana, Divyashree
Drexler, Simon
Hamed, Abdulrahman
Heinrich, Philipp
Jochmann, Maalon
Kalliana Raman, Subramania Sharma
Kashish Veda, Eluri
Kharel, Sambhav
Khorsandi, Erfan
Klitzen, Alexander
Krämer, Adrian
Krowiak, Martin
Lang, Johannes
Losert, Maximilian
Michael, Miji
Middelberg, Edwige
Murner, Franziska
Poojary, Saurabh
Ramesh, Rathan
Rauch, Charlotte
Reemoh, Geeta
Roksvaag, Johannes
Roy, Sohini
Satwik Reddy, Madyarla
Schmidt, Michael
Schoppe, Chiara
Selveroglu, Alperen
Setayesh, Ardalan
Shastry, Aniruddha
Shi, Zhe
Shinde, Sarthak Ajit
Skontnica, Maximilian
Surana, Harsh Vardhan
Tiefenthäler, Jonas
van de Goor, Joshua
Vennilavan Thenmozhi, Hariramkumar
Weißkopf, Dan
Zanjani, Elmira
Zare, Kimia
Ziegler, Marlene

# 2 Academic portfolio

## 2.1 Graduations and dissertation awards

(Lucie Spannraft) We are happy to announce that 5 staff members have successfully finished their dissertation projects in the year 2025 and that several theses were awarded.

On January 23, **Dr.-Ing. Reza Zabihyan** defended his dissertation project by giving a talk on 'Modeling and Computational Homogenization of Magnetorheological Composite Materials'. The dissertation project has been supervised by Professor Paul Steinmann and Professor Julia Mergheim.






*Reza Zabihyan giving his presentation (left) and wearing the custom-made graduation hat capturing his most memorable moments at LTM (right).*

On May 19, **Dr.-Ing. Mohammad Saeed Zarzor** earned a doctoral degree after defending his thesis titled 'Multifield Modelling of Human Brain Development: From Cells to Organ'. The dissertation project has been supervised by Professor Silvia Budday.





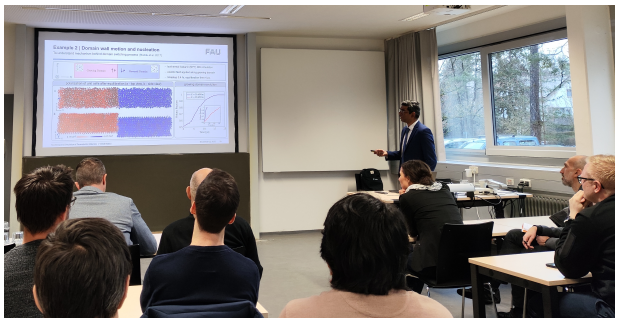

*Mohammad Saeed Zarzor during the defense (left top), with the committee announcing his success (left bottom), and trying on his graduation cap (right).*

On December 2, **Dr.-Ing. Benjamin Söhngen** presented his dissertation titled 'Untersuchungen zur effizienten Parameteridentifikation eines Materialmodells der finiten Inelastizität'. The project has been supervised by Professor Kai Willner.



*The custom hat.*

On December 3, **Dr.-Ing. Vishal Boddu** successfully defended his dissertation titled 'Modeling and Simulation of Ferroelectric Materials at Multiple Length Scales'. The project has been supervised by Professor Paul Steinmann.







*Vishal Boddu during his presentation (left top). The committee congratulating (left bottom). Vishal explaining his graduation cap (right).*

On December 12, **Dr.-Ing. Jana Wedel** defended her thesis 'Dancing with the flow: Numerical modelling of non-ideal micro-particles in fluids'. The dissertation project has been supervised by Professor Paul Steinmann and has been conducted in close cooperation with Professors Matjaž Hriberšek and Jure Ravnik from University of Maribor, Solvenia. The project included prolonged stays in Maribor.

**Dr. Malte Rolf** received two prizes for his outstanding dissertation titled 'Material and computational modeling of aortic dissection'. The project has been supervised by Prof. Gerhard A. Holzapfel. Dr. Malte Rolf received the Best PhD Thesis Award 2025 ('Förderpreis'), 2nd, *Forum für Technik und Gesellschaft* (alumniTUGraz 1887) for dissertations with particular social relevance. The award was presented at Graz University of Technology in Graz, Austria on June 25, 2025. He was further awarded Best PhD Thesis Award 2024, Central European Association of Computational Mechanics (CEACM) at the conference 'ECCOMAS MSF 2025 – VI International Conference on Computational Methods for Solids and Fluids' taking place in Split, Croatia, from June 25 – 27, 2025.




*Award ceremony in Graz.*



*Award ceremony in Split.*

On September 23, 2025, **Dr.-Ing. Maximilian Ries** received the award 'GACM Best PhD Thesis 2023' for this dissertation titled 'Characterization and modeling of polymer nanocomposites across the scales - a comprehensive approach covering the mechanical behavior of matrix, filler, and interphase'. The award was presented at the GACM Colloqium 2025 in Braunschweig, Germany.

On October 14, 2025, **Dr. Miguel Angel Moreno-Mateos** was awarded the Third Prize 'Premios Margarita Salas 2025' by Madrid City Council for this outstanding thesis titled 'Mechanical characterization, constitutive modeling and applications of ultra-soft magnetorheological elastomers'. The thesis included the collaboration with Prof. Paul Steinmann on magnetorheological elastomers.




*Award ceremony in Madrid.*

## 2.2 Teaching and student theses

### Lectures

LTM and LKM provide a wide variety of (fundamental and advanced) lectures, exercises and tutorials in German and English language to local and international students at the FAU. Only the help of the entire academic staff made the marking of the tremendous number of exams in 2025 possible.

AI in Mechanics
Dr.-Ing. H. Holthusen

Beyond FEM
Dr.-Ing. D. Pivovarov

Computational Dynamics
Dr. M. A. Moreno-Mateos

Fracture Mechanics
Dr.-Ing. P. Kumar

Höhere Festigkeitslehre
PD Dr.-Ing. habil. S. Pfaller

Introduction to the Finite Element Method
PD Dr.-Ing. habil. S. Pfaller

Lab Course Biomechanics
*Dr. J. Kolb*
*R. Gopalan Ramachandran, PhD*
*P. Scherm, M.Sc.*
*N. Tueni, PhD*

Linear Continuum Mechanics
Prof. Dr.-Ing. habil. P. Steinmann
*J. Friedlein, M.Sc.*

Materialmodellierung und -simulation
Prof. Dr.-Ing. J. Mergheim
*Dr.-Ing. P. Kumar*

MATLAB Praktikum
*E. Schaller, M.Sc.*
*P. Scherm, M.Sc.*

Methode der Finiten Elemente
Prof. Dr.-Ing. habil. K. Willner
*Dr.-Ing. Dipl.-Math. techn. G. Possart*

Mikromechanik
Prof. Dr.-Ing. J. Mergheim

Nonlinear Finite Element Method
Prof. Dr.-Ing. J. Mergheim
*Simon Wiesheier, M.Sc.*

Nonlinear Continuum Mechanics
Prof. Dr.-Ing. habil. P. Steinmann
*J. Friedlein, M.Sc.*

Numerische und Experimentelle Modalanalyse
Prof. Dr.-Ing. habil. K. Willner
*Ö. Akar, M.Sc.*

Praktikum Technische Mechanik
*E. Schaller, M.Sc.*
*P. Scherm, M.Sc.*

Statik und Festigkeitslehre
Prof. Dr.-Ing. habil. K. Willner
*Dr.-Ing. Dipl.-Math. techn. G. Possart*
*L. Spannraft, M.Sc.*

Strukturoptimierung in der virtuellen Produktentwicklung
Prof. Dr.-Ing. R. Meske

Technische Mechanik I+II (Statik, Elastostatik und Festigkeitslehre)
Prof. Dr.-Ing. habil. P. Steinmann
*Dr.-Ing. M. Ries*
*L. Spannraft, M.Sc.*

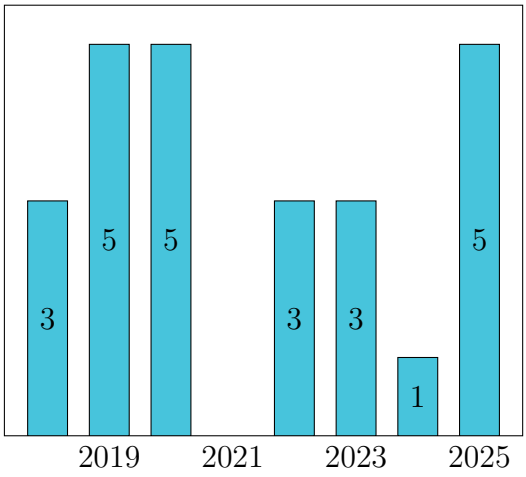
Technische Schwingungslehre
Prof. Dr.-Ing. habil. K. Willner
*Ö. Akar, M.Sc.*

### Teaching awards

High rankings in the teacher evaluation conducted by the Technical Faculty at FAU:

- Lecture "Statics and strength of materials" in winter-semester 2024/25 held by Dr.-Ing. Maximilian Ries: 3rd place GOP for B.Sc. (VG20)
- Exercise "Applied Mechanics I: Statics" in winter-semester 2024/25 held by Dr.-Ing. Maximilian Ries: 2nd place GOP for B.Sc. (ÜG20)
- Lecture "Applied Mechanics II: Elastostatics and strength of materials" in summer-semester 2025 held by Prof. Paul Steinmann: 3rd place GOP for B.Sc. (VG5)
- Exercise "Applied Mechanics II: Elastostatics and strength of materials" in summer-semester 2025 held by Dr.-Ing. Maximilian Ries: 1st place GOP for B.Sc. (ÜG5)
- Exercise "Methode der Finiten Elemente" in summer-semester 2025 held by Dr.-Ing. Gunnar Possart: 3rd place non-GOP mandatory for B.Sc. (ÜP5)

### Statistics of teaching distinctions 2018–2025




The constant high quality of our institute's teaching is confirmed by the student evaluation prizes, the Teaching Award of the Technical Faculty (Lehrpreis der TF) and the Teaching Award of the FAU (FAU-Lehrpreis) won by LTM staff members in recent years. Note that no teaching evaluation prizes were given between summer-semester 2020 and winter-semester 2021/22, i.e., during the pandemic.

### Student projects and theses

This year's list of finished student theses supervised by LTM/LKM staff members:

### Bachelor theses

[1] M. Krowiak. *Realistic Modeling of Crack Nucleation in Phase-Field Fracture Computations.*

[2] M. Skotnica. *Development of 2D-axisymmetric finite plasticity user-defined elements in LS-DYNA.*

### Project theses

[1] D. Breckner. *Konstruktion und Fertigung eines Haltersystems für MRT und MRE Messungen von menschlichen Gehirnen.*

[2] V. Dötschel. *Revealing the interphase in epoxy-based adhesive joints via coarse-grained molecular dynamics.*

[3] J. Fischer. *Vorbereitung eines eindimensionalen, inelastischen Finite-Elemente-Systems zur Kopplung mit der Molekulardynamik.*

[4] S. Frank. *Finite Elemente mit eingebettetem Scherband.*

[5] O. George. *Comparison of area correction algorithms in peridynamics.*

[6] N. U. Kavitkar. *FEA using Ansys for Design Optimization of a Gear Shaft and Bearing Sleeve Connection.*

[7] M. Pedata. *Calculation of the analytical tangent for implicit FEM solvers by symbolic differentiation using the example of the Three-Network-Model.*

**Master theses**

[1] D. Breckner. *Experimentelle Charakterisierung und numerische Simulation des Schädigungsverhaltens von AlSi7Mg0,3.*

[2] V. Dötschel. *Nichtlineare Modellierung und Kalibrierung für einen semistrukturellen Klebstoff.*

[3] V. R. Enugala. *Comparative analysis of the effect of measured and simulated EMAG forces on the vibration response of an electric machine.*

[4] S. Frank. *Numerische Bruchmodellierung von viskoelastisch-viskoplastisch gekoppelten Phasenfeldansätzen.*

[5] T. Gottipati. *Modelling continuum growth of the full-scale human brain during development.*

[6] A. Jaiswal. *Thermomechanical fatigue behaviour of thermoplastic polymers under the consideration of aging.*

[7] K. V. Kumaar. *Finite Element Analysis of Core Losses in Medium-Frequency Transformers for Use in Dual-Active Bridge Converters.*

[8] Q. Mao. *Clustering und Analyse der Kontaktkräfte aus Ansys.*

[9] K. Niel. *FEM-Simulation von Streckentrennern in Oberleitungen.*

[10] M. Pedata. *Analyse des Schwingungsverhaltens vereister Fahrleitungen unter Windbeanspruchung mittels CFD.*

[11] S. Popp. *Bestimmung von makroskopischen hyperelastischen Modellen für heterogene Implantatmaterialien mit CANNs.*

[12] B. Rauh. *Integration of Material Parameters Derived from Fractional Anisotropy into a Finite Element Model of the Human Brain.*

[13] A. K. Rejikumar Bindu. *Physics-Informed-Neural-Networks meet hyperelastic energy functions and inverse parameter identification.*

[14] E. Richter. *A "Capriccio light" approach to study the capabilities of multiscale fracture simulations of thermoplastics.*

[15] P. Saravanakumar. *Expression of Mechanosensitive (PIEZO 1 and PIEZO 2) Channels in Human and Mouse Meibocytes.*

[16] A. Selveroglu. *Analysis of low frequency vibratins of MR systems.*

[17] A. Sharma. *Adaptive grid refinement for fracture modelling in peridynamics.*

[18] A. Vayangankar. *Optimization of Modal Parameters for Headlamp Components in Linear FEA Simulations Under Vibration Load Cases.*

### Student award

Eva Maria Richter received the 'NAFEMS DACH-Preis' for her Master Thesis titled "A 'Capriccio light' approach to Study the Capabilities of Multiscale Fracture Simulations of Thermoplastics" in the category of 'Materialwissenschaften und Strukturmechanik'. The organization NAFEMS promotes the safe and reliable application of simulation methods.

### LTM juniors – a mentoring program for talented students

(LSp) The LTM juniors are a selected group of students who have distinguished themselves through outstanding performance in applied mechanics. Membership is based exclusively on nomination by LTM employees. This year, 10 students from different Bachelor and Master semesters were selected to participate in the program.

The mentoring program is based on monthly meetings and features:

- Arrangement of student assistant jobs & student theses
- Advice on studies & possible doctoral projects
- Introduction to academic work & academia
- Invitation to participate in seminars, lecture series, excursions, etc.
- Opportunity to network with students from other semesters

Special highlights of 2025:

- Vincent Dötschel was given the opportunity to accompany us to the "25. Kolloquium: Gemeinsame Forschung in der Klebtechnik" in Cologne, Germany, organized by DECHEMA, cf. https://dechema.de/GFKT2025.html. Thereby, he attended interesting talks from industry and academia on recent adhesive technology and took advantage of the networking opportunity.
- LTM alumnus Dr.-Ing. Michael Caspari joined a meeting to provide insight in his career path, thereby, giving great advice on how to choose a suitable research group, supervisor and topic for a doctorate. Further, he reported on the transition from academia to industry, the differences and how he now benefits from his time at LTM.

Mentors: Özge Akar, Maximilian Ries, Lucie Spannraft

Mentees:

- Elisabeth Boltyschew
- Liselotte Daub
- Vincent Dötschel
- Joshua van de Goor
- Maximilian Losert
- Benedikt Rauh
- Johannes Roksvaag
- Jonas Tiefenthäler
- Zixuan Zhao
- Marlene Ziegler

Former mentees and their testimonials:

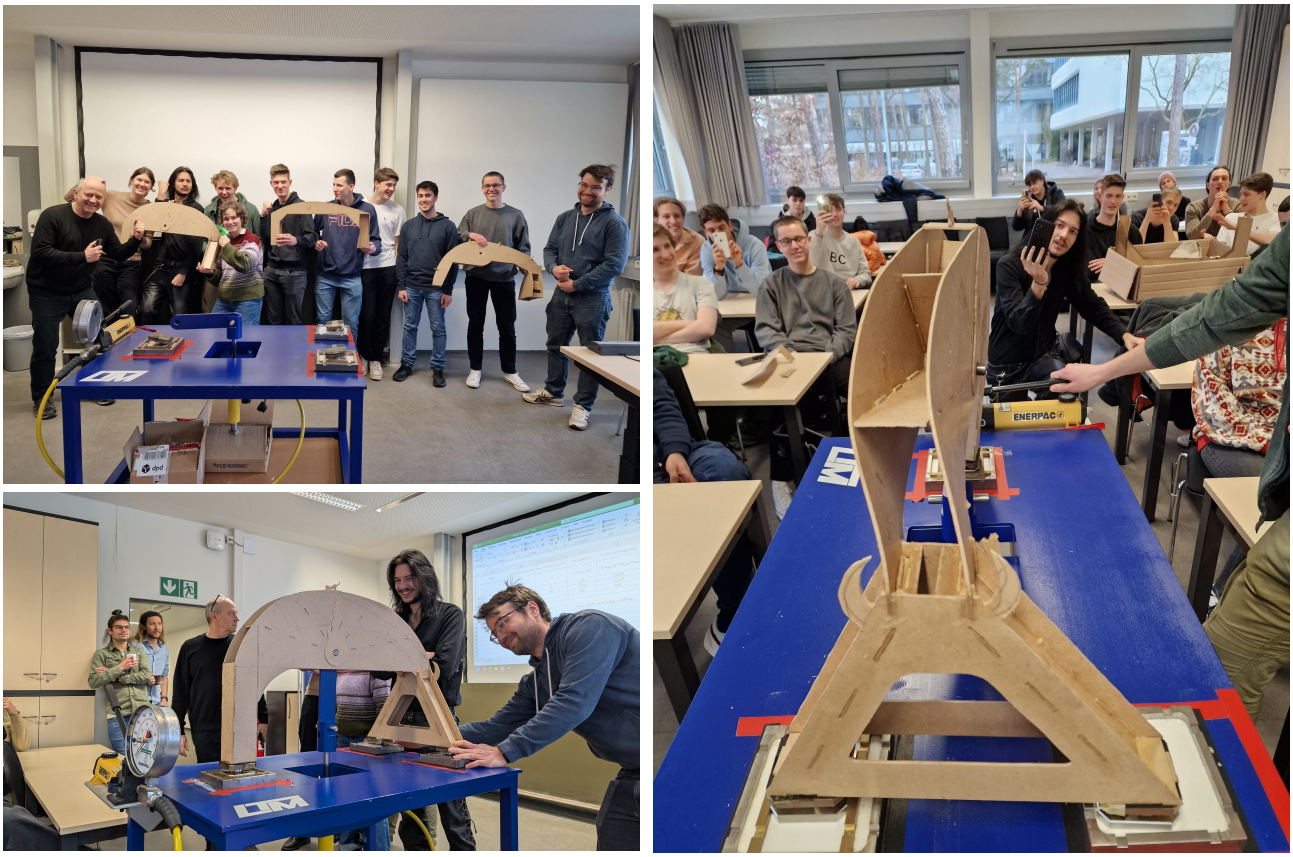
- Eva Maria Richter, doctoral researcher at LTM in RTG FRASCAL since January 2025: "The skills and insights I acquired through the LTM juniors have helped me not only during my master's degree, but also in making an informed decision about pursuing my PhD. Thanks to the program, I felt much more prepared for my PhD journey and the transition from master's to PhD student was significantly smoother."
- Vincent Dötschel, doctoral researcher at LTM in IGF 2024-01316 since August 2025: "The meetings not only fostered my methodological competencies in academic writing and research but also provided structured orientation and valuable insights into the challenges and opportunities of pursuing a PhD. The LTM juniors helped me feel well prepared and confident in making the right decision for my next step."




*Vincent Dötschel accompanying Lucie Spannraft and Maximilian Ries to the GFKT colloquium (top left). LTM juniors receiving a tour through our labs during one of the monthly meetings (top right). Our joint 'Capriccio Hiwis' and 'LTM juniors' BBQ with three traditionally 'not-invited' Brainiacs (bottom). Barbecuing in mid-October (bottom left) and Max sneakily taking photos at the buffet (bottom right).*

### Ultimate load contest (Traglastwettbewerb)

(Markus Mehnert, LSp) After the great success of conducting the Ultimate Load Contest last time (after 11 years of absence), it was offered again this year. The contest aims at attracting the attention of students to challenging problems in mechanics in a fun way. On January 24, 3 groups named "Gruppe 1", "Die Pfuscher" and "Beamergalaxy" participated in the event. The objective of this contest is an optimization problem in applied mechanics: built a bridge structure consisting of medium-density fiberboard and commercial glue with a maximum weight of 2 kg. During the contest, the structure is supported at three points and is loaded vertically. The designs handed in by the students showed distinctly different approaches and interesting ideas to handle the applied force. While the slender designs by the first two groups were relatively quickly destroyed, the behemoth (featuring a cat, flames and horns) built by "Beamergalaxy" posed a fierce challenge to the testing device and consequently won the contest by a landslide. All contestants were rewarded with a custom-made trophy cup, an invaluable experience in the field of mechanics and an invitation to work as student tutors. Both the participants and the spectators truly enjoyed the event. As an exciting supplement to an engineering students curriculum, the Ultimate Load Contest deepens and enhances the understanding of Applied Mechanics and was considered as a complete success.




*The three groups presenting their bridges, the moderator Prof. Paul Steinmann and the organizer Dr.-Ing. Markus Mehnert of the event (top left). Adjusting one of the bridges while the team explains their reasoning (bottom left). The bridge of the winning team starting to fail at an impressive amount of load (right).*

## 2.3 Seminars

### Advanced seminar on mechanics

Jointly with the Chair of Applied Dynamics, LTM and LKM organize a series of invited talks from researchers all around the world to present their current research projects and to stimulate discussion of their latest results among the staff members.

**31/3/2025** Prof. Saulo Martelli, Queensland University of Technology, Brisbane, Australia
*Bridging Length Scales in Musculoskeletal Biomechanics: Insights and Innovations*

**14/5/2025** Rodrigo J. Velasco-Guillen, LS für Autonome Systeme und Mechatronik, FAU, Erlangen, Germany
*User-Centered Design of Adaptive and Fault-Tolerant Control Strategies for Elastic Actuators*

**19/5/2025** Prof. Barbara Röhrnbauer, School of Engineering, Zurich University of Applied Sciences, Switzerland
*Applied and Translational Research in Soft Tissue Biomechanics at ZHAW School of Engineering*

**3/7/2025** Prof. Peter Pivonka, Queensland University of Technology, Brisbane, Australia
*Recent advances in simulating osteoporosis drug treatments: pathways to optimise and exploit currently approved drug therapies*

**18/9/2025** Dr. Oscar Cosserat, Mathematisches Institut, University of Göttingen, Germany
*Hamiltonian structures of the Timoshenko model and related numerical analysis*

**8/12/2025** Prof. Eran Bouchbinder, Weizmann Institute of Science, Rehovot, Israel
*Topological defects and multi-plane crack interactions in materials failure*

### LTM/LKM meeting

(LSp) LTM and LKM's weekly meetings provide an opportunity for scientific and organizational exchange among all colleagues. During these meetings, upcoming events, such as exams and conferences, are announced. Furthermore, a (post-)doctoral researcher gives a short presentation within the scope of the 'LTM/LKM Topical Overview Presentation *Zoom*posium', coordinated by Yashasvi Verma. These short presentations serve to provide insights in the different topics at our institutes and to initiate discussions.




*The announcement of LTM Capriccio/FRASCAL talks at the Long Night of Science.*

## 2.4 Science communication and gender equality

(LSp) In order to motivate more (female high-school) students to pursue a technical career in the future, we participate in the projects 'Girls' Day' in April, 'Mädchen und Technik Praktikum' in September and the 'Long Night of Science' in October.

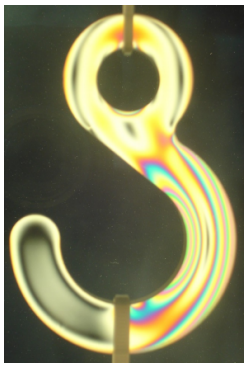
### Girls' Day

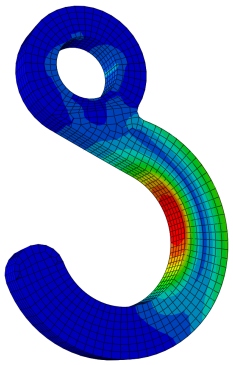
On the 'Girls' Day', Laura Ruhland (LTM) and Jan Hinrichsen (LKM) offered the dynamics experiment 'Bad Vibes - when your cellphone vibration alarm becomes an earthquake'. The partaking female high-school students were exited to gain insights into the fascinating world of structural dynamics and enjoyed participating in the practical experiments.

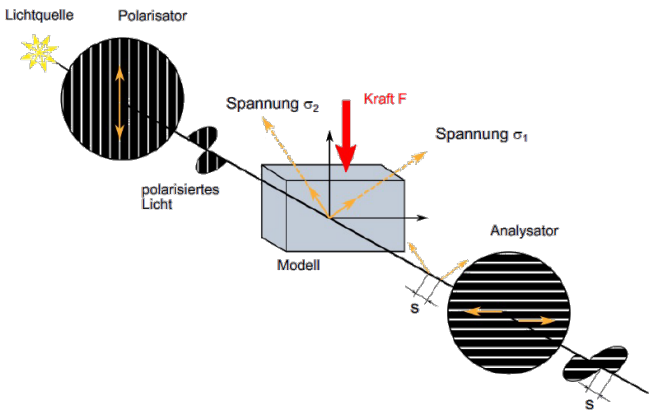
### Mädchen und Technik Praktikum

(Lukas Laubert) In September, the LTM and LKM conducted the "Mechanics for Future" experiment series as part of the "Mädchen und Technik Praktikum", a week-long program. Students from various schools, including Realschulen and Gymnasien, spent one day at our institute. They participated in four interactive experiments focused on the stress analysis of a crane hook. The experiments included stress birefringence, measuring material parameters, capturing strain maps via digital image correlation, and performing basic Finite Element Method simulations. This year, the activities were introduced and supervised by Eva Richter, Lukas Laubert, Marie Laurien, and Emily Schaller, with Lucie Spannraft leading the coordination and script preparation. The students expressed great enthusiasm for the hands-on experience, which deepened their understanding of key mechanical concepts and relationships.









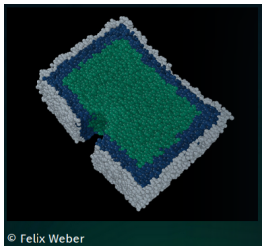

*Stress birefringence set-up (top left), result in a crane hook under tension (top middle) and corresponding FEM simulation (top right). Schematic setup of the photoelastic experiment showing polarized light passing through a stressed model to visualize the internal stress distribution (bottom).*

### Long Night of Science

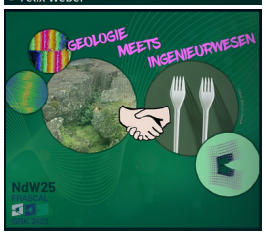
(LSp) At this year's 'Long Night of Science', LTM and LKM were involved in several projects:




'Warum reißt Supermans Anzug nicht? Von der Supersimulation zum Supermaterial' by **Eva Maria Richter (LTM)**. The visitors were taken on a 30-minute journey from small particles and tiny fractures all the way to heroes and giant computers to get an impression on how far or close we are from super-materials like Superman's indestructible suit and how 'super-simulations' help creating such materials.



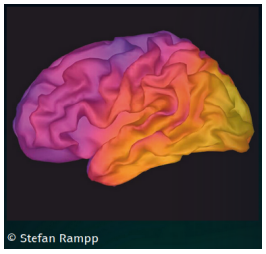

'Risse verstehen: eine virtuelle Expedition durch Zeit und Raum' by **RTG FRASCAL** with projects at LTM. The researchers offered a virtual expedition of fracture in different materials like bones, composites and rocks on the atomistic scale up to the geological scale.



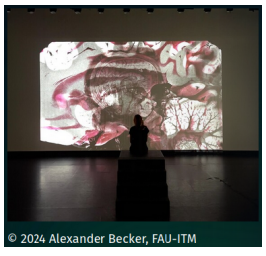

'Was Risse zwischen Kontinenten mit kaputtem Plastikbesteck gemeinsam haben' by **RTG FRASCAL**. In a dialogue between an engineer (Eva Maria Richter from LTM) and a geologist (Prof. Daniel Köhn) the connection between the smallest fractures in molecular chains and the largest fractures between continents were discussed.



'Panel: Wie ist es eigentlich als Frau in den Ingenieurwissenschaften?' moderated by **Eva M. Richter (LTM: Capriccio & FRASCAL)** including i.a. **Prof. Silvia Budday (head of LKM)** and **Marlene Ziegler (LTM Junior)**. The one-hour panel discussion gave an impression on studying an engineering subject and later working in the field as a woman.




'Faszination Gehirnmechanik – Entdeckt eine ganz neue Richtung der Hirnforschung!' by **CRC EBM** with projects at LTM & LKM. At interactive stations, visitors could touch brain models, explore 3D-scans and view real brain sections to uncover the mysteries of the human brain.




'Das Gehirn – musikalische Erkundungen'. Organist Susanne Hartwich-Düfel interpreted compositions by Johann Sebastian Bach, Arvo Pärt, Sofia Gubaidulina and Philip Glass. The organ concert was accompanied by video projections showing images of the human brain generated in the neuroscientific research by **CRC EBM**.

Further information on the involved groups can be found here:

- Capriccio: https://www.capriccio.research.fau.eu/,
- FRASCAL: https://www.frascal.research.fau.eu/,
- EBM: https://www.crc1540-ebm.research.fau.eu/.

All offered activities were very well received by the audience.

Here are some impressions from the night:








*Eva Maria Richter (LTM) giving a talk on how complex simulations across different length and time scales help to develop advanced materials with properties imagined in superhero stories. Eva posing with the – of course – real Superman visiting her great presentation.*





*The panel discussion capturing a wide range of impression from female engineering students up to professors featuring guests from different fields. From left to right: students Marlene Ziegler (MechEng, LTM Junior) and Julia Wimmer (EE), doctoral researchers Patricia Schmul (ChemEng) and Katharina Braun (CBE), Dr. Sabine Thürauf (AIROB), Prof. Silvia Budday (head of LKM, MechEng), and moderator Eva Maria Richter (doctoral researcher at LTM, RTG FRASCAL & Capriccio, former LTM junior).*




*Exploring brain mechanics at interactive stations: from brain sections via brain folds at different developmental stages to 3D prints.*

# 3 Scientific contributions

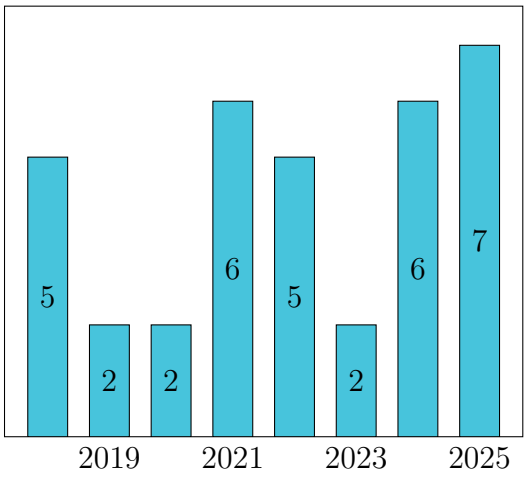
The following sections give a brief overview on the scientific output of LTM and LKM staff members during the year 2025. This does not only include multiple original contributions to international top-tier journals from the applied mechanics community, but also numerous presentations at international conferences, workshops, and symposia all around the globe. The high level of the scientific contributions is also emphasized by awards. Multiple research stays show the interconnectivity of the LTM and LKM with international research groups.

## 3.1 Awards and distinctions

- Jaimé Goedhals and Silvia Budday
  **3rd Place Poster Award:** *Modelling Mechanics-Induced Damage of Brain Tissue.* September 21 – 24, 2025. 11th GACM Colloquium on Computational Mechanics for Young Scientists from Academia and Industry (GACM).

- Dr. Miguel Angel Moreno-Mateos
  **EAM Starting Grant**. November 2025 – December 2026. FAU Competence Center Engineering of Advanced Materials (FAU EAM), Friedrich-Alexander-Universität Erlangen-Nürnberg.
  **GAMM-Junior** for the years 2025 – 2027. Gesellschaft für Angewandte Mathematik und Mechanik (GAMM).

**Statistics of scientific/theses awards and distinctions 2018–2025**




## 3.2 Research stays and summer schools

- Hagen Holthusen
  **Research stay** upon invitation of Prof. Ellen Kuhl. February 16 – March 16, 2025. Stanford University, California, United States.

- Annika Karweger
  **Research stay** upon invitation of Prof. Peter Pivonka. July 21 – August 4, 2025. Queensland University of Technology, Brisbane, Australia.

- André Krippner
  **Summer school** on Topology Optimization. June 11 – 17, 2025. Technical University of Denmark (DTU), Copenhagen, Denmark.

- Paras Kumar
  **HSM Special Topic School** on Optimality of adaptive finite element methods, organized by Hausdorff School of Mathematics (HSM), University of Bonn. September 22 – 26, 2025. Bonn, Germany
  **CISM-AMIETA Advanced School** on Machine Learning for Solid Mechanics, coordinated by Prof. Kaushik Bhattacharya and Prof. Antonio De Simone. September 29 – October 3, 2025. International Centre for Mechanical Sciences (CISM), Udine, Italy.

- Denisa Martonová
  **Research stay** upon invitation of Prof. Ellen Kuhl. April 23 - May 30, 2025. Stanford University, California, USA.

- Miguel Angel Moreno-Mateos
  **Visiting researcher** at Department of Mechanical Engineering, Massachusetts Institute of Technology (MIT). February 10 – 11, 2025. Department of Mechanical Engineering, Massachusetts Institute of Technology, United States.
  **Visiting researcher** at Department of Mechanical Engineering, Imperial College London. September 17 – 18, 2025. Department of Mechanical Engineering, Imperial College London, United Kingdom.

- Oskar Neumann
  **Research stay** at the Mechanobiology Lab of Prof. Thomas Franz. March 31 – April 27, 2025. University of Cape Town, South Africa.

- Eva Maria Richter
  **Research stay** upon invitation of Prof. Frederik Van Loock. September 29 – November 7, 2025. Eindhoven University of Technology, Eindhoven, Netherlands.

- Michael Schwarz
  **Research stay** as part of the IRTG 2495. January 7 – March 27, 2025. Nagoya Institute of Technology (NITech), Nagoya, Aichi, Japan.
  **Photo-Electro-Mechanical Energy Conversion Summer School 2025** as part of the IRTG 2495. July 28 – 30, 2025. FAU Erlangen-Nürnberg, Erlangen, Bavaria, Germany.

- Sebastian Pfaller
  **Research stay** upon invitation of Dr. Maxime Vassaux. March, 2025. Institut de Physique de Rennes, France.

- Malte Rolf
  11th **Summer school** on physics-informed modeling, simulation and experiments with emphasis on the cardiovascular system, coordinated by Gerhard A. Holzapfel and Ray W. Ogden. September 15 – 19, 2025. Graz University of Technology, Graz, Austria.

- Jana Wedel
  **Research stay** upon invitation of Prof. Jure Ravnik and Prof. Matjaz Hriberšek. January 1 – December 31, 2025. University of Maribor, Maribor, Slovenia.

- Sahar Zolghadr
  **Summer school** upon invitation of InsilicoHealth. September 3 – 12 , 2025. KU Leuven, Leuven, Belgium.

## 3.3 Conferences

### Organization

- Silvia Budday: Co-organizer jointly with Prashant Saxena
  **Euromech Colloquium 647 Stability and bifurcation problems in nonlinear solid mechanics.** April 23 – 25, 2025. Glasgow, UK.

- Silvia Budday: Co-organizer jointly with Giulia Luraghi, Michele Marino, and Tim Ricken
  **Italo-German meeting on in silico medicine: common problems and last advancements at 11th International Conference on Computational Bioengineering (ICCB).** September 8 – 10, 2025. Rome, Italy.

- Moritz Flaschel and Miguel Angel Moreno-Mateos: Co-Organizers jointly with Dominik Klein, Karl Kalina and Max Rosenkranz
  **Data-driven methods for constitutive modeling at the GACM Colloquium on Computational Mechanics (GACM).** September 21 – 24, 2025. Braunschweig, Germany.

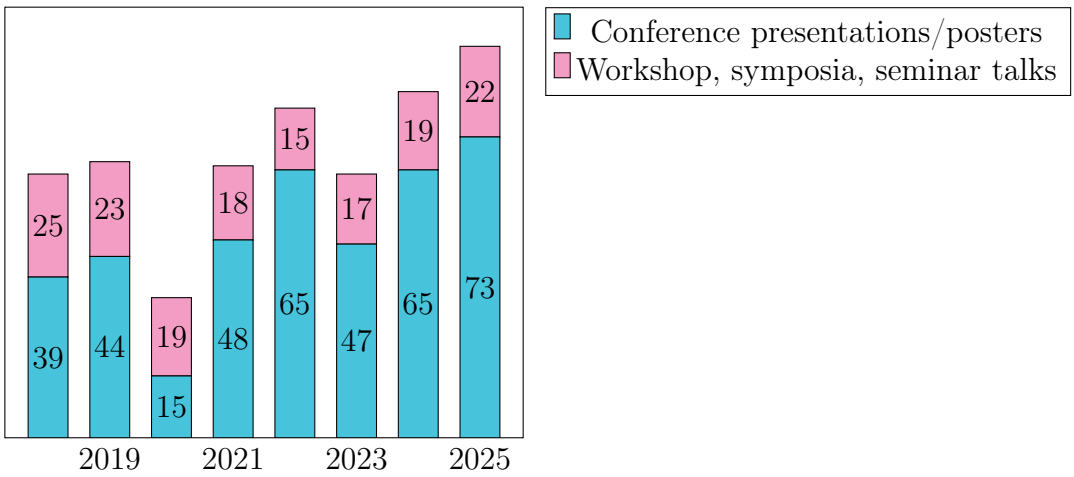
- Jan Hinrichsen and Nina Reiter: Co-Organizers jointly with Sebastian Brandstaeter, Christian Bleiler and Renate Sachse
  **Advances in modeling and simulation for biomechanics and biomedical engineering at the 11th GACM Colloquium on Computational Mechanics (GACM).** September 21 – 24, 2025. Braunschweig, Germany.

- Lukas Laubert and Maximilian Ries
  **Atomistic, Nano, and Micro Mechanics of Materials at the 8$^{\text{th}}$ Young Investigators Conference (YIC 2025).** September 17 – 19, 2025. Pescara, Italy.

- Sebastian Pfaller: Co-organizer jointly with Sylvain Patinet and Renald Brenner
  **Multiscale materials modelling from atoms to macroscale at the 12th European Solid Mechanics Conference (ESMC 2025).** July 7 – 11, 2025. Lyon, France.

- Sebastian Pfaller: Co-organizer jointly with Hung-Jue Sue and Andreas Delimitis
  **Nanomaterials, nanoparticles and nano-structuring at the 18th European Congress and Exhibition on Advanced Materials and Processes (FEMS EUROMAT 2025).** September 14 – 18, 2025. Granada, Spain.

### Statistics of conference contributions and talks 2018–2025



**Conference presentations**

**Advances in Applied Mechanics (AAM)**
January 5 – 9, 2025. Meloneras, Gran Canaria, Spain.

- Miguel Angel Moreno-Mateos and Paul Steinmann:
  *Variations in the degree of crosslinking allow for the control of soft fracture via sideways cracking.*

- Gabriel Stankiewicz, Chaitanya Dev and Paul Steinmann:
  *Topology and shape optimization with stress and curvature constraints to achieve precision in compliant mechanism design.*

**2025 GeoDICT Innovation Conference (2025 GIC)**
February 11 – 12, 2025. Ramstein, Germany.

- Gunnar Possart, Sebastian Pfaller, Paul Steinmann, Michael Redel and Dirk Schubert:
  *Non-linear inelastic 3-phase FE models for calendered nonwovens.*

**1st Artificial Intelligence and Computational Methods in Applied Science (AICOMAS 2025)**
February 17 – 21, 2025. Paris, France.

- Moritz Flaschel, Paul Steinmann, Laura De Lorenzis and Ellen Kuhl:
  *Convex neural networks learn generalized standard material models.*

**25th Colloqium: Joint Research in Adhesive Bonding Technology (GFKT)**
February 18 – 19, 2025. Köln, Germany.

- Lars Schmelzle, Gunnar Possart and Julia Mergheim:
  *Methodenentwicklung zur Simulation von hyperelastischen Klebverbindungen unter Crashbelastung.*

**XXIX Conference on Computer Methods in Materials Technology (KomPlasTech) 2025**
March 2 – 05, 2025. Krynica Zdrój, Poland.

- Sebastian Pfaller, Lukas Laubert, Eva Maria Richter, Maximilian Ries, Felix Weber, Wuyang Zhao and Maxime Vassaux:
  Plenary lecture: *Numerical predictions of fracture in amorphous materials: Current achievements and challenges.*

**32ième colloque sur la deformation des polymères solides (DEPOS 32)**
March 25 – 28, 2025. Poitiers, France.

- Sebastian Pfaller, Lukas Laubert, Eva Maria Richter, Maximilian Ries, Felix Weber, Wuyang Zhao, and Maxime Vassaux:
  *Simulations multi-échelles des polymères amorphes.*

**Meeting of ESIS TC8 and DVM-Working Group Simulation**
March 27 – 28, 2025. Munich, Germany.

- Felix Weber, Maxime Vassaux, Lukas Laubert, Sebastian Pfaller:
  *Concurrent Molecular Dynamics-Finite Element Fracture Simulations of Amorphous Materials.*

**95$^{\text{th}}$ Annual Meeting of the International Association of Applied Mathematics and Mechanics (GAMM 2025)**
April 7 – 11, 2025. Poznań, Poland.

- Rahul G. Ramachandran, Oskar Neumann, Paul Steinmann and Silvia Budday:
  *Multimodal mechanical characterization of spinal cord tissue.*

- Miguel Angel Moreno-Mateos and Paul Steinmann:
  *Sideways Cracks in Elastomers: Experimental Insights & Phase-Field Modelling.*

- Laura Ruhland and Kai Willner:
  *Experimental and numerical characterisation of a viscoelastic material by unifying different time scales.*

- Sebastian Pfaller, Lukas Laubert, Eva Maria Richter, Maximilian Ries, Felix Weber, Wuyang Zhao and Maxime Vassaux:
  *Predictability of fracture mechanical quantities based on chemically specific multiscale simulations.*

- Eva Maria Richter, Felix Weber, Sebastian Pfaller and Maximilian Ries:
  *A 'Capriccio light' approach to study the capabilities of multiscale fracture simulations of thermoplastics.*

**Euromech Colloquium 647 – Stability and bifurcation problems in nonlinear solid mechanics**
April 23 – 25, 2025. Glasgow, UK.

- Silvia Budday:
  *Mechanical instabilities in the developing human brain: from cells to cortical folding.*

- Paul Steinmann, Marie Laurien and Ali Javili:
  *Capturing nonlocal wrinkling instabilities in bilayered systems through peridynamics.*

**12th International Conference on Multiphase Flow**
May 11 – 16, 2025. Toulouse, France.

- Jana Wedel, Paul Steinmann, Matjaž Hriberšek and Jure Ravnik:
  *Soft deformable microparticles in dilute multiphase flow.*

**Computational Modeling of Complex Materials across the Scales (CMCS 2025)**
May 13 – 16, 2025. Champs-sur-Marne, France.

- Ali Javili, Fredrik Larsson, Kenneth Runesson and Paul Steinmann:
  Invited talk: *Canonical Interfaces With Application to Micro-Heterogeneous Solids.*

- Lucie Spannraft, Gunnar Possart, Paul Steinmann and Julia Mergheim:
  Poster: *Generalized interfaces modeling adhesives and their failure.*

**XI International Conference on Coupled Problems in Science and Engineering (COUPLED PROBLEMS 2025)**
May 25 – 28, 2025. Villasimius (Sardinia), Italy.

- Michael S. Schwarz, Ryota Yamamoto, Ken-ichi Kakimoto and Julia Mergheim:
  *Modeling and Simulation of Pyropiezoelectric Energy Harvesting.*

- Yashasvi Verma, Luca Heltai and Paul Steinmann:
  *Modelling of Vascular Influence on Brain Tissue Mechanics.*

- Jana Wedel, Paul Steinmann, Matjaž Hriberšek and Jure Ravnik:
  *Large numbers of non-spherical soft particles in dilute flows.*

**The 8$^{\text{th}}$ International Conference on Computational Modeling of Fracture and Failure of Materials and Structures (CFRAC 2025)**
June 4 – 6, 2025. Porto, Portugal.

- Maxim Rodschei, Julia Mergheim and Gunnar Possart:
  *Lifetime Simulations of Hygro-Thermo-Mechanically Loaded Adhesive Bonds.*

- Paras Kumar and Paul Steinmann:
  *Improving the Cost of Phase-Field Fracture Computations – Making 3D Crack Propagation Simulations Viable.*

**XII International Conference on Adaptive Modeling and Simulation (ADMOS 2025)**
June 9 – 11, 2025. Barcelona, Spain.

- Daniel van Huyssteen, Felipe Lopez Rivarola, Guillermo Etse and Paul Steinmann:
  *Quasi-optimal mesh generation using the virtual element method: A fully adaptive remeshing procedure.*

**ECCOMAS MSF 2025 – VI International Conference on Computational Methods for Solids and Fluids**
June 25 – 27, 2025. Split, Croatia.

- Malte Rolf-Pissarczyk, Kathrin Bäumler, Dominik Fleischmann, Alison L. Marsden and Gerhard A. Holzapfel:
  *Material and computational modeling of aortic dissection: local hemodynamic phenomena correlate with aortic remodeling.*

**30th Congress of the European Society of Biomechanics (ESB 2025)**
July 6 – 9, 2025. Zürich, Switzerland.

- Soheil Firooz, Daya Reddy, Vasily Zaburdaev and Paul Steinmann:
  *Cellular aggregate formation: continuum modelling and computational implementation.*

- Moritz Flaschel, Paul Steinmann, Laura De Lorenzis and Ellen Kuhl:
  Poster: *Convex neural networks learn generalized standard material models.*

- Rahul G. Ramachandran, Oskar Neumann, Paul Steinmann and Silvia Budday:
  *Multimodal mechanical characterization of spinal cord tissue.*

- Denisa Martonová, Mathias Peirlinck, Sigrid Leyendecker, Gerhard A. Holzapfel and Ellen Kuhl:
  *Robust material model discovery for human myocardium.*

- Oskar Neumann, Rahul Gopalan Ramachandran, Silvia Budday and Paul Steinmann:
  Poster: *Mechanical analysis of spinal cord tissue.*

- Malte Rolf-Pissarczyk, Michele Terzano, Maximilian P. Wollner, Nils Götzen and Gerhard A. Holzapfel:
  *Credibility assessment of polymeric scaffold material modeling for in situ tissue-engineered vascular implant.*

- Nicole Tueni, Emma Griffiths and Silvia Budday:
  Poster: *Incorporating regional material parameters in cerebral atrophy simulations.*

**12th European Solid Mechanics Conference (ESMC 2025)**
July 7 – 11, 2025. Lyon, France.

- Sanne Kwakman, Michele Terzano, Malte Rolf-Pissarczyk and Gerhard A. Holzapfel:
  *A 3D parametric model to simulate balloon angioplasty in atherosclerortic arteries.*

- Angel Santarossa, Miguel Angel Moreno-Mateos and Paul Steinmann:
  *Configurational Mechanics-Based Study of Mixed-Mode Fracture in Soft Hydrogels.*

- Sebastian Pfaller, Lukas Laubert, Eva Maria Richter, Maximilian Ries, Felix Weber, Wuyang Zhao and Maxime Vassaux:
  *Modelling and simulations of polymers across scales and methods.*

- Malte Rolf-Pissarczyk, Kathrin Bäumler, Richard Schussnig, Alison L. Marsden, Dominik Fleischmann and Gerhard A. Holzapfel:
  *Insights into aortic remodeling in type B aortic dissection using patient-specific fluid–structure interaction simulations.*

- Michele Terzano, Manuel P. Kainz, Malte Rolf-Pissarczyk and Gerhard A. Holzapfel:
  *A fracture mechanics-based approach to the structural integrity of fibrous scaffolds.*

- Mohammad Saeed Zarzor and Silvia Budday:
  *Exploring the link between cellular mechanisms and cortical folding in the developing human brain.*

- Wuyang Zhao:
  *Physical origin of strain hardening in glassy polymers and constitutive modeling based on molecular dynamics simulations.*

**18th U.S. National Congress on Computational Mechanics (USNCCM18)**
July 20 – 24, 2025. Chicago, Illinois, USA.

- Lukas Laubert and Sebastian Pfaller:
  *Evaluating the coupling quality of domain decomposition methods.*

- Maxim Rodschei, Julia Mergheim and Gunnar Possart:
  *Damage simulation and lifetime prediction of adhesives under coupled hygro-thermo-mechanical loads.*

- Paras Kumar and Paul Steinmann:
  *A Phase-Field Fracture Model for Predicting Rate-Dependent Fracture Response.*

- Simon Wiesheier, Miguel Angel Moreno-Mateos, Mokarram Hossain and Paul Steinmann:
  *BIAXIAL CHARACTERIZATION OF SOFT ELASTOMERS: DATA-ADAPTIVE MODELING & FRACTURE ANALYSIS.*

**XXX Congress of the International Society of Biomechanics (ISB)**
July 27 – 31, 2025. Stockholm, Sweden.

- Jan Hinrichsen, Nina Reiter, Lucas Hoffmann, Frauke Wilm, Mareike Thies, Ingmar Blümcke, Katharina Breininger, Friedrich Paulsen, Daniel Delev and Silvia Budday:
  *Mechanical characterization of epileptic human brain tissue.*

- Laura Ruhland and Kai Willner:
  *Viscoelastic characterization of porcine brain tissue in the quasi-static and high-frequency domains.*

- Nicole Tueni, Emma Griffiths, Johannes Weickenmeier, Stefan Rampp and Silvia Budday:
  *Modeling brain atrophy with region-specific material properties.*

- Yashasvi Verma, Luca Heltai and Paul Steinmann:
  Poster: *Modelling of Vascular Influence on Brain Tissue Mechanics.*

**Modern Finite Element Technologies (MFET)**
August 20 – 22, 2025. Aachen, Germany.

- Hagen Holthusen, Njomza Pacolli and Stefanie Reese:
  *A Taylor-Series-based reduced integration stabilization technique for large deformations.*

- Njomza Pacolli, Bjorn Sauren, Jannick Kehls, Sven Klinkel, Stefanie Reese and Hagen Holthusen:
  *A stabilization technique based on reduced integration for virtual elements at finite strains.*

**EUROMECH Colloquium 655: Cutting Mechanics of Soft Tissues, Nonlinear Fracture and Contact Mechanics**
August 25 – 27, 2025. Graz, Austria.

- Miguel Angel Moreno-Mateos and Paul Steinmann:
  *Crosslinking Degree Variations Enable Soft Fracture Modulation Via Sideways Cracking.*

**11th International Conference on Computational Bioengineering (ICCB)**
September 8 – 10, 2025. Rome, Italy.

- Jessica Faber, Alexander Greiner, Paula Büttner, Chiara Schoppe, Lars Bräuer, Friedrich Paulsen, Torsten Blunk, Mario Perl, Marcel Betsch and Silvia Budday:
  *Mechanical characterization of human articular cartilage and cell-laden thiolated hyaluronic acid (HA-SH) hydrogels during chondrogenesis.*

- Alexander Greiner, Nina Reiter, Jan Hinrichsen, Manuel P. Kainz, G. Sommer, Gerhard A. Holzapfel, Paul Steinmann, Ester Comellas and Silvia Budday:
  *Model-driven exploration of poro-viscoelasticity in human brain tissue: be careful with the parameters!*

- Nina Reiter, Sophia Auer, Lucas Hoffmann, Lars Bräuer, Friedrich Paulsen and Silvia Budday:
  *Direction-dependent behavior of human brain white matter: don't overestimate the role of axons.*

**18th European Congress and Exhibition on Advanced Materials and Processes (FEMS EUROMAT 2025)**
September 14 – 18, 2025. Granada, Spain.

- Sebastian Pfaller, Lukas Laubert, Eva Maria Richter, Maximilian Ries, Felix Weber and Wuyang Zhao:
  *Identification and evaluation of interphase properties of polymer nanocomposites based on a multiscale approach.*

**ECCOMAS 8th Young Investigators Conference (YIC 2025)**
September 17 – 19, 2025. Pescara, Italy.

- Lukas Laubert and Sebastian Pfaller:
  *Evaluating the coupling quality of domain decomposition methods.*

- Maximilian Ries, Vincent Dötschel, Eva Maria Richter, Gunnar Possart and Paul Steinmann:
  *Interphase formation in epoxy-based structural adhesive joints: a molecular dynamics study.*

- Maurice Rohracker and Julia Mergheim:
  *Efficient Phase-Field Fracture Simulations for Fracture Analysis in Heterogenous Materials.*

- Laura Ruhland and Kai Willner:
  *Experimental and numerical characterization of porcine brain tissue in the time and frequency domain.*

**Kuhljevi dnevi 2025**
September 17 – 19, 2025. Ankaran, Slovenia.

- Nika Harl, Jana Wedel, Paul Steinmann, Jure Ravnik and Matjaž Hriberšek:
  *CFD simulacija polnjenja vijale s suspenzijo deformabilnih mikrodelcev.*

**11$^{th}$ GACM Colloquium on Computational Mechanics for Young Scientists from Academia and Industry (GACM)**
September 21 – 24, 2025. Braunschweig, Germany.

- Moritz Flaschel, Trevor Hastie and Ellen Kuhl:
  *Non-smooth optimization meets automated material model discovery.*

- Jaimé Goedhals and Silvia Budday:
  Poster: *Modelling Mechanics-Induced Damage of Brain Tissue.*

- Jan Hinrichsen, Nina Reiter, Mohammad Saeed Zarzor, Lucas Hoffmann, Frauke Wilm, Mareike Thies, Ingmar Blümcke, Katharina Breininger, Friedrich Paulsen, Daniel Delev and Silvia Budday:
  *Modeling brain folding in epilepsy patients with focal cortical dysplasia.*

- Miguel Angel Moreno-Mateos and Paul Steinmann:
  *Soft Fracture Engineering: Programing Sideways Cracks via Crosslinking Degree Variations.*

- Nina Reiter, Lucas Hoffmann, Lars Bräuer, Ingmar Blümcke, Friedrich Paulsen and Silvia Budday:
  Poster: *Microstructure-Motivated Modeling of Human Brain Viscoelasticity.*

- Maximilian Ries and Gunnar Possart:
  *Identifying the Inelastic Structure-Property Relations of Thermosets via Coarse-Grained Molecular Dynamics.*

- Maximilian Ries:
  *Characterization & modeling of polymer nanocomposites across the scales.*

- Yashasvi Verma, Luca Heltai and Paul Steinmann:
  *Effect Of Vasculature On Direct Inversion Approach In Magnetic Resonance Elastography Of Brain Tissue.*

**Ansys EMEA Transportation Summit and LS-DYNA User Conference**
October 28 – 29, 2025. Munich, Germany.

- Maxim Rodschei, Julia Mergheim and Gunnar Possart:
  *Lifetime prediction of hygro-thermo-mechanically loaded adhesive joints using LS-DYNA and user-defined material models.*

**XLI Congreso Argentino de Mecánica Computacional (MECOM 2025)**
November 11 – 14, 2025. Buenos Aires, Argentina.

- Daniel van Huyssteen, Felipe Lopez Rivarola, Guillermo Etse and Paul Steinmann: *Quasi-optimal adaptive remeshing procedures for the virtual element method.*
- Paul Steinmann and Exploring Brain Mechanics Team: *From the Cellular via the Tissue to the Organ Level: A Journey Exploring Brain Mechanics.*

**9th China International Bonding Technology Symposium (CIB'09 2025)**
November 14 – 17, 2025. Beijing, China.

- Gunnar Possart, Vincent Dötschel, Eva Maria Richter, Paul Steinmann and Maximilian Ries:
  Invited talk: *Interphase formation in epoxy-aluminium bonds with coarse-grained molecular dynamics modeling.*
- Lucie Spannraft, Gunnar Possart, Paul Steinmann and Julia Mergheim: *Generalized interfaces modeling adhesives and their failure.*

**The 9th Asian Pacific Congress on Computational Mechanics**
December 7 – 10, 2025. Brisbane, Australia.

- Soheil Firooz, Daya Reddy, Vasily Zaburdaev and Paul Steinmann: *Cellular aggregate formation: continuum modelling and computational challenges.*

## 3.4 Workshops, symposia, seminars, and lectures

## Workshops

[1] J. Faber, A. Greiner, P. Büttner, C. Schoppe, L. Bräuer, F. Paulsen, T. Blunk, M. Perl, M. Betsch, and S. Budday. *Biomechanical characterization of healthy and osteoarthritic human articular cartilage*. Presentation, 15. Workshop junger Nachwuchswissenschaftler in der Mechanik, Zell am See, Austria. Mar. 2025.

[2] A. Greiner, N. Reiter, J. Hinrichsen, M. P. Kainz, G. Sommer, G. A. Holzapfel, P. Steinmann, E. Comellas, and S. Budday. *Model-driven exploration of poro-viscoelasticity in human brain tissue: be careful with the parameters!* Presentation, 15. Workshop junger Nachwuchswissenschaftler in der Mechanik, Zell am See, Austria. Mar. 2025.

[3] E. Kuhl, M. Peirlinck, S. S. Pierre, and M. Flaschel. *Automated model discovery - a hands-on experience*. ESB, Zürich, Switzerland. July 2025.

[4] J. Ravnik, J. Wedel, M. Hriberšek, and P. Steinmann. *Simulation and modelling of particle laden flows*. Lecture, Invited Tutorial at the 33rd International Conference on Software, Telecommunications, and Computer Networks, Split, Croatia. Sept. 2025.

[5] P. Steinmann and Exploring Brain Mechanics Team. *Exploring Brain Mechanics Across Scales: From the Cellular via the Tissue to the Organ Level*. Presentation, Multiscale Brain Modeling and Beyond: A Focus on Biological Tissues, School of Mathematics and Statistics, University of Glasgow, UK. June 2025.

[6] P. Steinmann and A. Karweger. *Introduction into Bone Cell Population Models*. Presentation, Binding Orthopedics Numerics and Engineering via Simulations, BONES, Stellenbosch University, South Africa. Nov. 2025.

[7] P. Steinmann and M. A. Moreno-Mateos. *Advances in the Fracture of Soft Matter: Multiphysics, Sideways Cracks, and Configurational Mechanics*. Presentation, Milling of Particles: Current Status, Industrial Needs, and Novel Applications, International Fine Particle Research Institute (IFPRI), Carry le Rouet, Marseille, France. June 2025.

## Symposia

[1] S. Firooz, D. Reddy, V. Zaburdaev, and P. Steinmann. *Cellular aggregate formation: continuum modelling and computational implementation.* Poster, EBM Symposium 2025: International Symposium on Brain Mechanics, Erlangen, Germany. Nov. 2025.

[2] J. Goedhals and S. Budday. *Modelling Mechanics-Induced Damage of Brain Tissue*. Poster, EBM Symposium 2025: International Symposium on Brain Mechanics, Erlangen, Germany. Sept. 2025.

[3] J. Hinrichsen, N. Reiter, M. S. Zarzor, L. Hoffmann, F. Wilm, M. Thies, I. Blümcke, K. Breininger, F. Paulsen, D. Delev, and S. Budday. *Towards an in silico model of brain malformations in FCD II epilepsies*. Presentation, EBM Symposium 2025: International Symposium on Brain Mechanics, Erlangen, Germany. Sept. 2025.

[4] J. Kolb and S. Budday. *Real-time visualization of the cellular responses to mechanical loading*. Poster, EBM Symposium 2025, Erlangen, Germany. Sept. 2025.

[5] O. Neumann, R. Ramachandran, and P. S. S. Budday. *In silico modeling of spinal cord regeneration*. Poster, EBM Symposium 2025: International Symposium on Brain Mechanics, Erlangen, Germany. Oct. 2025.

[6] O. Neumann, R. Ramachandran, and P. S. S. Budday. *Multimodal mechanical analysis of spinal cord tissue*. Presentation, SFB 1540 Retreat, Muggendorf, Germany. Oct. 2025.

[7] N. Reiter, J. Hinrichsen, L. Hoffmann, D. Delev, I. Blümcke, L. Bräuer, F. Paulsen, and S. Budday. *Effects of post mortem degradation on mechanical properties of human brain tissue*. Poster, EBM Symposium 2025: International Symposium on Brain Mechanics, Erlangen, Germany. Sept. 2025.

[8] M. Rodschei, J. Mergheim, and G. Possart. *Simulation der Schädigung und Lebensdauerprognose zyklisch und hygro-thermisch beanspruchter Klebeverbindungen*. Presentation, GAK Doktoranden-Kolloquium, Fraunhofer IFAM Bremen, Germany. Mar. 2025.

[9] L. Ruhland, V. Yashasvi, L. Heltai, K. Willner, and P. Steinmann. *Numerical and experimental charcterization of brain tissue across time scales and physiological conditions using MRE*. Poster, EBM Symposium 2025: International Symposium on Brain Mechanics, Erlangen, Germany. Sept. 2025.

[10] P. Scherm, N. Reiter, M. Tranchina, S. Falk, M. Karow, and S. Budday. *Challenges in Mechanical Characterization of Brain Organoids*. Poster, EBM Symposium 2025: International Symposium on Brain Mechanics, Erlangen, Germany. Oct. 2025.

[11] M. Zarzor and S. Budday. *Modeling Brain Development Through a Cell-Type-Driven GrowthComputational Framework*. Poster, EBM Symposium 2025: International Symposium on Brain Mechanics, Erlangen, Germany. Sept. 2025.

## Seminars

[1] H. Holthusen, B. Boes, T. Brepols, K. Linka, and E. Kuhl. *A Neural Network Companion to Inelasticity*. FAU MoD workshop. Sept. 2025.

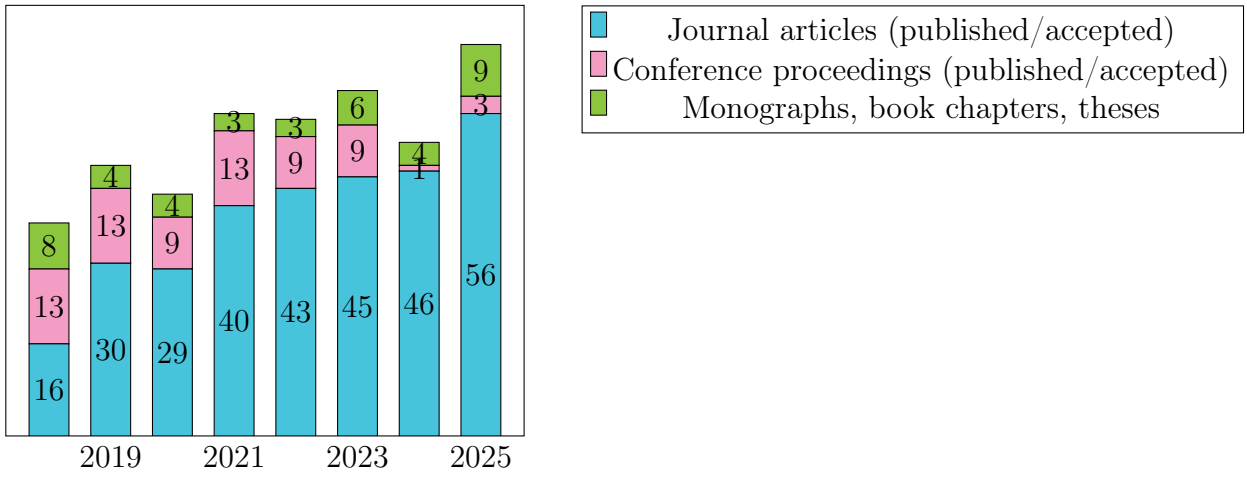
[2] H. Holthusen, B. Boes, J. Kehls, K. Linka, T. Brepols, and E. Kuhl. *AI in Mechanics*. MoD workshop: AI for maths and maths for AI. June 2025.

[3] F. Weber and S. Pfaller. *Fracture Modeling of Amorphous Materials: From Molecular to Continuum-Based Approaches*. Presentation, GRK 2423 FRASCAL - 11th RTG Seminar, Germany. June 2025.

## Lectures

[1] H. Holthusen. *Model discovery and inelasticity*. ME233 Automated Model Discovery, Stanford University, California, United States. Feb. 2025.

**Statistics of publications 2018–2025**




## 3.5 Journal articles

## Published

[1] M. Ahmadi, A. McBride, P. Steinmann, and P. Saxena. "Plane stress finite element modelling of arbitrary compressible hyperelastic materials". *Acta Mechanica* 236 (2025), pp. 3975–3994.

[2] V. Boddu, D. Davydov, and P. Steinmann. "A Fully Nonlocal Quasicontinuum Method for Ionic Crystals". *Multiscale Science and Engineering* 7 (2025), pp. 115–134.

[3] G. Chacón, F. L. Rivarola, D. van Huyssteen, P. Steinmann, and G. Etse. "An efficient procedure for concrete fracture analysis based on mesh refinement ergodicity". *Computational Mechanics* 75 (2025), pp. 369–387.

[4] A. de Villiers, J. Stadler, A. M. G. Limbert, A. Javili, and P. Steinmann. "Continuum-kinematics-inspired peridynamics for transverse isotropy". *Computer Methods in Applied Mechanics and Engineering* 437 (2025), p. 117780.

[5] V. Dötschel, E. M. Richter, G. Possart, P. Steinmann, and M. Ries. "Reactive coarse-grained MD models to capture interphase formation in epoxy-based structural adhesive joints". *European Journal of Mechanics - A/Solids* 116 (2025), p. 105801.

[6] C. Eckert, S. Schmidt, J. Faber, R. Detsch, M. Vielreicher, Z. Lamberger, P. Stahlhut, E. Sandor, T. Karimi, R. Schmid, A. Arkudas, O. Friedrich, S. Budday, G. Lang, A. Kengelbach-Weigand, and A. Bosserhoff. "An alginate-cellulose based bioink mimics the viscoelastic features of the melanoma microenvironment and its influence on cell cycle and invasion". *Bioprinting* 46 (2025), e00384.

[7] J. Faber, A. Greiner, P. Büttner, C. Schoppe, L. Bräuer, F. Paulsen, T. Blunk, M. Perl, M. Betsch, and S. Budday. "Poro-viscoelastic mechanical characterization of healthy and osteoarthritic human articular cartilage". *Journal of the Mechanical Behavior of Biomedical Materials* 173 (2026), p. 107226.

[8] J. Faber, J. Hinrichsen, A. A. Soufivand, H.-H. Lu, T. Rosenberger, E. Karakaya, R. Detsch, A. R. Boccaccini, and S. Budday. "Tuning the mechanical properties of alginate dialdehyde–gelatin (ADA–GEL) bioinks for bioprinting approaches by varying the degree of oxidation". *Journal of the Mechanical Behavior of Biomedical Materials* 163 (2025), p. 106871.

[9] C. Fan, P. Steinmann, J. Wang, and Y. Liang. "A two-step variational approach towards the modeling of high-frequency thermo-magneto-mechanical response of magnetic shape memory alloys". *Journal of the Mechanics and Physics of Solids* 204 (2025), p. 106272.

[10] S. Firooz, D. Reddy, and P. Steinmann. "A gradient-enhanced approach for stable finite element approximations of reaction-convection-diffusion problems". *Journal of Theoretical, Computational and Applied Mechanics* (2025), pp. 1–17.

[11] M. Flaschel, P. Steinmann, L. De Lorenzis, and E. Kuhl. "Convex neural networks learn generalized standard material models". *Journal of the Mechanics and Physics of Solids* 200 (2025), p. 106103.

[12] J. Friedlein, S. Lüder, J. Kalich, H. Schmale, M. Böhnke, M. Schlichter, M. Bobbert, G. Meschut, P. Steinmann, and J. Mergheim. "Application of stress-state-dependent ductile damage and failure model to clinch joining for a wide range of tool and material combinations". *Journal of Advanced Joining Processes* 11 (2025), p. 100299.

[13] J. Friedlein, J. Mergheim, and P. Steinmann. "Modelling of stress-state-dependent ductile damage with gradient-enhancement exemplified for clinch joining". *Journal of the Mechanics and Physics of Solids* 196 (2025), p. 106026.

[14] J. Friedlein, P. Steinmann, and J. Mergheim. "One-way coupled staggered implementation of gradient-enhanced damage models coupled to thermoplasticity". *Finite Elements in Analysis and Design* 253 (2026), p. 104471.

[15] T. Furlan, M. Schewe, P. Scherm, P. Retzl, E. Kozeschnik, and A. Menzel. "Modelling and finite element simulation of martensite and bainite phase transformations during quenching under consideration of carbon repartitioning". *Mechanics of Materials* 204 (May 2025), p. 105275.

[16] H. Holthusen, T. Brepols, K. Linka, and E. Kuhl. "Automated model discovery for tensional homeostasis: Constitutive machine learning in growth and remodeling". *Computers in Biology and Medicine* 186 (2025), p. 109691.

[17] H. Holthusen, K. Linka, E. Kuhl, and T. Brepols. "A generalized dual potential for inelastic Constitutive Artificial Neural Networks: A JAX implementation at finite strains". *Journal of the Mechanics and Physics of Solids* 206 (2026), p. 106337.

[18] D. van Huyssteen, F. L. Rivarola, G. Etse, and P. Steinmann. "Quasi-optimal mesh generation for the virtual element method: A fully adaptive remeshing procedure". *Computer Methods in Applied Mechanics and Engineering* 435 (2025).

[19] D. van Huyssteen, F. L. Rivarola, G. Etse, and P. Steinmann. "On mesh refinement procedures for polygonal virtual elements". *Applications in Engineering Science* 22 (2025), p. 100222.

[20] A. Javili, E. Ekiz, and P. Steinmann. "A Geometrically Nonlinear Correspondence Model for Continuum-Kinematics-Inspired Peridynamics". *Journal of Peridynamics and Nonlocal Modeling* 7.6 (2025), pp. 1–22.

[21] A. Javili, E. Ekiz, and P. Steinmann. "A nonlinear correspondence model for three-dimensional continuum-kinematics-inspired peridynamics". *Mechanics Research Communications* 150 (2025), p. 104563.

[22] A. Javili, F. Larsson, K. Runesson, and P. Steinmann. "On a canonical interface model with application to micro-heterogeneous elastic solids". *Computer Methods in Applied Mechanics and Engineering* 440 (2025), p. 117925.

[23] T. Lapina, Y. Xiang, Q. Yao, D. Chen, J. Li, P. Steinmann, and S. Rudykh. "Microstructural buckling in soft visco-hyperelastic laminates". *International Journal of Solids and Structures* 311 (2025), p. 113242.

[24] D. Martonová, A. Goriely, and E. Kuhl. "Generalized invariants meet constitutive neural networks: A novel framework for hyperelastic materials". *Journal of the Mechanics and Physics of Solids* (2025).

[25] D. Martonová, S. Leyendecker, G. A. Holzapfel, and E. Kuhl. "Discovering dispersion: How robust is automated model discovery for human myocardial tissue?" *Biomechanics and Modeling in Mechanobiology* (2025).

[26] M. S. A. Mier, E. Türker, J. Faber, M. Friedrich, Z. Lamberger, J. Weigelt, P. Suwannakot, B. Gantert, A. Singh, V. Mössler, A. Sodmann, N. Murenu, J. Schenk, N. Schäfer, T. Blunk, A. R. Boccaccini, T. C. Lühmann, J. Tessmar, J. M. Crook, E. Tomaskovic-Crook, a. G. L. Paul D. Dalton, R. Blum, R. Strick, S. Budday, K. G. Heinze, and C. Villmann. "3D In Vitro Glioma-Neuron-Astrocyte Biomimetic Composites Recapitulate Key Molecular Mechanisms Linked to Glioblastoma Multiforme Pathophysiology". *Advanced Functional Materials* 35.22 (2025), p. 2419211.

[27] M. A. Moreno-Mateos and P. Steinmann. "Cutting soft materials: how material differences shape the response". *npj Computational Materials* (2025).

[28] M. A. Moreno-Mateos, S. Wiesheier, A. Esmaeili, M. Hossain, and P. Steinmann. "Biaxial characterization of soft elastomers: experiments and data-adaptive configurational forces for fracture". *Journal of the Mechanics and Physics of Solids* 205 (2025), p. 106339.

[29] N. Murenu, J. Faber, A. A. Soufivand, M. Buss, N. Schäfer, and S. Budday. "Cell Behavior and Complex Mechanical Properties of 3D Printed Cell-Laden Alginate-Gelatin Macroporous Mesostructures". *Macromolecular Bioscience* (2025), e00204.

[30] N. Murenu, C. Mussoni, M. S. A. Mier, P. Büttner, N. Chicaiza-Cabezas, Y.-Y. R. Dai, J. Faber, M. Fiedler, Z. Lamberger, X. J. Ng, V. Mössler, A. Rederer, J. Röder, S. Stecher, K. Theis, S. Budday, G. Lang, and N. Schäfer. "Bioprinting organs - Science or fiction? - a Review from Students to Students". *Advanced Healthcare Materials* (2025), e02103.

[31] O. Neumann, H. Surana, S. Melly, P. Steinmann, and S. Budday. "Mechanical characteristics of spinal cord tissue by indentation". *Journal of the Mechanical Behavior of Biomedical Materials* 163 (2025), p. 106863.

[32] J. Pallares, A. Fabregat, A. L. A., N. Marques, B. Santos, G. Mosca, P. V. PO, J. Ravnik, N. Vovk, B. Fraga, A. Monka, M. Martinez, N. Mestre-Curto, F. Souza, D. Fontes, N. Jüngling, J. Niessner, R. Castilla, M. Garcia-Vilchez, D. Fletcher, K. Inthavong, M. Hriberšek, P. Steinmann, J. Wedel, F. Duchaine, S. Sankurantripati, L. Amari, G. Janiga, C. Marchioli, and S. Cito. "Computational fluid dynamics challenge on indoor dispersion of pathogen-laden aerosols". *Physics of Fluids* 37 (2025), p. 025226.

[33] A. Papastavrou, P. Pivonka, I. Schmidt, and P. Steinmann. "A cellular-meso-macro three-scale approach captures remodelling of cancellous bone in health and disease". *Biomechanics and Modeling in Mechanobiology* 24 (2025), pp. 975–998.

[34] D. Pivovarov. "Novel adaptive reduced order spectral non-deterministic FEM approach to problems with general interval-fuzzy-stochastic uncertainties". *Computational Mechanics* (2025).

[35] D. Pivovarov, K. Willner, and P. Steinmann. "Overview of eXtended IsoGeometrical FEM for non-deterministic problems". *Computational Mechanics* (2025).

[36] N. Reiter, S. Auer, L. Hoffmann, L. Bräuer, F. Paulsen, and S. Budday. "Do human brain white matter and brain stem structures show direction-dependent mechanical behavior?" *Acta Biomaterialia* 199 (2025), pp. 230–251.

[37] M. Ries. "Mechanical behavior of adhesive joints: A review on modeling techniques". *Computer Methods in Materials Science* 24.4 (2025), pp. 5–35.

[38] M. Rohracker, P. Kumar, P. Steinmann, and J. Mergheim. "Efficient phase-field fracture simulations for fracture analysis in heterogeneous materials". *Computational Mechanics* (2025).

[39] L. Ruhland and K. Willner. "Mechanical characterization of a brain phantom material by combining experiments in the time and frequency domain". *Journal of the Mechanical Behavior of Biomedical Materials* 170 (2025), p. 107114.

[40] E. Saliji and M. Jabareen. "An $\mathsf{MFE}^2$ framework for the computational homogenization of nearly incompressible soft composites". *Composite Structures* 373 (2025), p. 119611.

[41] E. Schaller, A. Javili, and P. Steinmann. "A novel energy-fitted hexagonal quadrature scheme enables low-cost and high-fidelity peridynamic computations". *Computer Methods in Applied Mechanics and Engineering* 440 (2025), p. 117918.

[42] L. Schmelzle, M. Striewe, J. Mergheim, G. Meschut, G. Possart, and D. Teutenberg. "Testing, modelling and parameter identification for adhesively bonded joints under the combined influence of temperature and strain rate". *Journal of Adhesion Science and Technology* (2025).

[43] A. A. Soufivand, S. J. Lee, T. Jüngst, and S. Budday. "Challenges and perspectives in using finite element modeling to advance 3D bioprinting". *Progress in Biomedical Engineering* 7.032004 (2025).

[44] G. Stankiewicz, C. Dev, and P. Steinmann. "Configurational-force-driven adaptive refinement and coarsening in topology optimization". *Structural and Multidisciplinary Optimization* 68.8 (2025), pp. 1–15.

[45] A. Titlbach, A. Papastavrou, A. McBride, and P. Steinmann. "Modelling the flexoelectric effect in human bone – A micromorphic approach". *Computer Methods in Applied Mechanics and Engineering* 446 (2025), p. 118234.

[46] G. K. Tshikwand, M. A. Moreno-Mateos, A. Santarossa, and P. Steinmann. "Experimental insights into the thermo-mechanical fracture performance of soft shape memory polymers". *Engineering Fracture Mechanics* 327 (2025), p. 111439.

[47] J. Wedel, I. Horvat, N. Vovk, M. Hriberšek, J. Ravnik, and P. Steinmann. "A novel data-driven surrogate approach for fast evaluation of the dynamics of soft ellipsoidal micro-particles in dilute viscous flow". *Computer Methods in Applied Mechanics and Engineering* 448 (2026), p. 118452.

[48] J. Wedel, M. Hriberšek, J. Ravnik, and P. Steinmann. "Ellipsoidal soft micro-particles suspended in dilute viscous flow". *Computer Methods in Applied Mechanics and Engineering* 441 (2025), p. 117973.

[49] J. Wedel, P. Steinmann, F. Prinz, F. Lízal, M. Hriberšek, and J. Ravnik. "Mass distribution impacts on particle translation and orientation dynamics in dilute flows". *Powder Technology* 452 (2025), p. 120424.

[50] R. Xiao, Z. Chen, Y. Shi, L. Zhan, S. Qu, and P. Steinmann. "A continuum model for novel electromechanical-instability-free dielectric elastomers". *Journal of the Mechanics and Physics of Solids* 196 (2025), p. 105994.

[51] L. Zhan, S. Wang, R. Xiao, S. Qu, and P. Steinmann. "Statistical theory for polymer elasticity: From molecular kinematics to continuum behavior". *Physical Review E* 112.2 (2025), p. 025404.

[52] W. Zhao, R. Xiao, S. Pfaller, and P. Steinmann. "Modeling strain hardening in glassy polymers based on the microscopic mechanisms revealed by molecular dynamic simulations". *Journal of the Mechanics and Physics of Solids* 206 (2026), p. 106384.

## Accepted

[1] D. Böhringer, J. Hinrichsen, S. W. R. Gataulin, M. Spörrer, S. Sherifova, P. Steinmann, G. A. Holzapfel, B. Fabry, and S. Budday. "Compression-Tension-Asymmetry and Stiffness Nonlinearity of Collagen-Matrigel Composite Hydrogels". *Advanced Healthcare Materials* (2025).

[2] M. Ries, J. Tiefenthäler, M. Loser, and G. Possart. "Deciphering elastoplastic properties from atomistic structure: reactive coarse-grained MD for epoxies". *Journal of Adhesion and Adhesives* (2025).

[3] N. Tueni, E. Griffiths, J. Weickenmeier, S. Rampp, and S. Budday. "Region-dependent mechanical parameters in simulating cerebral atrophy". *APL Bioengineering* (2026).

[4] E. Türker, M. Andrade Mier, J. Faber, M. Friedrich, Z. Lamberger, . Weigelt J, C. Stigloher, N. Murenu, N. Schaefer, J. Tessmar, G. Lang, S. Budday, K. Heinze, A. Appelt-Menzel, P. Strissel, R. Strick, and C. Villmann. "A 3D biofabricated disease model mimicking the brain extracellular matrix suitable to characterize intrinsic neuronal network alterations in the presence of a breast tumor disseminated to the brain". *Advanced Functional Materials* (2025).

## Under review


[1] C. Dev, G. Stankiewicz, and M. A. Moreno-Mateos. "Optimizing remanent magnetization in magnetorheological elastomers under external permanent magnet actuation".

[2] S. Firooz, D. Reddy, and P. Steinmann. "A micromorphic-based artificial diffusion method for stabilized finite element approximation of convection-diffusion problems".

[3] S. Firooz, V. Zaburdaev, D. Reddy, and P. Steinmann. "Cellular aggregate formation: continuum modelling and computational aspects".

[4] M. Flaschel, T. Hastie, and E. Kuhl. "Non-smooth optimization meets automated material model discovery".

[5] M. Flaschel, D. Martonová, C. Veil, and E. Kuhl. "Material Fingerprinting: A shortcut to material model discovery without solving optimization problems".

[6] H. Holthusen and E. Kuhl. "A Complement to Neural Networks for Anisotropic Inelasticity at Finite Strains".

[7] D. van Huyssteen, F. L. Rivarola, G. Etse, and P. Steinmann. "Quasi-optimal mesh generation for heterogeneous materials: A fully adaptive virtual element method".

[8] J. Kehls, E. Kuhl, T. Brepols, K. Linka, and H. Holthusen. "Autoencoder-based non-intrusive model order reduction in continuum mechanics".

[9] M. Laurien, A. Javili, and P. Steinmann. "A damage formulation for continuum-kinematics-inspired peridynamics to capture fracture experiments".

[10] D. Martonová, E. Kuhl, and M. Flaschel. "Material Fingerprinting for rapid discovery of hyperelastic models: First experimental validation".

[11] O. Neumann, R. Ramachandran, H. Surana, P. Steinmann, and S. Budday. "Multimodal mechanical characterization pipeline for spinal cord tissue".

[12] O. Neumann, H. Surana, M. Hintze, S. Kürten, T. Franz, R. Ramachandran, P. Steinmann, and S. Budday. "Spatial scale of indentation explains shift in ratio between spinal cord grey and white matter stiffness".

[13] M. Rodschei, G. Possart, P. Steinmann, and J. Mergheim. "A cycle jump method for accelerating damage simulations of adhesive joints under coupled hygro-mechanical loading".

[14] M. Rolf, S. Jayatissa, S. Posch, A. Clark, E. Kuhl, and H. H. Allerkamp. "Reanimating the past: From historical collections of the placenta and uterus to modern imaging, machine learning, and multi-scale modeling".

[15] A. Santarossa, N. V. Rosales, P. Steinmann, and M. A. Moreno-Mateos. "Configurational forces explain echelon cracks in soft materials".

[16] G. Stankiewicz, C. Dev, and P. Steinmann. "A novel multi-thickness topology optimization method for balancing structural performance and manufacturability".

[17] M. Striewe, L. Schmelzle, J. Mergheim, G. Meschut, G. Possart, and D. Teutenberg. "Analytical parameter identification for a viscoplastic material model for structural adhesive bonds".

[18] T. van der Velden, B. Boes, T. Brepols, E. Kuhl, and H. Holthusen. "A note on constitutive artificial neural networks for finite strain plasticity".

[19] N. Vovk, J. Wedel, P. Steinmann, and J. Ravnik. "Fluctuations, Clustering, and Interaction-Driven Dynamics in Sedimenting Particles at Low Galileo Numbers: A Neural Network Approach."

[20] F. Weber, M. Vassaux, L. Laubert, and S. Pfaller. "The Capriccio method as a versatile tool for quantifying the fracture properties of glassy materials under complex loading conditions with chemical specificity".

[21] J. Wedel, N. Catalán, P. Steinmann, M. Hriberšek, S. Cito, S. Varela, J. Pallarès, and J. Ravnik. "Ellipsoidal particle transport and deposition in an averaged human nasal airway – a CFD study."

[22] S. Wiesheier, M. A. Moreno-Mateos, and P. Steinmann. "Data-adaptive spline-based viscoelasticity for soft solids".

## In preparation

[1] F. Hofmann, J. Faber, F. Moser, A. Cianciosi, N. Murenu, J. Schenk, K. Heinze, N. Schäfer, S. Budday, and T. Jüngst. "Integration of customizable 3D printed mixing printheads for controlled and tuneable material and stiffness gradient fabrication with high cell viability in extrusion-based bioprinting".

[2] D. Pivovarov. "Masked Canonical Polyadic Decomposition for spectral non-deterministic FEM with geometrical and topological uncertainties".

[3] E. M. Richter, F. Weber, S. Pfaller, and M. Ries. "Investigation of multiscale fracture mechanisms of thermoplastics using large-scale molecular dynamics simulations reaching up to the microscale".

[4] M. S. Schwarz and J. Mergheim. "Analyzing the Combination of the Piezoelectric and Pyroelectric Effect for Hybrid Energy Harvesting with the Finite Element Method".

[5] N. Tueni, B. Rauh, S. Rampp, J. Hinrichsen, and S. Budday. "Integration of Material Parameters Derived from Fractional Anisotropy into a Finite Element Model of the Human Brain".

[6] N. Tueni, B. Wiestler, and S. Budday. "Modeling Tumor-induced brain herniation".

[7] M. Weichelt, G. Stankiewicz, M. S. Schwarz, S. Funk, P. Steinmann, J. Mergheim, A. Martin, K. Kakimoto, and T. Fey. "Process-driven Property Control of Auxetic Structures via Robocasting and Injection Molding".

## 3.6 Conference proceedings articles

## Published

[1] J. Friedlein, J. Mergheim, and P. Steinmann. "Influence of thermal effects on clinch joining of sheet metal". In: *21st International Conference on Sheet Metal (SHEMET 2025)*. Vol. 52. Materials Research Forum LLC, 2025.

[2] N. Harl, J. Wedel, P. Steinmann, J. Ravnik, and M. Hriberšek. "CFD simulacija polnjenja vijale s suspenzijo deformabilnih mikrodelcev". In: *Conference: Kuhljevi dnevi 2025*. Univerzitetna knjižnica Maribor, 2025.

[3] I. Horvat, J. Wedel, N. Vovk, B. Kamenik, P. Steinmann, and J. Ravnik. "Towards Implementation of Advanced Bioheat Models in Human Head Exposed to 5G Radiation". In: *Conference: The 33rd International Conference on Software, Telecommunications, and Computer Networks*. IEEE, 2025.

## Under review

[1] L. Ruhland and K. Willner. "Combined analysis of the mechanical behavior in the time and frequency domain of a viscoelastic brain phantom material".

[2] N. Vovk, J. Wedel, S. Rustico, B. Pulvirenti, P. Steinmann, and J. Ravnik. "A Practical Approach to Modelling Evaporation in 3D CFD Simulations of Domestic Ovens for EN60350 Testing".

## 3.7 Monographs, books and book chapters

**Model Validation and Uncertainty Quantification in Biomechanics: From Soft Biological Tissue to Blood Flow**
Editors: G. A. Holzapfel, M. Rolf and X. Yun Xu
Academic Press, in preparation.

**Constitutive Modelling of Solid Continua**
Editors: J. Merodio and R. W. Ogden
Springer Nature, 2025.

- P. Steinmann, A. McBride and A. Javili:
  *Nonlocal Integral-Type Elasticity: Foundations of Continuum-Kinematics-Inspired Peridynamics (CPD)*

**Encyclopedia of Continuum Mechanics**
Editor: H. Altenbach
Springer Nature, 2025.

- M. Mehnert, M.A. Moreno-Mateos and P. Steinmann:
  *On Coupled Problems in Soft Non-Conducting Materials*

**Progress in Powder Based Additive Manufacturing**
Editors: D. Drummer and M. Schmidt
Springer Nature, 2025.

- C. Burkhardt, D. Soldner, P. Steinmann and J. Mergheim:
  *Macroscopic Modeling, Simulation, and Optimization.*

- Z. Yang, L. Herrnböck, M. Markl, J. Mergheim, P. Steinmann and C. Körner:
  *Mesoscopic Modeling and Simulation of Properties of Additively Manufactured Metallic Parts.*

## 3.8 Doctoral theses

- A. Santarossa:
  *Experimental Research and Enhancement of Granular Gripping Systems.* Dissertation. Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 2025.

- G.K. Tshikwand:
  *Fully Coupled FEA Simulation of Re-programmable Origami Micro-Matter.* Dissertation. Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 2024.

- J. Wedel:
  *Dancing with the flow: Numerical modelling of non-ideal micro-particles in fluids.* Dissertation. Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 2025.

- R. Zabihyan:
  *Modeling and Computational Homogenization of Magnetorheological Composite Materials.* Dissertation. Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 2025.

- M.S. Zarzor:
  *Multifield Modelling of Human Brain Development: From Cells to Organ.* Dissertation. Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 2025.

# 4 Ongoing research projects

The following pages allow a short overview on the various ongoing research projects pursued at the Institute of Applied Mechanics and the Institute of Continuum Mechanics and Biomechanics during 2025. These are mainly financed by third-party funding of various (public and industrial) funding sources and are in addition supported by the core support of the university. We have a nice mix of continuations of previous projects with projects that started afresh in 2025.
Also the complementing expertise – as displayed in the five working groups for continuum mechanics, structural mechanics, computational mechanics, multi-scale simulation 'Capriccio' and the Emmy-Noether Group 'BRAIn mechaNIcs ACross Scales' established at the Institute of Applied Mechanics and the Institute of Continuum Mechanics and Biomechanics – is reflected by the variety of research that is performed. This spans from atomistic approaches to material modeling, from experimental investigations to computational challenges and from frictional contact to structural problems. Certainly, the research on these topics constantly produces new insights, thus the following reports can only shed a spot-light on the current state of affairs.

– Biomechanics –

# Finite element modeling (FEM) to advance extrusion-based 3D bioprinting

**Anahita Ahmadi Soufivand**[1], **Sang Jin Lee**[2], **Tomasz Jüngst**[3], **Silvia Budday**[1]

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Extrusion-based bioprinting is a trial-and-error process to find the best parameters for producing 3D structures with different bioinks and cells [1]. FEM can play a significant role in the progress of this printing method by providing a powerful tool for simulating and optimizing before, during, and after the printing procedure. It can predict and analyze the effect of functional parameters, e.g., printing patterns and pore size, on the mechanical properties of bioprinted constructs. FEM accelerates the optimization process and reduces material usage and costs. Additionally, access to parameters that are experimentally inaccessible becomes possible, such as internal stress distributions within bioprinted constructs and localized deformations during cross-linking, which enhances the success rate of fabricating complex constructs. Figure 1 demonstrates the differences between extrusion bioprinting with and without utilizing FEM.

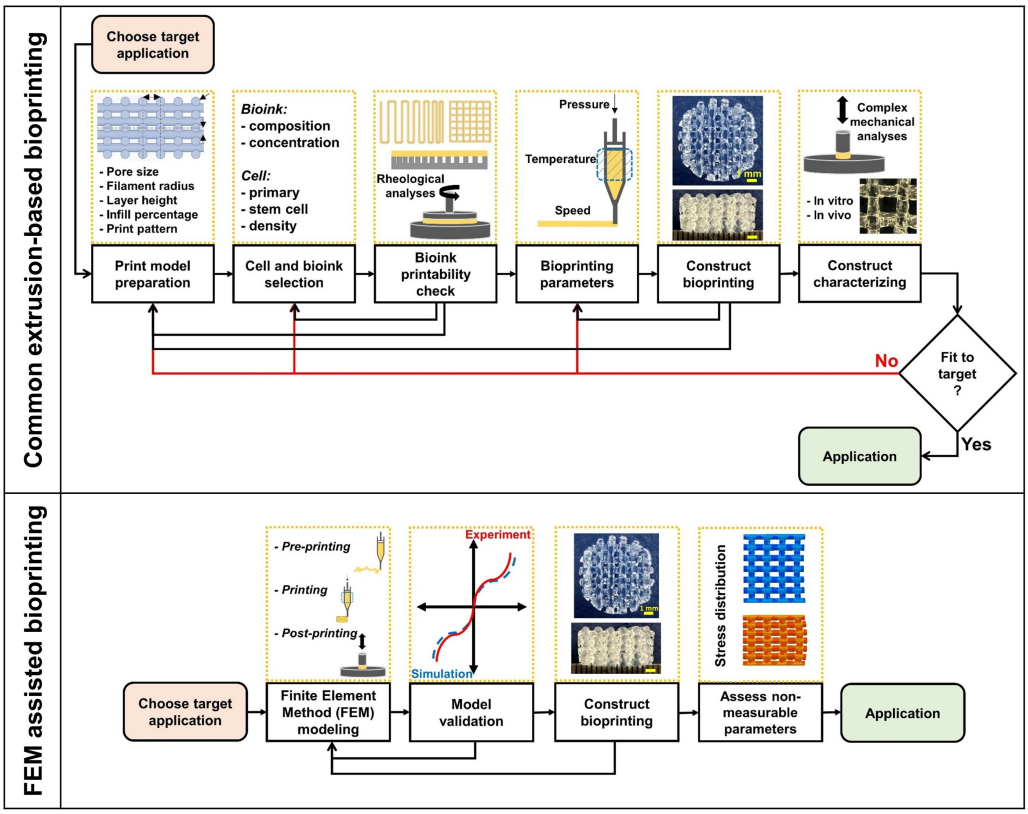


**Figure 1:** Schematic comparison of the typical bioprinting process (top) and FEM assisted bioprinting (bottom) for extrusion-based bioprinting applications.

## References

[1] A. A. Soufivand, S. J. Lee, T. Jüngst, and S. Budday. "Challenges and perspectives in using finite element modeling to advance 3D bioprinting". *Progress in Biomedical Engineering* 7.032004 (2025).

# Biomechanical properties and hyperelastic modeling of 3D bioprinted cell-laden hyaluronic acid-based hydrogels during chondrogenesis for cartilage repair

**Jessica Faber[1], Paula Büttner[2], Torsten Blunk[2], Silvia Budday[1]**

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[2] Department of Trauma, Hand, Plastic and Reconstructive Surgery, University of Würzburg

Articular cartilage (AC) serves an important mechanical function in the human body, i.e., load bearing and shock absorption. For the design of implants for cartilage repair after injury or disease, it is key to thoroughly understand the unique biomechanical properties of the native tissue and potential substitute materials. Based on our previous study on human healthy and osteoarthritic AC tissue [1], we use multimodal mechanical testing methods combined with hyperelastic nonlinear continuum mechanics modeling, finite element simulations, and immunohistochemistry to correlate the macroscopic behavior to the underlying microstructural properties of bioprinted cartilaginous samples generated from bone marrow-derived mesenchymal stromal cells (MSCs) embedded in thiolated hyaluronic acid (HA-SH) hydrogels. Our results confirm that the cartilaginous tissues based on chondrogenically differentiated MSCs in HA-SH hydrogels exhibit an increase in the maximal nominal stress with more pronounced mechanical characteristics, including nonlinearity, hysteresis, conditioning, and stress relaxation (Figure 1a-c) over 42 days. Furthermore, cartilaginous tissue after 42 days shows similar cyclic loading behavior with a classical shear modulus of 50.2 kPa and stress relaxation behavior up to 91 % within 300 s in compression compared to human AC tissue with a classical shear modulus of 60.4 kPa and a stress relaxation behavior between 79 % and 84 % within 300 s in compression [1]. Finally, our study reveals a strong linear correlation ($R^2 = 0.995$) between the amount of collagen and the classical shear modulus (Figure 1d), which could be used for the prediction of the classical shear modulus, as a measure of stiffness, of cell-laden HA-SH hydrogels. The presented results will help guide the design of implants that are able to restore cartilage structure and function, bridging biomechanics and regenerative medicine for osteoarthritis treatment.

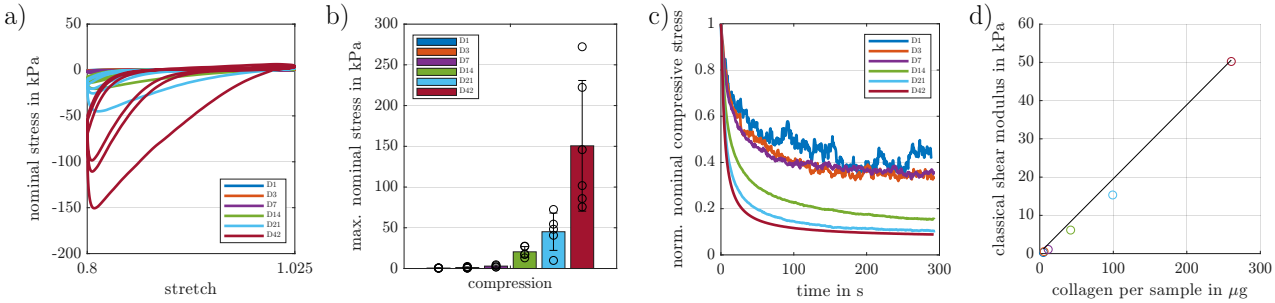


**Figure 1:** a) Cyclic loading behavior of cell-laden HA-SH samples over time on days 1, 3, 7, 14, 21, and 42. b) Average maximum nominal stress in compression. c) Stress relaxation behavior in compression. d) Linear correlation between the amount of collagen per sample and classical shear modulus of cell-laden HA-SH samples.

## References

[1] J. Faber, A. Greiner, P. Büttner, C. Schoppe, L. Bräuer, F. Paulsen, T. Blunk, M. Perl, M. Betsch, and S. Budday. "Poro-viscoelastic mechanical characterization of healthy and osteoarthritic human articular cartilage". *Journal of the Mechanical Behavior of Biomedical Materials* 173 (2026), p. 107226.

# A micromorphic-based artificial diffusion method for stable finite element approximation of reaction-convection-diffusion problems

**Soheil Firooz[1], B. Daya Reddy[2], Vasily Zaburdaev[3], Paul Steinmann[1]**

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[3] Department of Biology, FAU

In this project we developed a micromorphic-based artificial diffusion (MMAD) method to address the numerical instabilities that often occur in standard Galerkin finite element formulations of reaction-convection-diffusion problems. The approach enriches the classical formulation by incorporating an auxiliary micromorphic variable and its gradient, which enhances stability and accuracy across a range of challenging scenarios. Comprehensive theoretical analysis established conditions for well-posedness and convergence, and a series of numerical examples demonstrated the method's robustness and stability in reaction- and convection-dominated regimes [1, 2]. In Fig. 1, we examine a two-dimensional reaction–convection–diffusion problem with Dirichlet boundary conditions prescribed along all edges. The first row presents the reaction-dominated case, characterized by a large Damköhler number, while the second row corresponds to the convection-dominated case, where the Peclet number is large. For FEM, small oscillations are observed near the boundaries in the reaction-dominated case whereas for the convection-dominated case the solution becomes completely unstable. In contrast, the MMAD results remain stable and free of spurious oscillations across all parameter regimes. Future work will focus on extending the MMAD framework to biomechanical applications, specifically to the modeling of cellular aggregate formation, where sharp gradients arise at the aggregate boundaries [3].

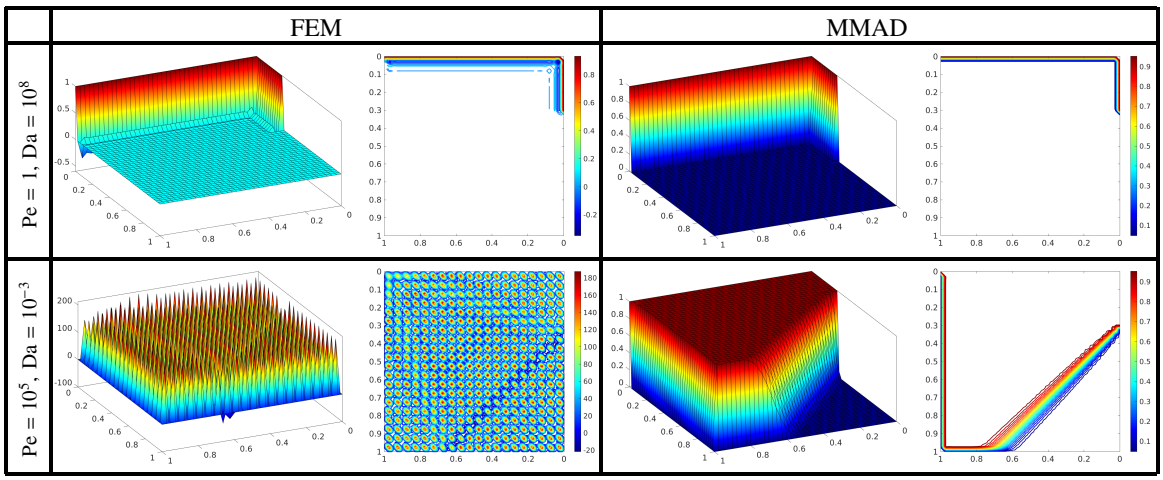


**Figure 1:** Comparison of FEM and MMAD solution for a reaction-convection-diffusion problem.

## References

[1] S. Firooz, D. Reddy, and P. Steinmann. "A gradient-enhanced approach for stable finite element approximations of reaction-convection-diffusion problems". *Journal of Theoretical, Computational and Applied Mechanics* (2025), pp. 1–17.

[2] S. Firooz, D. Reddy, and P. Steinmann. "A micromorphic-based artificial diffusion method for stabilized finite element approximation of convection-diffusion problems" (under review).

[3] S. Firooz, V. Zaburdaev, D. Reddy, and P. Steinmann. "Cellular aggregate formation: continuum modelling and computational aspects" (under review).

# Modelling Mechanics-Induced Damage of Brain Tissue

**Jaimé Goedhals, Silvia Budday**

Certain neurological disorders require treatment through surgery. However, due to the ultra-soft nature of brain tissue [1], large deformations of brain tissue may occur during such procedures, possibly causing damage. Therefore, the goal of this project, funded under Horizon Europe (ERC-StG, MAGERY, Project 101116420), is to better understand large-strain mechanical behavior of brain tissue, and develop a damage model for simulating mechanical tissue damage. We carried out cyclic compression experiments on porcine corona radiata using a rheometer. We subjected samples, of approximately 5mm in height and 8mm in diameter, to two cycles of 10% compression strain, then allowed the samples to rest for 20 minutes to allow for recovery, and then subjected the samples to a further two cycles of 25% compression strain.
A hyperelastic modified one-term Ogden model, including damage, (Eq. 1) was implemented in the C++ library deal.II.

$$\begin{aligned}\Psi &= (1-D)\Psi_{\text{iso},0} + \Psi_{\text{vol}} \\ &= (1-D)\frac{2\mu}{\alpha^2}\left(\bar{\lambda}_1^\alpha + \bar{\lambda}_2^\alpha + \bar{\lambda}_3^\alpha - 3\right) + \frac{\kappa}{4}\left(J^2 - 1 - 2\ln J\right)\end{aligned} \tag{1}$$

The scalar damage function, $D$, is given by Eq. 2 [2],

$$D = \begin{cases} \exp\left(\left(\frac{\lambda_m - \lambda_{\text{crit}}}{m}\right)^2\right) - 1, & \text{if } \lambda_m \geq \lambda_{\text{crit}} \\ 0, & \text{otherwise} \end{cases}, \qquad \text{where } \lambda_m = \max_{s\in(-\infty,t]}\lambda(s). \tag{2}$$

The experimental and simulation results are shown in Figs. 1 and 2. An overall good agreement is seen between the experimental and simulation results, however, the fit for the damage model (Fig. 2) could be improved.

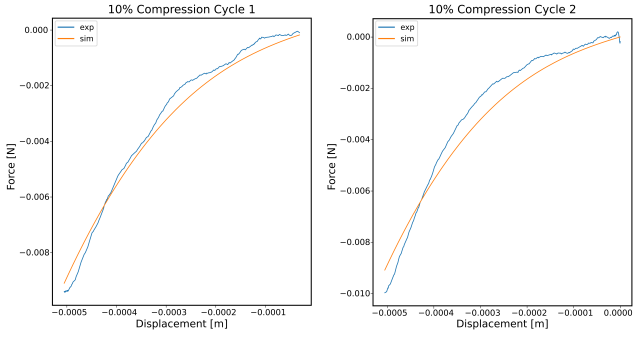


**Figure 1:** Force vs displacement curves comparing the experimental and simulation results for the 10% compression cycles.

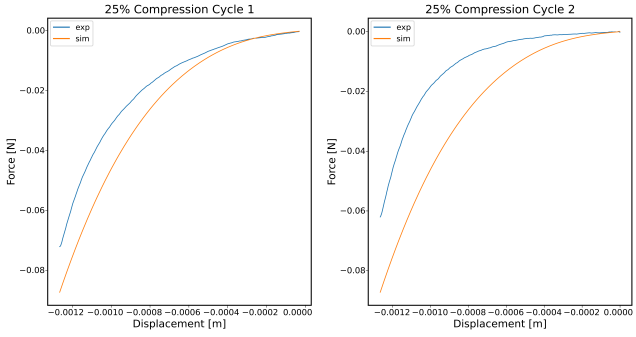


**Figure 2:** Force vs displacement curves comparing the experimental and simulation results for the 25% compression cycles.

## References

[1] S. Budday, T. C. Ovaert, G. A. Holzapfel, P. Steinmann, and E. Kuhl. "Fifty Shades of Brain: A Review on the Mechanical Testing and Modeling of Brain Tissue". *Archives of Computational Methods in Engineering* 27.4 (2020), pp. 1187–1230. DOI: 10.1007/s11831-019-09352-w.

[2] M. K. Rausch, G. E. Karniadakis, and J. D. Humphrey. "Modeling Soft Tissue Damage and Failure Using a Combined Particle/Continuum Approach". *Biomechanics and Modeling in Mechanobiology* 16.1 (2017), pp. 249–261. DOI: 10.1007/s10237-016-0814-1.

# A constitutive model for multimodal characterization of spinal cord tissue by indentation and large-strain cyclic loading

**Rahul G. Ramachandran, Oskar Neumann, Silvia Budday, Paul Steinmann**

Spinal cord tissue in mammals, including humans and pigs, is heterogeneous, with butterfly-shaped gray matter surrounded by white matter. Characterizing these distinct regions and the bulk response requires integrating multiple experimental modalities across scales. We present a modified two-term Ogden constitutive model that captures local white and gray matter properties via indentation testing and bulk response from compression–tension cyclic loading.

Indentation tests provide quantitative information on the shear modulus and compression stiffening, while complementary compression–tension experiments reveal pronounced tension–compression asymmetry: the tissue stiffens at low compressive strains but only at much larger tensile strains. Capturing both behaviors within a single constitutive framework presents a modeling challenge. To address this, we modify the classical two-term Ogden formulation [2]. In the standard model [1], the strain energy depends on two parameter sets, $(\mu_1, \alpha_1)$ and $(\mu_2, \alpha_2)$, which jointly describe nonlinear behavior. However, parameter coupling limits independent control over the tensile and compressive responses.

In the modified model, a proportionality factor $n$ links the second shear modulus to the total shear modulus ($\mu_2 = n\mu$) and reformulates the first as $\mu_1 = \frac{2-n\alpha_2}{\alpha_1}$. The isochoric strain energy density is:

$$\psi_{\text{iso}} = \mu \left[ \frac{2 - n\alpha_2}{\alpha_1^2} \left[ \bar{\lambda}_1^{\alpha_1} + \bar{\lambda}_2^{\alpha_1} + \bar{\lambda}_3^{\alpha_1} - 3 \right] + \frac{n}{\alpha_1} \left[ \bar{\lambda}_1^{\alpha_2} + \bar{\lambda}_2^{\alpha_2} + \bar{\lambda}_3^{\alpha_2} - 3 \right] \right], \tag{1}$$

where $\alpha_1 < 0$ governs compression stiffening and $\alpha_2 > 0$ governs tension stiffening. Sensitivity analysis identifies an optimal coupling factor of $n = 0.0005$ and a constant offset for $\alpha_2$, denoted $\alpha_2^o = 32.7$, which ensures effective decoupling of $\alpha_1$ and $\alpha_2$. This enables independent tuning of tensile and compressive responses (Fig.1b), including indentation behavior (Fig.1a).

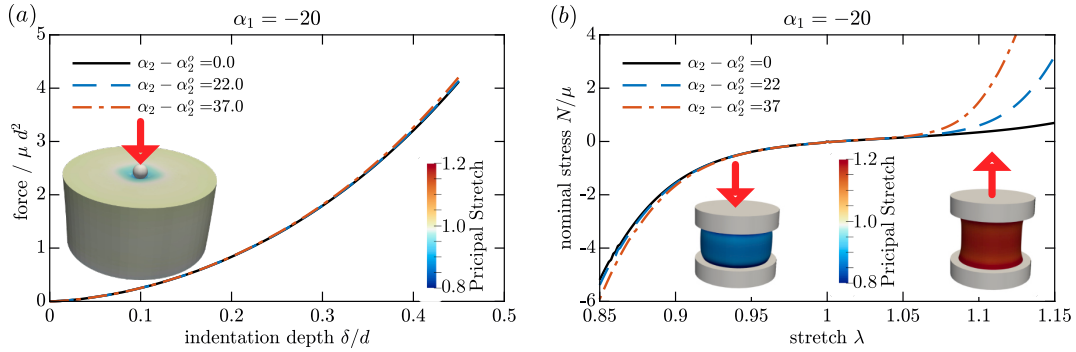


**Figure 1:** Predicted response of the modified two-term Ogden model under (a) indentation and (b) tension–compression loading. Varying $\alpha_2$ minimally affects compression but significantly modulates tensile stiffening. Extreme principal stretch is plotted on the deformed configurations.

## References

[1] O. Neumann, R. G. Ramachandran, H. V. Surana, P. Steinmann, and S. Budday. "Multimodal mechanical characterization of spinal cord tissue by indentation and large-strain cyclic loading". *Acta biomaterialia* (2025). Submitted.

[2] R. W. Ogden. "Large deformation isotropic elasticity". *Proceedings of the Royal Society of London. A. Mathematical and Physical Sciences* 326.1567 (1972), pp. 565–584.

# Poro-viscoelasticity of human brain tissue: towards robust material parameter identification.

**Alexander Greiner[1], Ester Comellas[3], Paul Steinmann[2], Silvia Budday[1]**

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[2] Institute of Applied Mechanics, FAU
[3] Department of Physics, UPC

Modeling the complex, biphasic material response of ultrasoft human brain tissue subjected to mechanical loading remains an ongoing challenge in the field of biomechanics. Our nonlinear poro-viscoelastic model based on the Theory of Porous Media has already proven its capability to model our experimental results and allows us to explore the underlying physical mechanisms, including interactions between solid matrix and free-flowing interstitial fluid. Thereby, we uncovered the strong coupling between porous, viscous and volumetric effects – highlighting the importance and influence of each individual model parameter [1].
But, high model complexity increases uncertainty regarding the material parameter uniqueness. In Figure 1, we perform a "numerical" relaxation experiment and then apply our inverse parameter identification algorithm [2] to fit the stress-time curve starting from 128 different sets of initial parameters. It turns out that the stress response is fitted reasonably well in most cases, but, the lateral displacement of a point located on the cylinder surface at half of the specimen height is virtually all over the place. This indicates that the same stress response can be caused by various actual deformations of a biphasic material, most of them not physically meaningful for human brain tissue. Figure 2 shows the results of the inverse parameter identification including the lateral displacement as an additional term in the objective function. Incorporating additional experimental data in terms of the "relatively easily" accessible lateral deformation increases the likelihood of physically reasonable material parameters significantly, even though the results are not yet unique.

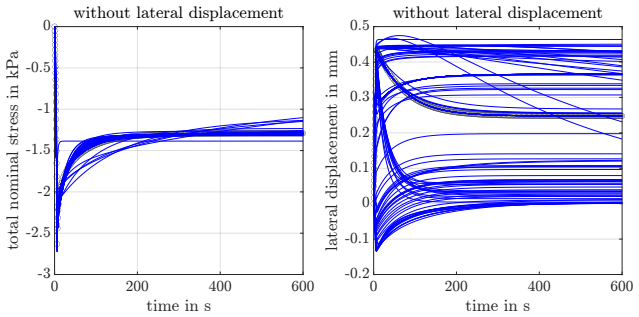


**Figure 1:** Inverse parameter identification based solely on the reaction force.

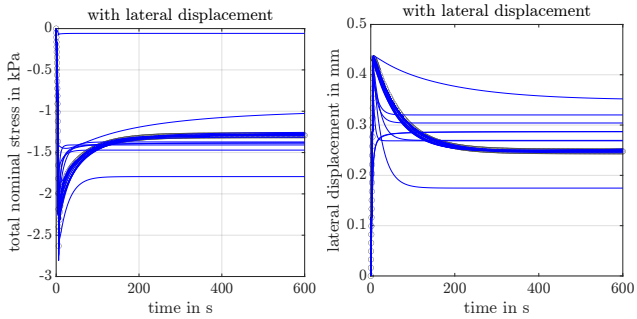


**Figure 2:** Inverse parameter identification including both, reaction force and lateral displacement.

## References

[1] A. Greiner, N. Reiter, J. Hinrichsen, M. P. Kainz, G. Sommer, G. A. Holzapfel, P. Steinmann, E. Comellas, and S. Budday. "Model-driven exploration of poro-viscoelasticity in human brain tissue: be careful with the parameters!" *Interface Focus* 14.6 (2024), p. 20240026.

[2] J. Hinrichsen, N. Reiter, L. Bräuer, F. Paulsen, S. Kaessmair, and S. Budday. "Inverse identification of region-specific hyperelastic material parameters for human brain tissue". *Biomechanics and Modeling in Mechanobiology* 22.5 (2023), pp. 1729–1749.

# *In silico* modeling of brain malformations

**Jan Hinrichsen[1], Mohammad Saeed Zarzor[1], Ingmar Blümcke[2], Silvia Budday[1]**

[1]Institute of Continuum Mechanics and Biomechanics, Friedrich-Alexander-Universität
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In drug resistant cases of focal cortical dysplasia (FCD) epilepsies the commonly chosen therapy is the surgical resection of the epileptic tissue at the lesion location. To achieve a successful outcome of the surgery, a seizure free life for the patient, while minimizing functional losses, it is of utmost importance to locate the lesion site as accurately as possible. We are developing a computational finite element model that predicts brain malformations as they are found in patients with FCD type IIb. The model captures cell density evolution during development, modeled as an advection-diffusion problem, and couples it to a mechanical finite growth problem. We extend the model developed by Zarzor et al. [2] and additionally capture pathological changes during the cellular development. As a first study we model how local overexpression of transcription factor Cux2 leads to additional folding in ferret brains, as observed by Singh et al. in their experimental studies [1]. They found that Cux2 overexpression leads to direct neurogenesis in radial glial cells. For the population of neuronal cells, this leads to an initially higher density close to the cortical plate, but a lower density in the cortex towards the end of gyrification. We integrate this mechanism into our model and observe brain malformations in the predicted morphology. Figure 1 shows the expected intially higher neuronal cell density in the Cux2-affected region at the beginning of brain development, as well as lower density in the resulting sharp central fold in Figure 2 due to the Cux2-induced direct neurogenesis.

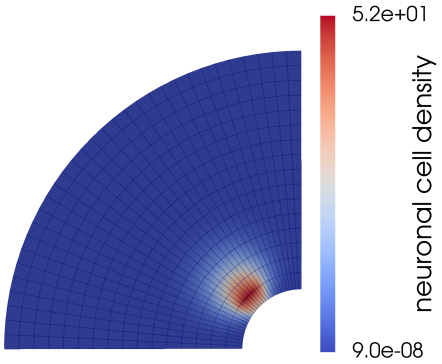


**Figure 1:** Higher neuronal cell density in Cux2-affected region.

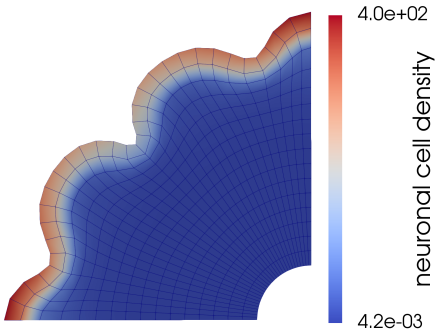


**Figure 2:** Lower cell density in resulting sharp fold.

## References

[1] A. Singh, L. Del-Valle-Anton, C. de Juan Romero, Z. Zhang, E. F. Ortuño, A. Mahesh, A. Espinós, R. Soler, A. Cárdenas, V. Fernández, R. Lusby, V. K. Tiwari, and V. Borrell. "Gene Regulatory Landscape of Cerebral Cortex Folding". *Science Advances* 10.23 (June 2024), eadn1640.

[2] M. Zarzor, S. Kaessmair, P. Steinmann, I. Blümcke, and S. Budday. "A Two-Field Computational Model Couples Cellular Brain Development with Cortical Folding". *Brain Multiphysics* 2 (2021), p. 100025.

# Multi-scale simulation of bone adaptation

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[2] Computer-assisted Biomechanics, Technische Hochschule Nürnberg Georg Simon Ohm, Germany
[3] Biomedical Engineering and Spinal Disorders, Queensland University of Technology, Brisbane, Australia

Bone tissue is a highly complex material that fulfils several different functions, including load-bearing and providing stiffness to the skeleton. Bone tissue renews continuously over a lifetime to ensure its functions are met, also referred to as bone remodelling. Due to their mechanosensory property, osteocytes in the bone matrix can detect damage. This initiates the process of bone resorption, whereby osteoclasts dissolve the mineralised bone matrix. Osteoblasts then form new bone tissue. Pivonka et al. [2] construct models of cell population dynamics by formulating the behaviour of cells in terms of proliferation, differentiation and apoptosis as differential equations, see figure 1.
In order to gain further insights into the relationship between the experienced mechanical load at a macro level and the adaptation of the bone structure, Papastravrou et al. [1] developed a three-scale approach, see figure 2. This approach involved the linkage of the bone at the macro level, the trabecular structure at the meso level, and the bone cell population at the micro level. This study aims to investigate the numerical stability of the underlying numerics, paying particular focus to the linearisation used for time integration and homogenisation across three scales, to gain a realistic and robust framework which could be applied to model, for example, the treatment of implants and scaffolds or immobilisation and bone diseases.

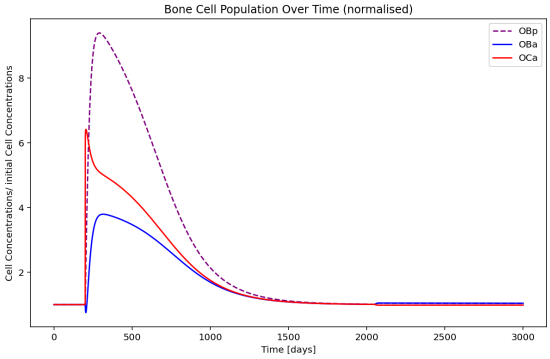


**Figure 1:** The evolution of bone cell concentrations in the event of disuse over a period of 200–2050 days. Abbr.: Precursor osteoblasts (OBp), active osteoblasts (OBa) and active osteoclasts (OCa).

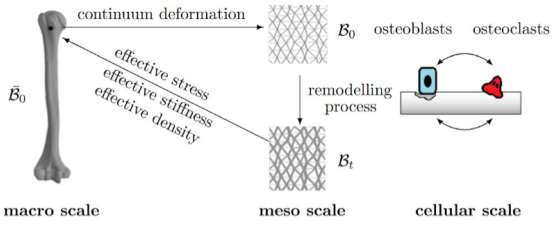


**Figure 2:** The three-scale approach to trabecular bone remodelling. Figure taken from [1].

## References

[1] A. Papastavrou, P. Pivonka, I. Schmidt, and P. Steinmann. "A Cellular-Meso-Macro Three-Scale Approach Captures Remodelling of Cancellous Bone in Health and Disease". *Biomechanics and Modeling in Mechanobiology* 24.3 (2025), pp. 975–998. ISSN: 1617-7940. DOI: 10.1007/s10237-025-01948-5.

[2] P. Pivonka, J.Zimak, D. Smith, B. Gardiner, C. Dunstan, N. T. J. Martin, and G. Mundy. "Model Structure and Control of Bone Remodeling: A Theoretical Study". *Bone* 43.2 (2008), pp. 249–263. ISSN: 87563282. DOI: 10.1016/j.bone.2008.03.025.

# Real-time visualization of the cellular responses to mechanical loading

**Julia Kolb, Silvia Budday**

Cellular behavior and function are significantly influenced by mechanical stimuli, including the mechanical properties of their environment and forces exerted on them. These forces can lead to local tissue deformation [2] and potential damage, depending on the applied loading, its direction, magnitude, duration, rate, as well as the local mechanical properties that can surpass functional tolerance [1]. Current research lacks comprehensive data on how complex three-dimensional (3D) loading scenarios translate to the cellular scale, limiting the examination of biochemical effects on cells in deeper tissue layers in response to loading. Multiphoton microscopy provides a solution allowing for deeper penetration depths, reduced phototoxicity, and enhanced 3D resolution compared to commercially available setups.

To address this, we have combined, for the first time, a rheometer for multi-modal large-strain mechanical measurements with a customized two-photon microscope for simultaneous imaging (1). This new setup enables us to investigate how tissue-scale mechanical loading translates to the cell scale, allowing real-time assessment of cellular behaviors (e.g., deformation (2), dysfunction or death) in their 3D environment, including tissue or *in vitro* systems, such as 3D cell cultures or organoids.

Overall, this combined approach aims to enhance our understanding of mechanically induced cellular responses and identify 3D thresholds for mechanics-induced tissue and cell damage under multi-modal loading.

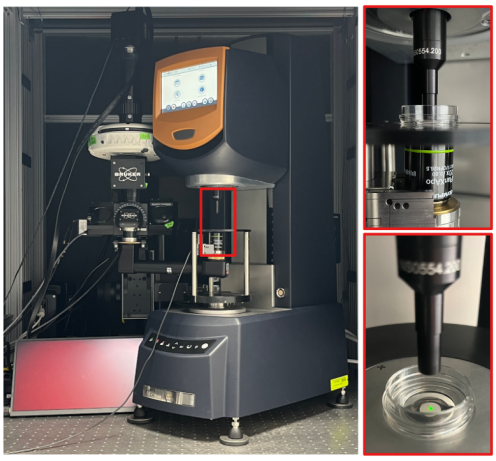

**Figure 1:** Combined setup comprising a rheometer (Discovery HR 30, TA Instruments) and a two-photon microscope (Ultima Investigator Plus, Bruker).

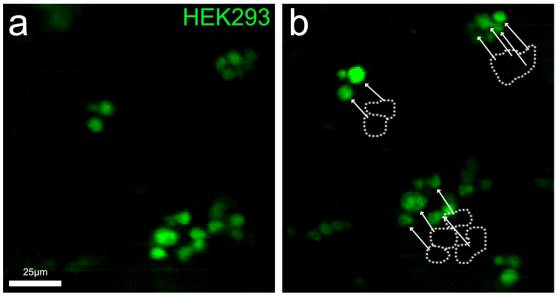


**Figure 2:** Displacement of human embryonic kidney (HEK293) cells (green) during compressive loading. Dashed lines in b) indicate initial position of the cells before compression. Arrows depict the displacement.

## References

[1] P. Bayly, T. Cohen, E. Leister, E. L. D. Ajo, and G. Genin. "Deformation of the human brain induced by mild acceleration". *Journal of Neurotrauma* 22.8 (2005), pp. 845–56. DOI: 10.1089/neu.2005.22.845.

[2] N. Reiter, B. Roy, F. Paulsen, and S. Budday. "Insights into the Microstructural Origin of Brain Viscoelasticity". *Journal of Elasticity* 145 (2021), pp. 99–116. DOI: 10.1007/s10659-021-09814-y.

# Material model discovery for human myocardium

**Denisa Martonová, Sigrid Leyendecker[1], Gerhard A. Holzapfel[2], Ellen Kuhl[3]**

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[2] Institute of Biomechanics, Graz University of Technology, Austria
[3] Department of Mechanical Engineering, Stanford University, United States

Computational modeling serves as a powerful approach to investigate how the structural organization of biological tissues influences their functional behavior, particularly in the human myocardium. Conventional constitutive models, as well as those generated through automated model discovery, typically assume perfectly aligned fiber orientations. However, experimental studies indicate that many fiber-reinforced tissues exhibit dispersed fiber arrangements as depicted in Figure 1, which significantly affect their mechanical response.

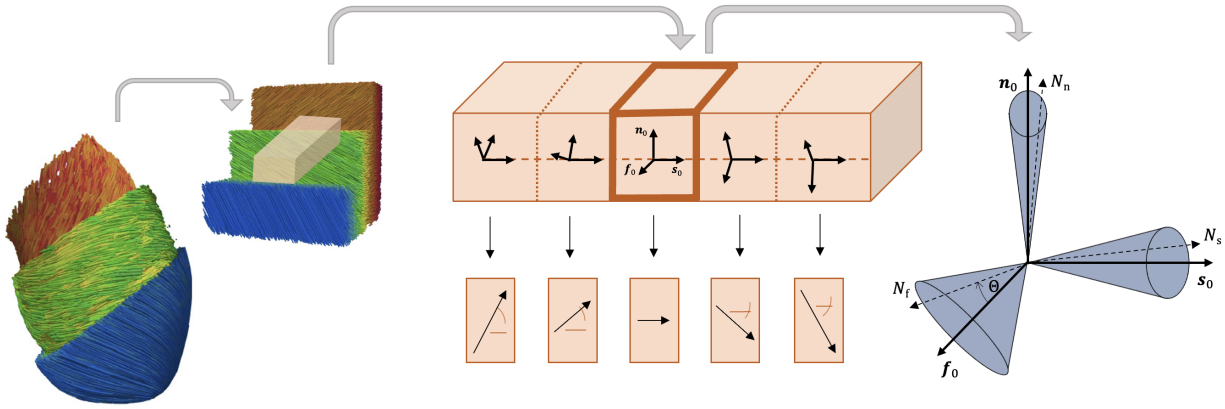


**Figure 1:** Fiber, sheet, and normal architecture in the left ventricle [1].

In our work [1], the generalized structure tensor framework is incorporated into an automated model discovery process to represent fibers distributed probabilistically around three orthogonal directions: fiber, sheet, and normal. Using biaxial extension and triaxial shear data from human myocardium, the research systematically examines the impact of directional dispersion and stress measurement noise on model robustness. The findings reveal that moderate fiber dispersion – and arbitrary dispersion in sheet and normal directions – enhances model accuracy and facilitates recovery of a known four-term constitutive model involving isotropic $I_2$, dispersed anisotropic $I^*_{4f}, I^*_{4n}$, and coupling $I^*_{8fs}$ invariants. Importantly, the approach remains robust, consistently identifying similar model structures even under stress data noise of up to 7%. Overall, the study demonstrates that automated model discovery using generalized structure tensors effectively captures microstructural variability and uncertainty in myocardial tissue mechanics.

## References

[1] D. Martonová, S. Leyendecker, G. A. Holzapfel, and E. Kuhl. "Discovering dispersion: How robust is automated model discovery for human myocardial tissue?" *Biomechanics and Modeling in Mechanobiology* (2025).

# Mechanical characterization of spinal cord tissue

**Oskar Neumann, Rahul Gopalan Ramachandran, Silvia Budday, Paul Steinmann**

Based on our previous study [3], we developed an experimental multi-scale approach to investigate how using different indenter diameters can explain contradicting results for central nervous system tissue in the literature. With regards to the available body of research, we observe that white matter is reported stiffer than grey matter tissue for large indenters (>500 $\mu$m in diameter), while the opposite is reported for smaller indenters. To test if this tendency can be replicated using a single experimental setup and tissue sample, we performed multiple indentation grid scans on spinal cord gray and white matter tissue with varying indenter diameters, ranging from 20 to 500 $\mu$m [2]. With this, we were able to observe a shift in gray to white matter stiffness ratio from $> 1$ (gray stiffer) to $< 1$ (white stiffer) for indenter diameters between 200 and 300 $\mu$m in diameter. Additionally, we showed that this tendency can only be measured for tests on the transverse anatomical plane of the spinal cord samples but not on the coronal plane. We hypothesize that these observations could be attributed to differences in diffusion properties and microstructural architecture of gray and white matter tissue.
Furthermore, we developed a multimodal experimental pipeline to test equidistantly spaced samples from the same spinal cord organ and computationally simulate these tests to characterize mechanical properties [1]. The multimodal pipeline comprises two mechanical test systems (see Figure 1). First, we perform indentation measurements on gray and white matter individually with three grids of ten points each on both tissue types with increasing loading rates. Subsequently, the same sample is mounted in a rheometer for the mechanical analysis of the bulk material properties during large-strain cyclic loading. We showed that the averaged shear moduli of the bulk material response during compression-tension tests on the whole samples (combined gray and white matter response) falls in between the individual gray and white matter shear moduli from the indentation tests on the same samples. This work provides a proof of concept for our multimodal experimental pipeline and computational characterization routine, enabling its future application to human spinal cord and other tissue samples.

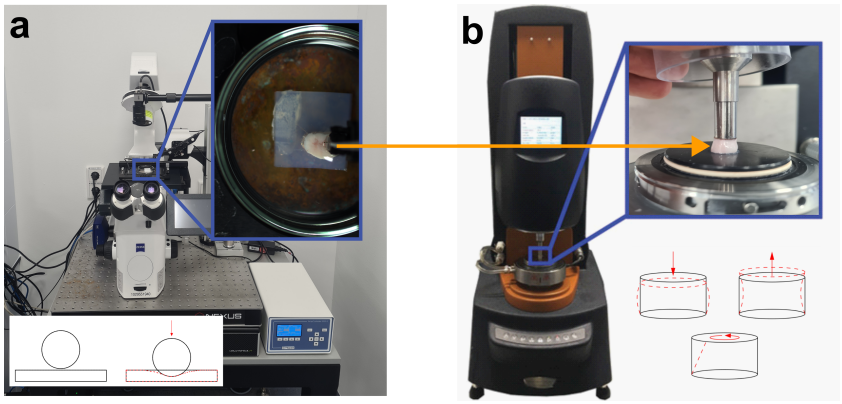


**Figure 1:** Experimental pipeline for multimodal mechanical analysis of spinal cord tissue. (a) Indentation, (b) rheometer test.

## References

[1] O. Neumann, R. Ramachandran, H. Surana, P. Steinmann, and S. Budday. "Multimodal mechanical characterization pipeline for spinal cord tissue".

[2] O. Neumann, H. Surana, M. Hintze, S. Kürten, T. Franz, R. Ramachandran, P. Steinmann, and S. Budday. "Spatial scale of indentation explains shift in ratio between spinal cord grey and white matter stiffness".

[3] O. Neumann, H. Surana, S. Melly, P. Steinmann, and S. Budday. "Mechanical characteristics of spinal cord tissue by indentation". *Journal of the Mechanical Behavior of Biomedical Materials* 163 (2025), p. 106863.

# Regional mechanics of human brain white matter and lower brain stem

**Nina Reiter[1], Sophia Auer[2], Lucas Hoffmann[3], Lars Bräuer[2], Friedrich Paulsen[2], Silvia Budday[1]**

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[2] Institute of Clinical and Functional Anatomy, FAU
[3] Institute of Neuropathology, Universitätsklinikum Erlangen

Brain tissue is often broadly categorized into gray and white matter. However, the brain is actually much more complex than that and tissues that look similar on a macroscopic scale can differ significantly on the microscale. While it is well known that gray matter from the cortex (where neurons are arranged in layers) is different from gray matter of inner brain regions (where neurons are more dispersed), the differences between white matter from different brain areas are usually not accounted for in biomechanical studies. Here, we have performed large-strain mechanical testing under compression, tension, and torsional shear on tissue from seven different human brain white matter and brain stem regions, as shown in Figure 1a [1]. Our results highlight that the different white matter and brain stem regions show distinct mechanical behaviors. These differences can be partially explained by differences in the corresponding microstructure, as described in [1]. Comparison of the averaged regional stress responses shows that the corpus callosum is substantially softer than the other brain regions. Cerebral white matter is generally softer than tissue from the hindbrain (pons, medulla oblongata, cerebellar white matter), as can be seen in Figure 1b. Our results suggest that experimental results and material parameters can not be transferred from one white matter region to another without compromising accuracy.

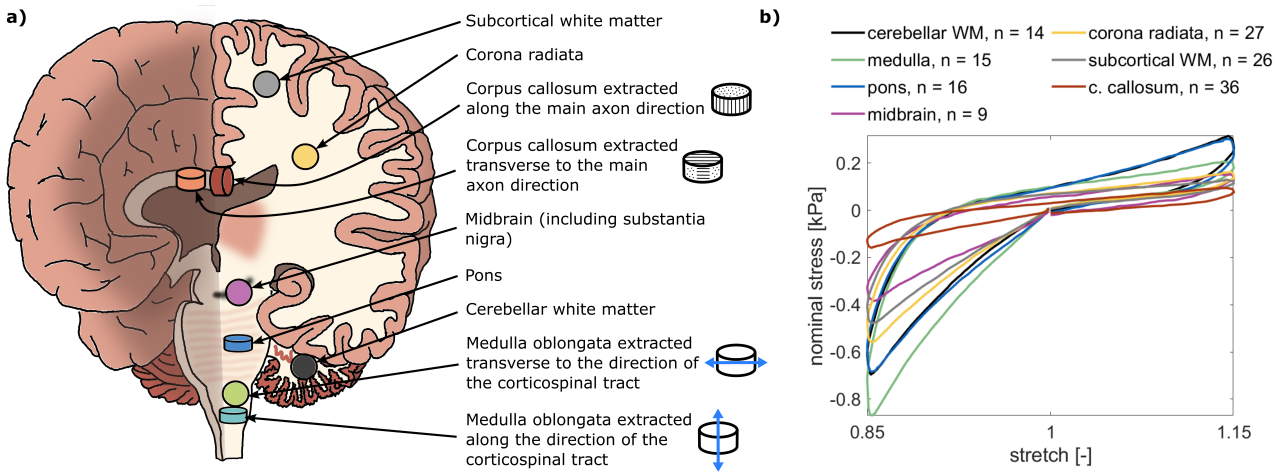


**Figure 1:** Sampling locations (a) and averaged stress response in cyclic compression-tension tests (b). Figure adapted from [1].

## References

[1] N. Reiter, S. Auer, L. Hoffmann, L. Bräuer, F. Paulsen, and S. Budday. "Do human brain white matter and brain stem structures show direction-dependent mechanical behavior?" *Acta Biomaterialia* 199 (2025), pp. 230–251.

# Mechanical characterization and model discovery of the maternal–fetal interface in health and disease

**Malte Rolf[1], Saverio Gardellin[2], Gerhard Sommer[2], Gerhard A. Holzapfel[2,3], Christian Wadsack[4], Ellen Kuhl[1,5]**

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[4] Department of Obstetrics and Gynaecology, Medical University of Graz,
[5] Department of Mechanical Engineering, Stanford University

The placenta is arguably the most important yet least understood organ in the body. During its transient existence, it fulfills functions later assumed by the lungs, liver, gut, and kidneys, primarily supplying the fetus with oxygen and nutrients. Pathological remodeling, as in preeclampsia, which affects up to one in ten pregnancies, can have severe short- and long-term consequences for both mother and child. Its hallmarks include impaired uteroplacental blood flow, abnormal vascular remodeling, and increased placental stiffness, all of which compromise fetal oxygenation and growth [1].

It is hypothesized that the fetal cardiovascular system may also be altered in preeclampsia. To test this, as a first step, we perform *ex vivo* mechanical tests on healthy and preeclamptic umbilical arteries, particularly inflation–extension tests, to compare arterial stiffness. Umbilical cords are collected at the Medical University of Graz (PlacentaLab) and tested fresh to prevent alterations caused by freezing. Each umbilical artery is isolated, cleared of connective tissue, and mounted in the experimental setup, see Fig. 1. A quasi-static internal pressure is applied, and the circumferential stretch is measured using digital image correlation (DIC) up to 100 mmHg, well above physiological pressures.

This developed protocol will be extended to a statistically relevant number of samples. Moreover, we will demonstrate that automated model discovery can identify the constitutive model and parameters that best describe the data, based on a thick-walled cylinder approximation.

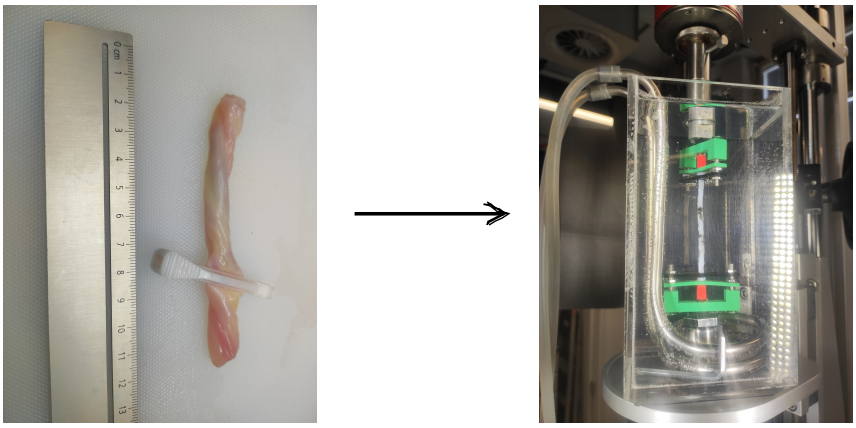

**Figure 1:** A section of the human umbilical cord (left) and an isolated umbilical artery in a pressure–inflation test setup (right).

## References

[1] M. Spiliopoulos, C. Y. Kuo, A. Eranki, and et al. "Characterizing placental stiffness using ultrasound shear-wave elastography in healthy and preeclamptic pregnancies". *Archives of Gynecology and Obstetrics* 302 (2020), pp. 1103–1112.

# Mechanical characterization of a brain phantom in the time and frequency domain

**Laura Ruhland, Kai Willner**

The characterization of brain tissue is often limited by inconsistent or contradictory mechanical responses when experiments in different time and length scales are conducted. This study presents an approach to overcome the problem of inconsistent responses and combines measurements performed in different time domains in a continuum-based model [1]. A brain phantom was characterized in different time scales and with varying testing temperatures. At 26°C and 37°C, multi-modality rheometer experiments in the time domain and magnetic resonance elastography (MRE) at high frequencies was examined. The behavior in the mid-frequency range was characterized at room temperature with a custom-built vibration table. In a vibration analysis the first eigenfrequency of two cubic samples with different edge length was determined. Based on the rheometer measurements in the time domain, an inverse parameter identification in ABAQUS was performed to obtain the mechanical parameters. As a material model the hyperelastic Ogden model combined with a time-dependent Prony series was used. To verify the calibrated model for an application in the frequency domain, the MRE and vibration table measurements were predicted with the calibrated model. The calculated material response for the MRE (Fig.1) and the vibration analysis (Fig.2) highly agrees with the measured response. This indicates that the model calibrated in the time domain is capable of modeling the material's frequency behavior.

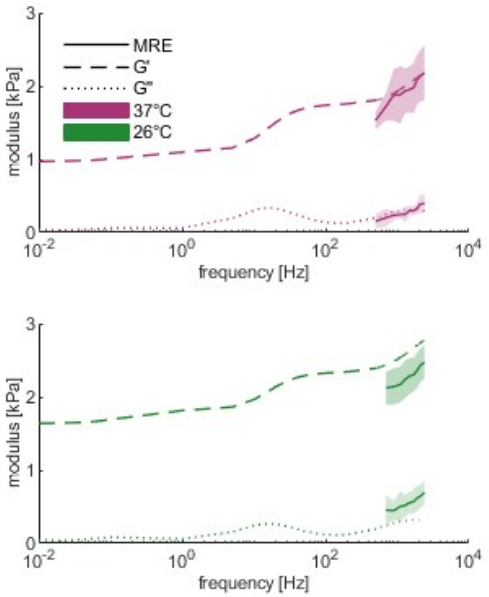


**Figure 1:** Storage (G') and loss modulus (G") measured with MRE and calculated with the in the time domain calibrated model.

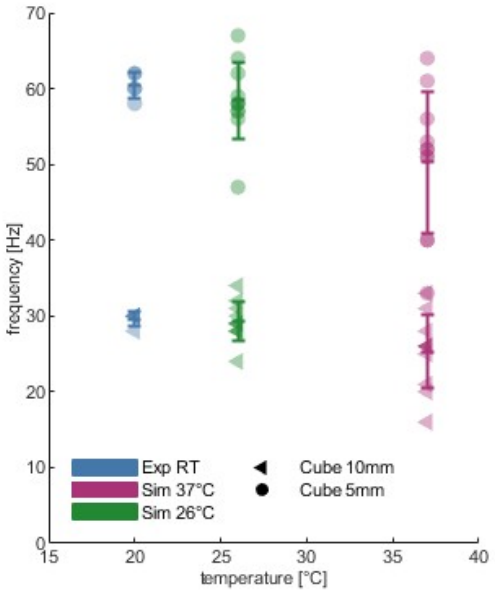


**Figure 2:** First eigenfrequency (Mean ± Std) measured with the vibration table and simulated with the in the time domain calibrated model.

## References

[1] L. Ruhland and K. Willner. "Mechanical characterization of a brain phantom material by combining experiments in the time and frequency domain". *Journal of the Mechanical Behavior of Biomedical Materials* 170 (2025), p. 107114.

# Grid-independent peridynamic quadrature scheme for efficient nonlocal bone remodeling

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[2] Department of Mechanical Engineering, Bilkent University, Turkey

The assumption that bone cells communicate via nonlocal mechano-sensing motivates the use of the peridynamic formulation for nonlocal bone remodeling presented in [2]. However, the integral-type peridynamic framework inherently entails high computational expenses. To address this bottleneck, we established a novel grid-independent quadrature scheme [1] which effectively reduces the computational cost while maintaining high-fidelity peridynamic computations. When applied to nonlocal bone remodeling, the novel quadrature scheme yields a relative density distribution throughout the proximal femur that is in good agreement with the local result, see Fig. 1. Moreover, the grid-independent quadrature scheme allows for the use of random grids for the spatial discretization of the proximal femur. This flexibility does not interfere with the accuracy of the solution, as demonstrated by the comparison in Fig. 1.

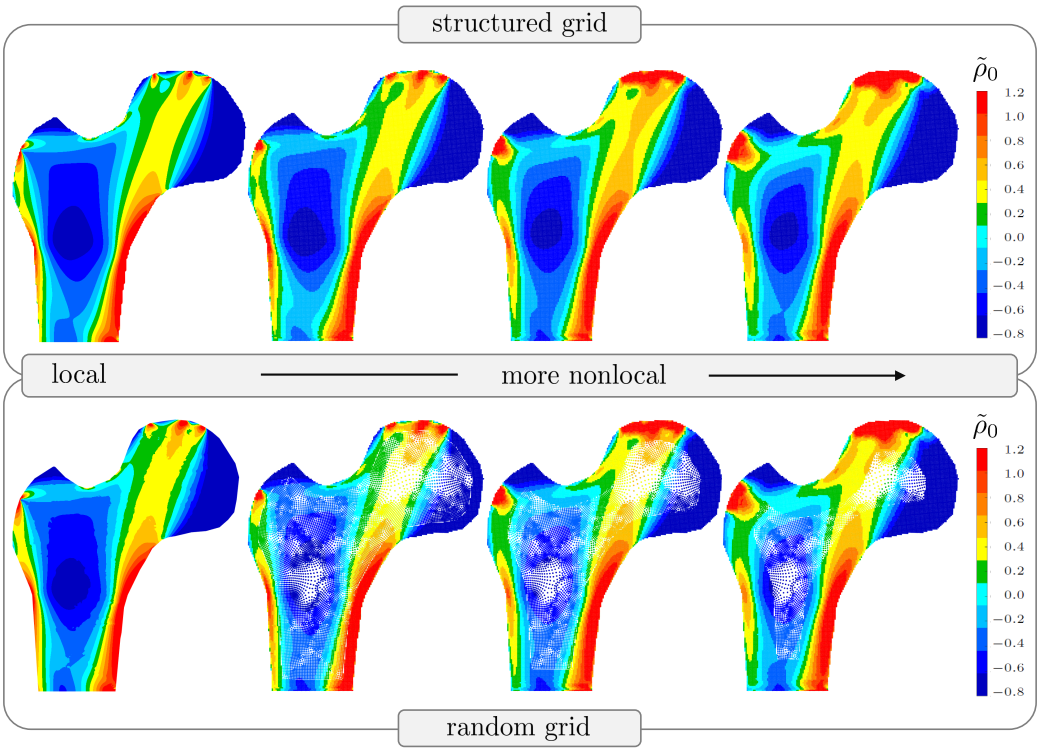


**Figure 1:** Relative density $\tilde{\rho}_0$ throughout the proximal femur resulting from mechanical stimuli using a grid-independent quadrature scheme for the peridynamic model.

## References

[1] E. Schaller, A. Javili, and P. Steinmann. "A novel energy-fitted hexagonal quadrature scheme enables low-cost and high-fidelity peridynamic computations". *Computer Methods in Applied Mechanics and Engineering* 440 (2025), p. 117918.

[2] E. Schaller, I. Schmidt, A. Papastavrou, A. Javili, and P. Steinmann. "A peridynamic formulation for nonlocal bone remodelling". *Computer Methods in Biomechanics and Biomedical Engineering* 25.16 (2022), pp. 1835–1851.

# Challenges in Mechanical Characterization of Brain Organoids.

**Philipp Scherm[1], Nina Reiter[1], Michael Tranchina[2], Sven Falk[2], Marisa Karow[2], Silvia Budday[1]**

[1] Institute of Continuum Mechanics, FAU [2] Institute of Biochemistry, FAU

Most of our mechanical testing of solid biological material is administered in fluid to prevent desiccation. For our standard testing [1], the forces are sufficiently large to neglect the influence of the surrounding fluid. However, when testing very small specimens such as brain organoids, shown in Figure 1, the measured forces approach the same order of magnitude as the forces exerted by the fluid.
As a remedy, we model the fluid forces acting during the testing of organoids to separate them from the organoid response. Simple hydrodynamic models are used to describe the fluid forces. In case of the liquid bridge in Figure 1, the following equation accounts for surface tension and Laplace pressure

$$F_{\mathrm{lb}} = \underbrace{2\pi\, R_{\mathrm{n}}\, \gamma}_{\text{surface tension}} + \underbrace{\pi\, R_{\mathrm{c}}^2\, \Delta P}_{\text{Laplace pressure}} \quad , \quad \text{with} \quad \Delta P = P_{\mathrm{inside}} - P_{\mathrm{outside}} = -\gamma \left( \frac{1}{R_{\mathrm{n}}} - \frac{1}{C} \right) \quad , \quad (1)$$

where the geometric dimensions $R_{\mathrm{n}}$ and $C$ are obtained from movies taken during the test, and $\gamma$ is the surface tension of the fluid. By subtracting the fluid forces from the measured forces

$$F_{\mathrm{organoid}} = F_{\mathrm{measured}} - F_{\mathrm{lb}} \quad , \quad (2)$$

we obtain the organoid response. This allows us to characterize the mechanical response of brain organoids from unconfined compression tests in a rheometer.

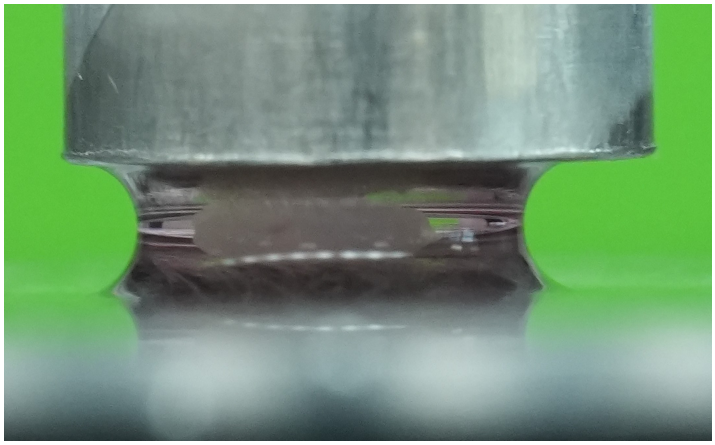

**Figure 1:** Brain organoid in a liquid bridge between rheometer plates.

## References

[1] J. Faber, J. Hinrichsen, A. Greiner, N. Reiter, and S. Budday. "Tissue-Scale Biomechanical Testing of Brain Tissue for the Calibration of Nonlinear Material Models". *Current Protocols* 2.4 (2022), e381.

# Modeling Tumor-induced brain herniation

**Nicole Tueni, Silvia Budday**

Brain tumor growth can displace surrounding brain tissue and produce large deformations. In severe cases, this process may lead to brain herniation, a life-threatening condition in which tissue is forced to shift or protrude through rigid intracranial partitions.
Our objective is to model tumor growth to quantify the resulting tissue displacements. To this end, we develop a 3D finite element brain model, subdivided into 17 anatomically and mechanically distinct regions [2] and include two additional rigid regions representing the dura mater [1], which act as mechanical barriers that mitigate lateral and downward tissue shifts.
In our simulations, a fictitious tumor is placed within the white matter and subjected to a prescribed growth law. This approach allows us to quantify growth-induced tissue displacements, to ultimately assess the risk of herniation.
Figure 1 illustrates the evolution of the displacement field for a synthetic white-matter tumor, showing both the increase in tumor size and the associated displacement of surrounding tissue.
Future work will focus on validating this modeling framework using in vivo tumor data, an essential step toward clinical translation for predicting adjacent tissue shift.

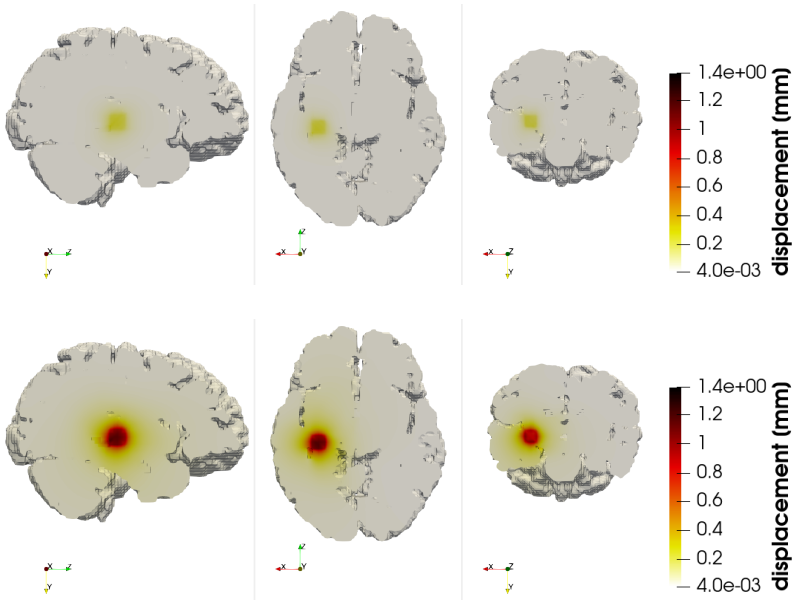


**Figure 1:** Evolution of the displacement field induced by a synthetic tumor placed in white matter, illustrating tumor growth and progressive deformation of adjacent tissue.

## References

[1] J. Glaister, A. Carass, D. L. Pham, J. A. Butman, and J. L. Prince. "Falx Cerebri Segmentation via Multi-atlas Boundary Fusion". In: *Medical Image Computing and Computer Assisted Intervention MICCAI 2017*. Vol. 10433. 2017, pp. 92–99.

[2] J. Hinrichsen, N. Reiter, L. Bräuer, F. Paulsen, S. Kaessmair, and S. Budday. "Inverse Identification of Region-Specific Hyperelastic Material Parameters for Human Brain Tissue". *Biomechanics and Modeling in Mechanobiology* 22 (2023), pp. 1729–1749.

# Finite Element Based Direct Inversion for Magnetic Resonance Elastography

**Yashasvi Verma**[1], **Luca Heltai**[2], **Paul Steinmann**[1]

[1] Friedrich-Alexander-Universität Erlangen-Nürnberg

[2] University of Pisa

Magnetic Resonance Elastography (MRE) is a non-invasive technique for assessing the mechanical properties of soft tissues *in vivo* [2]. Mechanical waves generated by an external actuator in organs such as the liver, brain, or kidney are captured using motion-sensitive MRI contrasts, and the resulting displacements are filtered to isolate shear waves. Assuming the tissue behaves as a linear elastic medium, shear wave propagation in one dimension is governed by:

$$2\mu\triangle u + \rho\omega^2 u = 0 \tag{1}$$

where $\rho$ is the tissue density, $\omega$ the angular frequency, and $\mu$ the shear modulus. Since the displacement field $u$ is measured, this equation can be *inverted* to estimate tissue properties [1]. Inversion can be performed using (i) Direct inversion (DI) which estimates properties point-wise assuming local homogeneity and is computationally efficient or (ii) Non-linear inversion which identifies parameters iteratively at higher computational cost. To enhance DI, we developed a hybrid inversion method that integrates DI's efficiency with the stability of Finite Elements. The formulation is given by:

$$2\mu Ku + \rho\omega^2 Mu = 0 \tag{2}$$

where $K$ and $M$ are the stiffness and mass matrices respectively. We validated this method using forward simulations of shear wave propagation in a cubic domain with a prescribed shear modulus. The simulated displacement field was then fed to the inversion algorithm, and the reconstructed material properties closely matched the chosen input values. This scheme is shown in figure 1. Where the input storage modulus of 2000 Pa is recovered as 2010 Pa.

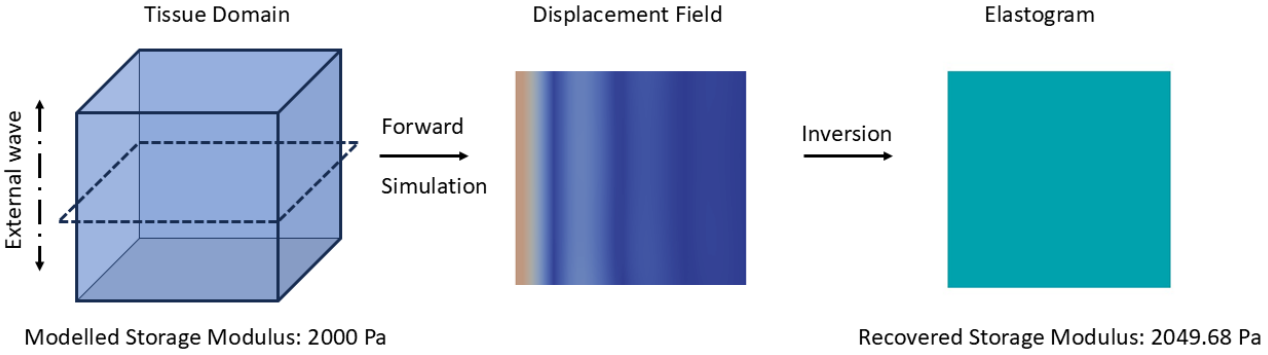


**Figure 1:** Validation Method of Inversion Scheme.

## References

[1] S. Hirsch, J. Braun, and I. Sack. *Magnetic Resonance Elastography: Physical Background And Medical Applications*. Boschstr. 12, 69469 Weinheim, Germany: WILEY-VCH Verlag GmbH & Co. KGaA, 2017.

[2] T. Meyer, S. M. Garcia, H. Tzschätzsch, H. Herthum, M. Shahryari, L. Stencel, J. Braun, P. Kalra, A. Kolipaka, and I. Sack. "Comparison of inversion methods in MR elastography: An open-access pipeline for processing multifrequency shear-wave data and demonstration in a phantom, human kidneys, and brain". *Magnetic Resonance in Medicine* 88.4 (2022), pp. 1840–1850.

# A Unified Framework for Validating Computational Models of Human Brain Development

**Mohammad Saeed Zarzor**[1], **Qiang Ma**[2], **Silvia Budday**[1]

[1] Institute of Continuum Mechanics and Biomechanics, Friedrich-Alexander-Universität Erlangen-Nürnberg
[2] Department of Computing, Imperial College London

Modeling the development of the human brain during gestation by linking cellular activities to morphological changes is a crucial step toward understanding how brain structure and function evolve. However, any computational model of this process remains incomplete and unreliable until it undergoes validation through comparison between simulated outcomes and empirical data. A major challenge in this field is the absence of a standardized framework for comparing and validating such computational results.

In our work, we address this gap by identifying distinctive morphological features of the human brain that reflect the complexity of cortical folding and can serve as quantitative criteria for evaluating simulation results. Specifically, we focus on the Gyrification Index (GI), which quantifies the degree of cortical folding; compactness, which measures how efficiently a shape encloses its area or volume; and the Hausdorff distance, which quantifies the maximum deviation between two surfaces and is widely used to assess shape similarity.

To measure these features, and based on reconstructed human fetal brain data obtained across different gestational weeks [1], we developed an in-house software platform capable of processing various types of brain data as shown in Figure 1. The developed platform provides a unified and robust approach for validating computational brain models regarding morphology, enabling consistent comparison of results across different studies and methodologies.

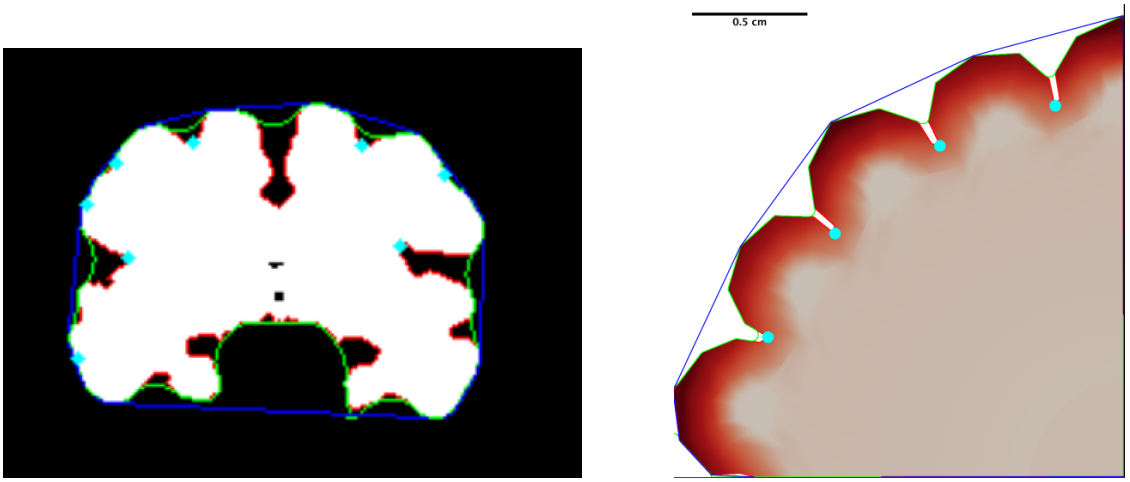


**Figure 1:** Two examples processed using the in-house software platform: an MRI coronal section of the fetal brain (left) and simulated images generated by the model (right). The red line denotes the buried cortical surface, the blue line highlights the convex surface, the green line represents the visible cortical surface, and the cyan dots mark the sulcal points. These delineations form the basis for measuring several other morphological hallmarks.

## References

[1] A. Edwards, D. Rueckert, S. Smith, S. A. Seada, A. Alansary, J. Almalbis, J. Allsop, J. Andersson, T. Arichi, S. Arulkumaran, and M. Bastiani. "The developing human connectome project neonatal data release". *Frontiers in neuroscience* 16.886772 (2022).

# Generation of a virtual twin for the human brain accounting for region- and age-dependent properties

**Sahar Zolghadr, Nina Reiter, Jan Hinrichsen, Silvia Budday**

In recent decades, health issues related to aging have become more important. Aging alters both the shape and mechanical characteristics of brain tissue, which finally affects brain and human health. Several studies have reported specific age-related changes, including changes in volume of white matter and grey matter, cortical thinning, ventricular enlargement and sulcal widening [1]. This project focuses on developing a virtual twin model that accounts for region- and age-specific mechanical properties of human brain tissue. To achieve this, we analyze large-strain experimental data using nonlinear continuum mechanics modeling and finite element (FE) simulations to understand how our brain's properties evolve during aging. In a first step, we utilized previously published hyperelastic material parameters determined through an inverse parameter identification method based on large-strain compression, tension, and shear testing data [2]. The dataset included seven human brains from body donors, which we categorized into healthy and unhealthy aging (diagnosed with dementia) groups, since they may exhibit different trends with respect to aging. For each region of the brain, we plotted the shear modulus as a function of age. The exemplary results for the corona radiata and cortex regions, illustrated in Figure 1, indicate that additional experimental data are still required to find a conclusive trend for aging.

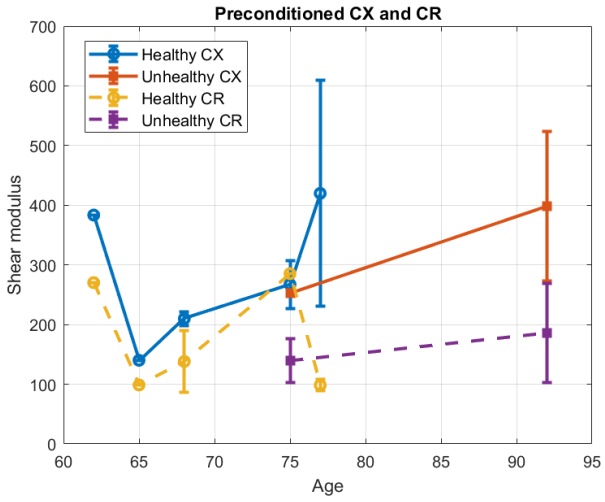


**Figure 1:** Shear modulus of samples from the cortex (CX) and corona radiata (CR) of seven human body donor brains plotted against chronological age.

## References

[1] Y. Blinkouskaya, A. Caçoilo, T. Gollamudi, S. Jalalian, and J. Weickenmeier. "Brain aging mechanisms with mechanical manifestations". *Mechanisms of Ageing and Development* 200.111575 (2021).

[2] J. Hinrichsen, N. Reiter, L. Bräuer, F. Paulsen, S. Kaessmair, and S. Budday. "Inverse identification of region-specific hyperelastic material parameters for human brain tissue". *Biomechanics and Modeling in Mechanobiology* 22 (2023), pp. 1729–1749.

**– Material mechanics –**

# Modeling strain rate-dependent hyperelastoplastic adhesive joints under temperature influence

**Vincent Dötschel, Gunnar Possart, Julia Mergheim**

The mechanical properties of hyperelastoplastic adhesive joints are significantly influenced by temperature and strain rate. To safely design adhesive joints, the effects of these dependencies on the mechanical behavior must be identified and described. While temperature-dependent models for structural adhesive joints under small strains, e.g., the extended TAPO (Toughened Adhesive Polymer) [3] already exist, models for semi-structural adhesive joints with hyperelastoplastic material behavior that cover the effects of temperature (cf. Figure 1) are still pending. The Three-Network-Model (TNM) by Bergström [1] (cf. Figure 2), suitable for modeling viscoelastic-viscoplastic material behavior, was extended by Schmelzle [2] to capture strain rate influences and to model damage. However, certain effects cannot be captured yet.
Based on this, the FOSTA Nr. P 1787 project plans to develop or extend a suitable hyperelastoplastic material model that includes strain rate, damage, and temperature influences up to large deformations and total failure. The Laboratory for Material and Joining Technology from the University Paderborn conducts the corresponding experiments, allowing the calibration of the material parameters and validation of the model for specific adhesives. Different strain rates and temperatures from $-20°C$ to $80°C$ will be covered.

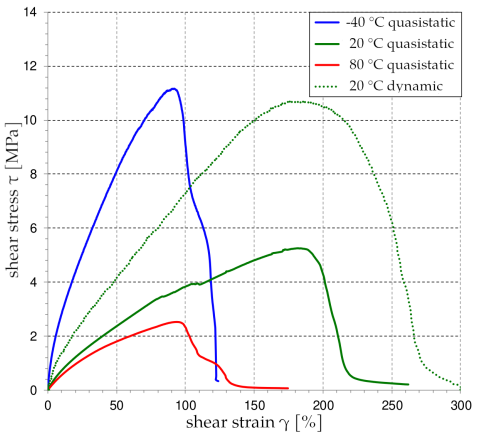


**Figure 1:** Shear loading of a BetaForce 2850L adhesive layer (2 mm thickness) with dependencies on the temperature and loading velocity.

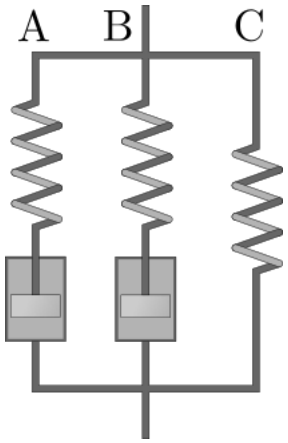


**Figure 2:** Three-Network-Model (TNM) by Bergstrom [1] with Maxwell elements in strand A and B as well as a spring in strand C.

## References

[1] J. S. Bergstrom. *Mechanics of solid polymers: theory and computational modeling.* William Andrew, 2015.

[2] L. Schmelzle, F. Beule, J. Mergheim, G. Meschut, G. Possart, D. Teutenberg, and P. Steinmann. "Methodenentwicklung zur Simulation von hyperelastischen Klebverbindungen unter Crashbelastung". *ech. rep. IGF-Projekt Nr. 21710 N* (2024).

[3] L. Schmelzle, M. Striewe, J. Mergheim, G. Meschut, G. Possart, D. Teutenberg, D. Hein, and P. Steinmann. "Testing, modelling, and parameter identification for adhesively bonded joints under the influence of temperature". *Journal of Adhesion Science and Technology* 37.16 (2023), pp. 2285–2316.

# Data-driven material characterization: Neural Networks, Sparse Regression, and Material Fingerprinting

**Moritz Flaschel[1], Paul Steinmann[1], Denisa Martonová[1], Carina Veil[2], Trevor Hastie[2], Laura De Lorenzis[3], Ellen Kuhl[2]**

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[2] Stanford University, California 94305, United States

[3] Department of Mechanical and Process Engineering, ETH Zürich, Zürich, Switzerland

Data-driven methods for material characterization become increasingly popular. One of the most popular approaches is to approximate the mechanical material behavior using neural networks. For instance, we have proposed Generalized Standard Material Networks for learning arbitrary dissipative material behavior within the thermodynamically consistent theory of Generalized Standard Materials [3]. Yet, because neural networks are uninterpretable black-box models which can be computationally expensive to evaluate, there is a recent trend in developing computer algorithms for the automated discovery of material models as closed-form mathematical formulas. Thus, we have proposed different numerical strategies for tackling sparse regression-based material model discovery [1]. However, both neural networks and sparse regression-based model discovery have in common that they rely on solving potentially non-convex optimization problems. Recognizing this issue, we proposed Material Fingerprinting [2]; an efficient and robust method for material model discovery that relies on a precomputed database and a pattern recognition algorithm and completely avoids solving an optimization problem. Figure 1 illustrates the pattern recognition algorithm at the core of Material Fingerprinting.

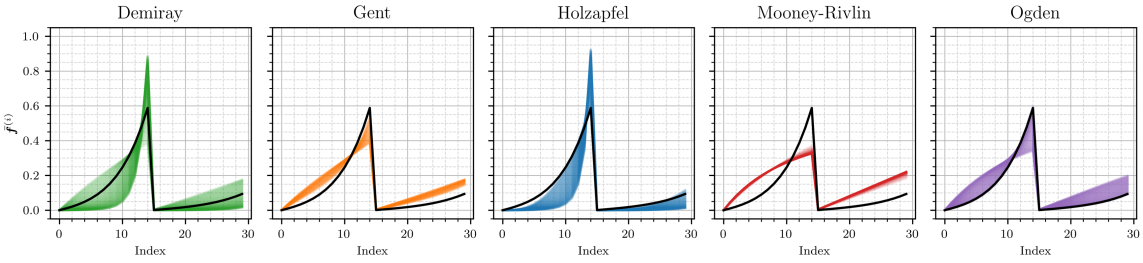


**Figure 1:** Material Fingerprinting discovers a material model by comparing a measurement with precomputed material fingerprints.

## References

[1] M. Flaschel, T. Hastie, and E. Kuhl. "Non-smooth optimization meets automated material model discovery".

[2] M. Flaschel, D. Martonová, C. Veil, and E. Kuhl. "Material Fingerprinting: A shortcut to material model discovery without solving optimization problems".

[3] M. Flaschel, P. Steinmann, L. De Lorenzis, and E. Kuhl. "Convex neural networks learn generalized standard material models". *Journal of the Mechanics and Physics of Solids* 200 (2025), p. 106103.

# Damage modelling for the simulation of mechanical joining processes

**Johannes Friedlein, Julia Mergheim, Paul Steinmann**

Modelling of ductile damage in forming processes is essential to predict the formability limits of parts and structures. However, damage evolution is known to strongly depend on the acting stress state and the loading path, and accumulates in every forming stage. The predictive capabilities of the in [1] proposed stress-state-dependent damage and failure model is validated in Fig. 1. First the clinch joining process was simulated to join two metal sheet by pure deformation. The thereby aggregated material history, including material damage, is then mapped to the 3D shear lap test specimen in Fig. 1 to characterise the joint's shear strength. By tracking the damage evolution throughout this two-stage process chain, it becomes possible to accurately predict the failure initiation point and failure mode of the shear specimen in Fig. 1 determined experimentally using in-situ computed tomography (CT).
Joining by friction spun joint connectors (FSJC) is another mechanical joining method that also relies on controlled deformation. Thereby, a metal rod rotates at around 10 000 rpm and is pushed against blunt tools. The high relative velocity at the contact interface generates substantial heat leading to thermal softening of the metal rod. This can be utilised to freely form the rod into a rivet and to join sheets. An arbitrary Lagrangian–Eulerian (ALE) method developed by [2] and extended herein is well suited to capture the fast rotation and excessive deformation of friction spinning as demonstrated in Fig. 2.

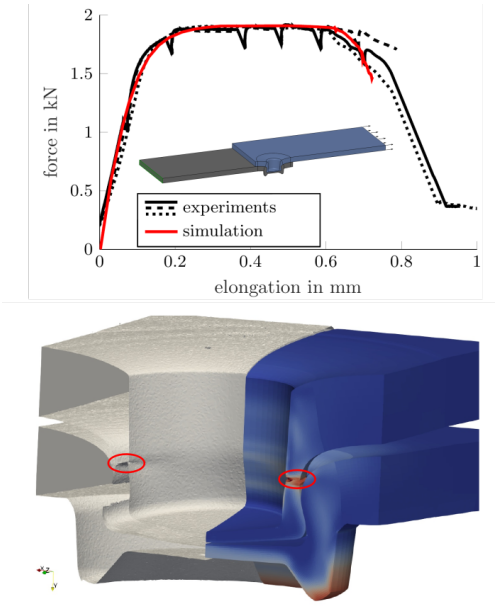


**Figure 1:** Shear lap test of clinch joint. Top: system response. Bottom: cut view of CT-reconstruction vs simulation.

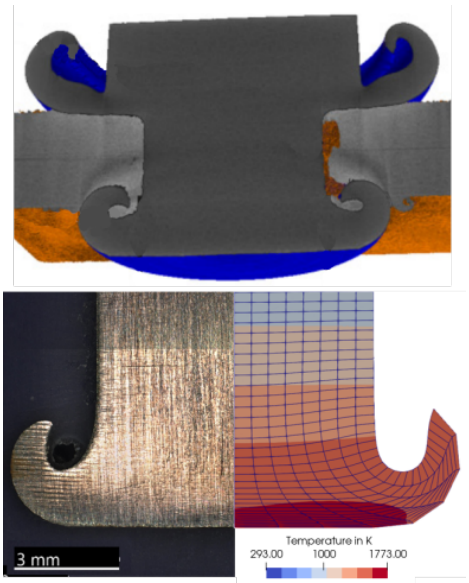


**Figure 2:** FSJC. Top: CT-image of joint. Bottom: Upsetting to form closing head.

## References

[1] J. Friedlein, J. Mergheim, and P. Steinmann. "Modelling of stress-state-dependent ductile damage with gradient-enhancement exemplified for clinch joining". *Journal of the Mechanics and Physics of Solids* 196 (2025), p. 106026.

[2] M. Hamed. "Numerical simulation of friction welding processes: An arbitrary Lagrangian-Eulerian approach". PhD Thesis. University of Cape Town, 2022.

# Automated Model Discovery of tensional homeostasis in living tissues

**Hagen Holthusen**[1], **Tim Brepols**[2], **Kevin Linka**[3], **Ellen Kuhl**[1,4]

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[2] Institute of Applied Mechanics, RWTH Aachen University, Germany
[3] Institute for Continuum and Material Mechanics, Hamburg University of Technology, Germany
[4] Department of Mechanical Engineering, Stanford University, United States

Patient-specific healthcare increasingly depends on data-driven models to capture individual biomechanical behavior. Conventional neural networks often fail under data scarcity and may produce unphysical predictions. Embedding physical laws into neural architectures alleviates these issues, ensuring data-efficient and physically consistent modeling. Such physics-embedded approaches help uncover mechanisms like *tensional homeostasis*—the ability of cells and tissues to maintain stable internal tension, preserving structural integrity and physiological function.

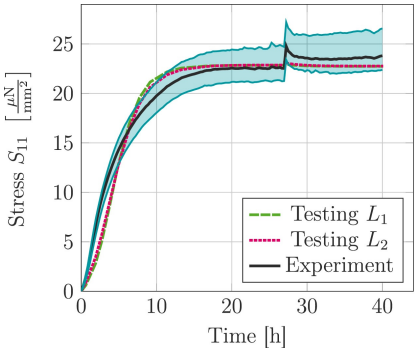



**Figure 1:** Testing of the discovered material model for tensional homeostasis with Lasso (L1) and ridge (L2) regularization [2].

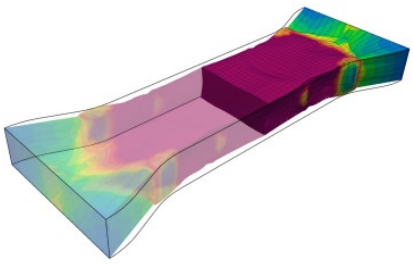


**Figure 2:** Predicted structural response after 8 hours [2]. Contour plots show the stress in longitudinal direction.

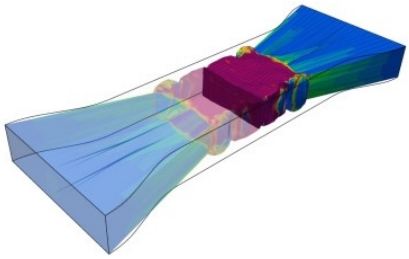


**Figure 3:** Unstable structural response after 10.4 hours [2]. Contour plots show the stress localization in longitudinal direction.

In our work [2], we introduce an automated model discovery framework using inelastic Constitutive Artificial Neural Networks (iCANNs) to identify mechanisms of tensional homeostasis in bioengineered tissues [1] under finite strains. The core idea is to define a *homeostatic surface* in principal stress space,

$$\Phi(\boldsymbol{\Sigma}) := \phi(\boldsymbol{\Sigma}) - 1 - \eta\,\gamma \stackrel{!}{=} 0,$$

analogous to a yield surface in plasticity, where $\phi$ is an isotropic function of the stress tensor $\boldsymbol{\Sigma}$, $\eta$ denotes growth time, and $\gamma$ is a Lagrange multiplier. Both the Helmholtz free energy $\psi$ and the growth potential $\phi$ are discovered via neural networks designed to satisfy thermodynamics and inelastic kinematics *a priori*. Our results show accurate material-level predictions (Fig. 1) and qualitatively consistent structural behavior (Fig. 2); however, late-stage instabilities (Fig. 3) likely stem from the limited training data, reducing generalization capability.

## References

[1] J. F. Eichinger, D. Paukner, J. M. Szafron, R. C. Aydin, J. D. Humphrey, and C. J. Cyron. "Computer-Controlled Biaxial Bioreactor for Investigating Cell-Mediated Homeostasis in Tissue Equivalents". *Journal of Biomechanical Engineering* 142.7 (2020), p. 071011.

[2] H. Holthusen, T. Brepols, K. Linka, and E. Kuhl. "Automated model discovery for tensional homeostasis: Constitutive machine learning in growth and remodeling". *Computers in Biology and Medicine* 186 (2025), p. 109691.

# Improving the Cost of 3D Phase-Field Fracture Simulations

**Paras Kumar, Paul Steinmann**

The phase-field approach to fracture, despite offering several advantages over sharp crack modeling approaches, suffers from extremely high computational costs stemming from (i) the extremely fine meshes necessary to resolve the diffuse crack zone, (ii) the need for small load increments, even more so for soft materials undergoing large deformation, and (iii) the large number of staggered iterations arising during the solution of incremental nonlinear coupled problem. Such high computational costs render this approach practically prohibitive for simulating crack propagation in realistic 3D structures. In order to improve the viability of 3D crack-propagation simulations, we explore two improvements - (i) exploring efficient linear solvers and preconditioners and (ii) an alternative stopping criterion based on change in fracture energy.

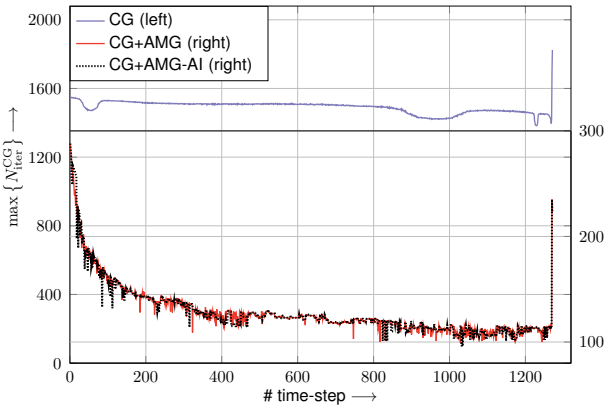



**Figure 1:** Influence of preconditioner choice on maximum CG iterations per time-step.

| $T_{\text{wall}}$ in s | CG | CG AMG | CG AMG-AI | Final |
|---|---|---|---|---|
| Total | 65600 | 49200 | 46900 | 19900 |
| SLE-$\boldsymbol{\varphi}$ | 32500 | 15500 | 13300 | 7710 |
| CG-$\boldsymbol{\varphi}$ | - | 11000 | 11100 | 6730 |
| initialize-$\boldsymbol{\varphi}$ | - | 4410 | 2160 | 929 |
| # setup-$\boldsymbol{\varphi}$ | - | 26052 | 12794 | 5494 |
| SLE-$z$ | 339 | 1060 | 652 | 188 |
| CG-$z$ | - | 157 | 158 | 47.9 |
| initialize-$z$ | - | 842 | 431 | 123 |
| # setup-$z$ | - | 22129 | 11268 | 3197 |

**Table 1:** Run-time comparison for various improvements.

Considering the concrete example of large-strain double-edge notched tension simulation (see [1, Sec. 4.3]) comprising of around 750K $\boldsymbol{\varphi}-$ (displacement) and 250K $z-$ (phase-field) degrees of freedom, it is evident that solving the system of linear equations (SLE) using a vanilla conjugate-gradient solver accounts for approximately 50 % of the total compute time. Utilizing the algebraic multigrid preconditioner (AMG) and supplying it with information about the near null-space of the matrix being solved [3], results in a significant reduction in the number of CG iterations required per SLE solve; cf. Figure 1. Consequently, the computational effort for solving SLE-$\boldsymbol{\varphi}$ becomes less than half, thus resulting in a significant reduction in the total run-time; cf. first two columns of Table 1. Initialization of AMG accounts for a significant portion of SLE-$\boldsymbol{\varphi}$, even more so for the smaller $z-$system. We devise an adaptive initialization (AI) algorithm wherein AMG is initialized only when $N_{\text{iter}}^{\text{CG}}$ across SLE solves increases beyond a certain relative threshold, thus resulting in further cost savings as the count of initializations decreases significantly; cf. the third column of Table 1. Lastly, coupling these improvements with the alternative combined convergence criterion (cf. [2]), the total simulation cost can be reduced to less than one-third of the base case as depicted by last column of Table 1.

## References

[1] P. Kumar. "Enhanced Computational Homogenization and Phase-Field Fracture Approaches for Polymer Nano-Composites". PhD thesis. Friedrich-Alexander Universität Erlangen-Nürnberg, Feb. 2024.

[2] M. Rohracker, P. Kumar, P. Steinmann, and J. Mergheim. "Efficient phase-field fracture simulations for fracture analysis in heterogeneous materials". *Computational Mechanics* (2025).

[3] P. Vaněk, J. Mandel, and M. Brezina. "Algebraic multigrid by smoothed aggregation for second and fourth order elliptic problems". *Computing* 56.3 (1996), pp. 179–196.

# On the numerical challenges of rate-independent strain gradient plasticity

**Jose Lara, Paul Steinmann**

Plastic deformation in metals can be traced back to the glide movement of dislocations along specific slip planes and directions dictated by the crystal lattice. This motion, referred to as plastic slip, is treated as an internal variable in classical crystal plasticity. However, in the strain-gradient formulation proposed by Gurtin[1], they are treated as kinematical quantities, allowing the inclusion of their gradients to capture intrinsic size effects. This approach yields

$$\boldsymbol{T} \cdot \nabla + \boldsymbol{b} = \boldsymbol{0} \qquad \text{and} \qquad \boldsymbol{\xi}_\alpha \cdot \nabla + \tau_\alpha = \pi_\alpha,$$

i.e., the local linear momentum balance and a pseudo-balance, which is equivalent to a non-local yield condition for the $\alpha$-th slip system. In our research, the solution of the resulting saddle-point problem has posed three major challenges:

- Size of the resulting linear-equation system: One additional degree of freedom is introduced for each slip system. Furthermore, the slips are not only coupled to the displacement but also with each other, increasing the bandwidth of the matrix.
- Rate-independency: The typical numerical problems of rate-independent phenomenological plasticity are exacerbated by the number of slip systems, especially in polycrystals. Although a visco-plastic regularization alleviates some issues, the artificial rate-dependency may not reflect the actual material behavior and it can introduce unwanted artefacts under cyclic loading[2]. Additionally, as the rate-independent case is better approximated, the NEWTON method looses its quadratic convergence; leading to an increase of NEWTON iterations in each load step (See Figure 1).
- Strong coupling: Although the saddle-point structure permits staggered solution strategies, the schemes tested so far converge considerably slower than a monolithic approach. We are currently working on verifying this hinted strong coupling.

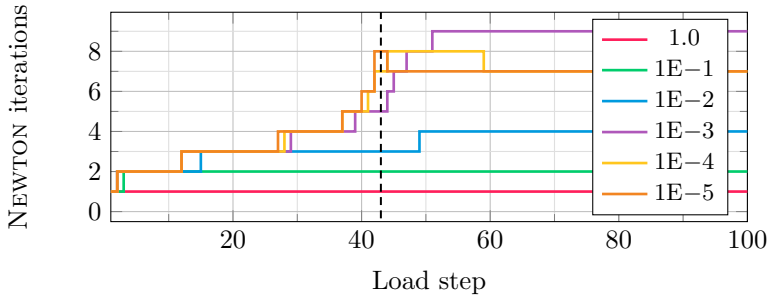



**Figure 1:** Number of NEWTON iterations in each load step for different values of the regularization parameter while solving the problem of a infinite strip under simple shear with symmetric slip systems. The dashed vertical line indicates the onset of plasticity in the rate-independent case.

## References

[1] M. E. Gurtin. "On the plasticity of single crystals: free energy, microforces, plastic-strain gradients". *Journal of the Mechanics and Physics of Solids* 48.5 (May 2000), pp. 989–1036.

[2] J. Lara and P. Steinmann. "A numerical study on the visco-plastic regularization of a rate-independent strain gradient crystal plasticity formulation". *Computational Mechanics* (2023).

# Damage in continuum-kinematics-inspired peridynamics

**Marie Laurien**[1], **Ali Javili**[2], **Paul Steinmann**[1]

[1] Institute of Applied Mechanics, Friedrich-Alexander Universität Erlangen-Nürnberg, Germany
[2] Department of Mechanical Engineering, Bilkent University, Turkey

Peridynamics is a nonlocal continuum formulation that naturally allows for discontinuities, such as cracks. Continuum-kinematics-inspired peridynamics (CPD) [1] extends the peridynamic framework to overcome the fundamental limitation of classical bond-based peridynamics, i.e., a fixed Poisson's ratio. Despite the potential of peridynamics for fracture modeling, CPD still lacks a comprehensive damage formulation. Therefore, the goal of this work [2] is the introduction of damage into the formulation of CPD. Here, nonlocal interactions between material points are captured via one-, two- and three-neighbor interactions, allowing to measure length, area and volume changes. For each type of interaction, a separate damage variable is employed, depending on the associated strain. For a two-dimensional problem, the damage parameters of the model are derived from the classical fracture energy in a semi-analytical procedure. In order to assess the model's performance in predicting experimental outcomes, we performed a series of fracture experiments. Diagonally loaded square plates with center cracks of varying inclination angle are tested to study different fracture modes. The results demonstrate the model's capability to capture the maximum loads and the crack paths observed in the experiments, see Fig. 1.

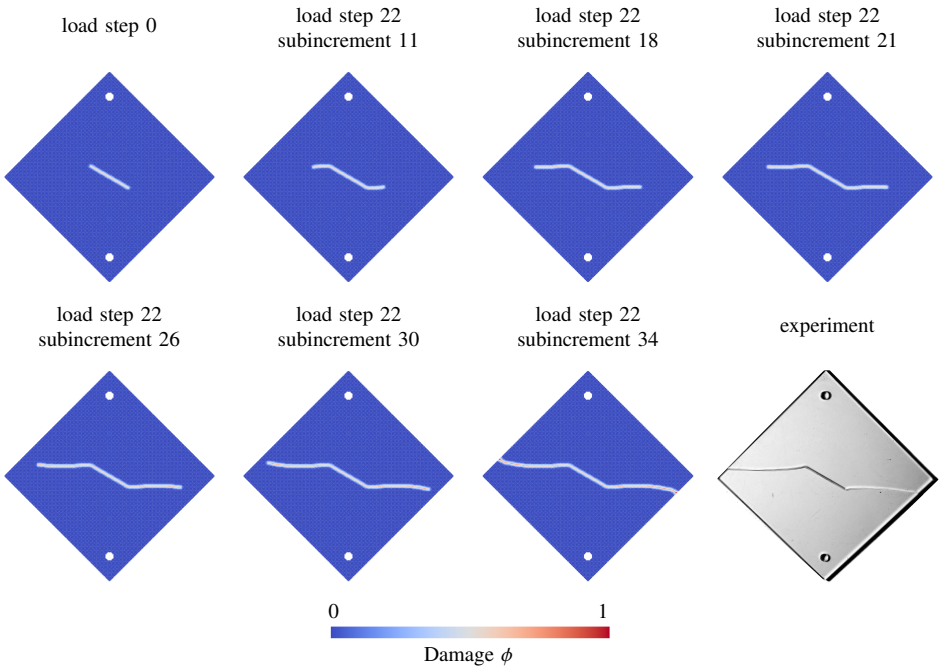



**Figure 1:** The evolution of the crack path in a diagonally loaded square plate: Comparison of the crack predicted by the CPD model with the experimental result.

## References

[1] A. Javili, A. T. McBride, and P. Steinmann. "Continuum-kinematics-inspired peridynamics. Mechanical Problems." *Journal of the Mechanics and Physics of Solids* 131 (2019), pp. 125–146.

[2] M. Laurien, A. Javili, and P. Steinmann. "A damage formulation for continuum-kinematics-inspired peridynamics to capture fracture experiments".

# Experimental investigations of photo-sensitive polymers with polarized light

**Markus Mehnert**

The the setup for the photo-mechanical experiments performed with Elastosil P7670 filled with azobenzene molecules (published in [1]) has been modified significantly by the inclusion of additional components as shown in the sketch in Figure 1:

- A lens (2) is placed directly in front of the UV LED (1) that collects the diverging light emitted by the diode into a parallel light path.
- A polarization filter (3) is mounted behind the first lens that enables us to control the polarization direction of the light in the collected light path.
- A second lens (5) is added behind the material sample (4) to collect the light that is not absorbed by the polymer.
- We focus the light on a photo-sensitive diode (6) that measures the remaining light intensity giving us information on the amount of light that is absorbed by the material.

In the present experiments we take into account that the angle between the azobenzene and the polarization direction of the light determines the switching probability from the stable *trans*- to the meta-stable *cis-state*. Thus, we use this information to determine if the orientation of the azobenzene molecules adapts to the deformation direction of the material. This is done by analyzing the photo-mechanical effect for various applied strains in combination with different polarization orientations of the illuminating light (relative to the deformation direction). Initial results clearly indicate a directional dependency in the coupled experiments. However, the reader should note that the light intensity is significantly reduced by the polarization filter. Therefore, the effect of the light on the material is decreased. This poses substantial challenges on the experiments in terms of the repeatability. Therefore, special care has to be taken to ensure that no other effects such as viscous stresses influence the results when an experiment is repeated.

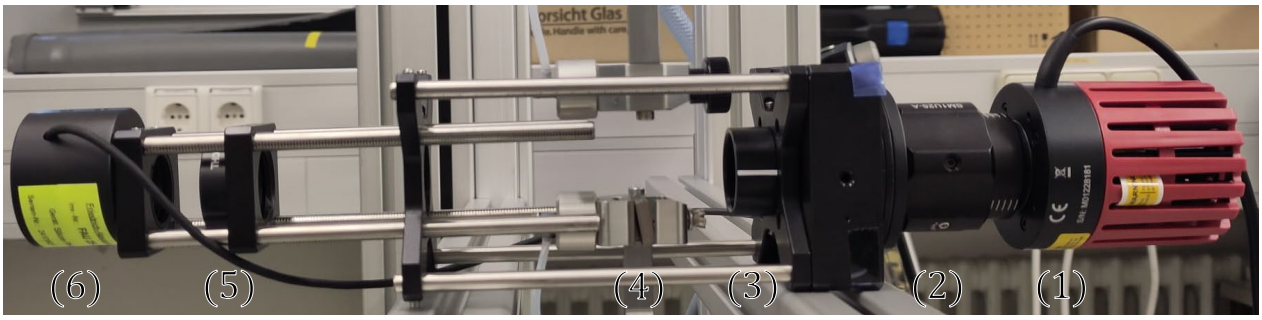



**Figure 1:** Picture of the modified experimental setup including (1) the UV-LED, (2) the first lens, (3) the polarization filter, (4) the material sample, (5) the second lens and (6) the photo-sensitive diode.

## References

[1] M. Mehnert, M. A. Moreno-Mateos, J. H. Griwatz, S. Müsse, H. Wegner, and P. Steinmann. "Experimental and numerical investigation of the photo-mechanical response of azobenzene filled soft elastomers, Part I: Experimental investigations". *Extreme Mechanics Letters* (2024), p. 102182.

# Soft Cutting Mechanics

**Miguel Angel Moreno-Mateos, Paul Steinmann**

Cutting soft materials is a complex process governed by the interplay of bulk large deformation, interfacial soft fracture, and contact forces with the cutting tool. Existing experimental characterizations and numerical models often fail to capture the variety of observed cutting behavior, especially the transition from indentation to cutting and the roles of dissipative mechanisms. We combine novel experimental cutting tests on three representative materials—a soft hydrogel, elastomer, and food materials—with a coupled computational model that integrates soft fracture, adhesion, and frictional interactions [1] (Figure 1a-c). Our experiments reveal material-dependent cutting behavior, with abrupt or smooth transitions from indentation to crack initiation, followed by distinct steady cutting regimes (Figure 1d). The computational model captures these responses and shows that adhesion and damping contributions in the cohesive forces dominate tangential stresses, while Coulomb friction plays a negligible role due to low contact pressures. Together, these results provide new mechanistic insights into the physics of soft cutting and offer a unified framework for soft cutting mechanics to guide the design of soft materials, cutting tools, and cutting protocols, with direct relevance to surgical applications and the engineering of food textures optimized for mastication.

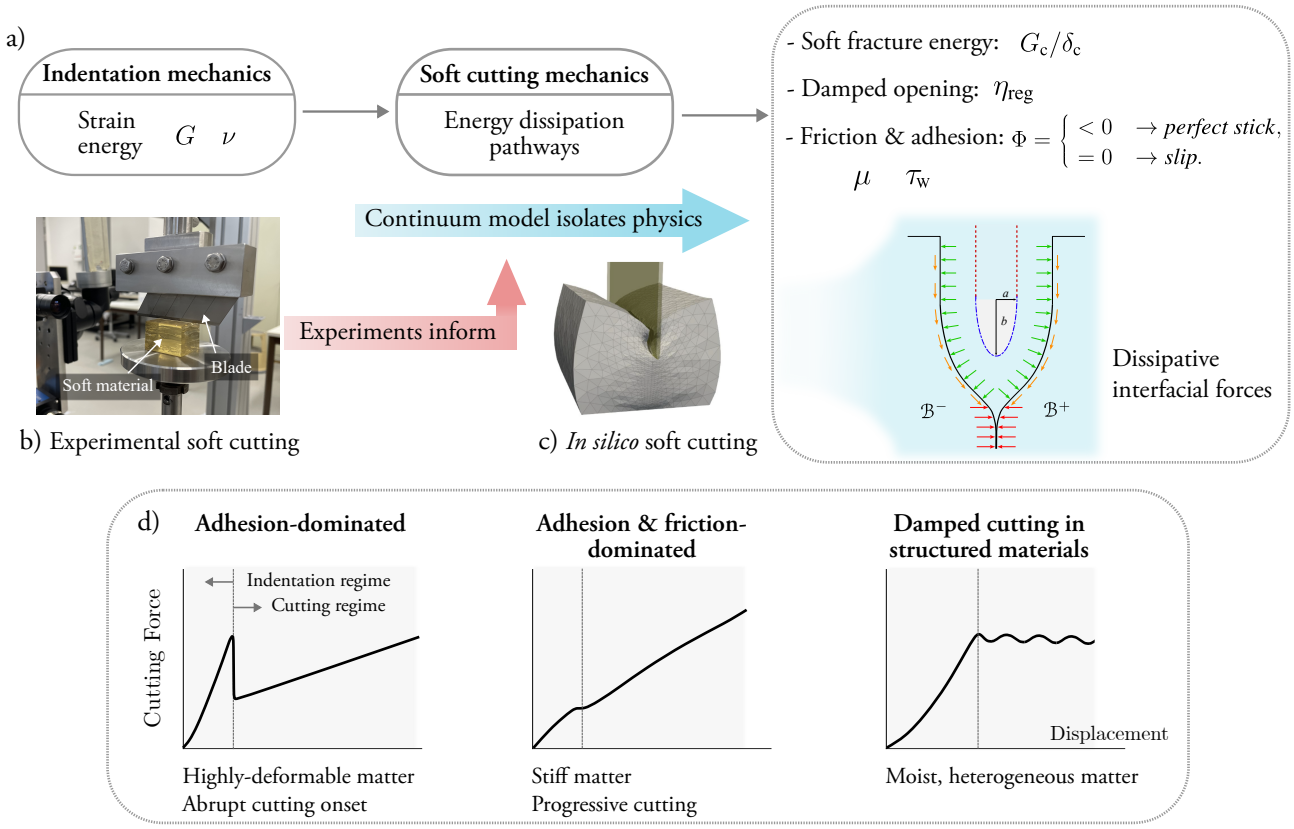



**Figure 1:** Overview of cutting mechanics in soft materials.

## References

[1] M. A. Moreno-Mateos and P. Steinmann. "Cutting soft materials: how material differences shape the response". *npj Computational Materials* (2025).

# A cycle jump method for accelerating cyclic loading simulations

**Maxim Rodschei, Gunnar Possart, Paul Steinmann, Julia Mergheim**

Engineering components and structures are often subjected to cyclic loading conditions. Simulating such scenarios, for instance in the context of fatigue and lifetime analyses, can pose significant numerical challenges. Since materials in structural engineering and industrial applications typically experience millions of load cycles, a comprehensive assessment based on simulating each cycle individually is often infeasible due to prohibitive computational cost.
A proven solution to this problem is the cycle jump method. This approach is based on the following procedure: Initially, a set of training cycles is simulated to identify global trends in state variables. Subsequently, a time jump is performed and the state is extrapolated forward, effectively skipping a large number of cycles. After the cycle jump, control cycles are simulated again to capture new trends before the next cycle jump.

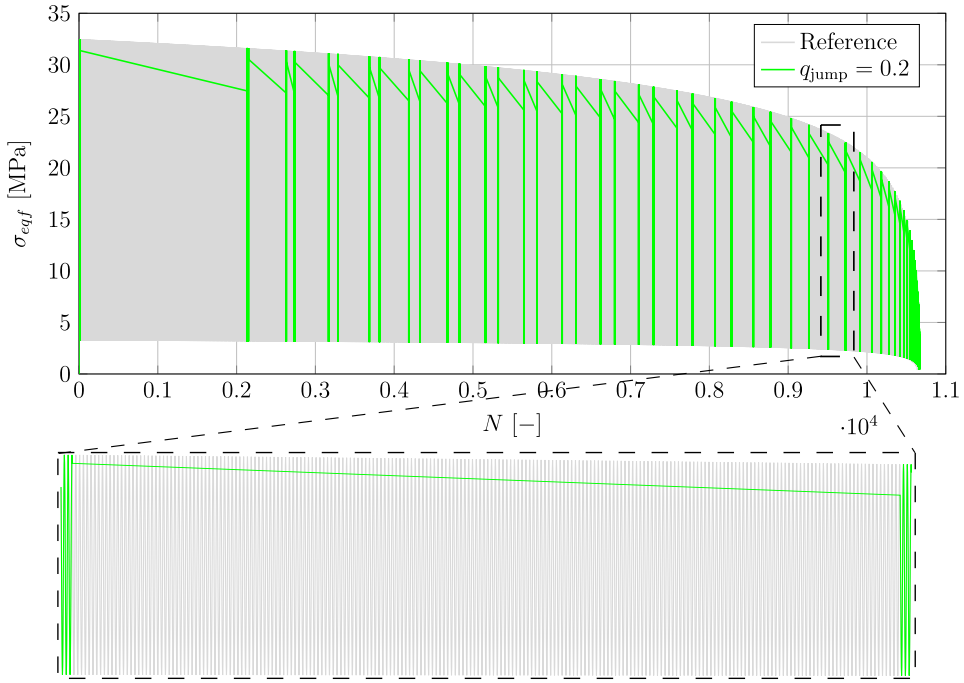



**Figure 1:** Comparison of regular cycle-by-cycle simulation with cycle jump method.

Figure 1 illustrates the technique using the cyclic evolution of the equivalent stress $\sigma_{eqf}$ over the cycle number $N$ in a cyclically loaded adhesive layer. The grey curve represents the reference solution from a full cycle-by-cycle analysis, while the green curve shows the cycle jump solution. The method reproduces the stress evolution with high accuracy. This is further highlighted in the inset below the diagram, which shows a zoomed-in view of a cycle jump: after computing three control cycles, a jump was applied, thereby skipping the subsequent 217 cycles. Then, three cycles were simulated again before the next jump was performed. Using this method, computation time was reduced by up to a factor of 144 while accuracy remained high.
Further details on this example and scheme are provided in our article [1], currently under review.

## References

[1] M. Rodschei, G. Possart, P. Steinmann, and J. Mergheim. "A cycle jump method for accelerating damage simulations of adhesive joints under coupled hygro-mechanical loading". *International Journal of Fatigue* (2026). Submitted.

# Efficient phase-field fracture simulations for fracture analysis in heterogeneous materials

**Maurice Rohracker, Julia Mergheim**

The phase-field fracture method is a popular fracture modeling technique; however, it is computationally expensive. The approach uses a smeared fracture field $z$ that is controlled by the length scale parameter $l_c$ to mimic a discrete crack. Three main numerical challenges contribute to the computational complexity: solving a non-convex coupled energy functional, requiring fine meshes to account for a feasible crack approximation due to the small length scale parameter, and necessitating small time step sizes to accurately capture fracture behavior. The phase-field fracture approach (cf. [1]) requires the solution of the following energy minimization problem in order to simulate fracture in brittle materials. With $z = 1 \Rightarrow$ intact and $z = 0 \Rightarrow$ broken, find $\mathbf{u} \in \mathcal{B} \rightarrow \mathbb{R}^{\mathrm{dim}}$, $z \in \mathcal{B} \rightarrow [0,\, 1]$, s. t.

$$\mathscr{E}\left(\boldsymbol{\varepsilon}, z\right) = \int_{\mathcal{B}} \left[\left[g\left(z\right) + k\right] \Psi^{+} + \Psi^{-}\right] dV + \int_{\mathcal{B}} \frac{\mathrm{G_c}}{c_\omega} \left[\frac{\omega\left(z\right)}{l_c} + l_c |\mathrm{grad}\, z|^2\right] dV - \mathscr{W}^{\mathrm{ext}} \rightarrow \min$$

Performance enhancement strategies are required, particularly for heterogeneous materials, to prevent simulations that are too computationally expensive (Rohracker et al. [2]). The fracture energy-based combined convergence check reduces the large number of staggered iterations. Spatial and temporal adaptivity complete the efficient and accurate simulation model as illustrated in the flowchart in Figure 1. Small time step sizes and fully refined meshes are eliminated throughout the simulation by these two adaptivity approaches. The efficient and accurate simulation framework enables fracture simulations in heterogeneous materials. The fracture contour of a tensile test of a heterogeneous structure with two notches is depicted in Figure 2, where stiff particles are randomly distributed in a weak matrix material.

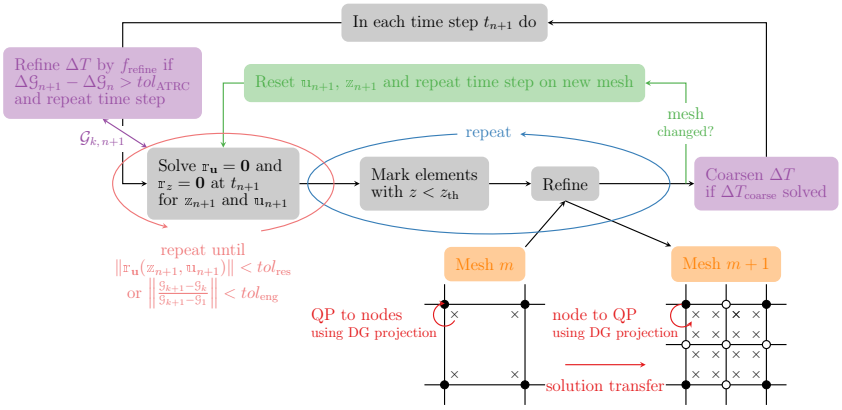



**Figure 1:** Solution scheme with the performance enhancement strategies.

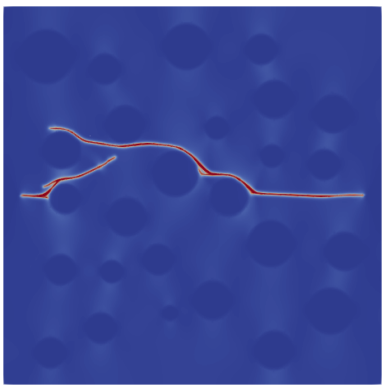


**Figure 2:** Fracture contour in a heterogeneous structure.

## References

[1] L. D. Lorenzis and T. Gerasimov. "Numerical Implementation of Phase-Field Models of Brittle Fracture". In: *Modeling in Engineering Using Innovative Numerical Methods for Solids and Fluids*. Ed. by L. D. Lorenzis and A. Düster. Cham: Springer International Publishing, 2020, pp. 75–101.

[2] M. Rohracker, P. Kumar, P. Steinmann, and J. Mergheim. "Efficient phase-field fracture simulations for fracture analysis in heterogeneous materials". *Computational Mechanics* (2025).

# Configurational forces in soft materials using the mixed formulation

**Erodita Saliji, Paul Steinmann**

Nearly incompressible materials pose significant computational challenges in finite element analysis due to volumetric locking phenomena, which severely degrade the accuracy of stress calculations and, consequently, configurational force computations. Standard displacement-based finite elements allow for accurate evaluations at low Poisson's ratios but suffer from volumetric locking as the material approaches incompressibility.

This work presents a thermodynamically consistent formulation of the Eshelby energy-momentum tensor specifically derived for the F-bar method (Saliji et al.[1]). The F-bar approach (reduced mixed formulation) circumvents volumetric locking. A rigorous expression for the Eshelby tensor accounting for the deviatoric-volumetric split inherent in mixed formulations has been derived.

The methodology is implemented through Pacman-shaped crack tip domains where boundary conditions are prescribed using analytical Linear Elastic Fracture Mechanics solutions for various energy release rates and Poisson's ratios. Configurational forces are compared against the prescribed J-integral values. Results demonstrate that the F-bar formulation with the consistent Eshelby tensor outperforms standard displacement-based elements at higher Poisson's ratios.

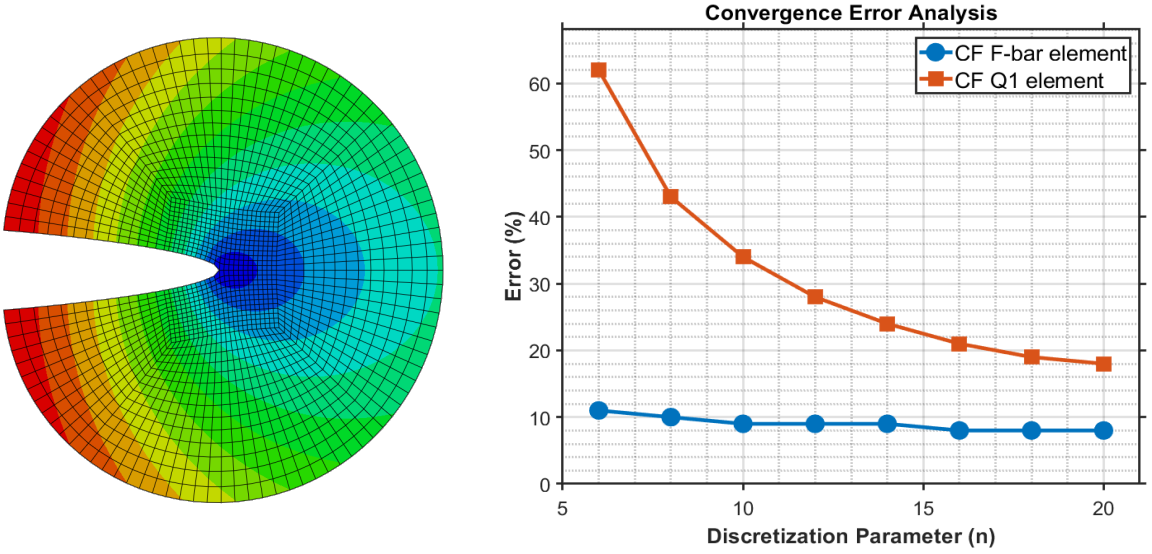



**Figure 1:** (Left) Deformed configuration of the Pacman. (Right) Mesh refinement study comparing configurational force accuracy: F-bar formulation with thermodynamically consistent Eshelby stress versus standard displacement-based Q1 elements.

## References

[1] E. Saliji and M. Jabareen. "An MFE$^2$ framework for the computational homogenization of nearly incompressible soft composites". *Composite Structures* 373 (2025), p. 119611.

# Configurational forces explain echelon cracks in soft materials

**Angel Santarossa, Miguel Angel Moreno-Mateos, Paul Steinmann**

Soft fracture in highly deformable solids involves both geometric and constitutive nonlinearities, necessitating advanced theoretical and computational frameworks for its accurate understanding. Tensile fractures subjected to mixed-mode loading deviate from their original planar shape, resulting in echelon crack patterns. When out-of-plane shear is superimposed, a crack front segments into an array of tilted facets. The physical interpretation of echelon cracks is only marginally understood, typically relying on rather limited approaches within Linear Elastic Fracture Mechanics.

In this project, we investigate mixed-mode I + III fracture within the framework of configurational mechanics. Using the Configurational Force Method, implemented as a post-processing algorithm in a finite-element-based simulation, we compute the configurational forces acting at the crack tip of model fracture geometries prior to propagation to unveil the underlying mechanism behind the fragmentation process. Configurational forces characterize both the magnitude and direction of propagation for the maximal energy release rate. The results of our work reveal the complex interactions between tilted facets and their critical role in shaping the fracture morphology [1]. In addition to the interaction of individual facets, we investigate the phenomenon of facet coalescence, in which neighboring facets merge, driven by the growth of the parent crack, into a unified crack front. Our work reveals how coalescence leads to asymmetric crack growth: it shields the propagation tendency in nearby facet regions while amplifying the driving forces in more distant parts of the coalescing front. These findings offer new insights into fracture processes in soft, quasi-brittle materials subjected to mixed-mode loading.

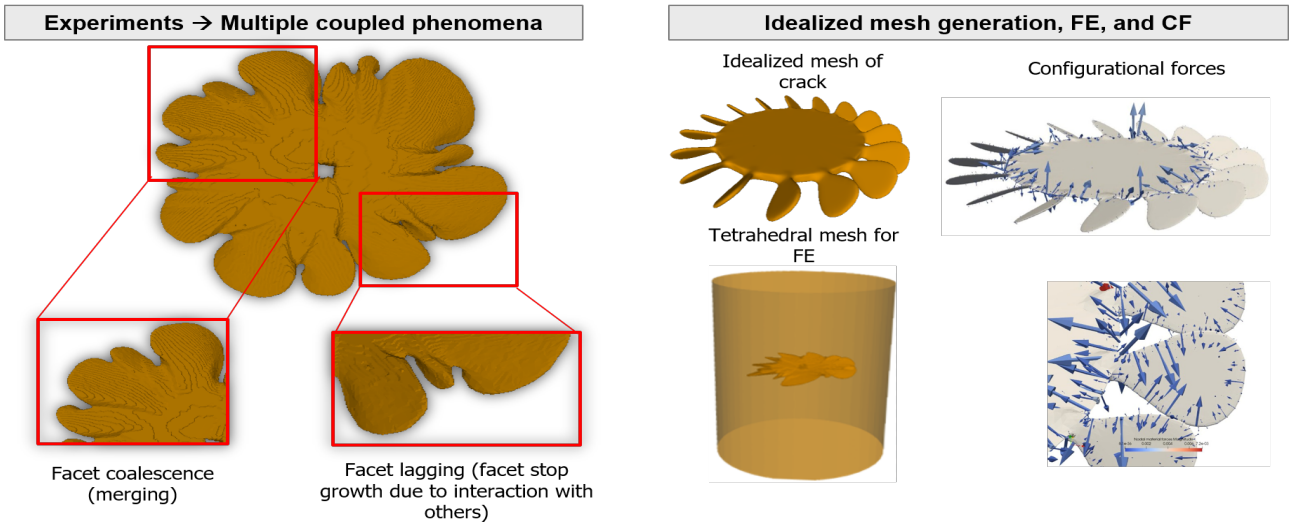



**Figure 1:** Left: 3D tomographic reconstruction of a crack under mixed I+III loading. Phenomena due to facets interaction are highlighted. Right: Numerical simulation framework: idealized mesh generation, material mesh for FEM and CF analysis.

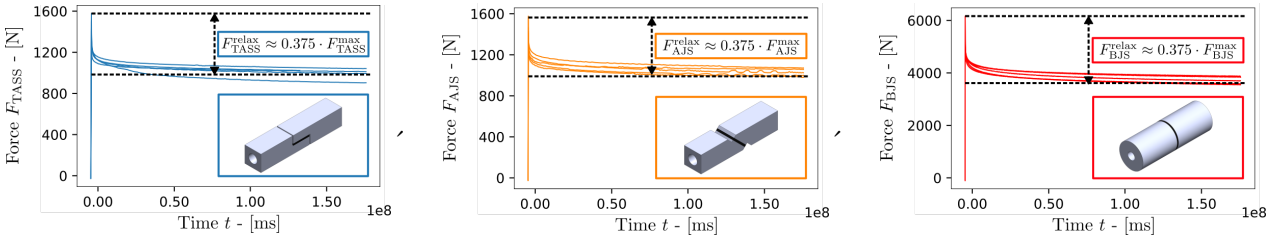
## References

[1] A. Santarossa, N. Varela-Rosales, P. Steinmann, and M. A. Moreno-Mateos. "Configurational forces explain echelon cracks in soft materials". *Journal of Mechanics and Physics of Solids* (2025). Submitted.

# Volumetric viscosity - an extension for the Three-Network-Model

**Lars Schmelzle, Gunnar Possart, Julia Mergheim**

The Three-Network-Model developed by Bergström [1] is considered a suitable model for hyperviscoelastoplastic thermoplastic materials. However, experimental data from relaxation tests performed for three different specimens made of the 2-component polyurethane adhesive BetaForce 2850L, indicate a significant limitation.
For the thick adherend shear specimen (TASS) the deformation is purely isochoric $\mathbf{F}_{\mathrm{TASS}} = \mathbf{F}^{\mathrm{iso}}_{TASS}$, but for the angle joint specimen (AJS) and butt joint specimen (BJS) the deformation $\mathbf{F} = \mathbf{F}^{\mathrm{iso}}\mathbf{F}^{\mathrm{vol}}$ has increasing volumetric parts $\mathbf{F}^{\mathrm{vol}}$ with $\mathbf{1} < \mathbf{F}^{\mathrm{vol}}_{\mathrm{AJS}} < \mathbf{F}^{\mathrm{vol}}_{\mathrm{BJS}}$.
For all three examined loadcases, roughly 37.5% of the maximum forces $F^{max}$ relax over time, as shown in Figure 1. Yet the TNM only allows for isochoric viscous deformations $\mathbf{F}^{\mathrm{v}} = \mathbf{F}^{\mathrm{v,iso}}$, which should result in higher relaxtion values for the TASS compared to the AJS and BJS from a modeling perspective, contradicting the experimental observations.




**(a)** TASS. **(b)** AJS. **(c)** BJS.

**Figure 1:** Experimental relaxation tests for different specimens.

To resolve this deficiency, we extended the evolution of the viscous part $\mathbf{F}^{\mathrm{v}}$ of the deformation gradient $\mathbf{F} = \mathbf{F}^{\mathrm{e}}\mathbf{F}^{\mathrm{v}}$ to a dependency on the so far neglected volumetric stresses $\boldsymbol{\sigma}^{\mathrm{vol}}$, highlighted in gray

$$\dot{\mathbf{F}}^{\mathrm{v}} = \dot{\gamma}_0 \left[ \frac{\left\| \boldsymbol{\sigma}^{\mathrm{iso}} + \alpha \boldsymbol{\sigma}^{\mathrm{vol}} \right\|}{\sigma_0 + a\langle p \rangle} \right]^m \mathbf{F}^{-\mathrm{e}} \frac{\boldsymbol{\sigma}^{\mathrm{iso}} + \boldsymbol{\sigma}^{\mathrm{vol}}}{\left\| \boldsymbol{\sigma}^{\mathrm{iso}} + \alpha \boldsymbol{\sigma}^{\mathrm{vol}} \right\|} \mathbf{F}. \tag{1}$$

The additional parameter $\alpha$ allows to scale the influence of the volumetric viscous effects relative to the isochoric ones. The original model parameters $\dot{\gamma}_0$, $\sigma_0$, $a$ and $m$ in Equation 1 remain unchanged regarding their interpretation. The parameter $\dot{\gamma}_0 = 1/s$ ensures correct units, while the combination of $\sigma_0$ and $m$ control the nonlinear dependency of the viscous effects on the stresses and the parameter $a$ implements a dependency on the pressure $p$.

## References

[1] J. S. Bergstrom. "Viscoplasticity Models". In: *Mechanics of Solid Polymers - Theory and Computational Modeling*. First Edition. San Diego, California ; William Andrew, an imprint of Elsevier, 2015. Chap. 8, pp. 417–425.

# Investigating neural network approaches for accelerating continuum-kinematics-inspired peridynamics simulations

**Aditi Sharma**[1], **Ali Javili**[2], **Paul Steinmann**[1]

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Continuum-kinematics-inspired peridynamics (CPD) is an alternative formulation of peridynamics and a geometrically exact framework proposed by Javili et al. [1]. In CPD, the numerical implementation requires discretising the continuum by a finite number of grid points; the interaction between these grid points is characterised by one-neighbour, two-neighbour and three-neighbour interactions within the horizon. The nonlocal governing equations involve a single, double, and triple integral over the horizon for one-, two-, and three-neighbour interactions, respectively. The numerical evaluation of these integrals is computationally expensive as it must be performed repeatedly for each material point and at every deformation step, making large-scale simulations computationally prohibitive. Additionally, problems involving intricate fractures are computationally expensive, as the fracture path is heavily influenced by the discretisation level. A finer discretisation increases the number of material points and, consequently, the computational cost. The research aims to explore the feasibility of developing a surrogate neural network to approximate the integral operations in CPD. The goal is to train the network to predict the outcomes of one-, two-, and three-neighbour interaction based on representative data, thereby bypassing the need for explicit numerical integration in each iteration. Such a surrogate model could significantly reduce computation time while maintaining acceptable accuracy, making large-scale CPD simulations more accessible. The study will begin by generating high-fidelity datasets from numerical CPD simulations for one-, two-, and three-neighbour interactions. These datasets will then be used to train and validate neural networks that can reproduce the integration results. Finally, the surrogate model will be integrated into the CPD framework to evaluate its performance in terms of accuracy and computational efficiency. Figure 1 shows a preliminary outline of the planned neural network architecture.

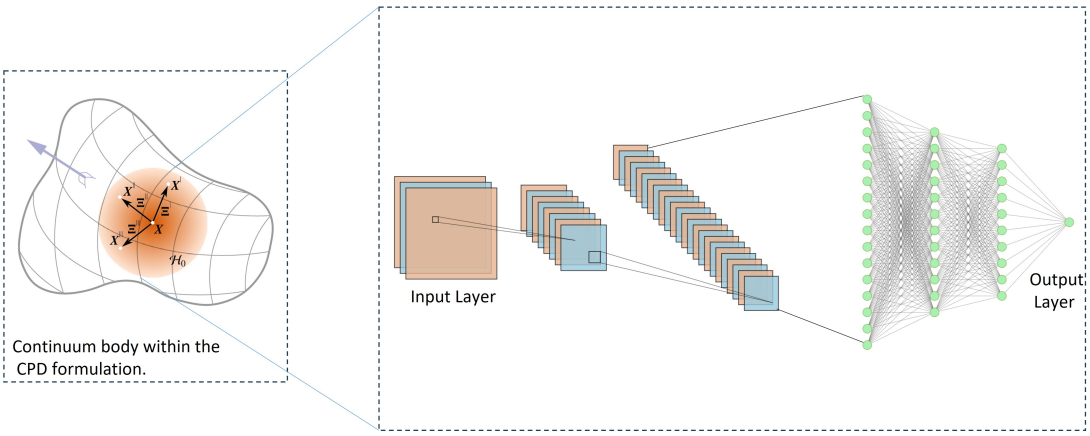


**Figure 1:** The preliminary framework of the neural network as an integral operator in CPD.

## References

[1] A. Javili, A. T. McBride, and P. Steinmann. "Continuum-kinematics-inspired peridynamics. Mechanical problems". *Journal of the Mechanics and Physics of Solids* 131 (2019), pp. 125–146.

# Generalized mechanical interfaces at finite strains

**Lucie Spannraft, Paul Steinmann, Julia Mergheim**

Interfaces exist on various size scales in numerous materials relevant for many engineering applications. For instance, microscopic grain boundaries in polycrystalline metals or macroscopic adhesive bonds in, e.g., aircraft production, lightweight construction or sealing applications. Interfaces significantly impact the overall behavior by, both, increasing the strength but also acting as a weak link in case of decohesion. In many applications, anisotropic decohesion arises with interacting normal and shear damage modes. Further, the cohesive damage is affected by in-plane stretch and the corresponding membrane response from interface (in)elasticity. For anisotropic decohesion at finite strains, additional cohesive stresses are required to fulfill the balance of angular momentum at the interface, i.e.,

$$[\bar{\boldsymbol{P}}^{\mathrm{c}} + \bar{\boldsymbol{P}}^{\mathrm{m}}] \cdot \bar{\boldsymbol{F}}^{\mathrm{T}} + \boldsymbol{T}^{\mathrm{c}} \otimes [\![\boldsymbol{\varphi}]\!] \in \mathrm{sym}(3)$$

with the cohesive and membrane Piola stresses $\bar{\boldsymbol{P}}^{\mathrm{c}}$ and $\bar{\boldsymbol{P}}^{\mathrm{m}}$, the interface deformation gradient $\bar{\boldsymbol{F}} := \bar{\nabla}\bar{\boldsymbol{\varphi}}$, the cohesive tractions $\boldsymbol{T}^{\mathrm{c}}$, and the displacement jump $[\![\boldsymbol{\varphi}]\!]$.

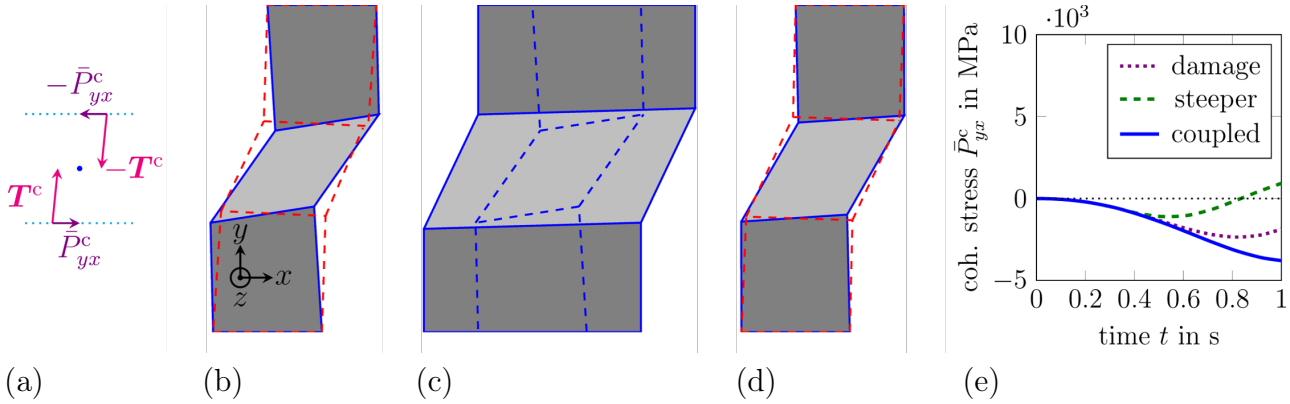


**Figure 1:** (a) Schematic representation of cohesive tractions and stresses at a generalized interface with displacement jump. (b–e) Tension-shear tests at an interface (light gray) with cohesive anisotropy comparing $\bar{\boldsymbol{P}}^{\mathrm{c}}$ calculated and non-physical $\bar{\boldsymbol{P}}^{\mathrm{c}} \stackrel{!}{=} \boldsymbol{0}$. (b) Elastic interface. (c) Elastic interface w(solid blue)/wo(dashed blue) in-plane stretch. (d) Damage mode coupling. (e) Cohesive stress for different damage progressions and coupling corresponding to (d). Cf. [1, 2].

When neglecting these shear like stresses, the cohesive tractions may cause non-physical rotations at the interface, which overall creates incorrect results, cf. Figure 1 (a,b). Different influences on the cohesive stresses can be observed in FEM simulations using our generalized interface model [2]. In-plane stretch (even when not accounting for a membrane formulation) reduces cohesive stresses by means of the interfacial determinant of the interface deformation gradient, i.e., the enlargement of the interface, compare Figure 1 (c). Cohesive damage initiation and progression (also due to damage mode coupling) affects cohesive anisotropy, and thus, the cohesive stresses. In general, cohesive damage reduces the stresses for constant or decreasing anisotropy, see Figure 1 (d,e).

### References

[1] L. Spannraft. "Mechanics of generalized interfaces and grain boundaries". Dissertation in preparation. Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU).

[2] L. Spannraft, P. Steinmann, and J. Mergheim. "A generalized anisotropic damage interface model for finite strains". *Journal of the Mechanics and Physics of Solids* 174 (2023), p. 105255.

# Modeling strain hardening in glassy polymers based on the microscopic mechanisms revealed by molecular dynamic simulations

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Strain hardening in glassy polymers remains challenging to quantify and predict, as it involves complex nonaffine molecular rearrangements that vary with strain rate and temperature. Using coarse-grained molecular model of thermoplastics with different chain lengths, we performed uniaxial tension simulations at various temperature and strain rate to reveal the microscopic mechanisms of strain hardening [1]. We first quantified the disentanglement viscosity and established its dependence on chain length and deformation rate as well as temperature (Figure 1), providing a microscopic measure of the resistance to segmental relaxation. We then identified a load-bearing mechanism within entangled segments, where the most extended bonds govern local deformation and collectively determine the macroscopic stress response, as evidenced by the correlation between bonded stress and load-bearing deformation gradient (Figure 2). Building on these molecular insights, we developed a constitutive model that integrates load-bearing and entanglement relaxation processes, enabling accurate prediction of the rate- and temperature-dependent stress–strain behavior of glassy polymers as various chain lengths. This work establishes a unified microscopic framework connecting polymer topology, segmental dynamics, and macroscopic mechanical response.

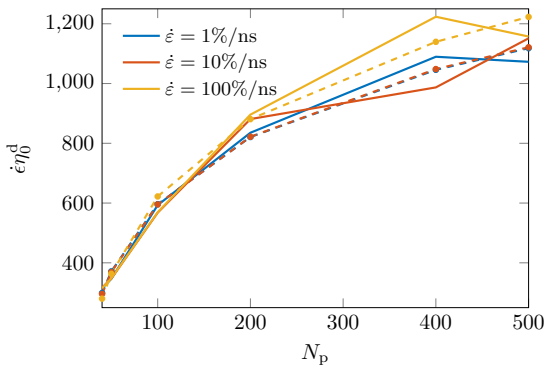


**Figure 1:** Scaled athermal relaxation viscosity at different strain rates and chain length (solid curves) and their fit curves. Adopted from 1.

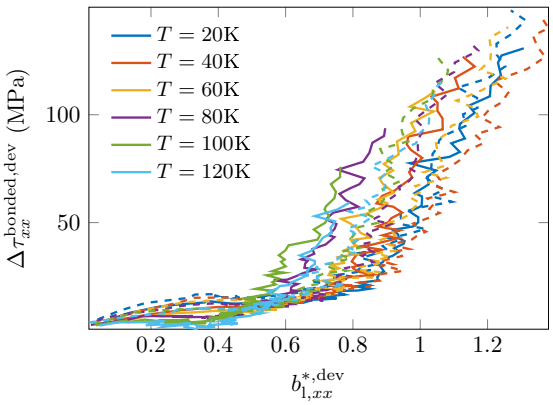


**Figure 2:** Bonded Kirchhoff stress as a functions of left Cauchy–Green tensor of load-bearing deformation of the system. Adopted from 1.

## References

[1] W. Zhao, R. Xiao, S. Pfaller, and P. Steinmann. "Modeling strain hardening in glassy polymers based on the microscopic mechanisms revealed by molecular dynamic simulations". *Journal of the Mechanics and Physics of Solids* 206 (2026), p. 106384.

# – Fluid mechanics –

# A novel data-driven surrogate approach for fast evaluation of the dynamics of soft ellipsoidal micro-particles in dilute viscous flow

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Predicting the motion of micro-particles is challenging, as they often deviate from simple spherical shapes and may deform under flow-induced stresses (e.g., liposomes, hydrogels). Existing models rely on computationally demanding surface or volume discretizations, restricting simulations to few particles. To address this, we developed an efficient pseudo-rigid body approach combined with point-particle tracking (meshless) for initially spherical and ellipsoidal soft particles [1, 2]. Extending this framework to more general shapes is limited by the lack of analytical solutions for flow-induced tractions, highlighting the potential of a Direct Numerical Simulation (DNS) database to estimate tractions on arbitrarily shaped particles.

In this context, we developed a data-driven surrogate model for fast prediction of the deformation dynamics of soft (ellipsoidal) particles in flow, see [1]. We show that the analytical force dyad can be represented as a linear combination of velocity gradient components, modulated by form coefficients that scale the shear, rotational, and extensional contributions. These coefficients depend only on particle shape and can therefore be learned using neural networks (NN). The employed NN structure is displayed in Fig. 1

Two training strategies were explored: one using analytical datasets, enabling computational savings, and another based on 3D DNS data using the Boundary Element Method. Validation against established benchmarks confirmed excellent agreement as shown in Wedel et al. [1]. Overall, this work is a first step towards extending our pseudo rigid body approach to more complex shaped particles, where analytical traction expressions are unavailable.

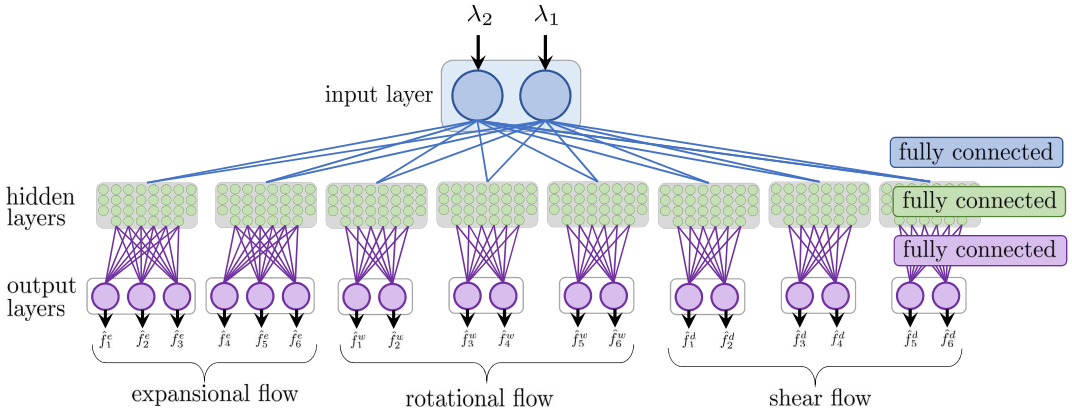


**Figure 1:** Employed fully connected neural network [1]: 2 input neurons, 4 hidden layers ($8 \times 8 \times 8 \times 6$), 3 output neurons for each considered expansional flow and 2 output neurons for each shear and rotational flow. Inputs: particle shape parameters $\lambda_1$ and $\lambda_2$. Outputs: form coefficients $\hat{f}$ associated with each flow-field contribution (expansional, rotational, and shear).

## References

[1] J. Wedel, I. Horvat, N. Vovk, M. Hriberšek, J. Ravnik, and P. Steinmann. "A novel data-driven surrogate approach for fast evaluation of the dynamics of soft ellipsoidal micro-particles in dilute viscous flow". *Computer Methods in Applied Mechanics and Engineering* 448 (2026), p. 118452.

[2] J. Wedel, M. Hriberšek, J. Ravnik, and P. Steinmann. "Ellipsoidal soft micro-particles suspended in dilute viscous flow". *Computer Methods in Applied Mechanics and Engineering* 441 (2025), p. 117973.

– Multi-scale modeling and simulation –

# Overcoming hurdles in concurrent discrete-to-continuum coupling

**Lukas Laubert, Sebastian Pfaller**

Discrete-to-continuum coupling techniques are applied in non-affine mechanical loading analyses of particle-based models. Our contributions [2] and [1] investigated the Capriccio method, a state-of-the-art FE–MD coupling approach, focusing on strain inconsistencies between coupled domains under mechanical loading. They revealed that the coupled region experiences motion resistance—counteracting forces opposing spatial motion. [2] confirmed that conducting a larger number of smaller displacement increments alleviate this effect, while [1] showed that the anchor point stiffness—crucial for force transmission between domains—not only penalizes spatial domain mismatches but also suppresses spatial motion, which in turn requires such temporary mismatches. As a remedy, we introduce an additional coupling constraint that decouples the rigid-body motion of a confined MD region from its deformation-related movement. With this extension, strain inconsistencies in load cases involving asymmetric displacements of the coupling regions are reduced to levels comparable to simulations where the MD sample's center of mass remains stationary. Moreover, the extension rules out certain dynamic contributions in the MD region and restores the FE stiffness matrix singularity typical of purely static FE problems. A simple demonstration is the rigid-body translation of a sandwich system in which an MD sample is coupled to two FE layers on opposite sides. Using the original coupling scheme, Figure 1 shows persistent strain accumulation, whereas the modified scheme in Figure 2 eliminates it—at the cost of minor strain fluctuations in the FE domain, likely due to local force fluctuations in the MD region and slightly asymmetric anchor point spring distributions across the two coupling zones. Overall, this extension enables more accurate deformation and fracture studies, such as bending simulations, where the MD sample traverses large spatial distances.

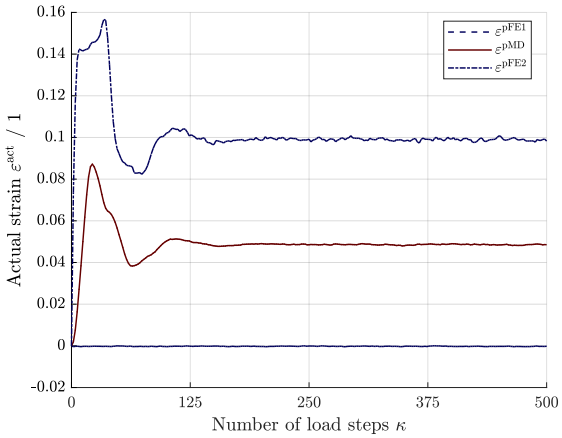


**Figure 1:** Original coupling scheme.

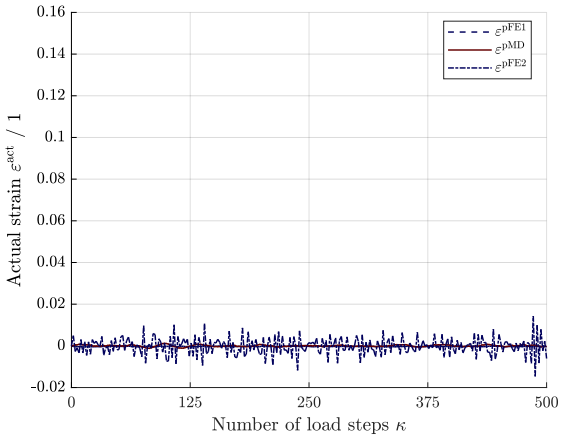


**Figure 2:** Extended coupling scheme.

## References

[1] L. Laubert, F. Weber, F. Detrez, and S. Pfaller. "Approaching and overcoming the limitations of the multiscale Capriccio method for simulating the mechanical behavior of amorphous materials". *International Journal of Engineering Science* 217 (2025), p. 104317. ISSN: 0020-7225. DOI: https://doi.org/10.1016/j.ijengsci.2025.104317.

[2] L. Laubert, F. Weber, and S. Pfaller. "Assessing the Capriccio method via one-dimensional systems for coupled continuum-particle simulations in various uniaxial load cases using a novel interdimensional comparison approach". *Computer Methods in Applied Mechanics and Engineering* 439 (2025), p. 117817. ISSN: 0045-7825. DOI: https://doi.org/10.1016/j.cma.2025.117817.

# Investigation of multiscale fracture mechanisms of thermoplastics using large-scale molecular dynamics simulations reaching up to the microscale

**Eva Maria Richter, Felix Weber, Sebastian Pfaller, Maximilian Ries**

Fracture in thermoplastics is a highly multiscale phenomenon. On the one hand, the process zone can make up to hundreds of micrometers in size, while on the other hand, the movement of individual polymer chains on the nanoscale is highly relevant to capture the global fracture process. Because neither traditional experiments nor simulation methods can access the fracture process at the microscale while maintaining a nanoscale resolution, it remains an enigma how fracture processes on different length scales are connected. This, however is crucial to understand the global fracture process of thermoplastics better. For this purpose, a lot of new simulation techniques are currently being developed that aim to capture the fracture process at multiple length scales. However, at this point, these newly developed simulation methods often stand on shaky feet, since barely any suitable benchmark results are available. In this contribution (in preparation) [1], we aim to provide exactly those benchmark results. Therefore, we upscale an existing molecular dynamics model of a generic thermoplastic polymer to an extend that not only multiple nanometers, but multiple micrometers of material can be covered, as sketched in Figure 1. In order for this to work, we are developing a suitable framework which makes this enormous upscaling-procedure possible. Our model is then able to entail up to 30 million course-grained superatoms. We then investigate the influence of boundary conditions, pre-crack length, chain length, chain entanglement and chain stiffness on the fracture process. In this context, two relevant observations could be made: First, we find that no minimal pre-crack length is necessary in order for a crack to propagate; all it needs, is a tiny notch or hole. Second, we can observe an area between the crack tip and establishing fibrils that we classify as an inactive zone. It can be seen as an obstacle that has to be overcome in order for the crack to propagate. In the end, the large-scale molecular dynamics simulations allow for valuable insights that connect the fracture process of thermoplastics on multiple scales and provide benchmark results for developing new, more up-to-the-task simulation methods.

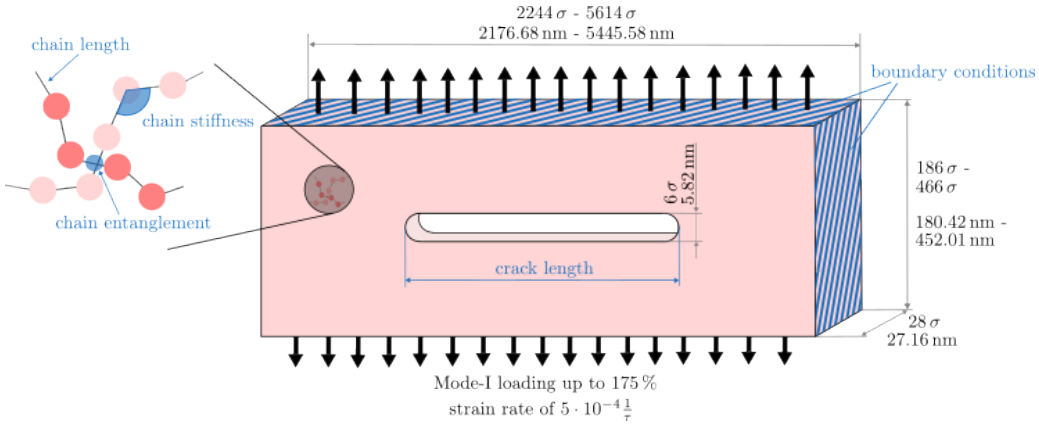


**Figure 1:** Illustration of simulated setups. All setups are flat, three-dimensional cuboids that entail 30 million coarse-grained superatoms. Varied variables are indicated in blue.

## References

[1] E. M. Richter, F. Weber, S. Pfaller, and M. Ries. "Investigation of multiscale fracture mechanisms of thermoplastics using large-scale molecular dynamics simulations reaching up to the microscale".

# Reactive coarse-grained molecular dynamics models to capture interphase formation in epoxy-based adhesives

**Maximilian Ries**

Adhesive joints offer a superior strength-to-weight ratio compared to conventional fastening methods, making them essential for achieving cost-efficiency and sustainability goals. The adherends influence the adhesive in their immediate vicinity, creating regions with altered microstructures. These regions, known as interphases, exhibit material properties that differ from those of the bulk adhesive and are not fully understood from an engineering perspective [2]. To address this issue, we introduce a novel coarse-grained molecular dynamics (CGMD) model for adhesive joints, which aims to study the interphase formation and its resulting properties at the molecular level [1]. We utilize a reactive epoxy model from the literature for the adhesive and implement matching aluminium substrates, along with the necessary adherend-adhesive interaction parameters. The resulting adhesive joint model allows us to investigate the formation of the adhesive's microstructure during the curing process and the mechanical properties of the joint. We conduct a parameter study on the adherend-adhesive interaction parameters, unravel the role of grafting bonds and their distribution, and examine the impact of the adhesive's thickness. Additionally, we identify an interphase based on variations in the local microstructure, estimate its size, and determine the influencing parameters. In this first contribution, we demonstrate the capabilities of our model in evaluating the mechanical behavior of the interphase, which is crucial for gaining a better understanding of adhesive joints [1].

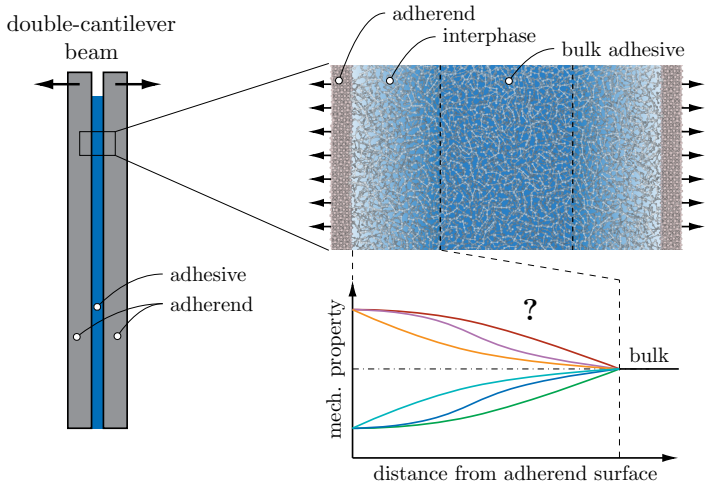


**Figure 1:** Interphases in adhesive joints: adherends affect the material in their vicinity resulting in an interphase region where material properties differ from the bulk adhesive, from [1].

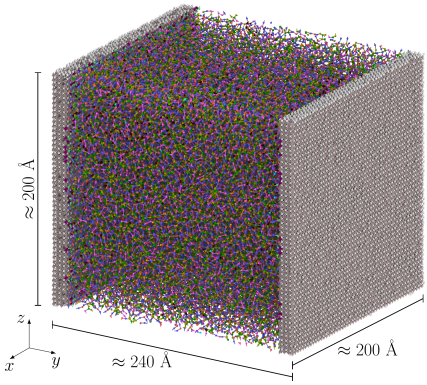


**Figure 2:** Cured and equilibrated CGMD adhesive joint specimen, from [1].

## References

[1] V. Dötschel, E. M. Richter, G. Possart, P. Steinmann, and M. Ries. "Reactive coarse-grained MD models to capture interphase formation in epoxy-based structural adhesive joints". *European Journal of Mechanics - A/Solids* 116 (2026), p. 105801.

[2] M. Ries. "Mechanical behavior of adhesive joints: A review on modeling techniques". *Computer Methods in Materials Science* 24.4 (2025), pp. 5–35.

# Generating quasi-optimal meshes of virtual elements for heterogeneous bodies: A fully adaptive remeshing procedure

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This work extends an adaptive remeshing procedure previously proposed by the authors for the virtual element method (VEM) for homogeneous bodies [2] to the application of heterogeneous bodies [1]. Furthermore, this work represents the first example of adaptive remeshing (i.e., refinement and/or coarsening) applied to heterogeneous bodies in the VEM context. The procedure novelly allows the user to specify either a global error target for an entire body or independent local error targets for the matrix and inclusion portions of the body. Then, from any initial mesh, the procedure performs local adaptive refinement and coarsening until the global or local error targets are met and the element-level error is distributed quasi-evenly across all elements in the mesh. In so doing, the procedure generates a quasi-optimal mesh for the particular problem domain and specified error target(s). The efficacy of the procedure has been demonstrated across a wide range of inclusion stiffnesses, sizes, aspect ratios, geometries, and for varying numbers of inclusions.

The performance of the fully adaptive procedure is exemplified in Figures 1-3. Here, an initially square body containing 9 stiff inclusions is considered. The body is horizontally constrained on its left-hand edge, while the right-hand edge is horizontally displaced. In this example a target global error of 3% is specified. Figure 1 depicts the deformed configuration of an initially uniform mesh from which the adaptive procedure will proceed. Figure 2 depicts the final adapted mesh after the adaptive procedure has concluded. Here, the combined adaptive processes are clearly evident with increased mesh density forming around the edges and corners of the inclusions, where stresses are highest, while coarsening is performed in areas further from the inclusions. Thus, yielding an intuitive mesh density distribution. The convergence of the energy error during the quasi-optimal mesh generation process is depicted in Figure 3 from various initial meshes. It is clear that the final adapted meshes (red markers) meet the global error target from any initial mesh.

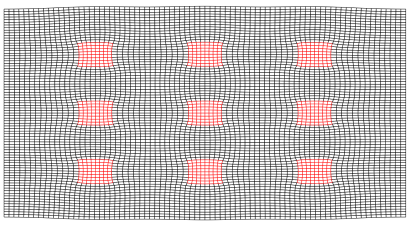

**Figure 1:** Initial mesh (B).

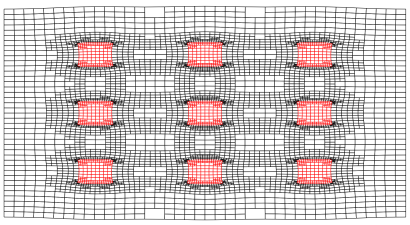

**Figure 2:** Adapted mesh.

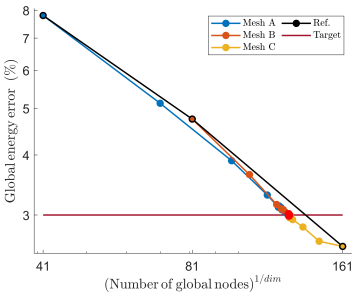


**Figure 3:** Error convergence.

## References

[1] D. van Huyssteen, F. L. Rivarola, G. Etse, and P. Steinmann. "Quasi-optimal mesh generation for heterogeneous materials: A fully adaptive virtual element method".

[2] D. van Huyssteen, F. L. Rivarola, G. Etse, and P. Steinmann. "Quasi-optimal mesh generation for the virtual element method: A fully adaptive remeshing procedure". *Computer Methods in Applied Mechanics and Engineering* 435 (2025).

# Validation of fracture simulations with the Capriccio method

**Felix Weber**[1], **Maxime Vassaux**[2], **Lukas Laubert**[1], **Sebastian Pfaller**[1]

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[2] Institut de Physique de Rennes, Université de Rennes, France

In [2], we show that the Capriccio method, which couples molecular dynamics (MD) with the finite element (FE) method, is capable of performing fracture simulations of amorphous materials that yield quantitatively plausible results. Using an atomistic model of silica glass [1], we derive the elastic properties to be used in the FE domain from pure MD simulations. We then couple MD domains to surrounding FE domains to which we apply boundary conditions typical for fracture mechanical test setups, see Figure 1. Specifically, we perform mode I, mode II and mode III simulations on a rectangular plate with an edge notch by applying far-field stresses and three- and four-point bending conditions. To compare the results obtained in the simulations with experimental values, we derive the critical stress intensity factors $K_{ic}$ $(i = \mathrm{I}, \mathrm{II}, \mathrm{III})$ for the three fracture modes. Using tabulated formulas, the applied boundary conditions, which are based on surface tractions, are translated into the currently applied stress intensity factors $K_i$. By determining the point at which the crack starts to propagate based on the maximum virial stress measured in front of the crack tip, we thus obtain the critical stress intensity factors $K_{ic}$. An important prerequisite for the evaluation of $K_{ic}$ is the applicability of linear elastic fracture mechanics (LEFM). LEFM assumes that plastic effects are limited to a sufficiently small area near the crack compared to the overall dimensions of the specimen. By measuring the distribution of different strain measures in the atomistic samples, we show that these conditions are fulfilled in the present setups. Since the values for $K_{ic}$ are within a plausible range both in terms of experimental values and analytical considerations based on LEFM, we conclude that the Capriccio method is a powerful tool to apply arbitrary mechanical boundary conditions to MD specimens in a facile manner while upscaling the overall specimen dimensions, yielding quantitatively reasonable results. This is an important insight for future studies using the Capriccio method to investigate fracture or other mechanical load cases.

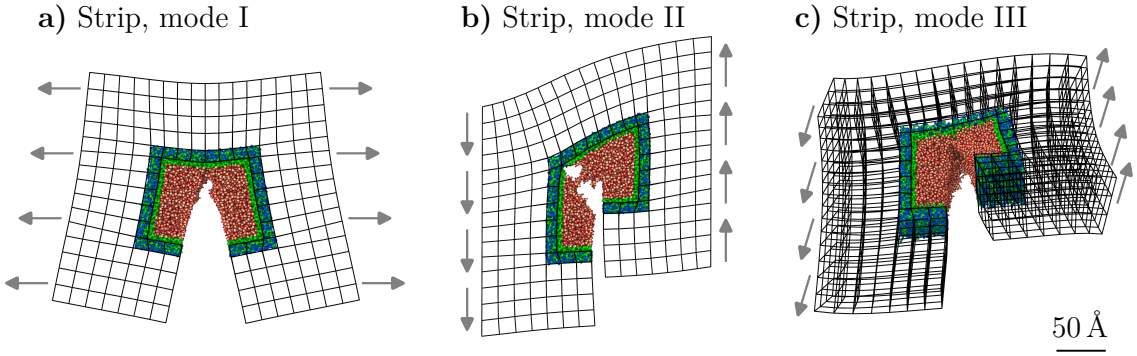



**Figure 1:** Deformed configurations of a rectangular plate with an edge notch ("strip") applying a) mode I, b) mode II, and c) mode III conditions [2].

## References

[1] S. Sundararaman, L. Huang, S. Ispas, and W. Kob. "New optimization scheme to obtain interaction potentials for oxide glasses". *The Journal of Chemical Physics* 148.19 (2018). ISSN: 1089-7690.

[2] F. Weber, M. Vassaux, L. Laubert, and S. Pfaller. "The Capriccio method as a versatile tool for quantifying the fracture properties of glassy materials under complex loading conditions with chemical specificity". Submitted.

– Multi-physics simulation –

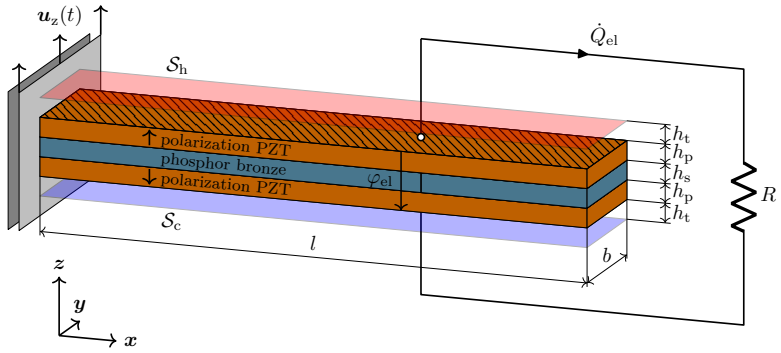
# Pyropiezoelectric energy harvesting using a serial bimorph

**Michael S. Schwarz, Julia Mergheim**

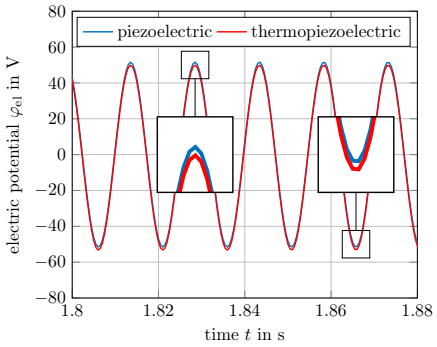
Piezoelectric energy harvesting is a promising approach to sustainable power generation for small-scale electronic devices. By exploiting the direct piezoelectric effect, mechanical vibrations can be converted into electrical energy. In order to rectify or store the electrical energy, an electric circuit must be connected. Since many piezoelectric materials also exhibit pyroelectric behavior, both effects often occur simultaneously in a single device. In order to accurately predict the energy harvested and thus evaluate the quality of a particular energy harvester, both effects must be taken into account. This can be done using the equations of linear thermopiezoelectricity [1]. All three fields (mechanical, electrical, and thermal) are coupled via three constitutive equations. Together with three kinematic equations and three balance equations, this results in a system of differential equations that can be solved for the unknown displacement $\boldsymbol{u}$, the electric potential $\varphi$, and the temperature change $\theta$ together with suitable initial and boundary conditions.

Figure 1a shows a serial bimorph with a connected resistor as an example of a typical energy harvesting structure. The resistor is attached to a grounded (top) and an ungrounded electrode (bottom). The beam is clamped on the left side and excited harmonically in $\boldsymbol{z}$-direction with $\boldsymbol{u}_z(t)$ near its first natural frequency. Besides the mechanical excitation, the cantilever is also heated or cooled when parts of it cross the surfaces $\mathcal{S}_\mathrm{h}$ or $\mathcal{S}_\mathrm{c}$ (parallel to the $\boldsymbol{x}$-$\boldsymbol{y}$-plane with an offset of $h_\mathrm{t}$ from the electrode surfaces in the initial state).

Figure 1b shows the resulting electric potential difference between the upper and lower electrode after a steady state is reached. The periodic heating and cooling leads to a small decrease in the electric potential $\varphi_\mathrm{el}$ between the electrodes. In contrast, an increase in potential would result if the heating and cooling regions were swapped. Overall, however, the oscillating temperature does not increase the amplitude of $\varphi_\mathrm{el}$ significantly, since the pyroelectric effect always increases the electric field on one of the electrodes and decreases it on the opposite electrode.




**(a)** Thermopiezoelectric bimorph with in series attached resistor of resistance $R$.




**(b)** Electric potential difference $\varphi_\mathrm{el}$ between top and bottom electrode.

**Figure 1:** Serial thermopiezoelectric bimorph with boundary conditions in (a) and resulting electric potential difference $\varphi_\mathrm{el}$ between the top and bottom electrode in steady state (b).

## References

[1] R. D. Mindlin. "On the equations of motion of piezoelectric crystals". *Problems of continuum mechanics* (1961).

# Experimental and computational characterization of the self-healing behavior in soft shape memory polymer

**Georgino K. Tshikwand[1], Antonella Caggiano[2], Ester Comellas[2], Paul Steinmann[1]**

[1] Friedrich-Alexander-Universität

[2] Universitat Politècnica de Catalunya

The current study investigates the self-healing behavior of shape memory polymers (SMPs). SMPs possess a thermo-responsive network architecture that enables them to recover shape and mechanical integrity upon thermal activation. In the transition phase, the material exhibits pronouced viscoelasticity and enhanced energy dissipation, leading to superior fracture resistance. Reducing the crosslink density further increases molecular chain mobility, allowing greater deformation at the crack tip and higher fracture toughness [1].

Experimentally, the essential work of fracture (EWF) is being employed to evaluate the macroscopic recovery of fracture parameters after thermal load. The total fracture work $w_f = w_e + \beta w_p l$ is used to extract the intrinsic surface energy term $w_e$, from which the healing efficiency is defined as $\eta_h(t_h) = w_{h_e}(t_h)/w_e$ to serve as a parameter for evaluating the SMP self-healing performance over time. Ongoing analysis involves fitting the experimentally obtained recovery curves $w_{h_e}(t_h)$ to the empirical kinetic model for the recovery function $R(t_h) = 1 - \frac{[1-R_0]}{[1+Kt_h]^a}$ to extract the healing rate constants $K$, rate exponent $a$, and the instantaneaous recovery fraction $R_0$ [2]. These kinetic constants provide quantitative insight into the time scales and efficiency of the macroscopic fracture recovery in SMPs with varying crosslink densities.

In parallel, computational modeling efforts are underway to represent self-healing as a reverse damage process. Healing is introduced as a time- and temperature-dependent reduction of the damage variable, such that the effective stiffness and fracture energy are gradually restored.

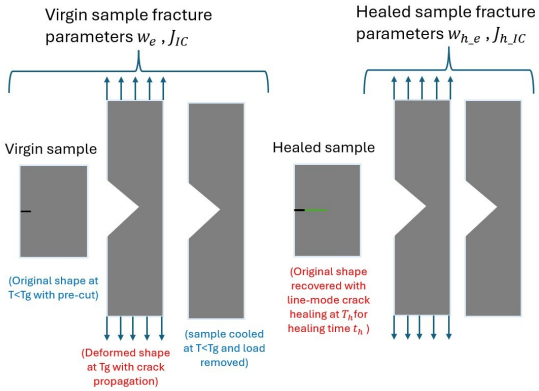



**Figure 1:** Experimental procedure in the characterization of the self-healing behavior of shape memory polymeric materials.

## References

[1] G. K. Tshikwand, M. A. Moreno-Mateos, A. Santarossa, and P. Steinmann. "Experimental insights into the thermo-mechanical fracture performance of soft shape memory polymers". *Engineering Fracture Mechanics* 327 (2025), p. 111439.

[2] R. Wool and K. O'Connor. "A theory crack healing in polymers". *Journal of applied physics* 52.10 (1981), pp. 5953–5963.

**– Optimization and inverse problems –**

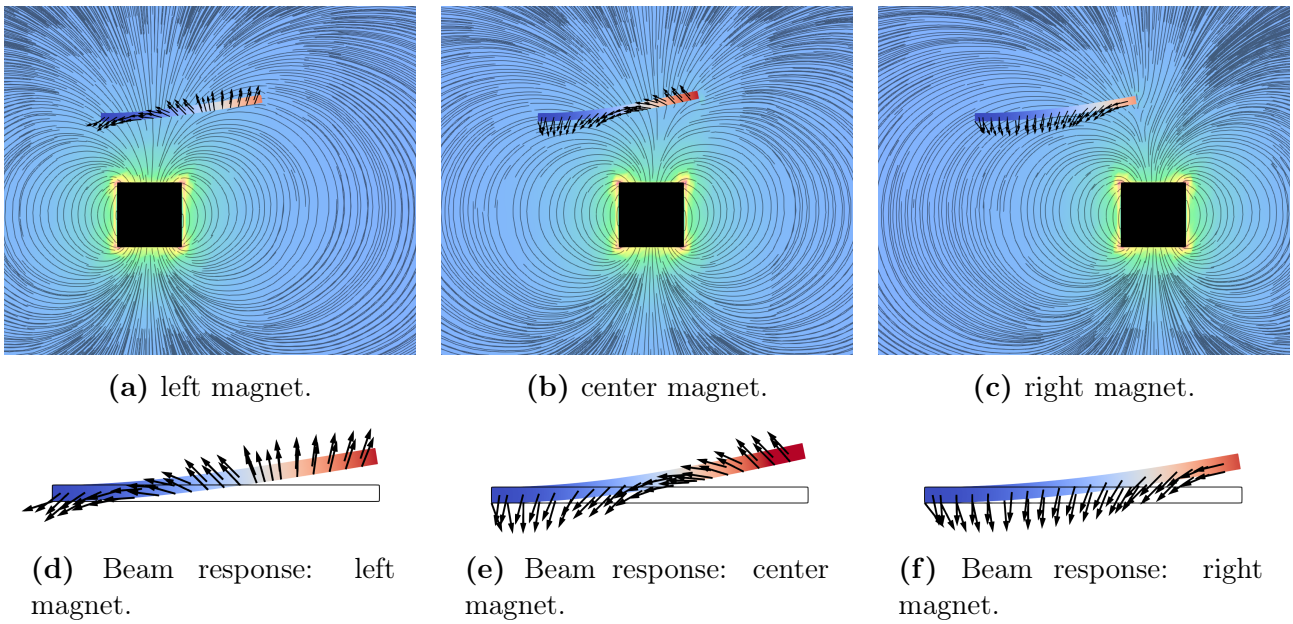
# Optimizing remanent magnetization in magnetorheological elastomers under under realistic magnetic actuation

**Chaitanya Dev, Gabriel Stankiewicz, Miguel Angel Moreno-Mateos, Paul Steinmann**

Magnetorheological elastomers (MREs) are promising materials for soft-robotic and biomedical actuation due to their ability to operate remotely and reversibly. However, a limitation in prior design studies is their reliance on idealized, homogeneous magnetic fields that neglect the influence of magnetic sources and free-space. This work addresses that gap by optimizing the spatial distribution of remanent magnetization within MREs while explicitly accounting for realistic permanent magnets and the surrounding free-space. The resulting designs are physically consistent and capture behaviors that simplified field models inherently miss.

Our benchmarks reveal several key findings: First, solutions exhibit *initialization independence*, the same optimal magnetization distribution emerges regardless of the starting pattern. Second, designs demonstrate *physical symmetry*, reversing the external magnet's direction correspondingly flips the optimized remanent magnetization. Third, *magnet placement influences* the final design, as shown in Fig. 1; the optimal magnetization distribution adapts to the source magnet's position. Finally, the framework successfully addresses *conflicting performance objectives* (e.g., push versus pull) by discovering distinct magnetization patterns tailored to each target behavior. The details regarding the method and results are available in [1].

These findings emphasize that modeling the magnetic source and free-space environment is not a mere refinement but a prerequisite for reliable actuator design. Neglecting these realistic conditions results in both suboptimal designs and inaccurate predictions of actuator behavior.



**(a)** left magnet. **(b)** center magnet. **(c)** right magnet.

**(d)** Beam response: left magnet. **(e)** Beam response: center magnet. **(f)** Beam response: right magnet.

**Figure 1:** Influence of permanent magnet position on optimized MRE remanent magnetization. Top row: full-system views showing field streamlines, magnitude, and deformation. Bottom row: detailed beam responses with displacement colormaps and optimized magnetization vectors. Repositioning the magnet (left/center/right) alters the optimal remanent magnetization distribution.

## References

[1] C. Dev, G. Stankiewicz, and M. A. Moreno-Mateos. "Optimizing remanent magnetization in magnetorheological elastomers under external permanent magnet actuation".

# Topology Optimization of Auxetic Structures for Compliant Mechanism Design

**André Krippner, Gabriel Stankiewicz, Chaitanya Dev, Paul Steinmann**

As part of the International Research Training Group *Energy Conversion Systems* (IRTG 2495), we will develop auxetic structures that enhance energy harvesting by applying the principles used to design compliant mechanisms. In contrast to conventional kinematic systems, compliant mechanisms do not use joints to enable movement. Instead, they generate motion through the elastic deformation of their flexible members (see Fig. 1). Compliant mechanisms have various advantages such as reduced complexity due to fewer components, simpler manufacturing and increased durability [1].

Auxetic structures and compliant mechanisms share common structural features, such as flexible, elastic joints. This allows approaches developed for compliant mechanisms to be transferred to auxetic structures. Auxetic designs have a negative Poisson's ratio, so when they are stretched, the material expands laterally instead of contracting (see Fig. 2). Such behavior leads to advantageous properties including improved energy absorption and increased impact resistance. These characteristics make auxetic structures suitable for applications in fields such as medicine, aerospace, and defense [1].

The basis for the planned work is established in [2], where a homogenization approach is applied to piezoelectric metamaterials. There, combined topology and shape optimization methods are used to generate different designs. The intended research will focus on implementing nonlinear material behavior. Furthermore, it is possible to consider stress or manufacturing constraints as well as to extend the approach to three dimensions.

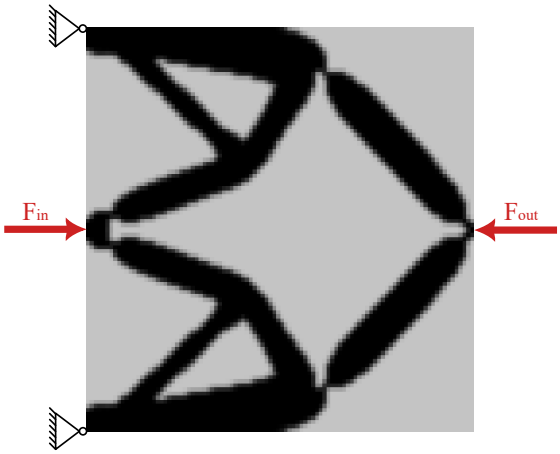



**Figure 1:** Example of a compliant mechanism design that maximizes the output force under given boundary conditions.

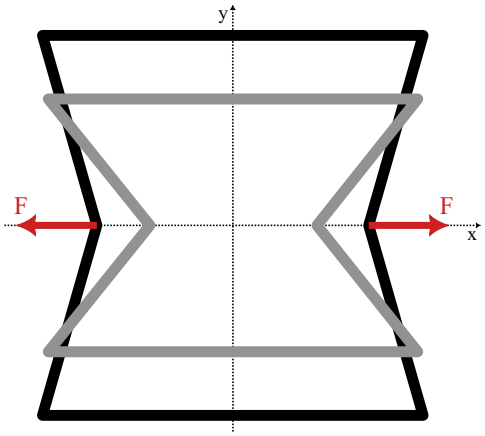



**Figure 2:** Example of an auxetic structure. Due to the force and the design, the arms of the gray structure move outward and upward.

## References

[1] C. D. Lima and G. Paulino. "Auxetic structure design using compliant mechanisms: A topology optimization approach with polygonal finite elements". *Advances in Engineering Software* 129 (2019), pp. 69–80.

[2] G. Stankiewicz, C. Dev, M. Weichelt, T. Fey, and P. Steinmann. "Towards advanced piezoelectric metamaterial design via combined topology and shape optimization". *Structural and Multidisciplinary Optimization* 67.2 (2024).

# A novel multi-thickness 2.5D topology optimization balances structural performance and manufacturability

**Gabriel Stankiewicz, Chaitanya Dev, Paul Steinmann**

Topology optimization (TO) in two dimensions often requires balancing structural performance with manufacturability. While unpenalized (variable thickness) approaches generate highly efficient but complex designs, standard penalized (SIMP) methods yield simpler, truss-like structures with reduced performance. To address this trade-off, we developed a multi-thickness, density-based TO framework that steers designs toward a chosen set of discrete thickness levels. This is achieved through a new multilevel penalization strategy combined with a smoothed Heaviside projection and an adaptive mesh refinement procedure. A continuation scheme ensures robust convergence and accurate geometric representation.

The method was tested on standard cantilever problem (see Fig. 1), showing that as the number of available thickness levels $n_t$ increases, the results smoothly transition from truss-like to high-performance, sheet-like designs. Remarkably, designs restricted to only three discrete thickness levels achieved compliance within 2% of fully variable thickness solutions (last column), while significantly outperforming SIMP (first column) by 15% in compliance. The approach naturally avoids impractically thin features, both in-plane and out-of-plane, and generates designs suitable for additive manufacturing as well as traditional fabrication with standard-thickness materials, maximizing both efficiency and practical applicability.

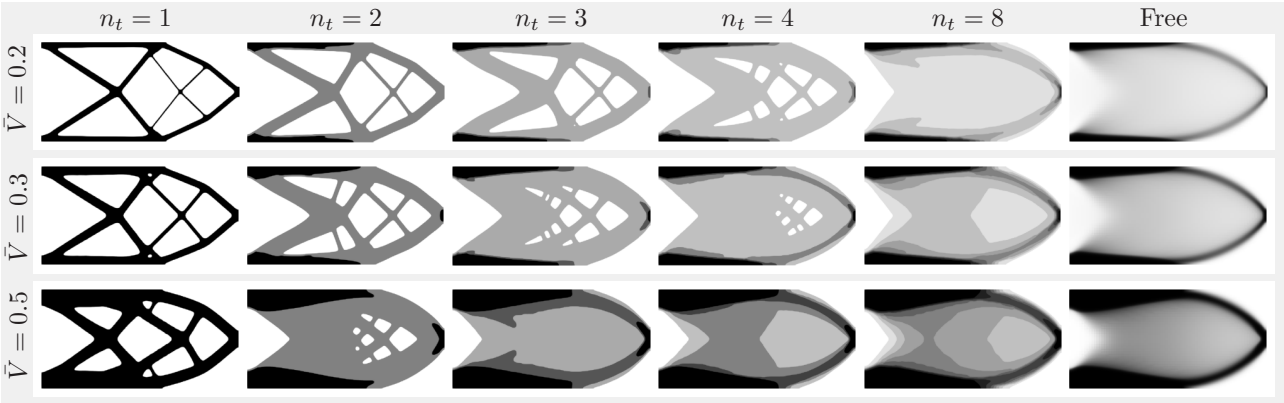



**Figure 1:** Case study for the cantilever benchmark, conducted for three different volume fraction constraints $\bar{V} \in \{0.2, 0.3, 0.5\}$. The $n_t = 1$ case is equivalent to standard SIMP-based TO. The last column shows the variable thickness TO. The columns in between contain the multi-thickness cases ($n_t = 2 \to 8$). As the number of target thicknesses increases, the designs gradually transition from standard to variable thickness TO [1].

## References

[1] G. Stankiewicz, C. Dev, and P. Steinmann. "A novel multi-thickness topology optimization method for balancing structural performance and manufacturability". *arXiv preprint arXiv:2507.19388* (2025).

# Data-adaptive configurational forces for fracture

**Simon Wiesheier, Miguel Angel Moreno-Mateos, Paul Steinmann**

Understanding fracture mechanics in soft solids remains a challenge due to their complex, nonlinear behavior under large deformations. Here, we introduce a combined experimental–computational framework to study fracture in soft elastomers under equi-biaxial loading. We perform quasi-static fracture experiments on various elastomers, revealing behaviors ranging from brittle-like fracture to highly stretchable responses with crack tip strains exceeding 150 percent [1]. To complement the experiments, we develop a hybrid computational testbed that mirrors the setup and enables virtual biaxial testing. The framework includes: (i) a data-adaptive hyperelastic energy formulation that flexibly captures material response, and (ii) a post-processing implementation of the Configurational Force Method for efficient evaluation of the $J$-integral at the crack tip. Figure 1 (top) shows the experimental setup and a schematic of the data-adaptive formulation. The bottom panel presents results for Elastosil 1:1, including the calibrated strain energy function, reaction forces, and nodal configurational forces at crack onset. This data-driven approach effectively captures the complex hyperelastic behavior observed in biaxial tests—crucial for applying configurational force methods to soft fracture.

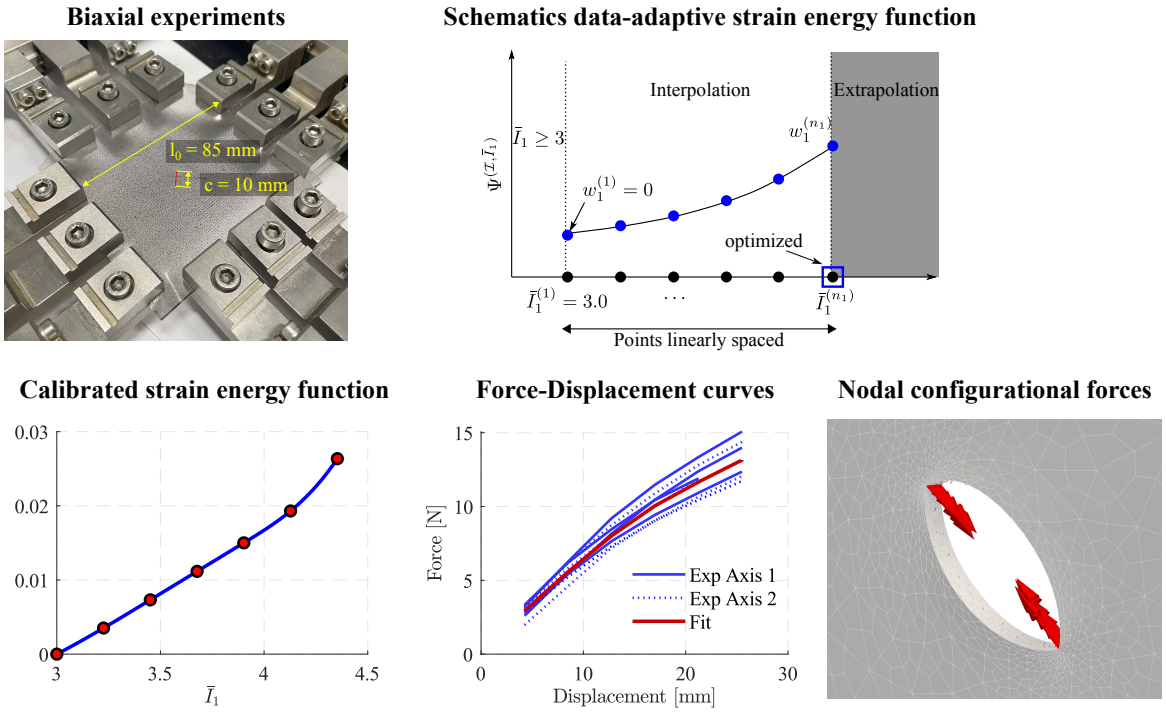



**Figure 1:** Experimental setup for equi-biaxial quasi-static tests on notched specimens. The data-adaptive hyperelastic energy formulation is built using univariate B-splines defined over the space of invariants. Interpolation values are calibrated from experimental data, with the interpolation domain tailored using Kernel Density Estimation. For the material Elasotsil 1:1, the calibrated strain energy function, corresponding force–displacement curves, and nodal configurational forces at the crack tip are shown as an example.

## References

[1] M. A. Moreno-Mateos, S. Wiesheier, A. Esmaeili, M. Hossain, and P. Steinmann. "Biaxial characterization of soft elastomers: Experiments and data-adaptive configurational forces for fracture". *Journal of the Mechanics and Physics of Solids* 205 (2025), pp. 106–339.

– Structural dynamics –

# The Impact of Air Conditions on the Eigenfrequencies of a Violin

**Özge Akar**

The Finite Element Method allows for the investigation of how the air contained within the violin's body affects its vibrational behavior. The impact of air has been explored in various studies, both qualitatively and quantitatively. However, the influence of air conditions, which fluctuate significantly with altitude and temperature, is often overlooked. These parameters influence both the adiabatic bulk modulus $K_{\mathrm{ad}}$ and the air density $\rho_{\mathrm{air}}$. The effects of air modulation on the violin body's signature modes are illustrated in Figure 1. It is clear that the signature modes A0 and A1, which are primarily affected by the air, exhibit greater frequency variations compared to the structural "breathing" modes B1+, B1-, and the center-bout-rotation mode CBR. For instance, the Helmholtz mode A0 has a frequency of 252 Hz in laboratory conditions (Erlangen, 296 m above sea level), while at a high altitude, such as La Rinconada (which is 5100 m above sea level), it rises to 264 Hz – an increase of 12 Hz. This change can significantly alter the instrument's radiated sound. [1]

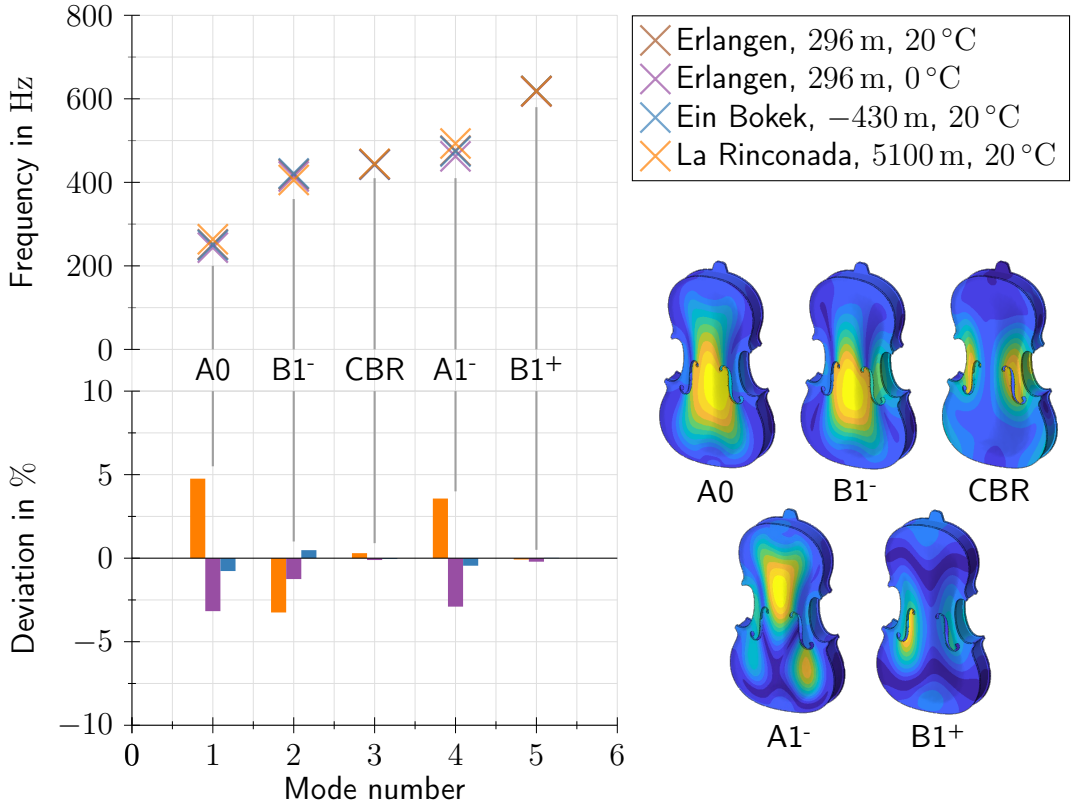



**Figure 1:** Influence of air temperature and altitude on the eigenfrequencies of the violin body [1].

## References

[1] Ö. Akar. "Structural Dynamics of a Violin – From Raw Wood to Bowed String Motion". In preparation. Dissertation. Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 2025.

# – Uncertainty quantification –

# Adaptive Canonical Polyadic Decomposition for a General Class of Uncertainties

**Dmytro Pivovarov**

The project advances fast, accurate methods for structural and material analysis under uncertainty. Modern engineering systems are increasingly affected by general polymorphic uncertainty, a term that refers not only to diverse sources (e.g., material variability, geometric imperfections, modeling error) but also to multiple mathematical descriptions (stochastic, fuzzy, interval). This dual heterogeneity exceeds the capabilities of conventional workflows, which are either too rigid to accommodate mixed representations or too costly at scale.

To address this, we develop an adaptive reduced-order modeling framework based on separated representations and low-rank tensor approximation via Canonical Polyadic Decomposition (CPD), embedded in a universal non-intrusive spectral finite element formulation [1].

The approach incorporates three algorithmic variants: UCPD (CPD on unstructured grids) for efficient handling of irregular sample distributions, ACPD (adaptive CPD) for adaptive refinement in the parametric domain, and the new MCPD (masked CPD), designed to capture geometrical and topological uncertainties through masked decomposition. This structured representation yields a parsimonious surrogate model, enabling targeted refinement and significant computational savings without sacrificing accuracy.

The framework further exploits B-splines and IsoGeometrical Analysis to ensure smooth, stable, and efficient representations, overcoming the limitations of classical polynomial chaos expansions.

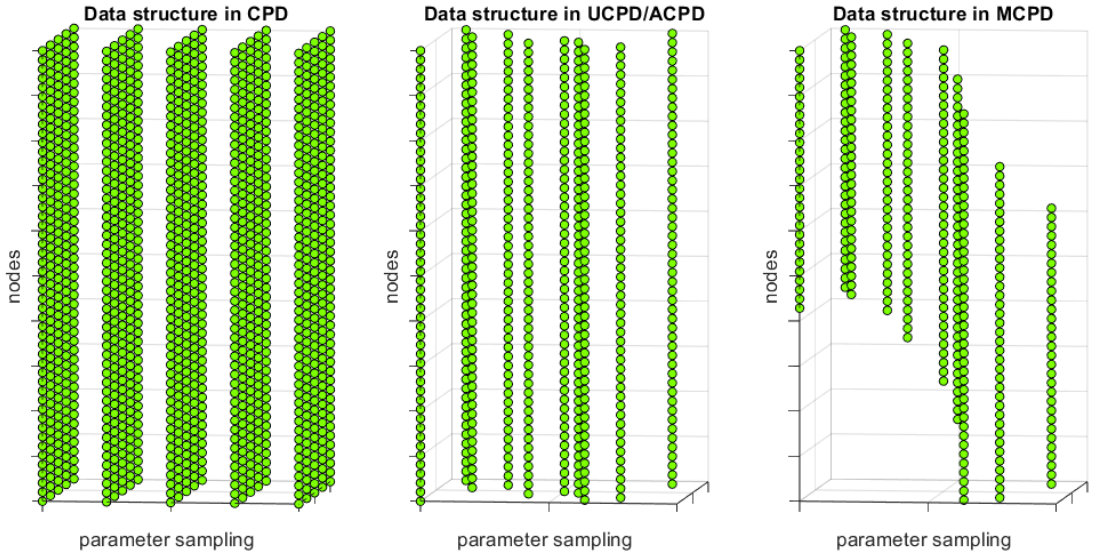



**Figure 1:** Schematic representation of data structure in classical CPD and its modified variants. UCPD/ACPD and MCPD work with sparse, unstructured, and masked data, removing strict limits on model and sampling strategy.

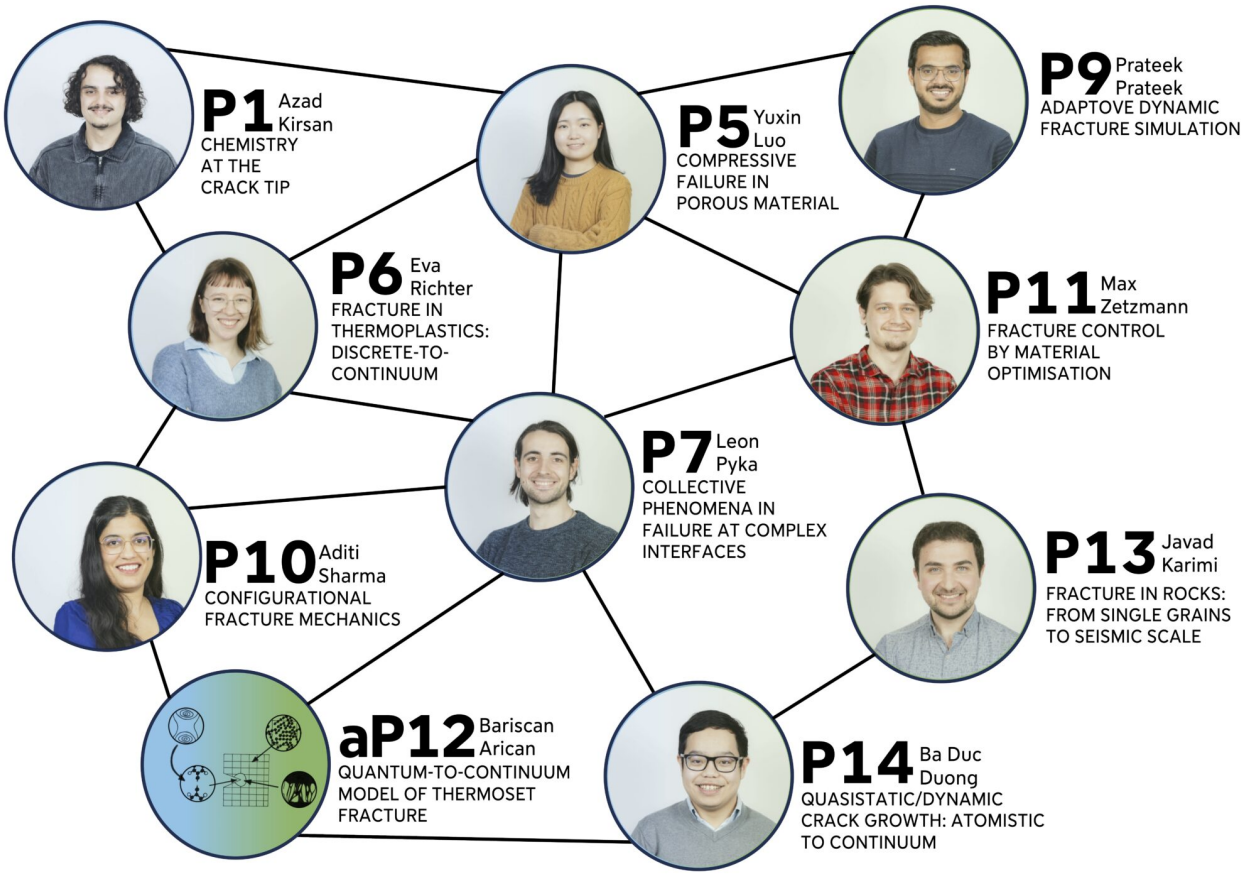
## References

[1] D. Pivovarov. "Novel adaptive reduced order spectral non-deterministic FEM approach to problems with general interval-fuzzy-stochastic uncertainties". *Computational Mechanics* (2025). DOI: 10.1007/s00466-025-02658-6. URL: https://doi.org/10.1007/s00466-025-02658-6.

# 5 Highlights and social activities

## 5.1 FRASCAL activities

(LSp) The research training group GRK2423–FRASCAL (Fracture across scales) consists of 13 projects from different departments of the Faculty of sciences (Physics, Chemistry, Mathematics) and the Faculty of Engineering (Chemical and Biological Engineering, Materials Science, Mechanical Engineering). FRASCAL aims to improve the understanding of fracture in brittle heterogeneous materials by developing simulation methods at (and across) different length and time scales able to capture the multiscale nature of failure.




*FRASCAL projects of the third cohort, cf.* https://www.frascal.research.fau.eu/

### FRASCAL RTG Retreat

On May 8 and 9, the FRASCAL Retreat 2025 took place in Waischenfeld.




[Pictures: Andrea Dakkouri-Baldauf, Anna Donhauser]

Firstly, the 2nd cohort reported on their respective FRASCAL journey and gave advice to the next cohort. In an interactive workshop with amusing games and teamwork, Dr. Iris Wangermann introduced the FRASCALi to the world of international communication. After a barbecue dinner, an informal get-together with music playing to the early morning hours enriched the retreat. The next day, the 3rd cohort presented their scientific projects in a poster session. Afterwards, PD Dr. Sebastian Pfaller outlined what an academic career could look like. In the afternoon, the FRASCALi set off on a challenging hike while enjoying some ice cream or beer. Finally, the new doctoral and gender representatives were elected: Leon Pyka (P7) and Ba Duc Duong (P14).




[Pictures: Andrea Dakkouri-Baldauf, Anna Donhauser]

For a more detailed report and additional pictorial impressions, see the homepage entry.

**Start-up workshop @ ZOLLHOF**

On May 20, a 'start-up workshop' was offered to the FRASCALi and EBMer at ZOLLHOF, one of Germany's leading tech incubators, located in Nuremberg.









[Pictures: Andrea Dakkouri-Baldauf, Anna Donhauser]

After introductory speeches by Prof. Kathrin Möslein (Vice President Outreach, FAU) and Christoph Heyen (FAU Startup Service), the participants used the LEGO® Serious Play method to build themselves, their startup idea, possible costumers and users. Four people gave a pitch on their ideas to the other participants and answered their questions. Next, Matthias Trost (Amperial Technologies GmbH) presented his path of funding a start-up and briefly mentioned intellectual property, working relations between scientists/engineers and business people, as well as, financing options. Dr. Judit Klein (Startups-Lead, ZOLLHOF) discussed, i.a., the ranking of viability, feasibility and desirability, which was counterintuitive for many engineers who wanted to focus on the feasibility and development of a technology first, rather than checking the actual market need and viability beforehand. After watching a video introducing a new technology, groups of three developed their three best and worst ideas for promoting that technology. The three worst were discarded and each group had to develop a need, solutions and values for one of the worst ideas from another group. This exercise showed how differently each group evaluated their ideas, how the group interacted and how easy/hard it was to break away from their original best ideas and work with the "bad" idea. The very interesting and productive workshop ended with a tour of the ZOLLHOF building.

For a more detailed report and additional pictorial impressions, see the homepage entry. For more information on ZOLLHOF, see https://zollhof.de/.

**FRASCAL Symposium**

On November 20, the FRASCAL Symposium 2025 took place in the Orangerie in Erlangen. The diverse program covered fracture in various materials from microscopic up to geological scales. The coffee and lunch breaks allowed for interesting discussions among the researchers.



**Prof. Tristan Baumberger**, Université Paris Cité, France

*Length- and time-scales of crack growth in a polymer hydrogel*



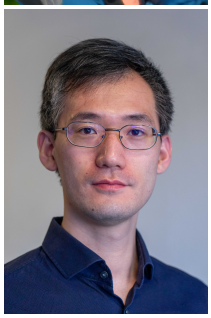
**Prof. Daniel Köhn**, FAU, Germany
Professor for tectonics
Principle advisor of FRASCAL P13

*Fractures across scales from microstructures to mid ocean ridges*



**Prof. Nina Kirchner**, Stockholm University, Sweden
Professor of glaciology
Director of Tarfala Research Station

*Fractures in northern icy environments: challenges for glaciological and cryospheric research*



**Dr.-Ing. Wuyang Zhao**, FAU, Germany
Post-doctoral researcher with own DFG single fund
Associate to FRASCAL P6

*Microscopic mechanisms of plasticity and fracture in glassy polymers*



**Dr. Miguel Ángel Moreno-Mateos**, FAU, Germany
Post-doctoral researcher in ERC grant 'SoftFrac' raised by Prof. Paul Steinmann (Principle advisor of FRASCAL P10)

*Advances in soft fracture (and cutting) mechanics*

## 5.2 Capriccio activities

### Conference organisation and participation by the Capriccio group

(Sebastian Pfaller)

**Participation at DEPOS 32 in France.** From March 25th to 28th, Stephanie Chedid and Agustín Ríos (Institut de Chimie et des Matériaux Paris-Est), Fabrice Detrez and Moussa Lamamra (Université Gustave Eiffel), Maxime Vassaux (Institut de Physique de Rennes) and Sebastian Pfaller attended the 32nd edition of the "Colloque sur la Déformation des Polymères Solides" (DEPOS32), which took place at Futuroscope close to Poitiers in France (region Nouvelle-Aquitaine). This conference brought together scientists and industry representatives with explicit focus on the behaviour and applications of polymers and their composites. Among others, it addressed the relations between the materials' microstructure and their properties in applications, the coupling of multiple physical effects, the impact on the environment, aspects of recycling, contact mechanics, innovative manufacturing approaches, various questions of fatigue, rupture, and ageing as well as advanced simulation techniques. DEPOS32 was an excellent opportunity to present the activities within the French-German project "BIO ART" on epoxy resins and composites from bio-based sources, to meet experts from different backgrounds and to discuss scientific questions as well as future joint research activities. It was a great pleasure to attend this colloquium and we are looking forward to future editions!



*Fabrice Detrez, Stephanie Chedid, Sebastian Pfaller, and Agustín Ríos at DEPOS 32.*

**Plenary Lecture at KomPlasTech 2025.** Sebastian Pfaller gave a plenary lecture on "Numerical predictions of fracture in amorphous materials: Current achievements and challenges" at the XXIX Conference on Computer Methods in Materials Technology (KomPlasTech 2025) in Krynica Zdrój, Poland, upon invitation by the Department of Applied Computer Science and Modelling at AGH University of Kraków. In his lecture, Sebastian revisited the foundations of the Capriccio method and gave an overview of current achievements with respect to Felix Weber's multiscale fracture simulations of silica glass. After this, he focused on challenges faced by Wuyang Zhao and Eva Richter when it comes to associated simulations of polymers, particularly due to the much larger fracture process zone size of these materials. During the conference, Sebastian had many very insightful discussions with the other participants, which put different foci on material simulation across scales

and provided links to experimental evidence. After the conference, Sebastian visited the Industrial Digitalization and Multiscale Modeling Group at the Department of Applied Computer Science and Modelling at AGH University of Krakow, where he was warmly welcomed by prof. dr hab. inż. Łukasz Madej and dr inż. Konrad Perzyński. Sebastian thanks the organisers very much for giving him this opportunity to present the research of the Capriccio group and for the very friendly welcome at KomPlasTech and at AGH Kraków!

**FEMS 2025 EUROMAT.** The 18th European Congress and Exhibition on Advanced Materials and Processes (EUROMAT) was held by the Federation of European Materials Societies (FEMS) in Granada, Spain, from 14 to 18 September 2025. Together with Prof. Hung-Jue Sue (Director of the Polymer Technology Center at Texas A&M University, USA) and Prof. Andreas Delimitis (Professor at the Department of Condensed Matter and Materials Physics at the Aristotle University of Thessaloniki, Greece), Sebastian organised the Symposium A2 "Nanomaterials, Nanoparticles and Nano-Structuring". Within this symposium, almost 50 presentations were given, thereof 8 keynote lectures and 14 highlight presentations, together with 14 poster contributions. In addition, a best oral and a best poster presentation prize were awarded due to the kind support of MDPI's journal "Minerals". In summary, EUROMAT was a highly inspiring platform for bringing together experimentalists, researchers with numerical background, and practitioners.

**Research visits to the Capriccio group**

(Lukas Laubert, Sebastian Pfaller, Eva Richter)

**Visit of Prof. Agustín Ríos from ICMPE.** We had the great pleasure to welcome Prof. Agustín Ríos from ICMPE (Institut de Chimie et des Matériaux Paris-Est) within the ERASMUS+ programme. Agustín Ríos gave a lecture series on polymers with particular focus on the relation between the chemistry of these materials and their properties relevant in engineering. Based on his long-standing expertise in the development of polymers from renewable resources, he gave detailed insights into the current challenges in the field of bio-based polymer materials. Agustín Ríos motivated all participants to actively contribute, among others by using construction kits for long-chain molecules. We thank Agustín Ríos very much for sharing his knowledge and experience in the field of these fascinating materials!



*Prof. Ríos demonstrating polymer molecules.*

**Visit of Prof. Fabrice Detrez from UGE, France.** From July 14th to 17th, Prof. Fabrice Detrez visited the Capriccio group for scientific exchange within our collaborative project "BIO ART" and beyond. Fabrice is an assistant professor at the Université Gustave Eiffel with profound background in mechanics, materials science, geophysics, mechanical engineering, and nanotechnology. We started with joining a seminar on fracture simulations based on phase-field modelling given by Prof. Laura de Lorenzis from ETH Zürich, which was followed by various discussions on possible connection points between our research. The next day, we had a joint 'Capriccio Science' seminar, where György Hantal from FAU's PULS group who works on our adjoint project P12 (fracture of thermosetting polymers) in the research training group FRASCAL (FRActure across SCALes) gave a detailed overview of his research activities and recent achievements. Due to the complementary nature of his project and BIO ART's numerical work packages, his presentation stimulated in-depth scientific exchange. Fabrice's visit was accompanied by various bilateral discussions in the field of modelling and simulation of polymers across the scales as well as on methods with particular focus on BIO ART's research activities. It was a pleasure to host Fabrice and we are looking forward to future exchanges!

**Moussa Lamamra's research stay in Erlangen.** In June 2025, Moussa Lamamra, a researcher from the University Gustave Eiffel in Paris, embarked on a research stay at the Institute of Applied Mechanics as part of the joint French-German BIO ART project. Collaborating with Lukas Laubert and Sebastian Pfaller, Moussa focused on preparing a

molecular dynamics (MD) based epoxy system to subsequently perform coupled simulations using the Capriccio method. His work involved identifying essential mechanical quantities from MD deformation simulations and exploring the polymer network to extract the quantities of interest to calibrate a suitable constitutive model for the finite element (FE) part. The ultimate goal is to enable coupled FE-MD simulations for fracture analysis, obtaining detailed insights from MD while enabling a classical fracture mechanical setup through the FE surrounding. This research aims to significantly advance the understanding of thermosetting polymers and their fracture properties.

**Jolan Thierry's research internship.** Jolan Thierry from ENS Rennes visited the Capriccio group for two months as part of a research internship. Jolan explored the capabilities of atomistic simulations of tropocollagen molecules in water as a basis for future studies of collagen fibrils and fibres. Among others, he consulted various publications on this topic and conducted molecular dynamics simulations on the clusters of the National High Performance Computing Center (NHR@FAU). Besides the scientific activities, we also found some time to explore Nuremberg and its surroundings. It was a pleasure to host Jolan and we wish him all the best for his future!



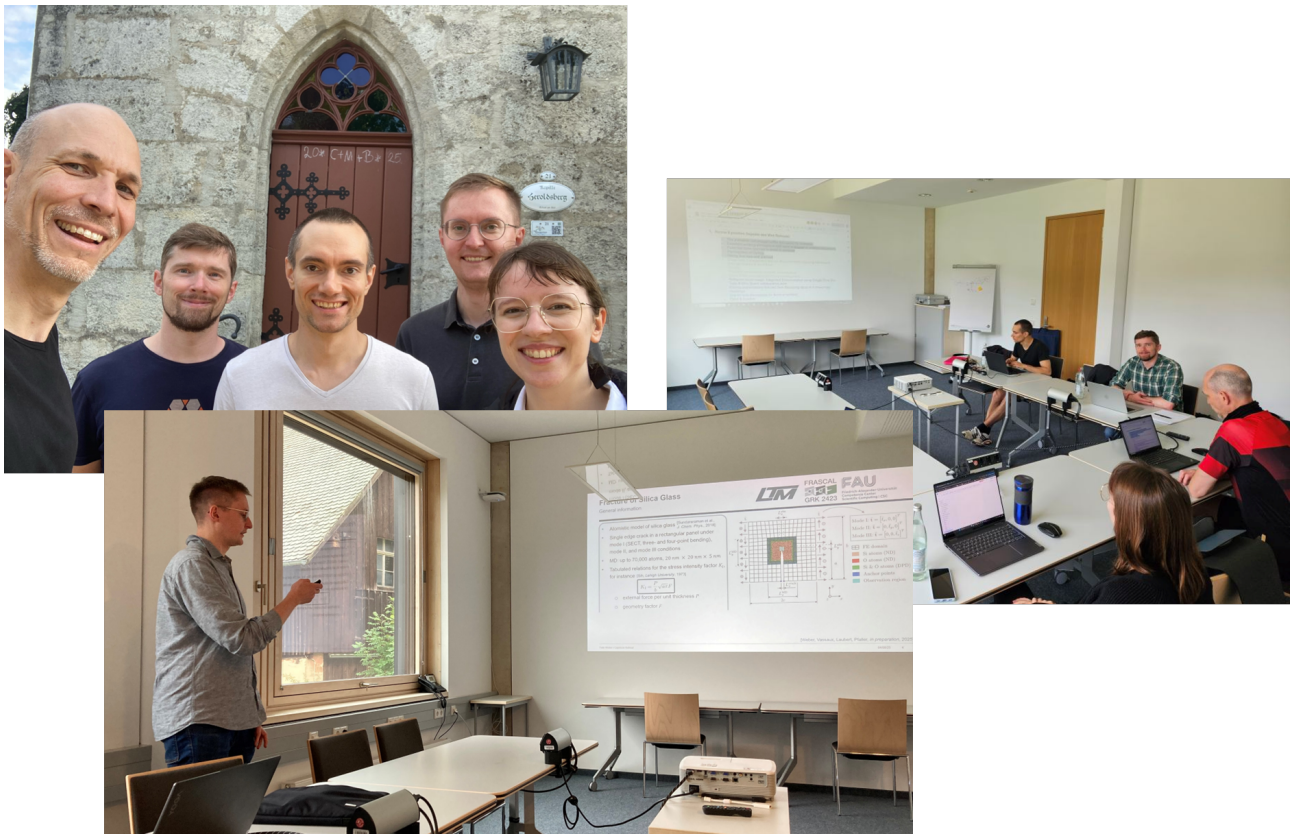

*Jolan Thierry, Sebastian Pfaller, and Mathis Delleimat returning from exploring Bavaria.*

**Mathis Demeillat's research internship.** From June to August, Mathis Demeillat visited the Capriccio group within the context of a six-week research internship. Mathis studies for a master's degree in "physical engineering and embedded systems" at the École nationale supérieure d'ingénieurs de Caen. During his time with us, Mathis investigated the fracture of thermoplastics under the supervision of Eva Maria Richter. He conducted molecular dynamics simulations with LAMMPS on the clusters of the National High Performance Computing Center (NHR@FAU) and focused mainly on a parameter study regarding the coupling of different domains within molecular dynamics. Of course, in the off-time, joint trips to Garmisch, Mittenwald and the Anna-Fest in Forchheim were a must. It was great to have Mathis on the team and we wish him all the best for his future!

**Capriccio Mini Retreat 2025**

(Sebastian Pfaller)

In August 2025, we held our annual Capriccio Mini Retreat at the Fraunhofer Forschungscampus Waischenfeld in Franconian Switzerland. There, we reviewed the group's achievements in the past year, discussed current challenges, and formulated future research paths. During this three-day event, we had a rather tight scientific schedule consisting of presentations of ongoing research activities, individual discussions in sub-groups and strategic planning for the entire group. Furthermore, this year we had the great pleasure to welcome György Hantal from FRASCAL's project P12 and to intensify our collaboration in simulations of polymers and their fracture. Beyond science, we also found some time to explore the landscape around Waischenfeld and to even make music together.




*Social activities, presentations, and discussions at the Capriccio Mini Retreat.*

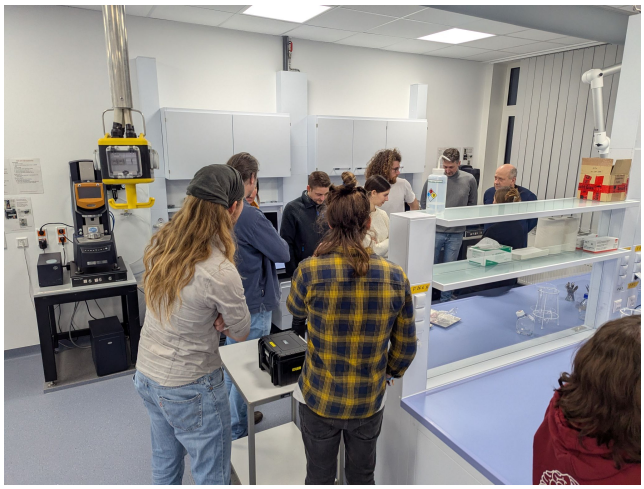
## 5.3 Brainiacs activities

### Laboratory reception

(Nicole Tueni)

This year, the Institute of Continuum Mechanics and Biomechanics has officially moved into its new premises in Uferstadt Fürth, combining modern office space with a fully equipped laboratory. To celebrate, the team hosted a lab reception that welcomed neighbors from the Uferstadt campus and colleagues from various FAU departments, to showcase ongoing research, introduce the new offices, and accompany visitors through the laboratory, where devices and setups were presented together with their purpose and the scientific questions they enable. The event aimed to spark cross-department collaborations by highlighting the capabilities and potential of the lab. The conversations continued over finger food and drinks.









**Brainiacs retreat**

(Nicole Tueni)

This year, the Brainiacs team once again met at the end of summer and kicked off the new year with a retreat at Bromnachsee. It offered a focused space to present the current status of their research, discuss obstacles and possible solutions to address them, identify opportunities for collaboration within the team, and cover lab and organizational topics. Afterwards, they cooled off with a swim in the lake and enjoyed the surrounding scenery. Everyone contributed by bringing food and drinks and organizing fun team-building games.







## 5.4 EBM activities

### EBM symposium

(Nicole Tueni)

The International EBM (CRC 1540 Exploring Brain Mechanics) Symposium 2025, held 30 September–1 October at the Max Planck Institute for the Science of Light, brought together researchers from all over the world to exchange recent advances in brain mechanics from experimental, clinical and computational perspectives. The program featured 14 invited talks that prompted substantive discussion, alongside additional talks, and poster sessions, where early-career researchers presented work ranging from cellular mechanics and brain organoids to clinical applications and modeling. Mentorship was a central element, with "Meet the Mentor" lunches allowing open conversations about research paths, methods, and collaboration opportunities. Informal networking continued during extended coffee breaks and a conference dinner at Kulturforum Logenhaus Erlangen, accompanied by music from a DJ, where discussions continued and participants could simply enjoy the evening.








**EBM retreat**

(Nicole Tueni)

The 3rd EBM Retreat was held on 9–10 October 2025 at Hotel Goldener Stern in Muggendorf, set in the Franconian Switzerland region. Researchers presented progress on brain mechanics, prompting focused questions and constructive discussion. The aim was to test new ideas and spark collaborations, complemented by a team-building session in which participants tried their hand at archery, improving skills and, in some cases, discovering new talents.







## 5.5 Research Stay at the Nagoya Institute of Technology (NITech)

(Michael Schwarz) From January 7 to March 27, I had the honor of visiting the research group of Prof. Ken-ichi Kakimoto at the Nagoya Institute of Technology (NITech). Nagoya, located in central Japan, is the capital of Aichi Prefecture and one of the country's major industrial and cultural hubs. NITech itself is a prominent research university in Japan, renowned for its focus on applied sciences and engineering. Within this context, Prof. Kakimoto's group specializes in lead-free ceramics to develop environmentally friendly and efficient energy harvesting devices. As a member of the International Research Training Group between FAU and NITech (IRTG 2495, Project C), the primary goal of the stay was to gain practical experience with energy-harvesting structures and to conduct experiments that could later be compared with numerical results.

After a lot of bureaucracy and an intense three-day journey from Erlangen to Nagoya, the first few days were dominated by a series of organizational tasks. Since my dormitory — located directly on the university campus — was not furnished with much furniture, the local AEON shopping center became my best friend when it came to shopping. From pans to bed linen, you can find everything there. Navigating Japanese bureaucracy also proved to be an important part of the experience. Registering and deregistering at the local ward office, taking care of insurance matters, and dealing with the Japanese pension system were just some of the administrative tasks. To the author's great surprise, digitization in Germany seems to be relatively advanced in this regard. Since Japanese officials are not well prepared for limited Japanese language skills, on-site translation by a Japanese colleague was not only helpful but absolutely essential. In the first few weeks of settling in and after, interacting with colleagues became an integral part of everyday life from the very beginning – even if it sometimes took a few extra attempts to fully understand each other. Outside of work, bouldering sessions at local climbing gyms provided a welcome break from the usual office routine. For many Japanese colleagues, it was their first experience on the wall, which led to the discovery of some unexpected talents – and perhaps even alternative career opportunities, should academic life ever fall short of expectations.




*Arrival: View on Mount Fuji during the approach to Tokyo (left), Japanese security guidelines with Pokémon (middle) and welcome meal with the Japanese colleagues (right).*




*During the stay: Nagoya at night (left) on the way to the gym for bouldering with Japanese colleagues (right).*

In the middle of my stay, I attended the IRTG Yearly School 2025 in Osaka, which is covered in a separate article in this report, and had the opportunity to visit Osaka Castle and parts of the city before returning to Nagoya. The weeks passed with regular work in the office/laboratory, bouldering sessions, and dinners at local restaurants. Towards the end of my stay, I once again had the opportunity to explore the rest of Japan for 10 days. In the first part, I visited Hakone and Lake Achi with a friend from Germany who came to visit, and experienced the beautiful nature of Japan. In the second part, I was able to enjoy the lively nightlife in Tokyo and the view of it from Tokyo Skytree. The view from 450 m above ground at night, with the city and lights in all directions, is probably one of the most impressive views I have ever had.

When the cherry blossoms began to bloom in Tokyo and Nagoya, my stay was already coming to an end. After quickly completing all possible experiments, a joint lunch at Tsuruma Park near the university marked the end of my stay. In summary, I will always remember the warmth of my Japanese colleagues und the constant support of my supervisors Prof. Kakimoto and Prof. Martin. I can say that it was a time I will never forget and will always look back on with many fond memories.




*Departure: Starting cherry blossom in the Shinjuku Gyoen Park in Tokyo (left) and farewell lunch at Tsuruma Park near NITech in Nagoya before departure (right).*

## 5.6 IRTG 2495: Yearly School in Osaka

(Michael Schwarz) From February 27 to March 4, three members of LTM participated in the annual school of IRTG 2495 *Energy Conversion Systems* in Osaka, Japan. Osaka is located in the Kansai region in the southern center of Japan's main island of Honshu and is the third largest city in the country. It is an important economic and cultural center and is known for its local specialties. As the last major meeting within the second group of doctoral students, the focus was on presenting the results achieved and creating a space for personal exchange between members of the Japanese and German side.

The first day of the meeting began with an opening and welcome round by the IRTG and JGGE coordinators from FAU and NITech (Nagoya Institute of Technology). This included a memorial session for the recently deceased Prof. Haneda, with a tribute to his achievements. After a short lunch break, the main part of the meeting began with project presentations by the doctoral students of the twelve subprojects A to L. A short coffee break between the two rounds of presentations later, the program included a meeting of all PIs (Principal Investigators) of the subprojects and time for lively discussions among the participants. The day ended with dinner and an award ceremony honoring the best presentations of the day. After the official part, the discussions continued in Osaka, where a large number of participants sang karaoke and exchanged ideas in a relaxed atmosphere (the sources of this information are, of course, protected by the author).

The second day began with a keynote speech by Dr. Noboru Maeda (career expert and research engineer, SOKEN, Inc.) on the topic of "How electrically charged air affects aerodynamics". This was followed by presentations on the collaborative projects. The subsequent questions led to a lively discussion. This concluded the main part of the meeting, with only a short boat trip and a visit to Osaka Castle as social activities remaining on the agenda. The visit to Osaka Castle marked the end of the meeting for all participants except the doctoral students. After a break over the weekend and a move to Nagoya, they had two days of interesting workshops on the agenda, which also provided opportunities for the students to exchange ideas among themselves. This meant that all participants who were not currently in Japan were able to fly back to Germany as planned. Several days full of exchanges, interesting lectures, and new impressions came to an end.

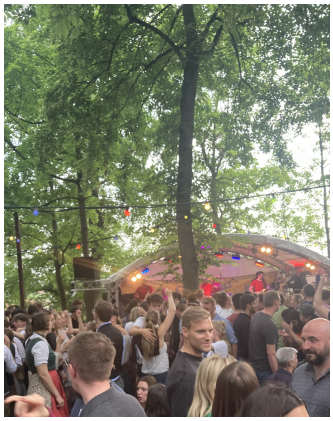




*Impressions from the meeting venue in Osaka with all participants from Japanese and German side (left), presenters for one of the collaborative projects (middle) and view at the foot of Osaka Castle (right).*

## 5.7 Berg

(Maurice Rohracker)
This year's Berg outing began with a beer bottle walk from EGS to Berg. The positive feedback encourages us to repeat the walk and even upgrade it next year. With excellent seats and a lively atmosphere, some stayed until the party band played. Everyone enjoyed the day. Another highlight was colleague quickly making stickers with the LTM and LKM logo. The people distributed these stickers to the band and others at the Berg to promote both institutes. We look forwad to making next year's outing even better. See you then - cheers!






*The view of the music band and the crowded audience (left), the stickers with the LTM and LKM logo (middle), and an used sticker with the LTM logo (right).*

## 5.8 Retreat Kloster Speinshart

(Annika Karweger)

At the end of June, we convened at the Scientific Center for AI and SuperTech in Speinshart Monastery to discuss upcoming opportunities in research topics and identify the resulting potential. During this retreat, we also gained insights into the monastery, which was founded in 1145. The special atmosphere of this historic location provided an impressive setting for our discussions. In addition to presenting research ideas and debating appropriate implementation in an inspiring environment, the monastery garden also provided a place with a breath of fresh air where creativity flourished. In addition to the substantive work, the unique surroundings of the monastery also contributed to the day's atmosphere, which was both open-minded and motivating. The workshop was professionally enriching and promoted exchange and cooperation between the chairs of technical mechanics and applied mathematics. Overall, the event made a valuable contribution to joint research, and we would be pleased to return to this excellent location.









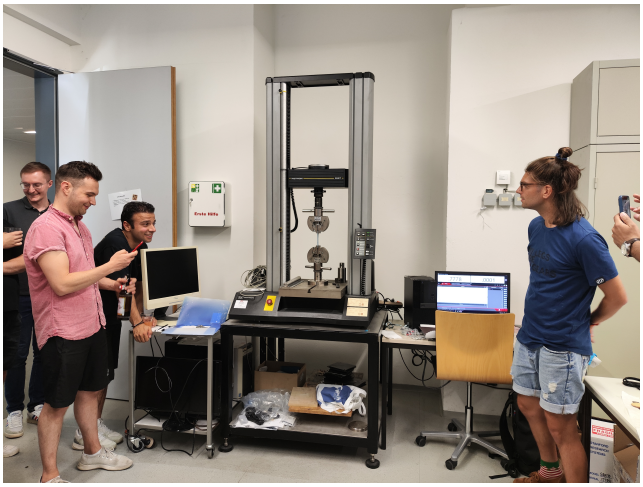
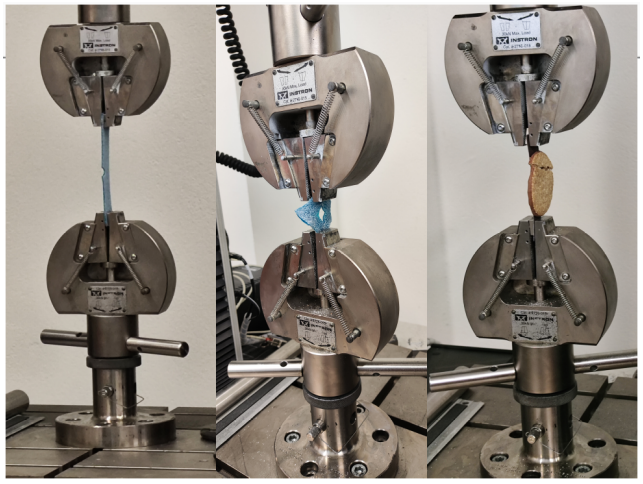

*Pictures: Top left: the monastery garden. Top center: the monastery building. Top right: the monastery church in baroque style. Bottom: all retreat participants, from left to right: Prof. Silvia Budday, Prof. Paul Steinmann, Annika Karweger, Dr. Anna Donhauser, Prof. Michael Stingl, Dr. Fabian Wein, Ph.D. Miguel Moreno Mateos, PD Dr. Sebastian Pfaller.*

## 5.9 Summer Party

(Maurice Rohracker)
At the summer party in July, the people of LTM and LKM gathered in the afternoon for a delicious barbecue organized by Gunnar, appetizing cocktails made by Gabriel, and a game rally. The game rally included various games: the candy test lottery, mechanics bingo, pylon and frisbee archery, and different beer games. In each game, victory points could be gathered. The winner of the game rally, Gabril, was honored by the Continuum Mechanic potato trophy, which was 3D printed by Jan. The party was again accompanied by some music by Alex. Thanks to everyone who contributed to and participated in the party. Many thanks also to the head of the institute, who sponsored the drinks. We are looking forward to next year's summer party!




*Barbecue chef Gunnar is in his element (left), and the Continuum Mechanic potato trophy for the winner of the game rally (right).*



*(LSp) Also a big 'thank you' to Maurice for organizing the Summer Party and game rally with, e.g., the candy lottery (top) and the mechanics bingo (bottom left). Of course, the band provided a great performance (bottom right: Soheil, Dominik, Eva, Lukas, Julia D., Gabriel) with Alex handling the light and sound equipment.*

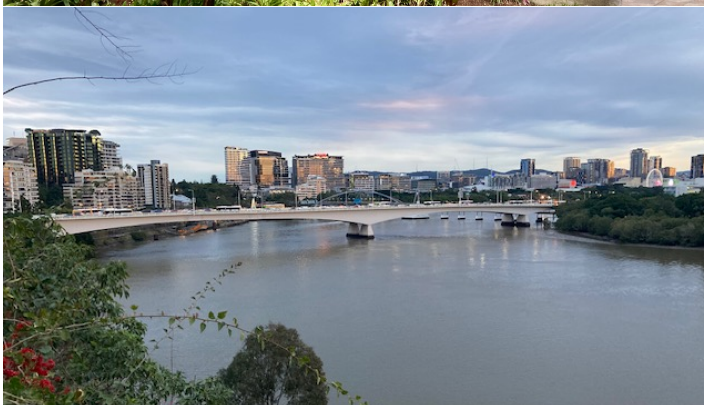
## 5.10 Visiting at QUT

(Annika Karweger)

As part of the QLD-Bavaria Collaborative Research Programme, another scientific exchange took place. The visit occurred in the opposite direction after Prof. Peter Pivonka had already visited Erlangen and given a presentation on osteoporosis and drug interventions. Annika Karweger travelled to the Queensland University of Technology (QUT), where she met Prof. Peter Pivonka and Prof. Davide Fontanarosa. She was able to discuss the direction of her research with renowned experts in the field of biomechanics in constructive discussions. This exchange provided valuable impetus for her future research and further expanded international cooperation within the programme. Additionally, the trip to Australia allowed Annika to gain valuable initial scientific experience and insights into a new academic environment.





*Pictures: Left: Exchange at the QUT, from left to right: Annika Karweger, Prof. Peter Pivonka, Corinna Modiz. Top right: QUT's Garden Point campus. Bottom right: View over Brisbane.*

## 5.11 GAMM Juniors Fall Meeting

(Miguel Angel Moreno-Mateos) This year's GAMM Juniors Fall Meeting, hosted by LTM, brought together young researchers for an inspiring and collaborative few days. Miguel Angel, the 2025 Secretary of the GAMM Juniors, organized the event to spark lively discussions on new ideas and projects, connect with members of the GAMM Board and invited experts, and enjoy a few social activities around Erlangen and Nürnberg. Simone—zoom in the upper photo—kindly assisted in organizing the event.






| Monday, 06.10 | Tuesday, 07.10 | Wednesday, 08.10 |
|---|---|---|
| | **Scientific talks** (with coffee break)<br>09.00 – 09.30<br>Mischa Blaszczyk<br>09.30 – 10.00<br>Emil Løvbak<br>10.00 – 10.30<br>Andreas Warkentin | 09.00 – 11.00<br>**Discussion on Juniors' projects**<br>(with coffee break) |
| | 10.30 – 12.00<br>**Discussion on Juniors' projects** | 11.00 – 12.00<br>**Prof. Silvia Budday** (FAU Erlangen-Nürnberg) |
| 13.15 – 13.30<br>**Welcome**<br>@ Lehrstuhl für Technische Mechanik (LTM), Egerlandstr. 5. | 12.00 – 13.30<br>**Lunch @ LTM** (*) | 12.00 – 16.00<br>**Trip to Nürnber** |
| 13:30 – 14:30<br>**Executive board report** | 13.30 – 14.30<br>**Q&A with GAMM Board (Prof. Claudia Schillings)** | |
| 14.30 – 16.00<br>**Reports on Juniors' projects** (with coffee break) | 14.30 – 15.30<br>**Discussion on Juniors' projects** (with coffee break) | |
| 16:00 – 18:00<br>**Discussion on Juniors' projects** | 16.30 – 18.00<br>**Visit botanical garden** | |
| 19.00 – open end<br>**Dinner** | 19.00 – open end<br>**Dinner** | |

## 5.12 ICCB 2025 in Rome

(nr,jf,ag) From September 8 to September 10, Jessi, Alex and Nina attended the ICCB in Rome, where we met former LTM member and long-term collaborator Ester Comellas.
Once we located the conference venue after a short scavenger hunt (see Figure, bottom right), we enjoyed three days with enlightening talks and fruitful discussions on various topics across the broad field of biomechanics. Accompanied by delicious food and Italian espresso, time passed by quickly and we found ourselves on an exhausting city tour led by a friendly guide who felt a special love for obelisks – which were by the way stolen from Egypt. Importantly, the hotel pool (see Figure, top right) allowed for some cooling and sporting activities to compensate for the Italian heat and lifestyle. The conference was crowned by an excellent dinner and lovely conversations!




*Nina, Jessi, Ester and Alex at ICCB in Rome. A stolen obelisk. The hotel pool. Enlightening talks. Scavenger hunt.*

## 5.13 Christmas party

(Annika Karweger)

As the year was coming to an end, it was time for the Christmas party. As usual, it was the responsibility of the new members of the team to organise it. The band performed an outstanding Christmas story based on mechanics. Once the buffet had made its way to the right floor, it was varied and tasty. After dinner, Secret Santa brought joyful presents and we played some fun games to test our knowledge. With hot and cold drinks on hand and loud music playing, we enjoyed a wonderful evening together.



